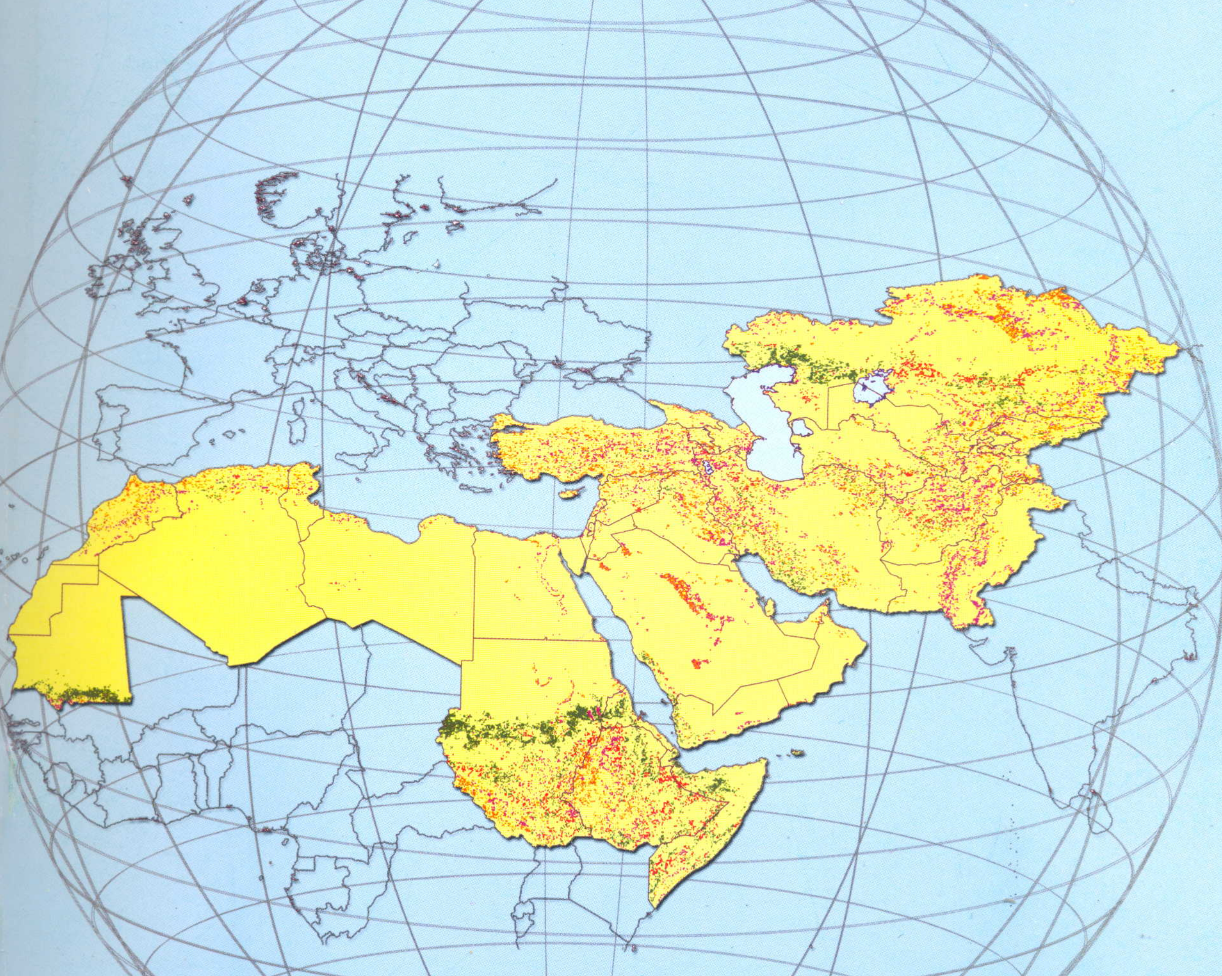
Assessment of Land Cover and Land Use in Central and West Asia and North Africa

Part 2. Hot Spots of Land Cover Change and Drought Vulnerability



David Celis, Eddy De Pauw, and Roland Geerken

ICARDA

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 2. Hot Spots of Land Cover Change and Drought Vulnerability

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Within ICARDA this report, which is the second and final volume of a regional study of land use/land cover, was reviewed by Richard Thomas whose valuable comments have added much to its quality.

This study is an outcome from the collaboration between the former Agroecological Characterization Project at **ICARDA** and the Center for Earth Observations at **Yale University**, USA. This collaboration, and the current report, have been sponsored by the **USAID** Linkage Fund.

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CONTENTS

FOREWORD

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

At the same time it is an outcome of the 1998-2002 collaboration between ICARDA and the Center for Earth Observations of Yale University in 'Remote Sensing for Natural Resource Management and Environmental Assessment', undertaken with the financial support of the USAID Linkage Fund to the CGIAR.

One of the major challenges in desertification research is of distinguishing processes, related to aridity and natural climatic fluctuations, from human-induced negative trends. Land use/land cover change, monitored over a substantive period of time and linked to secondary data, is the key to understanding which dryland areas are subject to degradation, as a result of either human-induced processes or of climatic fluctuations.

In this volume an effort has been made to identify hot spots of land use/land cover changes and drought vulnerability in the CWANA region during the period 1982-2000, based on observations of low-resolution AVHRR satellite imagery. In addition, the authors interpret the results in terms of likely trends of land use intensification or 'extensification', which themselves could be related to either changes in the policy environment, water resource availability, or indicative of climatic variability or change. The methodology described in this report contributes to the distinction of processes related to aridity and natural climatic fluctuations, from human-induced change trends. Moreover, the study underscores the ability of a 'hot spots' approach, using regional-scale remote sensing, in detecting macro-scale patterns of change, with considerable savings in time and financial resources.

It is hoped that this report will be useful both for researchers and policymakers.

Mahmoud Solh
Director General
ICARDA

SUMMARY

Land degradation is one of the most serious threats to the prosperity of rural populations in dryland areas. One of the major problems in combating land degradation in ICARDA's mandate region is a shortage of reliable basic data on the extent and severity of land degradation. An unequivocal identification of land degradation in dryland areas requires that processes related to aridity and natural climatic fluctuations are separated from human-induced negative trends. This may be easy for some forms of land degradation, e.g. water erosion, but can be difficult for others, such as vegetation degradation, a widespread phenomenon in North Africa and West Asia.

In a dryland region, as huge and diverse as CWANA, with limited reliable ground-based resource inventories and monitoring systems, remote sensing presents a highly valuable tool to get a grip on the highly complex issue of land degradation. Through the system of the Advanced Very High Resolution Radiometer (AVHRR) satellites, a global platform exists for the continuous space-based monitoring of the vegetation cover of the world since 1982. Although covering a relatively short period and with rather coarse resolution (8 km), it is the only consistent dataset that permits the detection of trends in land use/land cover change at global and regional scales. At the level of CWANA a time series of AVHRR imagery could thus be used for delineating 'hot spots' of land use/land cover change. The main advantage of the 'hot spot' approach is that it allows zooming into 'target areas' for more detailed observations, through ground-based characterization and monitoring assisted by high-resolution satellite information, such as Landsat. In view of the problems of the short time series, the low resolution, and the difficulties involved in distinguishing genuine trends in the land cover from short-term fluctuations in biomass as a result of year-to-year weather variations, it was necessary to develop a new methodology.

Six hundred and twelve 10-daily composites of 8-km AVHRR reflectance data, covering the period from January 1982 until December 2000, were downloaded from the relevant NASA Web site for band 1 (0.58-0.68 m.) and band 2 (0.725 -1.1 m.). No complete time series was available for the year 1994. These data consisted of separate subsets for Africa (top left: 37.9 N, -20 W; lower right -2 S, 59.9 E) and Asia (top left 59 N, 26.5 E; lower right 4.5 S, 91 E), in 16-bit unsigned format and in Goode's Homolosine Interrupted Space projection. The data were imported as layer stacks and both subsets were mosaiced to form a complete coverage of the CWANA-region. The Normalized Difference Vegetation Index (NDVI) was calculated and aggregated into monthly NDVI composites in order to reduce the effects of cloud cover. Additional corrections for noise and sensor drift were made, as well as conversion to geographic projection and merger into a single CWANA-dataset.

In order to convert this temporal NDVI dataset into a land use/land cover classification, two procedures were developed. The first procedure consisted of a hierarchical decision-tree based on the average values of the classifiers (NDVI max and NDVI mean), which take account of average weather conditions. To account also for the fact that in any particular year the actual weather can differ substantially from the average, a second procedure was developed to adjust the NDVI thresholds of the hierarchical decision-tree for different agroclimatic zones.

Using the above algorithm for land use/land cover classification, 17 annual land cover maps were produced for each year in the period 1982-1999. This dataset was further condensed into four maps, showing the majority land cover classes for the following three-year key periods: 1982-1984, 1987-1989, 1992-1994, and 1997-1999. For each of the sampled three-year periods the majority land cover type in each pixel was retained. Depending on the value and sequence of this majority land cover type, the following kinds of change were allocated to each pixel: noise, stable land use/land cover, stable land use/land cover mosaic and change pattern. Seventeen stable classes were recognized, as well as 66 change patterns, which were regrouped into 22 change classes and four change trends ('intensification of agriculture', 'intensification of natural vegetation', retrenchment of agriculture', and 'retrenchment of natural vegetation'). On the basis of this hierarchical classification 'change maps' were prepared for the CWANA region, and areas belonging to individual change combinations, change classes and change trends were calculated.

Building on this exploratory assessment for CWANA, it is concluded that in terms of land area, the most dramatic changes in land cover have occurred in the Sahel, followed by North Central Asia. In the former region approximately 75 million hectare changed from one land cover to another, in the latter 43 million hectare. In relative terms, the sub-regions where the most change occurred are the Middle East and the Sahel, where about 14% of the land cover changed. In addition, even in the sub-regions with the highest change in land cover, most of the land has remained stable during the period 1982-1999.

At the onset of this study it was expected that within CWANA two major trends in land use/land cover change would occur: intensification of agriculture and land degradation, as evidenced by biomass decline in both natural vegetation and agriculture. However, the analysis of the 1982-2000 AVHRR time series indicates a more complex picture, with some remarkable and often unexpected trends of land use/land cover change in different sub-regions of CWANA. In most sub-regions intensification of agriculture is a major, if not the predominant trend. Particularly the Near East has experienced a remarkable degree of intensification of agriculture, mainly by the conversion of rainfed into irrigated croplands. However, retrenchment of agriculture and natural vegetation, which are potential indicators of land degradation, but also intensification of natural vegetation, are other important trends throughout CWANA, with significant differences between sub-regions.

On a sub-regional basis the change trends can be quite different. The main trend in the Maghreb is an intensification of agriculture . This occurred mostly through deforestation to develop irrigated and rainfed cropland in the coastal zone, and by converting bare land into irrigated croplands inland. A second trend involves a retrenchment of agriculture, which occurred inland, where both rainfed and irrigated fields were taken out of cultivation to become barren/sparsely vegetated areas. A third, less important, trend is one of intensification of the natural vegetation. This occurred mostly as a change from bare areas to grasslands/ open shrublands in the Atlas mountains of Algeria.
The only noticeably trends in Egypt are a retrenchment of agriculture on the right bank of the Nile, and intensification of agriculture at the western edge of the Nile delta.

The major trend in the Sahel sub-region was an intensification of natural vegetation , mainly in the form of a change from barren/sparsely vegetated areas to grasslands/open shrublands. In northern Sudan and Mauritania, the desert border shifted 100 to 150 km to the North. The Sahel experienced a drought from 1961 until 1984, followed by a period with normal rainfall. The northward shift of the desert boundary after 1984 can therefore be interpreted as a regeneration of the grasslands/open shrublands when rainfall returned to normal after the long drought cycle. In contrast with this general Sahelian trend, a retrenchment of the natural vegetation occurred in scattered areas. Intensification of agriculture occurred in southwestern Sudan and western Ethiopia, in the form of a change from rainfed field crops to tree crops or from woodland savannah to rainfed field crops. In the center of both Sudan and Ethiopia, a retrenchment of agriculture occurred , mainly in the form of a change from rainfed field crops to woodland savannah.

During the period 1982-1999 two contrasting trends of land cover change are observed in the Arabian Peninsula. A first trend of intensification of agriculture is due to the fact that since 1982 huge areas were converted into irrigated croplands, mostly in Saudi Arabia. In the same period a trend of retrenchment of agriculture is caused by the fact that large irrigated areas were also taken out of cultivation in Saudi Arabia. The observed intensification of natural vegetation at the edges of the Asir and Yemen Highlands in the form of a change from barren/sparsely vegetated areas to grassland/open shrublands is probably also related with increased rainfall after the Sahel drought.

The Near East is the sub-region of CWANA with the highest degree of land cover change in the period 1982-1999, both in absolute terms as in relation to its size. Of the different change trends, intensification of agriculture is the most important one. Intensification occurred both towards irrigated as well as rainfed cropland. Retrenchment of agriculture occurred mostly in inland Turkey, in the form of a change from rainfed cultivation to grasslands/open shrublands, and in Iraq in the form of irrigated fields taken out of cultivation by change to barren/sparsely vegetated areas.

In the Caucasus intensification of agriculture occurred mostly in the form of a change from rainfed fields to either tree crops or irrigated fields. A retrenchment of agriculture occurred mainly in the form of a change from irrigated fields to rainfed fields or from rainfed fields to grasslands/open shrublands.
A major change trend in Central Asia is the intensification of agriculture, mostly in the form of a change from grasslands/open shrublands into rainfed cultivation. However, in other parts of the sub-region the reverse trend, with a change from rainfed cultivation to grasslands/open shrublands, has occurred. In addition, intensification of natural vegetation did occur in a major part of the sub-region, mostly as a result of change from barren/sparsely vegetated areas to grasslands/open shrublands. This intensification trend is very noticeable in Southwest Kazakhstan near the Caspian Sea. The inverse trend, a change from grasslands/open shrublands into barren/sparsely vegetated areas, is particularly clear in Central Kazakhstan.

The main trend in Southwest Asia is one of retrenchment of agriculture. This trend is particularly noticeable in Pakistan and Afghanistan, and affected in particular the irrigated croplands. On the other hand, intensification of agriculture occurred as well throughout the sub-region without any particular focus.
A general conclusion of this study is that, even after the year-to-year weather variations were compensated for, it is still difficult to understand the causes of the land cover changes. An intensification of agriculture is the easiest to interpret because it is always human induced, whereas a retrenchment of agriculture can have three possible causes: a long term weather change, a lack of inputs to maintain the cultivation or a degradation of the natural resource base (too intensive use of natural resources). Both the intensification and the retrenchment of natural vegetation could be either human-induced or result from a longer-term change in weather. The identification of a trend towards denser natural vegetation proves the possibility of natural regeneration and puts the issue of land degradation in a more positive perspective.

There are two limitations in this study which may restrict its interpretative value. Due to the low resolution of the AVHRR imagery sparsely vegetated areas can not be separated from bare ground. As a result it is not possible to see vegetation degradation in the arid rangelands. A second limitation is that the areas, which result from the classification, are only indicative because the majority land cover class gets all the area of the pixel even if it only occurs on a fraction of it. On the other hand the areas of minority classes are not taken into account.

1. INTRODUCTION

Land degradation refers to the decline in quality of natural land resources, commonly caused by improper use of the land by humans (ISSS, 1996). This decline in quality expresses itself in a reduced productivity of the land use systems that make use of these land resources, or in a reduction of the biodiversity of the natural ecosystems. Land degradation is one of the most serious threats to the prosperity of rural populations worldwide. Land degradation is both a cause and effect of rural poverty (Figure 1). It contributes to land shortage and therefore poverty, and is accelerated by non-sustainable land management induced by rural poverty.

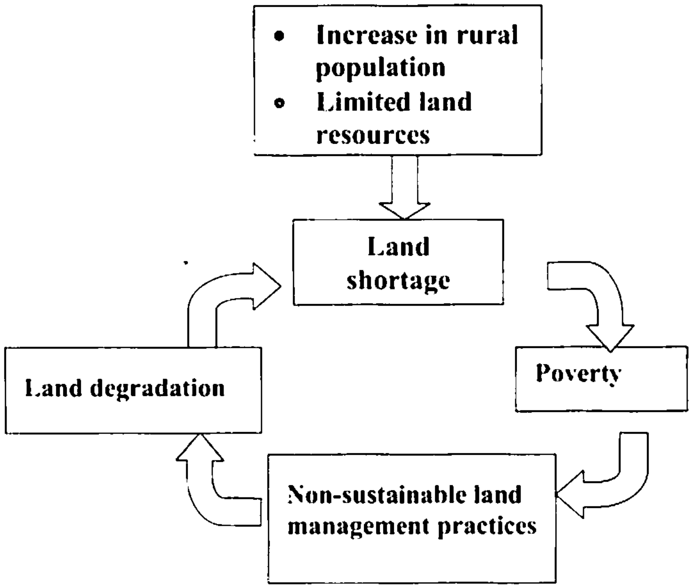

Figure 1. Cause-effect relationships between land resources, population, land degradation and poverty (from FAO, 1994)

One of the major problems in combating land degradation is the lack of good data on the extent of different forms of land degradation.
FAO (1994) in its review of land degradation in South Asia notes that estimates about the extent of different types of land degradation vary as much as 100%, for the following reasons:

- failure to define the degree of degradation that is being assessed;
- absence of reliable surveys of land degradation;
- repeated copying of land degradation estimates from one source to another, making it difficult to trace the original source and its base.

Particularly in ICARDA's mandate region, which covers the drylands of North Africa, the Horn of Africa, West Asia and Central Asia (CWANA), there is a shortage of reliable basic data on the extent and severity of land degradation. Because the basic data are so uncertain, governments are often reluctant to spend scarce development funds on measures to combat a degradation problem that is so fuzzily defined and located. For this reason alone, there is a strong case for better resource inventories. However, there are several difficulties:

- resource inventories, particularly if they have to cover large areas and involve field work, are inherently expensive;
- in dryland areas processes occur which are closely linked to aridity and, in themselves, do not constitute forms of land degradation.

Examples of processes linked to aridity are primary salinization and wind erosion and deposition. 'Drought' is linked to aridity and to normal precipitation fluctuations, and can thus not be seen as an expression of land degradation, unless it could be demonstrated that rainfall decreases as a result of human activities. This has, however, not been established.

An unequivocal identification of land degradation in dryland areas requires that processes related to aridity and natural climatic fluctuations are separated from human-induced negative trends. This may be easy for some forms of land degradation, e.g. water erosion, but difficult for others, such as vegetation degradation, a widespread phenomenon in North Africa and West Asia.

In a dryland region as huge and diverse as CWANA, with limited reliable ground -based resource inventories and monitoring systems, remote sensing presents a highly valuable tool to get a grip on the extremely complex issue of land degradation. Through the system of the Advanced Very High Resolution Radiometer (AVHRR) satellites, a global platform exists for the continuous space-based monitoring of the vegetation cover of the world since 1982.

Although covering a relatively short period and with rather coarse resolution (8 km), it is the only consistent dataset that permits the detection of trends in land use/land cover change at global and regional scales. At the level of CWANA a time series of AVHRR imagery could thus be used for delineating 'hot spots' of land use/land cover change. Whereas the identification of consistent changes in land use/land cover is no substitute for dedicated ground-based monitoring systems, it is, in their absence, a valuable proxy indicator of trends that could eventually be associated with certain forms of land degradation. The main advantage of the 'hot spots' approach is that it allows zooming into 'target areas' for more detailed observations, through ground-based characterization and monitoring assisted by high-resolution satellite information, such as Landsat. However, it is not an infallible approach, in view of the previously mentioned problems of the short time series and low resolution, but also the difficulties involved in distinguishing genuine trends in the land cover from short-term

fluctuations in biomass as a result of year-to-year weather variations.
For this reason a specific methodology is required that allows distinguishing these causes of variations in vegetation biomass. The objective of this report is to summarize the results obtained through a novel approach to identify the 'hot spots' of land use/land cover change in ICARDA's mandate region, using an AVHRR imagery time series, and its implications for land degradation and drought vulnerability assessment.

2. METHODOLOGY FOR LAND COVER CHANGE MAPPING

2.1. Image pre-processing

2.1.1. Download and import

Six hundred and twelve 10-daily composites of 8km-AVHRR reflectance data, covering the period from January 1982 until December 2000, were downloaded from the NASA Web site[1] for band 1 (0.58-0.68 m.) and band 2 (0.725-1.1 m.). No complete time series was available for the year 1994. These data consisted of separate subsets for Africa (top left: 37.9 N, -20 W; lower right -2 S, 59.9 E) and Asia (top left 59 N, 26.5 E; lower right 4.5 S, 91 E), in 16-bit unsigned format and in Goode's Homolosine Interrupted Space projection (Figure 2).
The data were imported as layer stacks and both subsets were mosaiced to form a complete coverage of the CWANA-region.

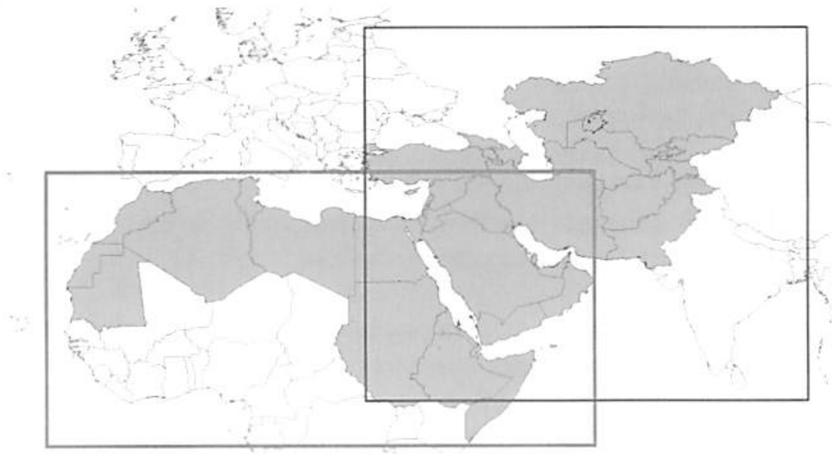

Figure 2. Location of AVHRR subsets

2.1.2. Monthly NDVI composites

10-daily NDVI-composites were calculated as the ratio:

$$\frac{Band2 - Band1}{Band2 + Band1}$$

To reduce cloud cover, they were grouped into monthly composites by retaining the highest NDVI value of three consecutive 10-daily composites.

[1] http://daac.gsfc.nasa.gov/data/dataset/AVHRR/01_Data_Products/04_FTP_Products/01_ftp_subsets/index.html

2.1.3. Noise correction

To assess whether pixels with a much higher NDVI than the surrounding pixels constituted an authentic signal or were just 'noisy', several procedures were tested. The best noise correction was obtained by selecting two 'high value' pixels on top of each other (Figure 3a) and two 'high value' pixels next to each other (Figure 3b). The best NDVI-threshold was 0.02. These high values were replaced by the mean value of the pixels above and below them.

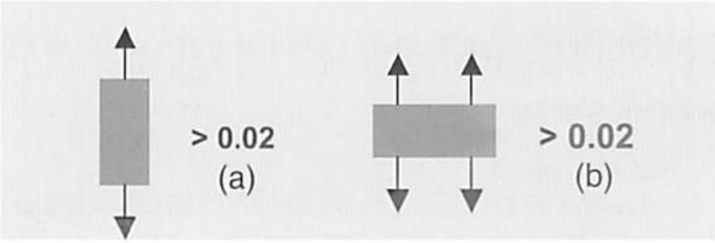

Figure 3. Selection of pixels for noise correction

2.1.4. Calibration

To correct for sensor-drift, the noise-corrected monthly NDVI-composites were calibrated to each other by first calculating their standard deviation (STD). Six pixels, representing the regional peaks of lowest STD, were selected from different parts of the CWANA-area (example in Figure 4). These pixels are located in hyper-arid areas and their NDVI-value can be considered as constant over time. For each pixel, the correction coefficient could be calculated as follows:

$$C_i = NDVI_{mean} / NDVI_i$$

where C_i = correction coefficient for month i

$NDVI_{mean}$ = mean NDVI from 1982 until 2000

NDVI I = NDVI for month i

Then the calibration was done by multiplying all NDVI-values of month i by the average of the six calibration coefficients of month i.

2.1.5. Georeferencing

The dataset was cut into two subsets, respectively south and north of latitude 40°44"N. In the Goode's Homolosine Interrupted Space projection, the northern part has a Mollweide projection (central meridian 30° E) and the southern part has a Sinusoidal projection (central meridian 30° E). Both subsets were georeferenced with their four corner point coordinates, transformed to Geodetic projection and merged together again.

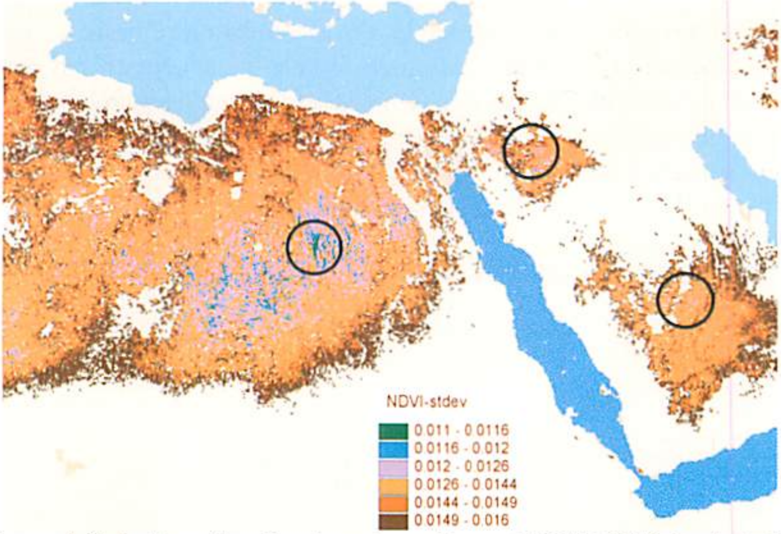

Figure 4. Selection of regional centers of lowest NDVI-STD (encircled)

2.2. Land cover/land use classification

The land cover/land use algorithms consist of two parts. The basic algorithm was developed with average values of the classifiers ($NDVI_{max}$ and $NDVI_{mean}$), which correspond with average weather conditions (Celis and De Pauw, 2002). To take into account the actual (i.e. different than average) weather conditions in a certain year, an additional algorithm had to be applied.

2.2.1. Basic Algorithm

2.2.1.1. Classifiers

As main classifiers the annual maximum ($NDVI_{max}$) and mean ($NDVI_{mean}$) were selected. To characterize the variations in macroclimatic conditions in CWANA, the classifiers selected were *agroclimatic zone, period of dry season*, and *latitude zone*.

The agroclimatic zones of CWANA were determined from the UNESCO map of agroclimatic zones (UNESCO, 1979). This map is based on a simple classification system, which differentiates climatic zones according to three major criteria: *moisture regime, winter type*, and *summer type*.

The *moisture regime* is determined by the ratio of annual rainfall over annual potential evapotranspiration, calculated according to the Penman method. This ratio is also referred to as the aridity index. The winter type is determined by the average mean temperature in the coldest month of the year. The summer type is determined by the average mean temperature during the warmest month of the year. The thresholds for defining the agroclimatic zones according to these three criteria are given in Table 1.

An agroclimatic zone is thus defined by the combination of moisture regime, winter and summer type. While extremely simple in concept, this system is able to capture the major variations in moisture and temperature conditions at a regional scale, and the associated variations in biomass productivity. An example of the agroclimatic zoning, covering the Horn of Africa and the southern part of the Arabian Peninsula, is shown in Figure 5.

Table 1.Classification of moisture regime, winter type and summer type after UNESCO (1979)

	Aridity index					
	< 0.003	< 0.2	< 0.5	< 0.75	> 0.75; <1	≥ 1
Moisture regime	*Hyper-arid*	*Arid*	*Semi-arid*	*Sub-humid*	*Humid*	*Per-humid*
	Average temperature coldest month					
	> 20°C	> 10°C		> 0°C	≤ 0°C	
Winter type	*Warm*	*Mild*		*Cool*	*Cold*	
	Average temperature warmest month					
	> 30°C	> 20°C		> 10°C	> 0°C	
Summer type	*Very warm*	*Warm*		*Mild*	*Cool*	

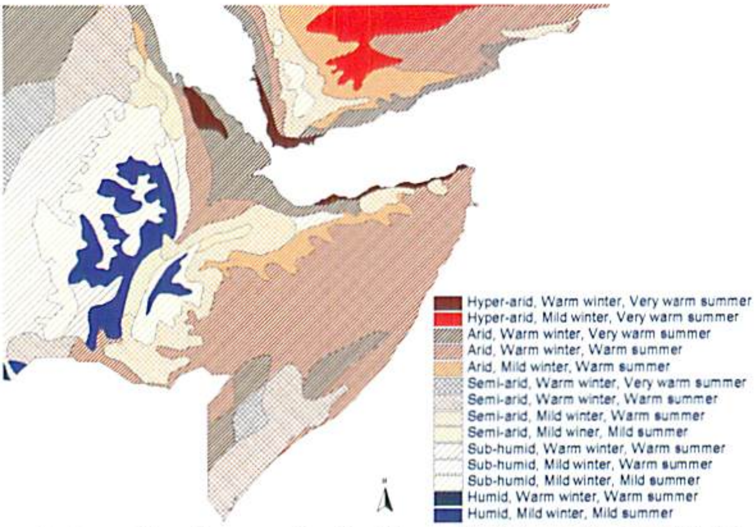

Figure 5. Agroclimatic zones for the Horn of Africa (after UNESCO, 1979)

The second variable, latitude zone, enables taking account of typical features of global and regional climate, such as the summer precipitation in the southern hemisphere and the lower winter temperatures in the northern hemisphere, which may explain some shifts in NDVI patterns across the CWANA region (Table 2).

Table 2. Definition of dry season

Latitude	Period of NDVI increase
< 23 ° N	None
23° - 39 ° N	May-August or June-September
> 39 ° N	June-September

The third ancillary classifier, period of the dry season, enables to distinguish croplands very effectively. The best match with ground data was achieved when 'the dry season' is defined, according to latitude, as two possible periods of two months (Table 2).

2.2.1.2. Hierarchical decision tree

To assign a pixel to a particular LCLUT, a hierarchical decision tree approach is followed, using 'sliding thresholds' for the annual maximum and mean NDVI, which vary according to the agroclimatic zone. To detect the same LCLUT, a higher threshold is applied in regions with more humid growing conditions. The thresholds were determined by visual comparison of the classification results of different values with ground data. Field surveys together with vegetation maps, land cover maps and climatic data from the CWANA region were used as particular forms of ground data. The thresholds that gave the best match with these information sources were retained as the most appropriate. The decision tree for allocation of pixels to a particular LCLUT is outlined in Figure 6 and discussed in the following paragraphs.

0) Pixels with an NDVI max that equals zero are classified as '*Inland water*'
1) All conditions, except the last one (selection of 'Open shrublands/grasslands') are only applied to those pixels with a NDVI max higher than 0.176.
2) For pixels that lie between latitudes 23° N and 48° N, condition 3 is applied, for the others condition 4b. North of 48° N, no distinct dry season can be separated and south of 23° N the period of dry season varies regionally, so the class '*Dry season irrigated field crops*' was not applicable to these zones.
3) For pixels within a humid agroclimatic zone, condition 4b is applied first, for the others condition 4a.
4) If the NDVI increases in the dry season (definition in table) or when the moisture regime is Hyper-arid a pixel is classified as '*Dry season irrigated field crops*'.
4a) If the NDVI mean is higher then a threshold value, which increases with the humidity of the agroclimatic zone (Table 3), the land cover class will be '*Forests/tree crops/closed shrublands*'.
4b) For the remaining pixels, if the NDVI max is higher then a threshold value, which increases with the humidity of the agroclimatic zone (Table 4), the land cover class will be '*Rainfed/wet season supplementary irrigated field crops - dry season uncultivated*'.

5) For the remaining pixels below latitude 23° N, if the NDVI max is higher than a threshold value, which increases with the humidity of the agroclimatic zone (Table 5), the land cover class will be '*Woodland savannah*'.
6) For the remaining pixels, if the difference ($NDVI_{max} - NDVI_{mean}$) > 0.096 (reflecting a distinctive vegetation change throughout the year), the land cover class will be '*Open shrublands/grasslands*'.
7) All remaining pixels are classified as '*Barren/sparsely vegetated*'

Table 3. Thresholds NDVI mean for *Forests/tree crops/closed shrublands*

Moisture regime	Winter type	Threshold
Semi-Arid	Other than warm	0.296
Subhumid	Other than warm	0.336
Humid	Cool or Cold	0.416
Semi-Arid	Warm	0.496
Subhmid	Warm	0.496
Humid	Mild	0.496
Humid	Warm	0.576

Table 4. Thresholds NDVI max for '*Rainfed/wet season upplementary irrigated field crops - dry season uncultivated*'

Moisture regime	Winter type	Threshold
Arid	Mild or cool	0.256
Semi-Arid	Mild or cool	0.336
Subhumid	Mild or cool	0.416
Arid	Cold	0.496
Semi-Arid	Cold	0.496
Subhumid	Cold	0.496
Humid	Cold	0.496
Humid	Cool	0.576
Arid	Warm	0.616
Semi-Arid	Warm	0.616
Humid	Mild	0.616
Subhumid	Warm	0.656
Humid	Warm	0.656

Table 5. Thresholds $NDVI_{max}$ for *Woodland savannah*

Moisture regime	Winter type	Threshold
Arid		0.456
Semi-Arid		0.536
Subhumid	Other than warm	0.536
Humid	Other than warm	0.536
Subhumid	Warm	0.576
Humid	Warm	0.576

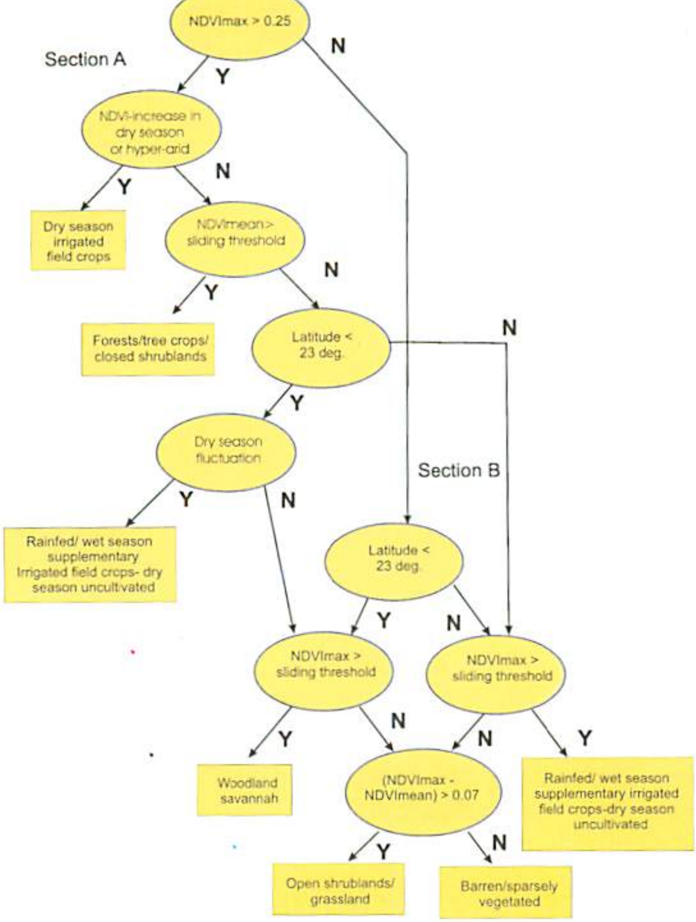

Figure 6. Hierarchical decision tree for land cover/land use classification

2.2.2. Algorithm to compensate for climatic variability

As the NDVI thresholds used in the decision tree of Figure 6 apply to average climatic conditions, there is the risk that a given LULCT might be misclassified, if weather conditions at a given place deviated substantially from normal. Actually, it has been well established that the NDVI is particularly sensitive to variations in weather. Strong correlations between NDVI and precipitation, particularly in tropical areas, have been much reported in the literature (e.g. Hielkema et al., 1987, Nicholson et al., 1990, Lotsch et al., 2003). Schutz and Halpert (1993) highlighted the influence of both precipitation and temperature on NDVI in temperate regions. This is confirmed by our own results in a climatologically homogeneous region, covering southern Anatolia, northern and western Syria.

Figure 7. Pixels retained from semi-arid zone and location of weather stations

To investigate the correlation between critical climatic indices and the NDVI max, pixels were retained from a semi-arid agroclimatic zone in Syria and southeast Turkey with a NDVI $_{max}$ value not influenced by the soil brightness (NDVI $_{max}$ > 0.5), and not classified as 'Dry season irrigated field crops' (Fig.7). The average annual NDVI $_{max}$ of all retained pixels was calculated from 1983 to 1991.

For the same period, daily precipitation and minimum temperature data were collected for 6 weather stations, evenly spread across this region (Figure 7). For each year from 1983 to 1991, the total precipitation and the absolute minimum temperature were calculated from 1 September until 31 August, as well as their averages over the 6 stations.

The result is shown in Figure 8. Both parameters show correlations higher than 70%. A linear combination of both parameters, which corresponds with their combined effect, corresponds almost perfect with the NDVI pattern (Fig. 9). This indicates that the change in the regional average NDVI max correlates very strongly with the change in actual weather conditions from year to year.

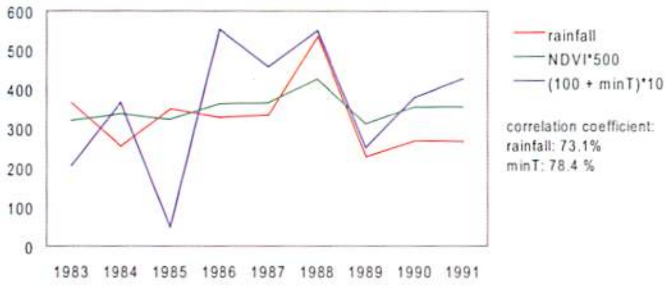

Figure 8. Correlation of average annual rainfall (mm) and average absolute minimum temperature (°C) with average NDVI $_{max}$

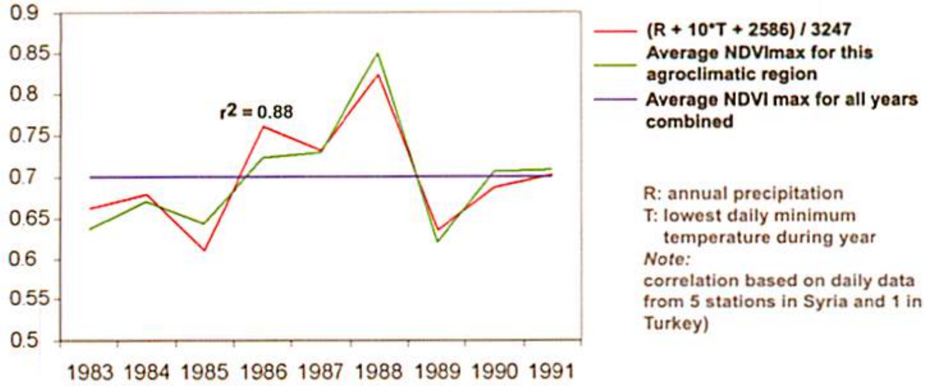

Figure 9. Agreement between average NDVI max and a linear combination of aver age annual rainfall (R) and minimum temperature of the coldest month (T) for 6 stations in the red-bounded agroclimatic zone of Figure 10.

The observed correlation between the climatic variables and NDVI implies that the application of the same $NDVI_{max}$ or $NDVI_{mean}$ thresholds from the basic land cover classification algorithm every year would cause larger areas to exceed the thresholds in years with more favorable weather conditions, independent from the real land cover change. To correct for this error the following algorithm was applied:

1) Using the UNESCO classification the whole CWANA area was subdivided into 152 local zones with homogeneous agroclimatic conditions. An example is shown for West Asia in Figure 10. Those pixels with no influence from the soil brightness ($NDVI_{max} > 0.5$) and not classified as 'Dry season irrigated field crops' were retained.

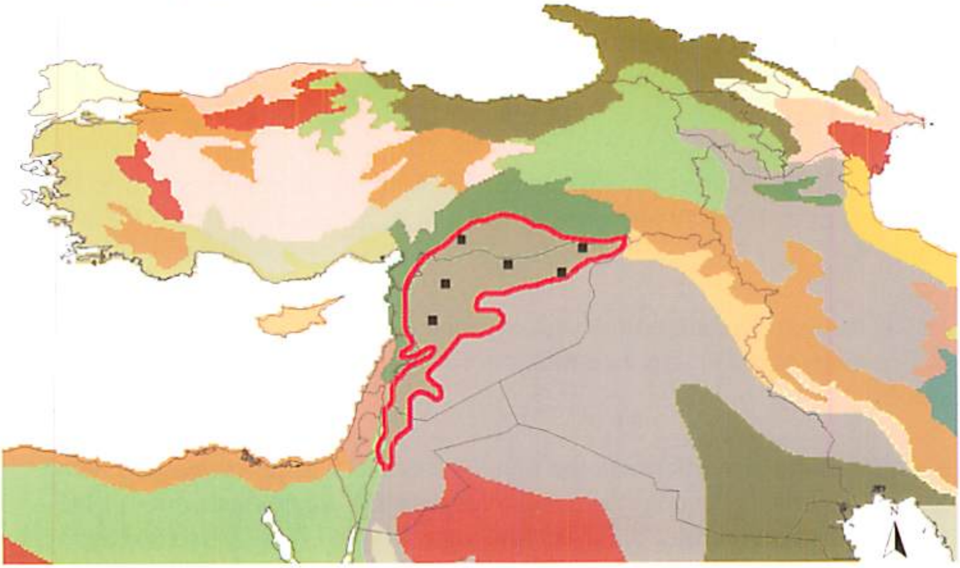

Figure 10. Local zones with homogeneous agroclimatic conditions in West Asia.

2) For the retained pixels, the average NDVI max from 1982 until 2000 was calculated as well as its average over the local zones. Similarly the average annual NDVI max values were averaged over the local zones.

3) Instead of applying the average thresholds from the basic algorithm, these thresholds were corrected as shown in the following equation:

$$[Threshold]_{i,j} = Threshold_{av\_j} * \frac{NDVI\_\max_{i,j}}{NDVI\_\max_{av\_j}} \quad (1)$$

With i: year; j: zone; av_j: average for zone j
Example: Zone j has an average NDVImean threshold of 0.8 for the class 'Forests/tree crops/closed shrublands'. The average NDVI $_{max}$ in zone j is 0.66 and the NDVI $_{max}$ for 1982 is 0.74, which reflects better than average growing conditions. So for a correct classification the NDVI $_{mean}$ threshold also has to be higher. Following the above equation it will be equal to 0.897.

For condition 6 of the basic classification algorithm (selection of 'Open shrublands/ grasslands), no such correction is necessary since a threshold for [NDVI $_{max}$ – NDVI $_{mean}$] is used, a parameter which is already independent from annual weather fluctuations.

2.3. Change detection

2.3.1. Decision rules for detecting change

Using the method described above, 17 annual land cover maps were produced covering the period 1982-1999. This dataset was further condensed into four maps, showing the majority land cover for four key periods of three years each: 1982-1984, 1987-1989, 1992-1994, and 1997-1999. If the three years had three different classes, the pixel was classified as 'noise'. Figure 11 illustrates this process for the region around Syria's northwestern border with Turkey, using the period 1987-1989.

The majority land cover for various periods is shown in Annexes 2 to 5: 1982-84 in Annex 2, 1987-89 in Annex 3, 1992-94 in Annex 4, and 1997-99 in Annex 5.

The advantage of retaining the majority land cover class is that short-term fluctuations in land cover, due to a rotation within the same land use system, can be masked.

A simple comparison between the four sub-periods of a pixel's majority land cover class allows the detection of change over the whole time series (1982-1999). The decision rules are the following:

1) If all four classes are equal, the land cover remains stable.
2) If a permanent change occurs from one class to another, a change class results;
3) If the change from one class to another is not permanent, the combination is interpreted as a stable mosaic of both classes.
4) If there are three or four different classes or a 'noise' class, the classification is 'noise'.

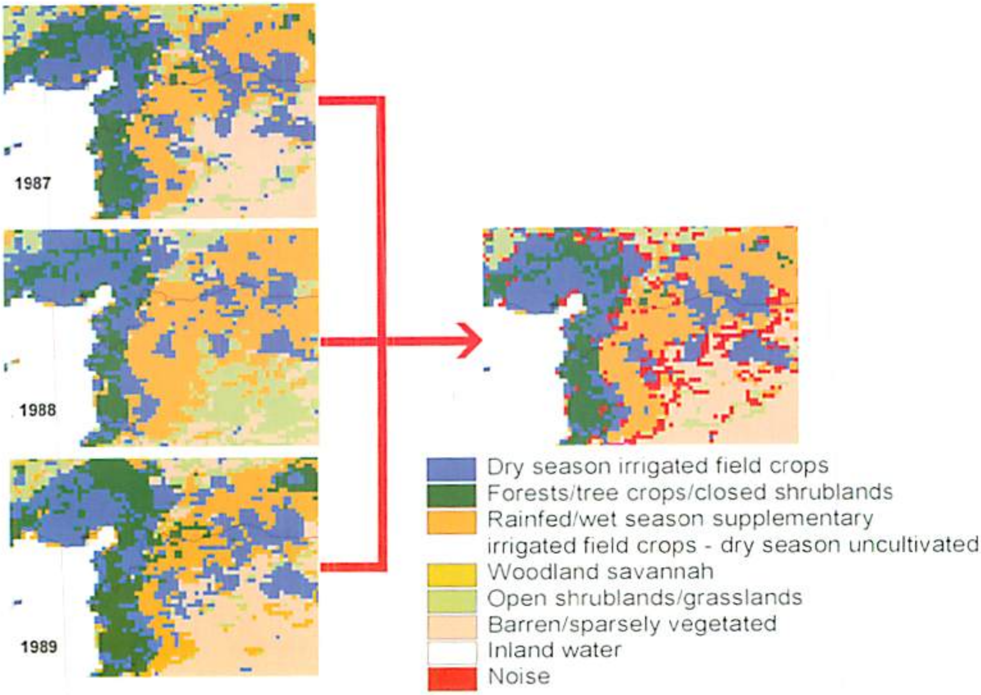

Figure 11. Majority land cover classes for different years, subset northwest Syria (on the left the land cover classes for the years 1987, 1988, 1989; on the right the majority land cover class).

In addition, the following special cases are considered:
(i) If one of both classes is 'Open shrublands/grasslands' or 'Barren sparsely vegetated', the result will be a 'low density' stable class.
(2) A change from 'Open shrublands/grasslands' or 'Barren sparsely vegetated' to 'Dry season irrigated field crops' or 'Rainfed/wet season supplementary irrigated field crops' and back to the original class is also interpreted as a clear change in which cropland was first taken into cultivation, and then taken out again.

The decision rules for classifying the change status during the period 1982-1999 are summarized in Table 6.

Table 6. Change detection scheme

4 equal classes: A A A A; B B B B	=	**Stable**
Permanent change from one class to another: A B B B; A A B B; A A A B; B A A A; B B A A; B B B A	=	**Change**
Other combinations of two classes with A = 'Grasslands/open shrublands' or 'Barren/sparsely vegetated' C = 'Dry season irrigated field crops' or 'Rainfed/wet season supplementary irrigated field crops': A C A A; A C C A; A A C A	=	Change from A to C
A C A C; C C A C; C A C A; C A A C; C A C C	=	**Stable mosaic A/C**
Other combinations: A A B A; A B A A; A B A B; A B B A; B B A B; B A B B; B A B A; B A A B	=	**Stable mosaic A/B**
Three or Four classes or noise class (E): A B C A; A B C D; A E A A; A A B E	=	**Noise**

2.3.2. Hierarchical structure of change patterns

Using Table 6 as a guide, a large number of change patterns emerged over the period 1982-1999. To allow a coherent interpretation of these changes throughout a very large region as CWANA, a hierarchical structure of change patterns was adopted.

At the lowest level of the structure are the 'change combinations'. These are the raw patterns that result from the combination of the majority land cover classes in each of the three-year periods considered. For example, the combination '2211' indicates majority land cover class 2 (forest/tree crops) in the periods 1982-1984 and 1987-1989, followed by majority land cover class 1 (irrigated croplands) in the periods 1992-1994 and 1997-1999. The list of change combinations is shown in the first column of Table 7.

At the next level are the 'change classes'. These are the patterns that emerge by regrouping the change combinations into land cover classes, that are either stable throughout the period 1982-1999, or show a consistent change. For example, the change combinations 2111, 2211 and 2221 are part of the change class 'Forest/tree crops' to 'Irrigated cropland'.

If no change occurs in the majority land cover class in the 4 reference periods, 'stable classes' were differentiated, which are either homogeneous or mixed (mosaics), in accordance with the decision rules of Table 6.

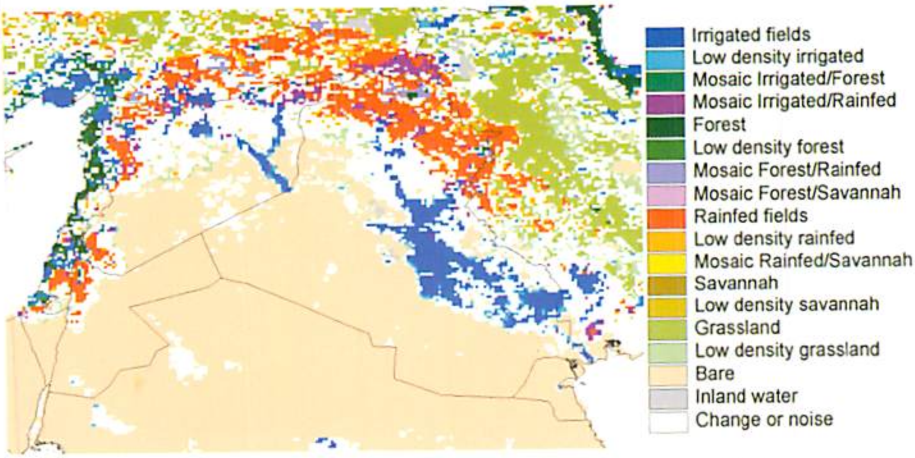

Figure 12. Spatial distribution of stable classes in parts of West Asia

Seventeen stable classes and 22 change classes were differentiated, as listed in the second column of Table 7. The spatial distribution of the stable classes is shown in Figure 12 (for West Asia) and Annex 6 (for CWANA). The CWANA map of the change classes is shown in Annex 7.The 22 change classes can be summarized into four major 'change trends' (Column 3 of Table 7).

1) Intensification of Agriculture:
A change from a less intensive (lower biomass producing) form of agriculture to a more intensive one. The trend encompasses the following change classes: *Rainfed to Forest (tree crops); Forest to Irrigated; Rainfed to Irrigated; Grassland to Irrigated; Bare to Irrigated; Forest to Rainfed; Savannah to Rainfed; Grassland to Rainfed; Bare to Rainfed.*

2) Retrenchment[2] of Agriculture:
A change from a more intensive (higher biomass producing) form of agriculture to a less intensive one. The trend encompasses the following change classes: *Irrigated to Rainfed; Irrigated to Grassland; Rainfed to Grassland; Irrigated to Bare; Rainfed to Bare; Rainfed to Savannah.*

3) Intensification of Natural Vegetation (towards the climax vegetation):
A change from a more dense, more biomass producing kind of natural vegetation to a less dense one. This trend encompasses the change classes *Savannah to Forest, Grassland to Forest, Bare to Grassland,* and *Grassland to Savannah.*

4) Retrenchment of Natural Vegetation (away from the climax vegetation):
A change from a more open, less biomass producing kind of natural vegetation to a denser one. This trend encompasses the change classes *Forest to Grassland, Savannah to Grassland,* and *Grassland to Bare.*

The CWANA map of change trends is shown in Annex 8.

[2] A synonym for 'retrenchment' could be 'extensification'

Table 7. Change patterns in CWANA

Change combinations	Stable or change classes	Change trends	Change categories
Noise combinations	None	Unknown	Noise
None	Irrigated croplands Irrigated croplands, low density Irrigated croplands+Forests Irrigated+rainfed croplands Forests Forests+rainfed croplands Forests+savannah Forests, low density Rainfed croplands Rainfed croplands, low density Rainfed croplands+savannah Savannah Savannah, low density Grasslands Grasslands, low density Barren Lakes	No change	Stable
2111 2211 2221	Forest > Irrigated cropland	Intensification of agriculture	Change
3111 3311 3331	Rainfed cropland > Irrigated cropland		
5111 5511 5551	Grassland > Irrigated cropland		
6111 6611 6661	Bare > Irrigated cropland		
3222 3322 3332	Rainfed > Tree crops		
2333 2233 2223	Forest > Rainfed cropland		
4333 4433 4443	Savannah > Rainfed cropland		
5333 5533 5553	Grassland > Rainfed cropland		
6333 6633 6663	Bare > Rainfed cropland		

Table 7. Change patterns in CWANA (continued)

1333			
1133	Irrigated > Rainfed cropland		
1113			
1555			
1155	Irrigated cropland > Grassland		
1115			
1666			
1166	Irrigated cropland > Bare		
1116		Retrenchment of agriculture	
3444			
3344	Rainfed cropland > Savannah		
3444			
3555			
3355	Rainfed cropland > Grassland		
3335			
3666			
3366	Rainfed cropland > Bare		
3336			
4222			
4422	Savannah > Forest		Change
4442			
5222			
5522	Grassland > Forest		
5552		Intensification of natural vegetation	
5444			
5544	Grassland > Savannah		
5554			
6555			
6655	Bare > Grassland		
6665			
2555			
2255	Forest > Grassland		
2225			
4555			
4455	Savannah > Grassland	Retrenchment of natural vegetation	
4445			
5666			
5566	Grassland > Bare		
5556			

Note: Codes used for change combinations

1	Irrigated croplands
2	Forest/Tree crops
3	Rainfed croplands
4	Savannah
5	Grassland
6	Bare land

At the highest level the change trends can be regrouped into three 'change categories' (Column 4 of Table 7):

1) Noise: change signal is not consistent
2) Stable: no change has occurred
3) Change: some consistent kind of change has occurred.

2.4. Area estimation

In order to calculate geometrically correct areas, the change map was reprojected from the Geodetic to the Sinusoidal projection in which each pixel represents an area of 64 km^2. To summarize regional trends, the CWANA area was divided into 8 regions. For each region the areas belonging to individual change combination, change classes and change trends were calculated. The results are summarized in Figures 23-30. In addition, Tables 8-22 in the Annex show the results for regions and individual countries. All areas are given in hectares. Given the low resolution of the pixels, the area calculations represent estimations and therefore need to be used with caution, particularly for individual and small countries.

3. LAND COVER/LAND USE CHANGE IN CWANA

3.1. Overview

3.1.1. Stability of land cover

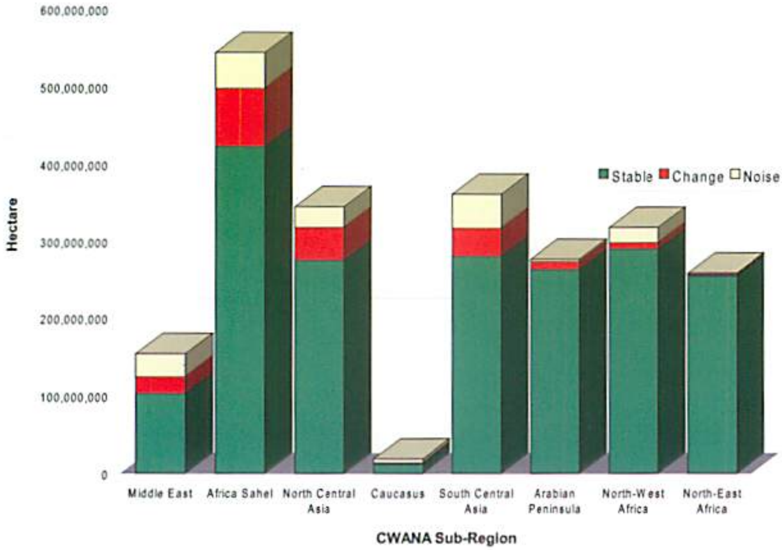

Figure 13. Stability of land cover (absolute)

In terms of land area, the most dramatic changes in land cover have occurred in the Sahel, followed by North Central Asia (Figure 13). In the former region approximately 75 million hectare changed from one land cover to another, in the latter 43 million hectare (Table 8). In relative terms, the regions where the most change occurred are the Middle East and the Sahel, where about 14% of the land cover changed (Figure 14).

A second conclusion is that, even in the regions with the highest change in land cover, *most of the land has remained stable*.

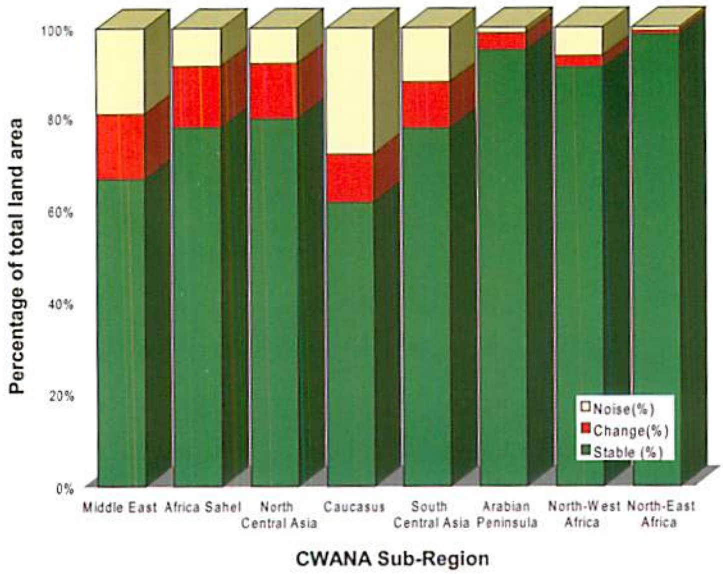

Figure 14. Stability of land cover(relative)

3.1.2. Kinds of change

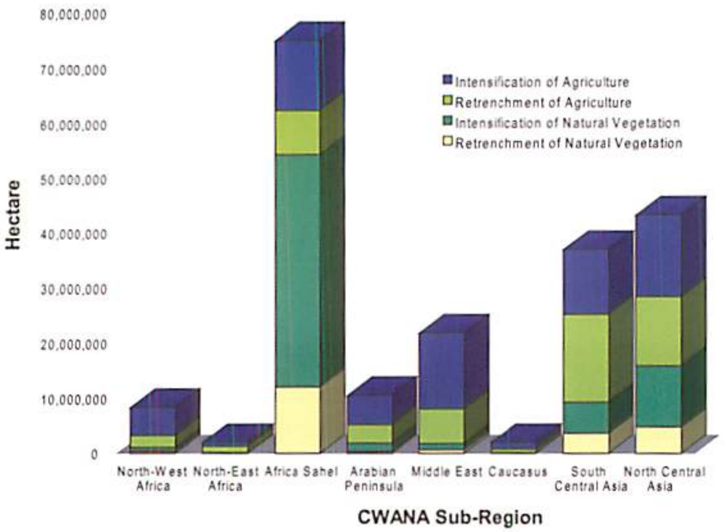

Figure 15. Kinds of changes (absolute)

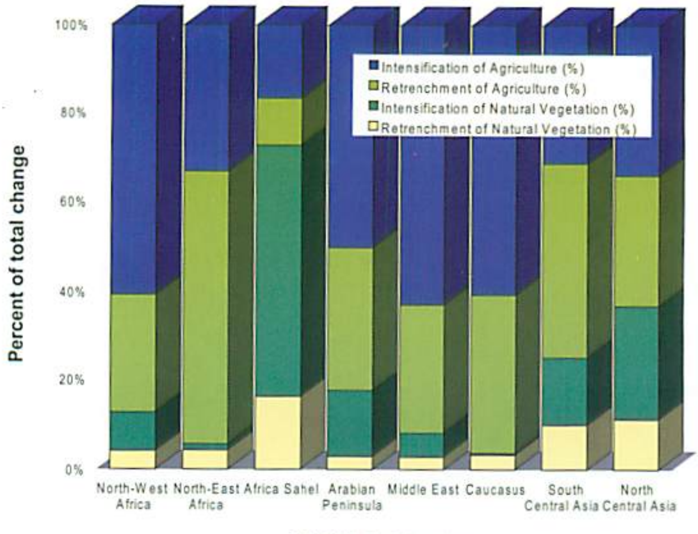

Figure 16. Kinds of changes (relative)

Figure 15 shows a remarkable greening trend of the natural vegetation in the Sahel, mimicked to a lesser extent in Central Asia. This greening trend is not important in the other sub-regions. In all sub-regions, with the exception of North-East Africa and the Caucasus, there is also a notable trend of intensification of agriculture. At the same time a trend of significant retrenchment of agriculture can be noted in Central Asia.

The Sahelian greening is all the more remarkable when compared to the total land area of the Sahel that has undergone change (Figure 16). Similarly, the scale of the retrenchment or intensification of agriculture in most sub-regions becomes obvious when related to the land areas in those sub-regions that underwent change.

3.1.3. Land use/land cover change trends

3.1.3.1. Intensification of agriculture

Changes to irrigated croplands
Figure 17 indicates that in most sub-regions the change to irrigated crops occurred by developing previously bare or sparsely vegetated areas. However, in North-West Africa and the Middle East, it was mainly by deforestation. In the Caucasus more rainfed crops were converted to irrigated croplands (Figure18), whereas in North Central Asia mainly grassland areas were converted.

Changes to rainfed croplands
The main changes to rainfed crops occurred in the Sahel and Central Asia

(Figure 19), in the former sub-region due to the conversion of savannas, in the latter due to the conversion of grasslands. The grasslands were also the major contributor to rainfed cropland in the Middle East, the Caucasus and North-East Africa (Figure 20).

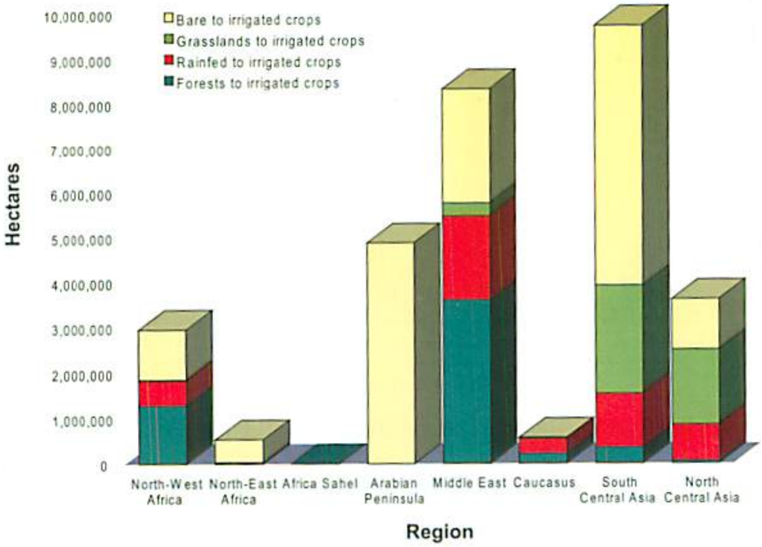

Figure 17. Increase of irrigated croplands (absolute)

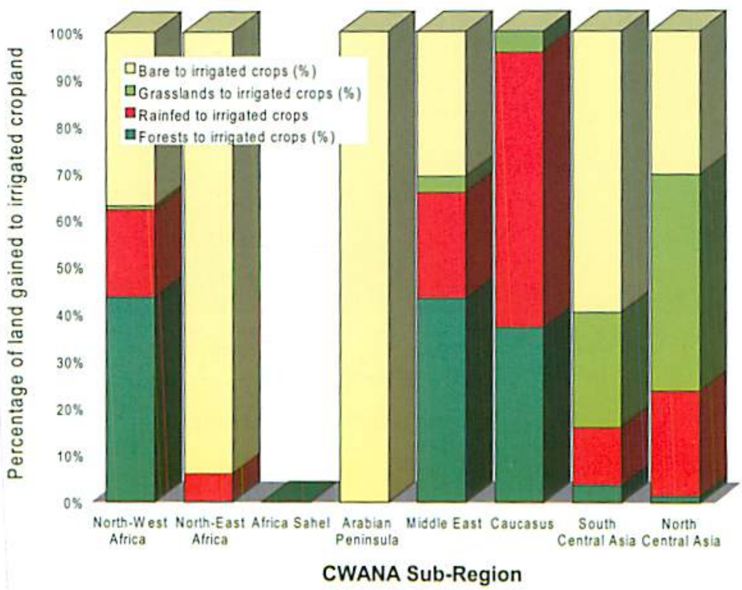

Figure 18. Increase of irrigated croplands (relative)

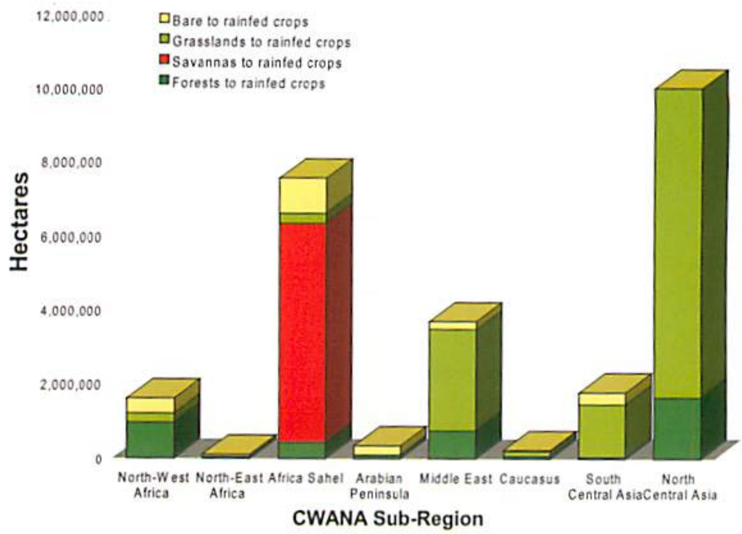

Figure 19. Increase of rainfed crops (absolute)

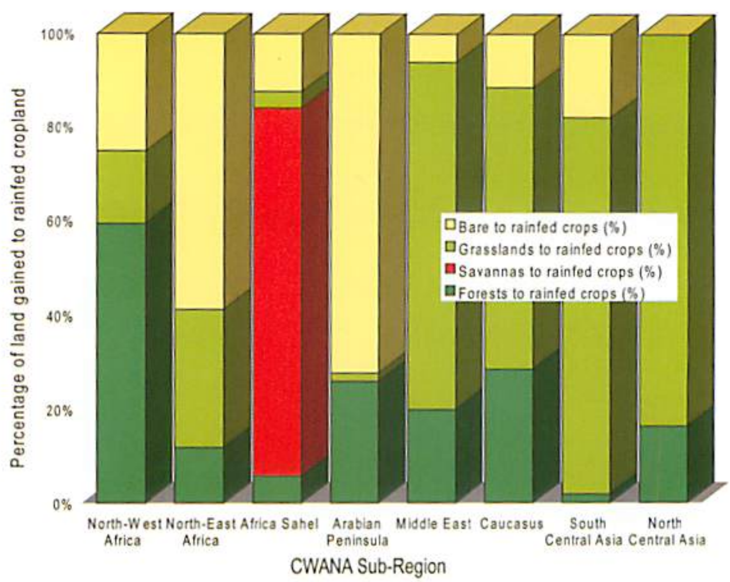

Figure 20. Increase of rainfed crops (relative)

3.1.3.2. Retrenchment of agriculture

Changes from irrigated croplands

Figure 21 indicates a pronounced decline in the irrigated croplands in South-Central Asia, most of it by reverting to either grasslands or bare/sparsely vegetated land (Figure 22). The decline is minimal in the Sahel and the Caucasus, and intermediate in the other regions.

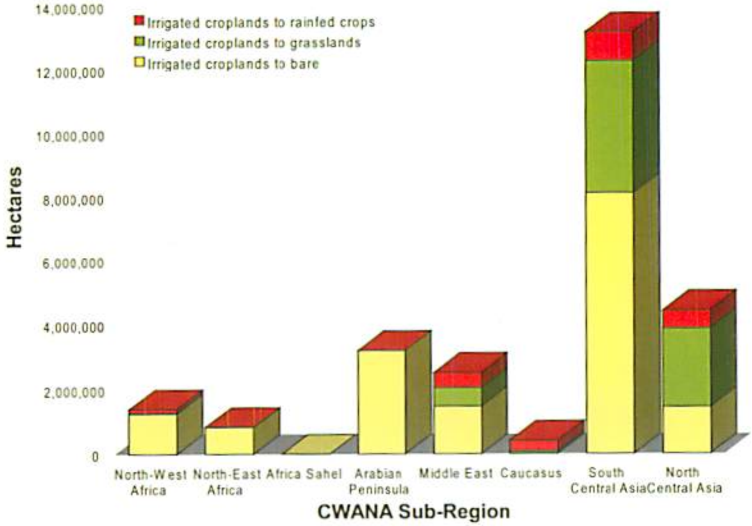

Figure 21. Decrease of irrigated croplands (absolute)

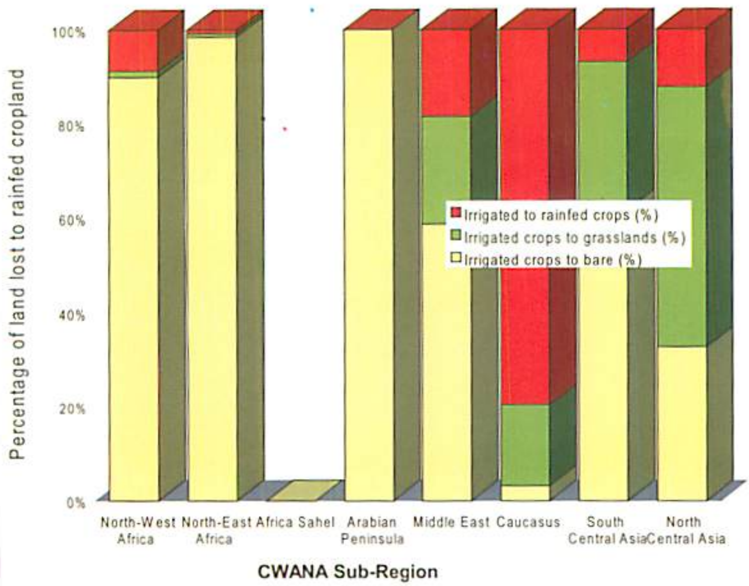

Figure 22. Decrease of irrigated croplands (relative)

Changes from rainfed croplands

The decline of rainfed croplands is most pronounced in the Sahel and North-Central Asia (Figure 23), where the main trend in the former sub-region is conversion into savanna, and into grasslands in the latter (Figure 24). The decline of rainfed croplands is minimal in North-East Africa, the Arabian Peninsula and the Caucasus, and intermediate in the Middle East and South-Central Asia (Figure 23).

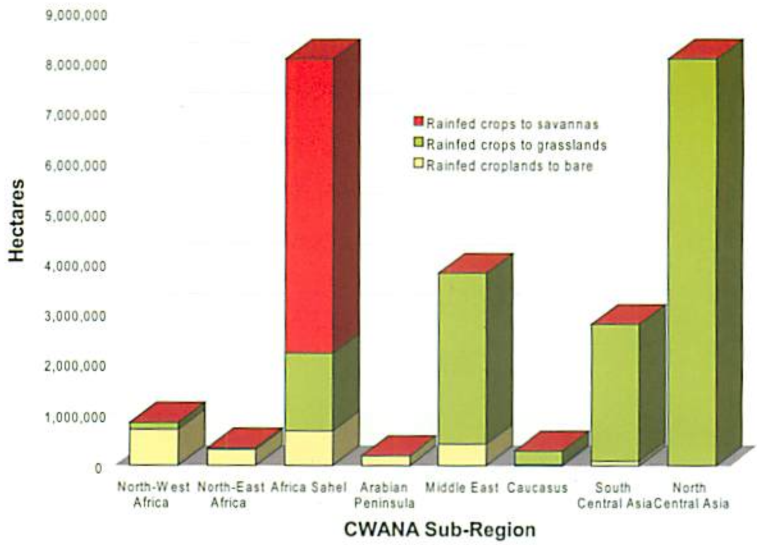

Figure 23. Decline of rainfed crops (absolute)

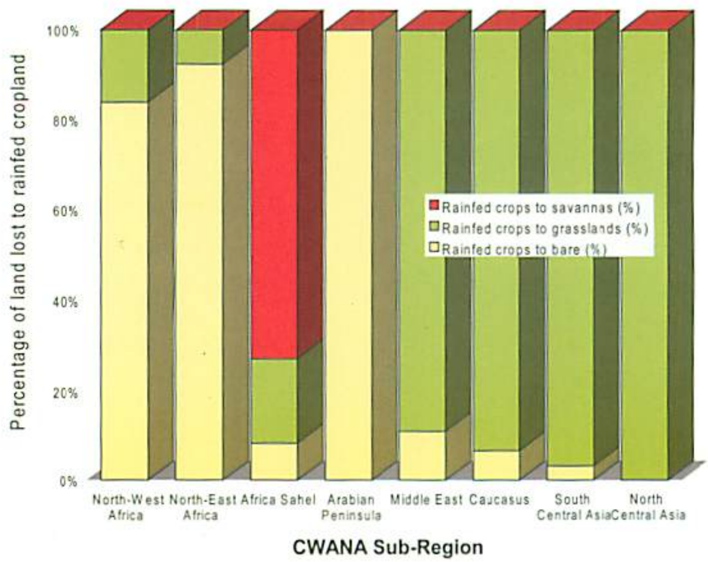

Figure 24. Decline of rainfed crops (relative)

3.1.3.3. Intensification of natural vegetation

A remarkable trend of biomass increase of the natural vegetation occurred in the Sahel, most of it due to the transition from bare/sparsely vegetated lands to grasslands, or, to a lesser extent, to savanna (Figure 25). Less pronounced intensification occurred in North-Central Asia, where it was mostly due to the transition from bare to grasslands, and in North-West Africa, where it was mostly due to transition to forests (Figure 26).

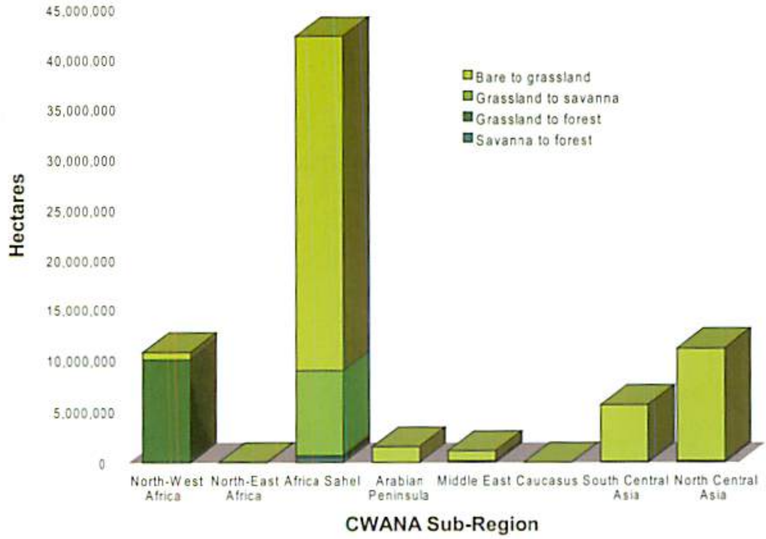

Figure 25. Intensification of natural vegetation (absolute)

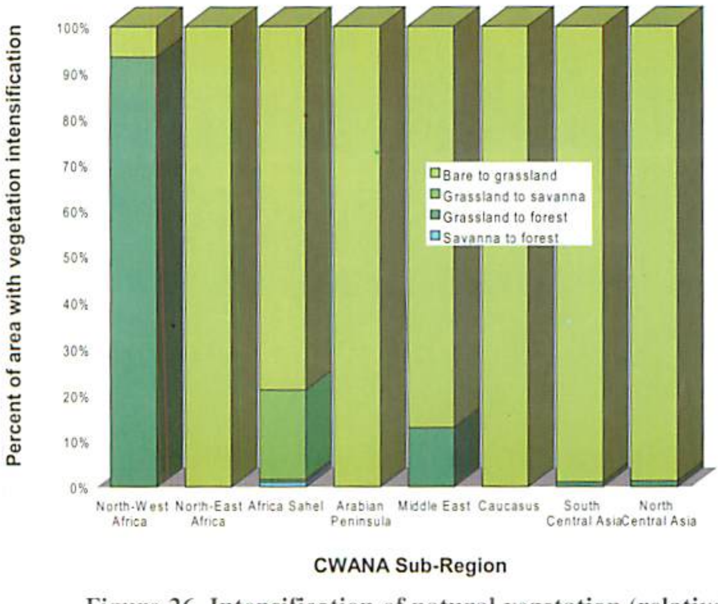

Figure 26. Intensification of natural vegetation (relative)

3.1.3.4. Retrenchment of natural vegetation

In parallel with the intensification trend observed in the Sahel, there has been in other parts of the Sahel a less extensive trend of retrenchment of the natural vegetation, mostly due to the conversion of savannas to grasslands, and to a lesser extent, of grasslands to bare or sparsely vegetated land. In other sub-regions the retrenchment trend has been less important.

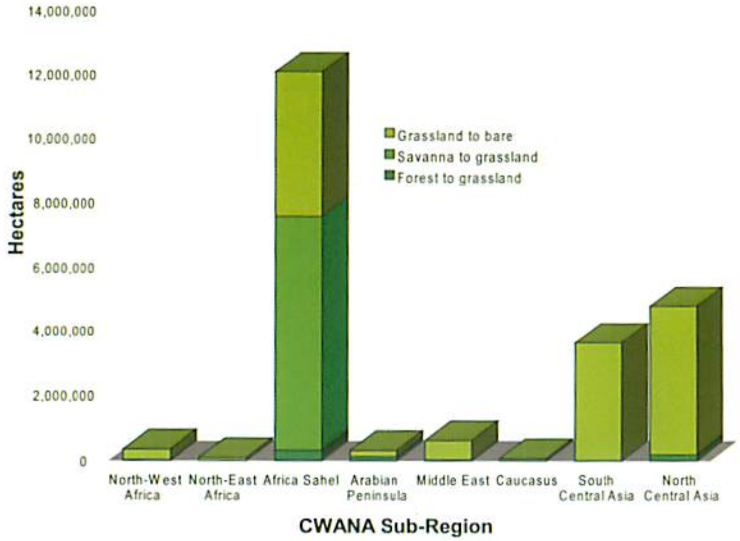

Figure 27. Retrenchment of natural vegetation (absolute)

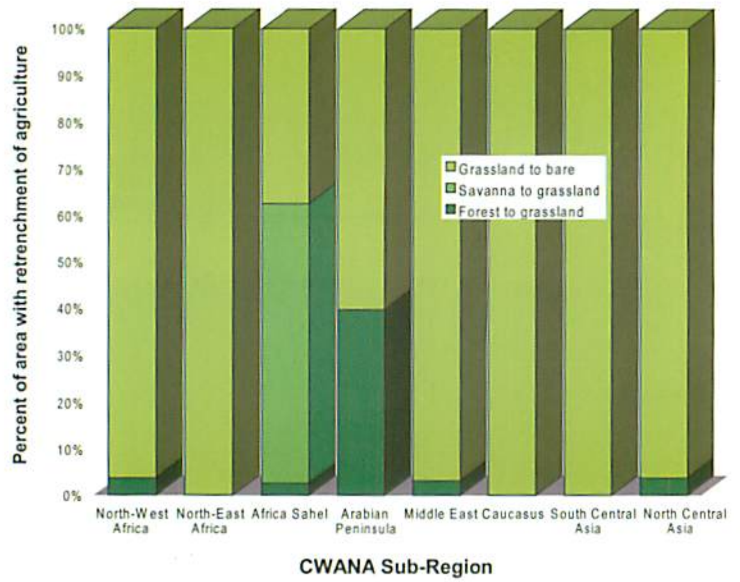

Figure 28. Retrenchment of natural vegetation (relative)

3.2. Sub-regional trends

In this section we look at the nature and extent of the changes at the level of the CWANA sub-regions, which show considerable differences.

3.2.1. North-West Africa (Maghreb)

Figure 29 summarizes the spatial distribution of land cover change trends in the Maghreb.

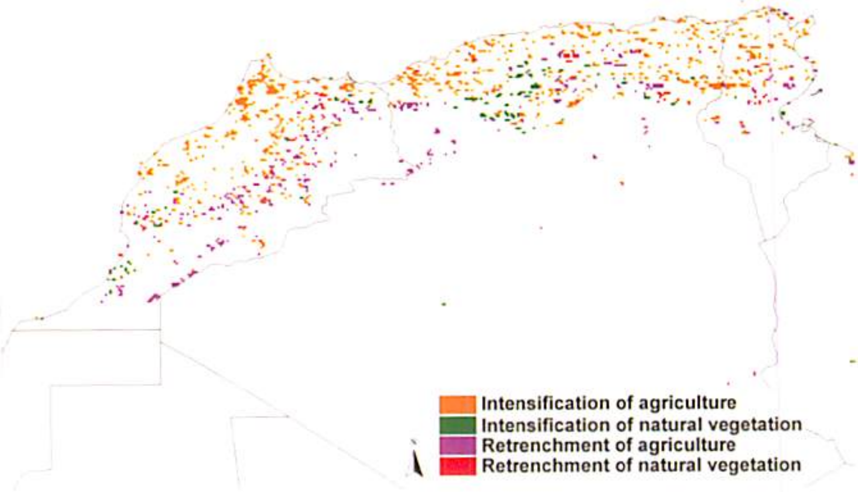

Figure 29. Spatial distribution of land cover change trends in the Maghreb

The main trend in the Maghreb is an intensification of agriculture (5,081,600 ha). This occurred mostly through deforestation to develop irrigated (1,286,400 ha) and rainfed cropland (960,000 ha) in the coastal zone, and by converting bare land into irrigated croplands (1,094,400 ha) inland.

A second trend involves a retrenchment of agriculture (2,240,000 ha), which occurred inland, where both rainfed (704,000 ha) and irrigated fields (1,260,800 ha) were taken out of cultivation to become barren/sparsely vegetated areas.

A third, less important, trend is one of intensification of the natural vegetation. This occurred mostly as a change from bare areas to grasslands/ open shrublands in the Atlas mountains of Algeria (480,000 ha). Also some retrenchment of the natural vegetation seems to have occurred on 345,600 hectares.

3.2.2. Egypt and Libya

The only noticeably trends in this sub-region are a retrenchment of agriculture on the right bank of the Nile (total 1,184,000 ha; irrigated cropland to bare land: 704,000 ha) and intensification of agriculture (total 646,400 ha; bare land to irrigated cropland in Egypt: 467,200 ha) on the western part of the Nile delta (Figure 30).

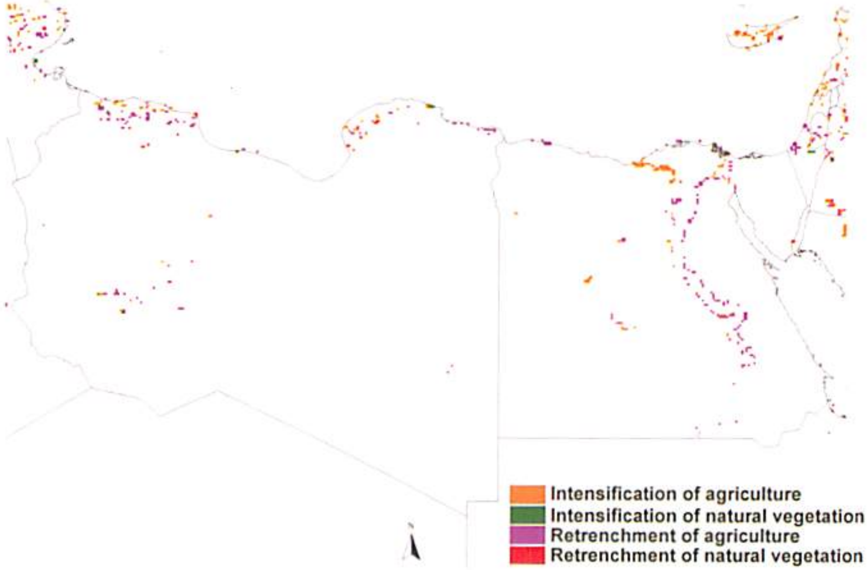

Figure 30. Spatial distribution of land cover change trends in Egypt and Libya

3.2.3. The Sahel and Horn of Africa

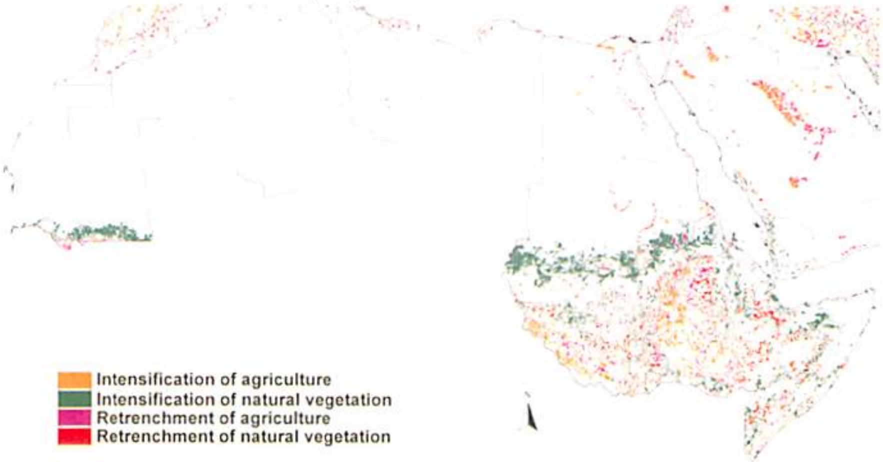

Figure 31. Spatial distribution of land cover change trends in the Sahel sub-region

The major trend in the Sahel sub-region (Figure 31 and Figure 32) was an intensification of natural vegetation (42,259,200 ha), mainly in the form of a change from barren/sparsely vegetated areas to grasslands/open shrublands (33,312,000 ha). In addition, 8,288,000 ha of grasslands/open shrublands changed into woodland savannah. In northern Sudan and Mauritania, the desert border shifted 100 to 150 km to the North.

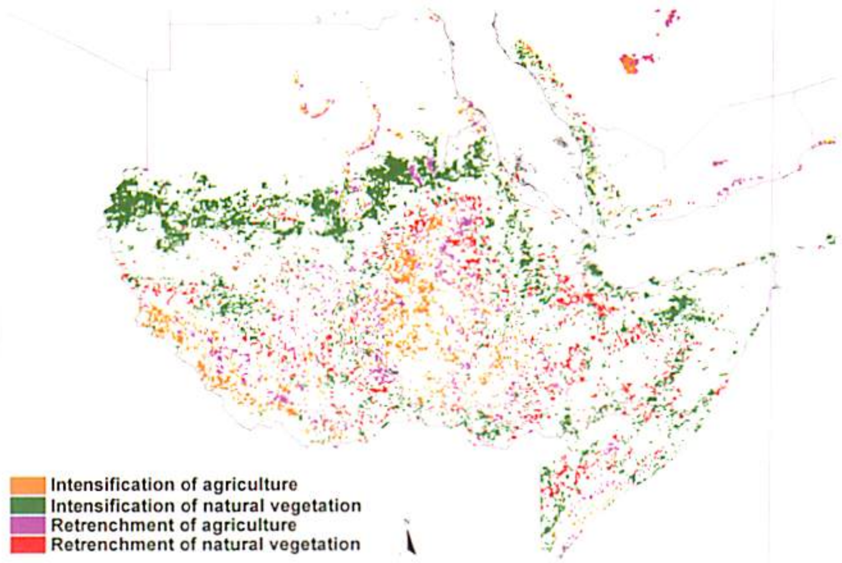

Figure 32. Spatial distribution of land cover change trends in the Horn of Africa

In contrast with this general Sahelian trend, a retrenchment of the natural vegetation occurred in scattered areas totaling 1,2096,000 ha. This occurred mainly in the form of a change from woodland savannah to grassland/open shrubland (7,264,000 ha) and, at the border between Somalia and Sudan, in the form of a change from grassland/open shrubland into barren/sparsely vegetated areas (4,524,800 ha).

Intensification of agriculture occurred on 12,550,400 ha in Southwest Sudan and West Ethiopia, in the form of a change from rainfed field crops to tree crops (4,972,800 ha) or from woodland savannah to rainfed field crops (5,932,800 ha). In the center of both Sudan and Ethiopia, a retrenchment of agriculture occurred on 8,076,800 ha, mainly in the form of a change from rainfed field crops to woodland savannah (5,881,600 ha).

3.2.4. The Arabian Peninsula

During the period 1982-1998 two contrasting trends of land cover change are observed in the Arabian Peninsula (Figure 33). A first trend of intensification of agriculture is due to the fact that since 1982 huge areas (4,883,200 ha) were converted into irrigated croplands, mostly in Saudi Arabia (4,422,400 ha). In the same period a trend of retrenchment of agriculture is caused by the fact that large irrigated areas (2,732,800 ha) were also taken out of cultivation in Saudi Arabia (38,400 ha between 1984 and 1987, 832,000 ha between 1989 and 1992, and 1,862,400 ha between 1995 and 1997).

Intensification of the natural vegetation occurred at the edges of the Asir and Yemen Highlands in the form of a change from barren/sparsely vegetated areas to grassland/open shrublands (1,536,000 ha).

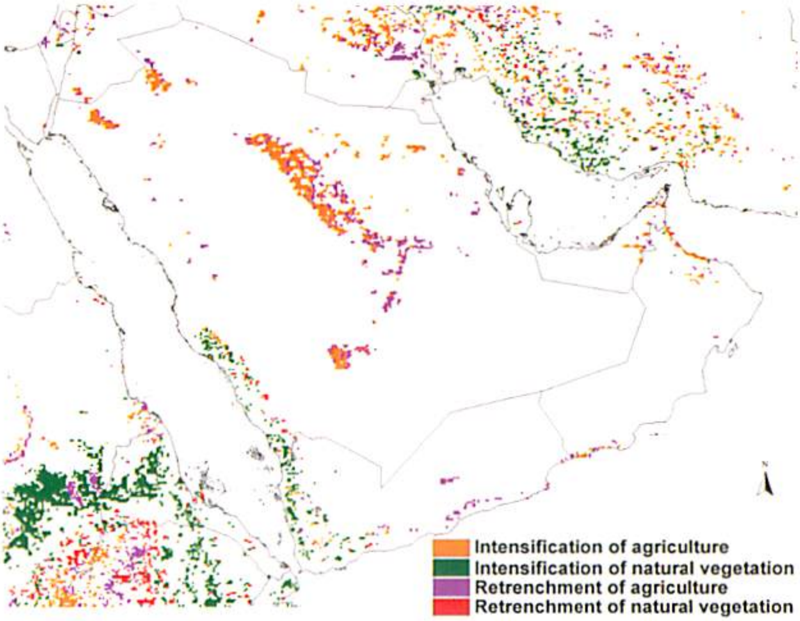

Figure 33. Spatial distribution of land cover change trends in the Arabian Peninsula

3.2.5. West Asia and the Caucasus

The change trends in West Asia and the Caucasus are mapped in Figure 34. In relation to its size, West Asia is the sub-region with the highest degree of land cover change in the period 1982-1999 (Figure 14). Of the different change trends, intensification of agriculture is the most important one. Intensification occurred both towards irrigated (8,332,800 ha) as well as rainfed cropland (5,376,000 ha). At the coast of Turkey and Syria deforestation occurred to establish irrigated fields (3,603,200 ha), in North-East Syria rainfed cultivation intensified to irrigated cultivation (1,868,800 ha), and in Iraq barren/sparsely vegetated areas were taken into irrigation (2,560,000 ha). In central Turkey, grasslands/open shrublands were taken into rainfed cultivation (2,758,400 ha).

Retrenchment of agriculture (total 6,348,800 ha) occurred mostly in inland Turkey, in the form of a change from rainfed cultivation to grasslands/open shrublands (3,398,400 ha), and in Iraq in the form of irrigated fields taken out of cultivation by change to barren/sparsely vegetated areas (1,484,800 ha).

In the Caucasus intensification of agriculture (total 1,184,000 ha) occurred mostly in the form of a change from rainfed fields to either tree crops (390,400 ha) or irrigated fields (332,800 ha). A retrenchment of agriculture (total 697,600 ha) occurred mainly in the form of a change from irrigated fields to rainfed fields (326,400 ha) or from rainfed fields to grasslands/open shrublands (268,800 ha).

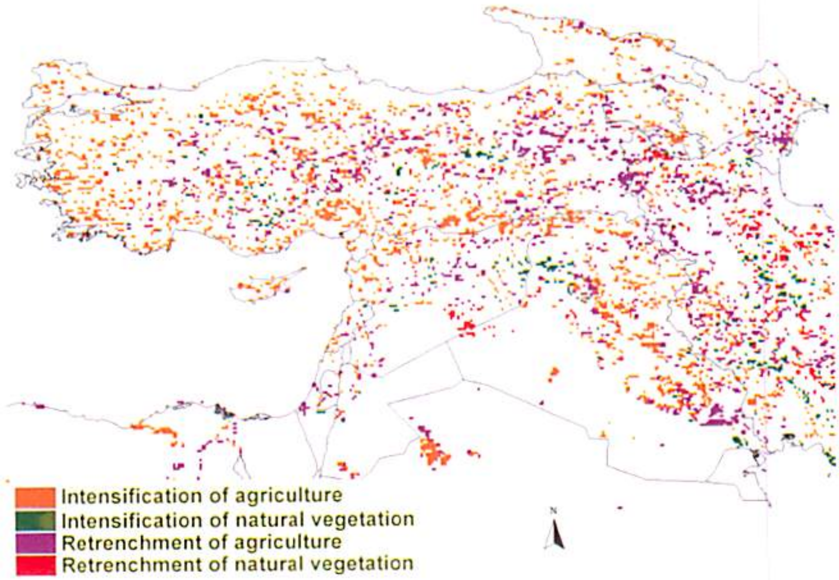

Figure 34. Spatial distribution of land cover change trends in West Asia and the Caucasus

3.2.6. Central Asia

All major land cover change trends in Central Asia (Figure 35) involve grasslands/open shrublands. An intensification of agriculture occurred on 14,752,000 ha, mostly in the form of a change from grasslands/open shrublands into rain-fed cultivation (8,416,000 ha).

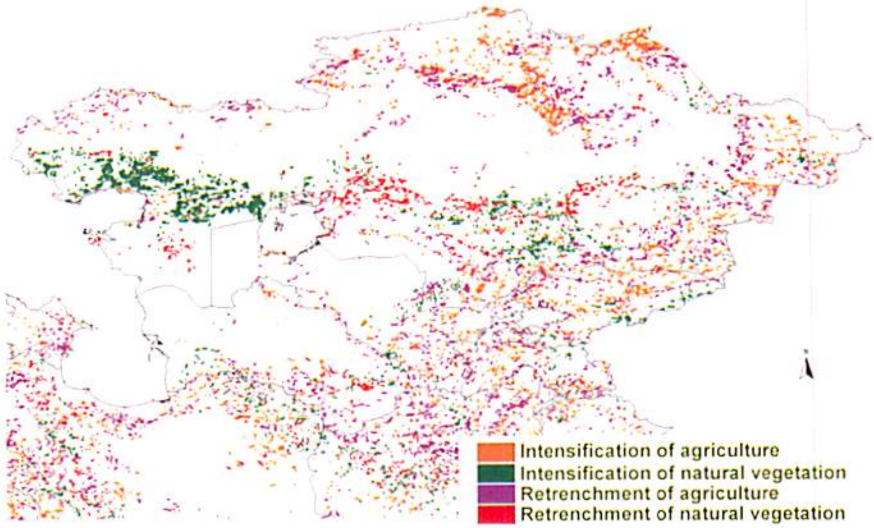

Figure 35. Spatial distribution of land cover change trends in Central Asia

The inverse trend, a change from rainfed cultivation to grasslands/open shrublands, occurred on 8,096,000 ha and is the major component of the retrenchment of agriculture (12,524,800 ha). Intensification of natural vegetation occurred on 11,104,000 ha, almost all (10,969,600 ha) as a result of change from barren/sparsely vegetated areas to grasslands/open shrublands. This intensification trend is very noticeable in Southwest Kazakhstan near the Caspian Sea. The inverse trend, a change from grasslands/open shrublands into barren/sparsely vegetated areas, occurred on 4,627,200 ha and is particularly clear in Central Kazakhstan.

3.2.7. Southwest Asia

The main trend in Southwest Asia is one of retrenchment of agriculture (Figure 36). This trend covers about 15,968,000 ha and is particularly noticeable in Pakistan and Afghanistan. In about 8,115,200 ha irrigated croplands reverted to barren/sparsely vegetated areas, mostly in Pakistan, whereas about 4,147,200 ha reverted from irrigated croplands to grasslands/open shrublands, particularly in Afghanistan.

Intensification of agriculture occurred throughout the sub-region without any particular focus. This trend was observed in about 11,603,200 ha, of which 5,811,200 ha changed from barren/sparsely vegetated areas to irrigated croplands. Intensification of natural vegetation occurred in a smaller area (5,644,800 ha) and almost entirely (5,587,200 ha) as a result of change from barren/sparsely vegetated areas into grasslands/open shrublands.

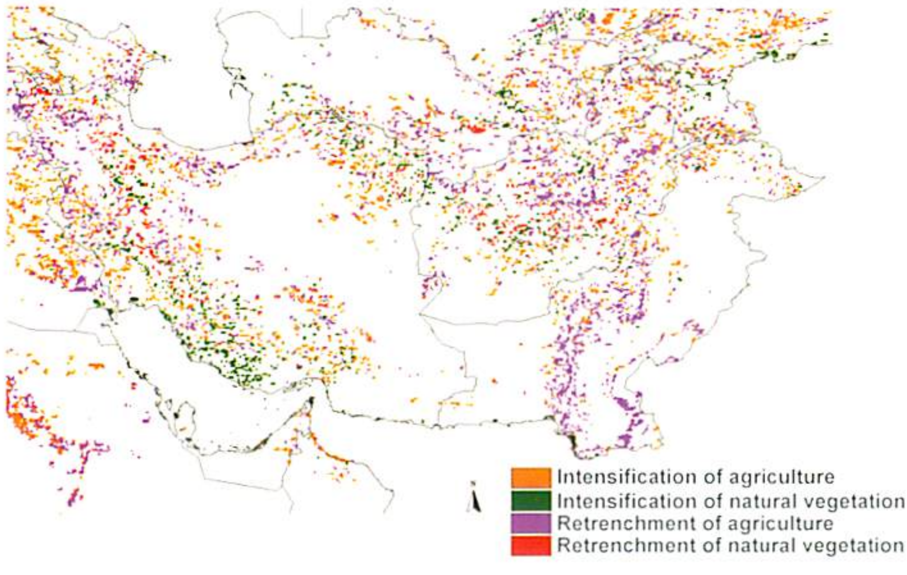

Figure 36. Spatial distribution of land cover change trends in Southwest Asia

3.3. Interpretation

A first issue to consider in the interpretation of the results is the resolution of the imagery used. The 8-km grid cell resolution of the Pathfinder dataset entails that in many situations the pixels are not internally homogeneous in their land use/land cover categories. This would certainly be the case in agricultural areas, where rotation practices ensure proximity between fields under crops and fallow areas. For such mixed pixels the total reflectance is the sum of the relative reflectance contributions by all elements in the pixel. For this reason the area estimates of land use/land cover changes provided in the previous sections are only indicative. Since the majority land cover class in each 3-year period takes all the area of the pixel, even if it only occurs on a fraction of it, it may be overestimated. On the other hand the areas of minority classes are not taken into account and may thus be underestimated.

Another concern is the interpretation of the observed land use/land cover changes in terms of causes, triggers and degradation trends in different parts of the CWANA region.

In the Sahel the likely reason for the trend towards intensification of natural vegetation is a recovery of the natural vegetation, after the drought, experienced in the Sahel between 1961 until 1984, was followed by a period with normal rainfall. This greening of the Sahel' has been described by many authors (e.g. Hellden, 1988; Tucker et al., 1991, Olsson et al., 2005). The northward shift of the desert boundary after 1984, also described by Tucker (Tucker et al., 1991) can therefore be interpreted as a regeneration of the grasslands/open shrublands when rainfall returned to normal after the long drought cycle. Anyamba and Tucker (2005) associate the recovery of the Sahelian vegetation with the transition from a high-deficit precipitation regime in the early part of the time series (1982-85) to a slight surplus pattern at the end (1994-99). However, it is not certain that a decadal-scale precipitation cycle is the only factor involved. Herrmann et al. (2005) hypothesizes a human-induced trend on top of the climatic trend, whereas Olsson et al. (2005) considers the possibility of a contribution from migration and land use changes.
As for the trends in agriculture, intensification in the southwest of Sudan and the west of Ethiopia, retrenchment in the center of both Sudan and Ethiopia, no clear explanation suggests itself. In Ethiopia the areas with retrenchment of agriculture coincide with areas affected by severe drought in the early 1980s. It is therefore possible that the intensification of agriculture in western Ethiopia is due to settlement and agricultural development in parts of the country that were less affected by the drought.

In the Arabian Peninsula the area under irrigation more than doubled between 1980 and 1996 (FAO, 2001), aided by the use of modern irrigation technology, such as center-pivot and drip irrigation. Spectacular growth in irrigated agriculture occurred mostly in the center of Saudi Arabia, with barely any irrigated areas in 1983 and ten years later reaching their maximum extent (De Pauw, 2002). This trend towards intensification of agriculture was driven by pumping fossil water, itself made possible by generous government subsidies on fuel for well drilling (FAO, 1997).

The reverse trend, retrenchment of agriculture, is the mirror image of the intensification trend. It was caused by the fact that large irrigated areas were also taken out of cultivation in Saudi Arabia, initially due to the depletion of the fossil aquifers and, as the unsustainability of the practices became clear to the government, by policy changes in respect of groundwater use. From the change analysis it appears about 400 km^2 was taken out of production between 1984 and 1987, 8,300 km2 between 1989 and 1992, and the largest contingent (18,600 km^2) between 1995 and 1997. The policy reversal, stopping fuel subsidies to save water and conserve the environment, came in 1994 (O'Sullivan, 1994). This is another example, in addition to the case studies reported by Nielsen and Adriansen (2005), of how government policies can impact on the spread or containment of land degradation.
The observed intensification of natural vegetation at the edges of the Asir and Yemen Highlands is probably related to increased rainfall after the Sahelian drought.

With some notable exceptions, the change patterns in other sub-regions are more fragmented. A first exception is a clear linear intensification trend of the natural vegetation in Central Asia, resembling in pattern, but at smaller scale, the Sahelian greening. With focus north of the Caspian Sea and extending along parallel 48°N to the west of the former Aral Sea, there is no clear explanation for this trend in the literature. It is possible that the trend is related to the decline of livestock herds and corresponding decrease in grazing intensity after the collapse of the Soviet Union in the early 1990s, a cause proposed for the NDVI patterns in other parts of Kazakhstan (de Beurs and Henebry, 2004).

A second exception are the trends of intensification and retrenchment of agriculture in the Nile Valley in Egypt, with a clear pattern of retrenchment along the right bank of the Nile, mirrored to a lesser extent on the left bank of the Nile, and an intensification trend west of the Nile delta. This area coincides with the 'Mubarak' land reclamation project, which was initiated in 1987, as reported by Nielsen et al. (2005). The areas with retrenchment of agriculture along both banks of the Nile are probably related to urban encroachment and expansion of public infrastructure. Urban expansion at the expense of agricultural land is a long-term trend in Egypt, comprehensively documented by El Hefnawi (2005), and its extent has been quantified in several case studies using remote sensing with higher-resolution data (e.g. Lenney et al., 1996; Ghar et al., 2005).

In Pakistan a clear trend of retrenchment of agriculture is evidenced in two distinct strands, one running along the Kirthar, central Brahui and Sulaiman ranges in Balochistan Province, the other one bordering the Thar desert in Sindh Province. These arid to semi-arid areas are well known for resource and degradation problems, such as deforestation, sand encroachment, falling water tables, and soil erosion (e.g. Government of Pakistan et al., 2000; International Union for Conservation of Nature and Natural Resources et al., 2000). However, given the general lack of resource inventories there is no direct evidence linking these problems to the observed retrenchment trend.

3.4. Conclusions

The results of the land use/land cover change assessment in the CWANA region are summarized in Table 8.

Table 8. Summary of land cover/land use stability and change trends 1982-1999 in CWANA by sub-region (areas in km²)

Sub-region	Stability/Change			Change trends			
	Stable	Change	Noise	IA	RA	INV	RNV
North-West Africa	2,907,004	83,712	203,328	50,816	22,400	7,040	3,456
North-East Africa	2,554,686	19,392	21,632	6,464	11,840	256	832
Africa Sahel	4,232,252	749,824	458,368	125,504	80,768	422,592	120,960
Arabian Peninsula	2,636,992	105,408	34,240	52,928	34,048	15,360	3,072
West Asia	1,024,512	218,112	296,512	137,088	63,488	11,392	6,144
Caucasus	114,688	19,520	52,224	11,840	6,976	64	640
South-West Asia	2,810,688	368,576	444,352	116,032	159,680	56,448	36,416
Central Asia	2,754,040	431,872	272,320	147,520	125,248	111,040	48,064
TOTAL CWANA	19,034,862	1,996,416	1,782,976	648,192	504,448	624,192	219,584

Notes: IA: intensification of agriculture; RA: retrenchment of agriculture; INV: intensification of natural vegetation; RNV: retrenchment of natural vegetation.

At the onset of this study it was expected that within CWANA two major trends in land use/land cover change occur: intensification of agriculture and land degradation, as evidenced by biomass decline in both natural vegetation and agriculture. However, the analysis of the 1982-2000 AVHRR time series indicates a more complex picture, with some remarkable and often unexpected trends of land use/land cover change in different sub-regions.
In most sub-regions intensification of agriculture is a major, if not the predominant trend. Particularly the Near East has experienced a remarkable degree of intensification of agriculture, predominantly by the conversion of rainfed into irrigated croplands.

A general conclusion is that, even after the year-to-year weather variations were compensated for, it is still difficult to understand the causes of the land cover changes. An intensification of agriculture is the easiest to interpret because it is always human-induced. On the other hand, a retrenchment of agriculture can have three possible causes: a long term weather change, a lack of inputs to maintain the cultivation or a degradation of the natural resource base (too intensive use of natural resources). Both the intensification and the retrenchment of natural vegetation could be either human-induced or result from a longer-term change in weather. The identification of a trend towards denser natural vegetation proves the possibility of natural regeneration and puts the issue of land degradation in a more positive perspective.

The biggest limitation of this study is the grouping of the classes 'bare ground' and 'sparsely vegetated areas' into one class (due to the extreme difficulty of separating them at 8-km resolution). Important changes from one to the other subclass, reflecting either intensification or retrenchment of vegetation, result as stable 'barren/sparsely vegetated areas'.
The areas, which result from the classification, are only indicative because the majority land cover class gets all the area of the pixel even if it only occurs on a fraction of it. On the other hand the areas of minority classes are not taken into account.

4. ASSESSMENT OF RESPONSE AND VULNERABILITY TO CLIMATIC FLUCTUATIONS

4.1. General

As Figure 9 demonstrated, the good correlation of the maximum NDVI for each year of record with critical climatic factors (precipitation and temperature), makes it a suitable indicator to assess the response of vegetation, natural or crops, to weather fluctuations, particularly precipitation (Figure 8). This added benefit of the AVHRR NDVI time series is all the are useful given the fact that, with the exception of coarse-grid data[3] , there is no complete dataset of meteorological data covering the entire CWANA region for a long time series at a sufficient spatial resolution.

4.1. Methodology

For 17 years, from 1982 until 2000 (with 1994 missing), the maximum NDVI was calculated. The mean and standard deviation were extracted from these 17 values in order to calculate the coefficient of variation (CV). The CV of the maximum NDVI is a measure of the fluctuations in agricultural or natural

[3] E.g. from the Climate Research Unit (CRU), Reading, UK:http://www.cru.uea.ac.uk/cru/data/hrg.htm

biomass. To ensure that the CV does not result from land use changes, and hence is attributable to variations in climatic conditions, only CV-values for pixels with stable land cover over time were retained. Figure 37 (a) gives an example for Syria, with the grey color showing the areas where land cover change has occurred during the period 1982-2000. In order to reduce noise and smoothen the map, a 3x3 median filter was applied.

Finally, the missing pixels were filled up using a rudimentary interpolation technique. In different iterations, pixels without CV-values (in grey) were replaced by the average of those neighbouring pixels, which had a CV-value (minimum of 2 neighbors), until all pixels obtained a CV-value. Figure 37(b) illustrates the result for Syria. Only East Pakistan remained without values after 25 iterations.

4.2. Results

The regional maps obtained according to the methodology in section 4.1, are shown in Figures 38-44. The CWANA map of vegetation response and vulnerability to climatic fluctuations over the period 1982-1999 is shown in Annex 9. The CV-values are in the range 0-20%, with low values (0-6.5%) indicated by pastel colors and 'hot-spots' by yellow, orange or red color (CV: 6.5-20%). The CV values are proxy indicators of biomass variability due to climatic variations. With increasing CV of the maximum NDVI, the vegetation becomes more responsive and, at the same time, more vulnerable to unfavourable climatic conditions.

The results need to be interpreted as 'relative' rather than absolute indicators of vulnerability to drought.

It is to be noted that the CV-values for the maximum NDVI are not as high as the coefficients of variation of precipitation in CWANA. The main reason is that the CVs indicate a response to the fluctuations of natural causative factors, hence, depending on the resilience of the vegetation or agricultural system, the response will be less pronounced than the causative agent.

Caution is also necessary in interpreting the map patterns arising from the masking of pixels, in which land use changes have occurred, by interpolated values.
From these maps, it appears that 'hot-spots' of response and vulnerability to climatic fluctuations in CWANA are fairly confined in CWANA, and to be found mainly in the following areas:

- Central Morocco
- The Sahel in Darfur and Eastern Sudan, the Ogaden and Afar Triangle in Ethiopia
- The grain belt of northeastern Syria and northern Iraq.

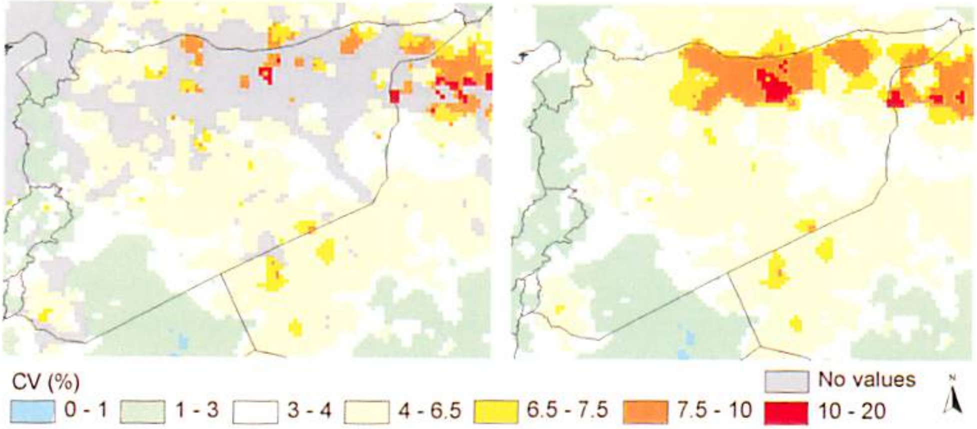

Figure 37. CV-values in Syria before (left) and after 25 interpolation iterations (right)

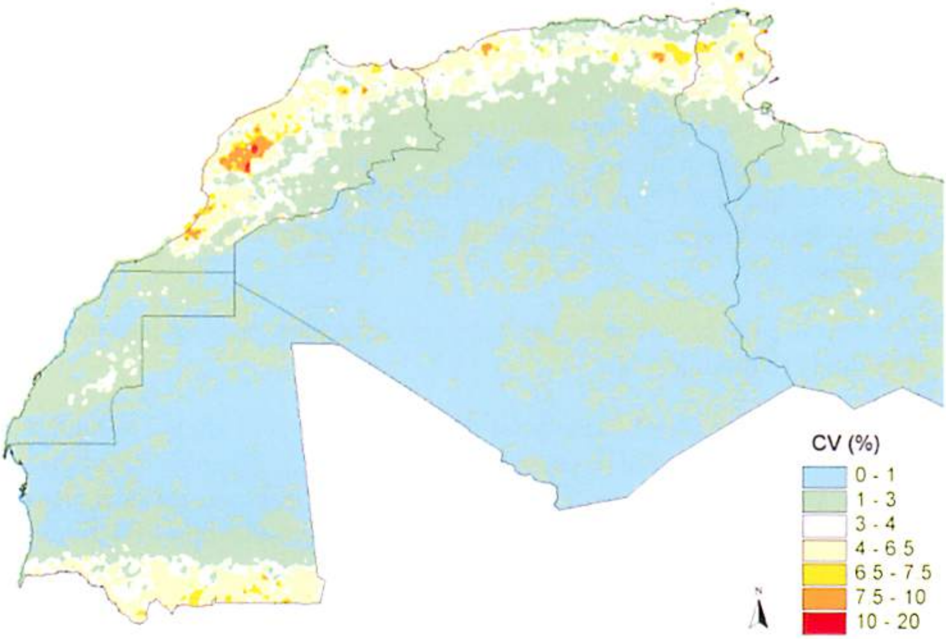

Figure 38. Spatial distribution of biomass fluctuations in Northwest Africa

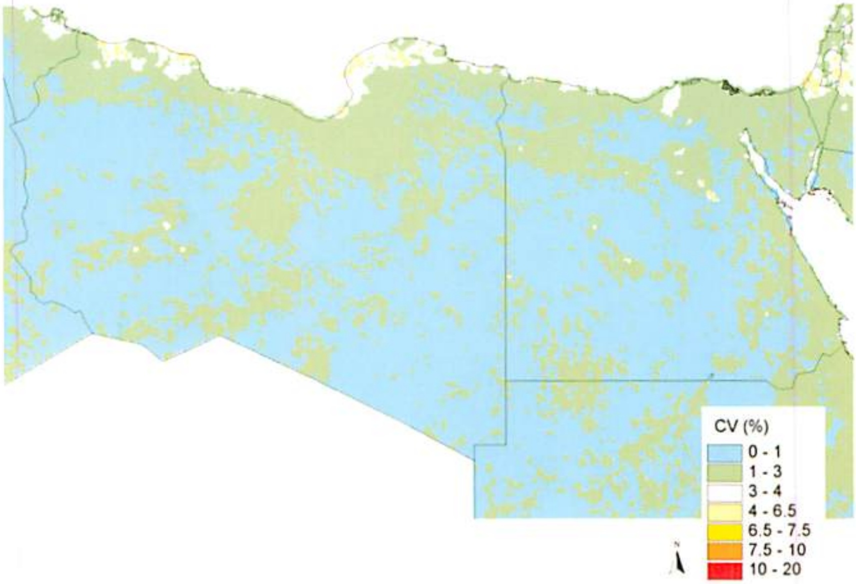

Figure 39. Spatial distribution of biomass fluctuations in Northeast Africa

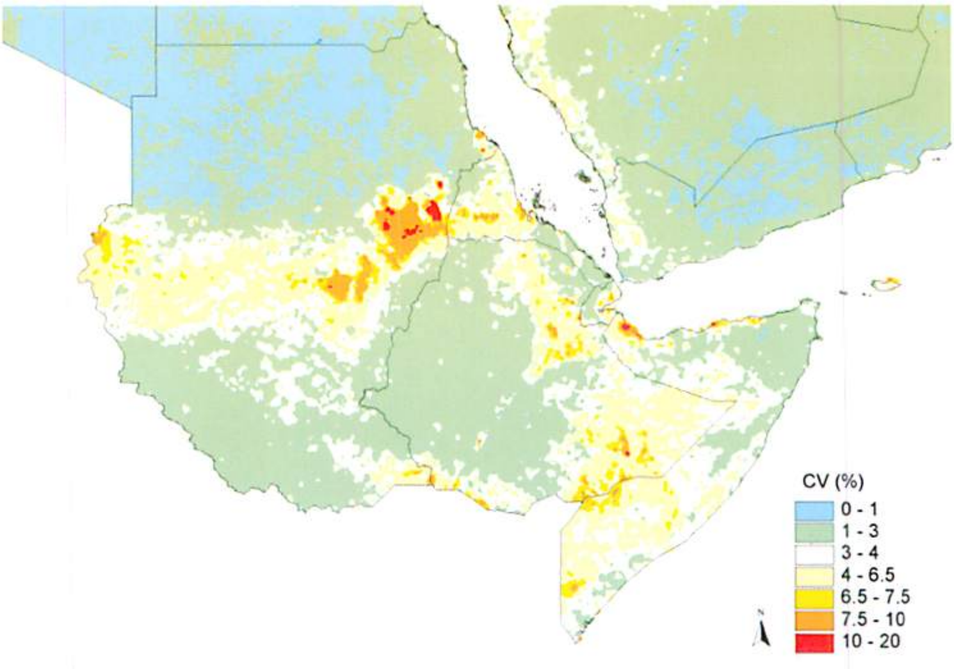

Figure 40. Spatial distribution of biomass fluctuations in the Horn of Africa

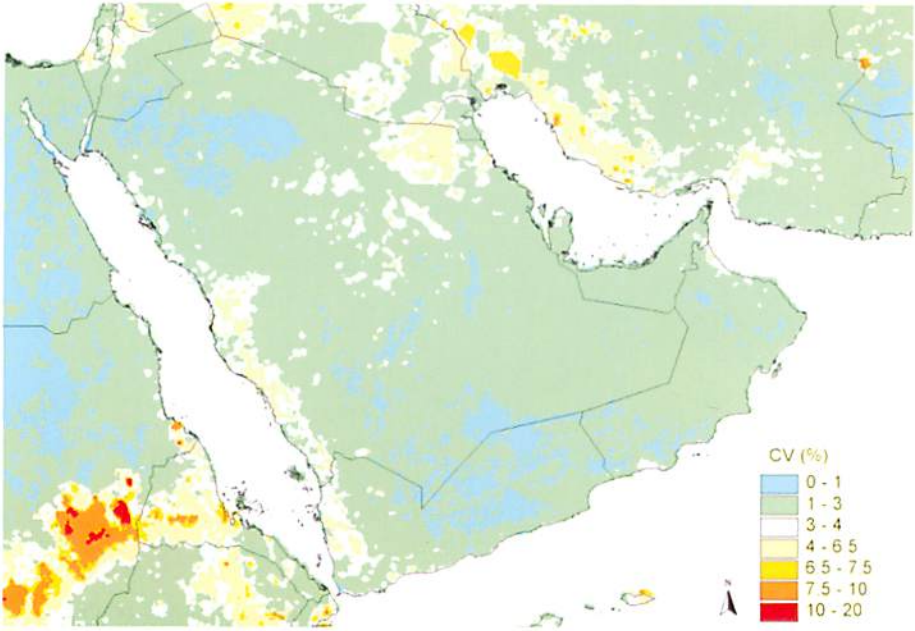

Figure 41. Spatial distribution of biomass fluctuations in the Arabian Peninsula

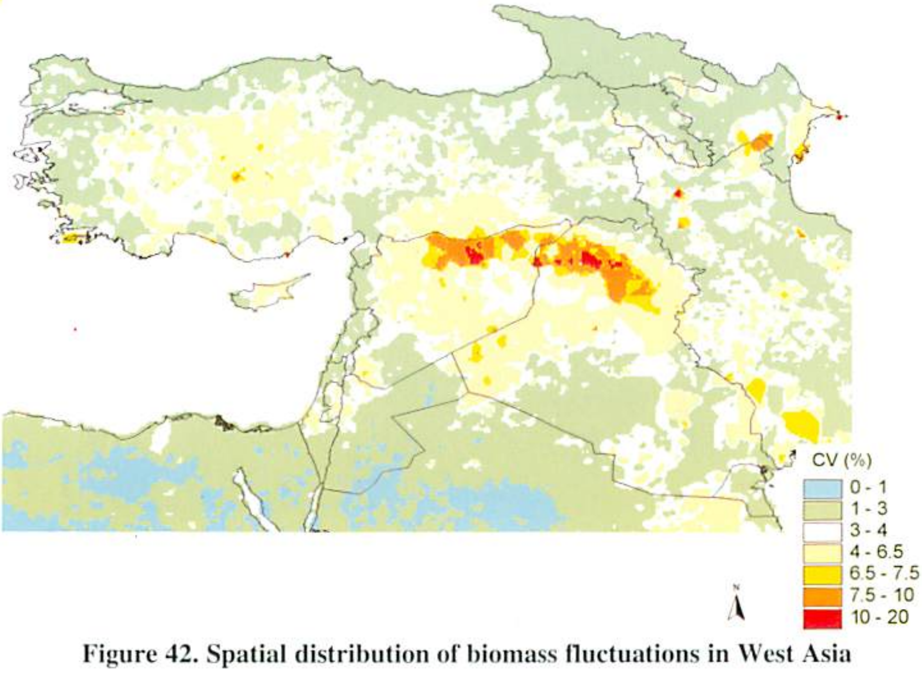

Figure 42. Spatial distribution of biomass fluctuations in West Asia

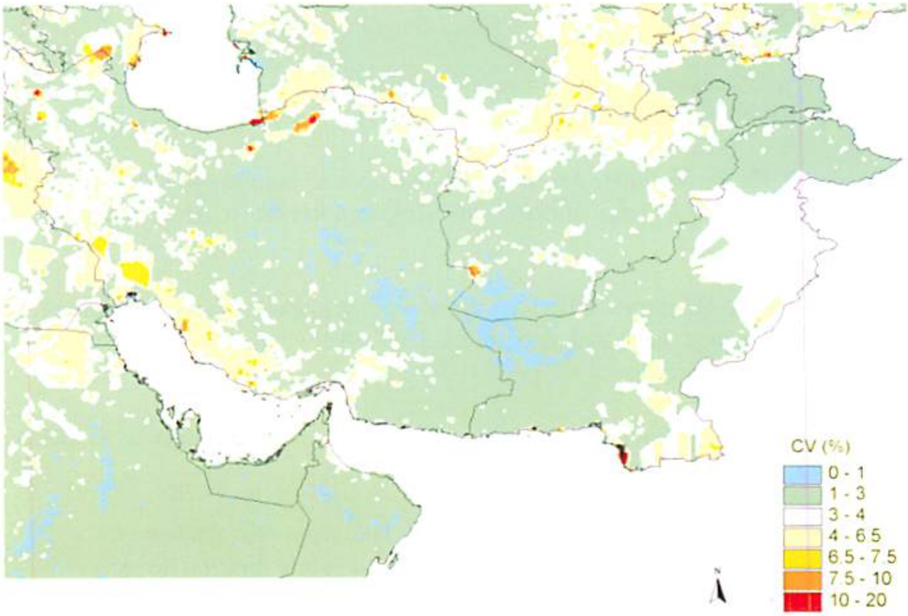

Figure 43. Spatial distribution of biomass fluctuations in Southwest Asia

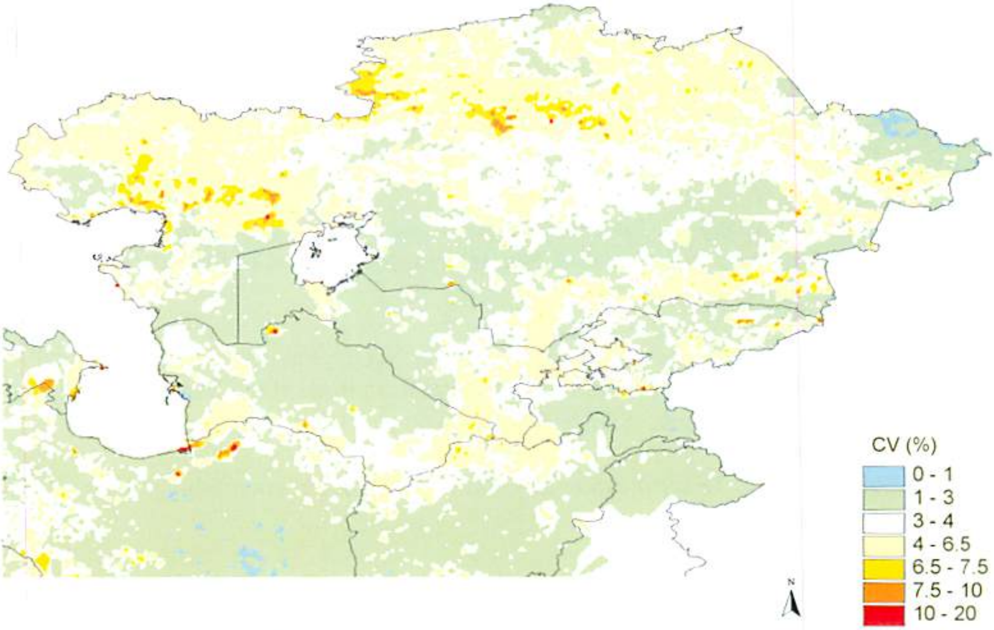

Figure 44. Spatial distribution of biomass fluctuations in Central Asia

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ANNEX 1. SUMMARY STATISTICS OF LAND COVER CHANGES

Table 9. Overview for CWANA: areas (hectare) per country for the three major change categories

Country	Change categories			
	Stable	Change	Noise	Total
Morocco	27,116,800	3,718,400	9,427,200	40,262,400
West. Sahara	26,425,600	0	128,000	26,553,600
Algeria	225,580,400	3,692,800	7,948,800	237,222,000
Tunisia	11,577,600	960,000	2,828,800	15,366,400
North-West Africa	**290,700,400**	**8,371,200**	**20,332,800**	**319,404 ,400**
Libya	159,180,600	697,600	1,510,400	161,388,600
Egypt	96,288,000	1,241,600	652,800	98,182,400
North-East Africa	**255,468,600**	**1,939,200**	**2,163,200**	**259,571,000**
Sudan	186,047,600	36,320,000	27,424,000	249,791,600
Ethiopia	78,860,800	20,595,200	12,486, 400	111,942,400
Eritrea	10,208,000	2,451,200	179,200	12,838,400
Djibouti	1,920,000	256,000	0	2,176,000
Somalia	49,932,800	8,793,600	4,428,800	63,155,200
Mauritania	96,256,000	6,566,400	1,318,400	104,140,800
Africa Sahel	**423,225,200**	**74,982,400**	**45,836,8 00**	**544,044,400**
Yemen	38,009,600	1,478,400	1,625,600	41,113,600
Oman	30,585,600	518,400	102,400	31,206,400
U.A.E.	7,417,600	256,000	44,800	7,718,400
Bahrain	1,094,400	25,600	6,400	1,126,400
Kuwait	1,580,800	0	12,800	1,593,600
Saudi Arabia	185,011,200	8,262,400	1,632,000	194,905,600
Arabian Peninsula	**263,699,200**	**10,540,800**	**3,424,000**	**277,664,000**
Turkey	47,654,400	13,728,000	16,601,600	77,984,000
Jordan	8,236,800	217,600	563,200	9,017,600
Israel	2,156,800	166,400	537,600	2,860,800
Syria	10,764,800	2,233,600	5,632,000	18,630,400
Lebanon	601,600	134,400	281,600	1,017,600
Iraq	32,755,200	5,132,800	5,600,000	43,488,000
Cyprus	281,600	198,400	435,200	915,200
Middle East	**102,451,200**	**21,811,200**	**29,651,200**	**153,913,600**
Azerbaijan	4,595,200	844,800	2,649,6 00	8,089,600
Armenia	1,779,200	480,000	1,312,000	3,571,200
Georgia	5,094,400	627,200	1,260,800	6,982,400
Caucasus	**11,468,800**	**1,952,000**	**5,222,400**	**18,643,200**
Iran	118,604,800	17,504,000	25,792,000	161,900,800
Afghanistan	46,675,200	8,896,000	8,646,400	64,217,600
Turkmenistan	39,756,800	3,385,600	5,644,800	48,787,200
Pakistan	76,032,000	7,072,000	4,352,000	87,456,000
South Central Asia	**281,068,800**	**36,857,600**	**44,435,200**	**362,361,600**
Tajikistan	9,638,400	2,163,200	2,265,600	14,067,200
Kyrgizstan	14,048, 000	3,596,800	2,374,400	20,019,200
Uzbekistan	36,748,800	3,008,000	2,777,600	42,534,400
Kazakhstan	214,968,800	34,419,200	19,814,400	269,202,400
North Central Asia	**275,404,000**	**43,187,200**	**27,232,000**	**345,823,200**
TOTAL CWANA	***1,903,486,200***	***199,641,600***	***178, 297,600***	***2,281,425,400***

Table 10. Areas per sub-region for Change Classes of 'Intensification Agriculture' to irrigated croplands

Sub-region	For-Irrig	Rain-Irrig	Grass-Irrig	Bare-Irrig	Total to Irrigation
North-West Africa	1,286,400	550,400	25,600	1,094,400	2,956,800
North-East Africa	0	32,000	0	505,600	537,600
Africa Sahel	0	0	0	0	0
Arabian Peninsula	0	0	0	4,883,200	4,883,200
Middle East	3,603,200	1,868,800	300,800	2,560,000	8,332,800
Caucasus	211,200	332,800	25,600	0	569,600
South Central Asia	345,600	1,196,800	2,380,800	5,811,200	9,734,400
North Central Asia	44,800	806,400	1,664,000	1,100,800	3,616,000
CWANA	5,491,200	4,787,200	4,396,800	15,955,200	30,630,400

Notes: For: Forests; Irrig: Irrigated croplands; Grass: Grasslands

Table 11. Areas per sub-region for Change Classes of 'Intensification Agriculture' to rainfed croplands

Sub-region	Rain-For	For-Rain	Sav-Rain	Grass-Rain	Bare-Rain	Total to Rainfed
North-West Africa	505,600	960,000	0	249,600	409,600	2,124,800
North-East Africa	0	12,800	0	32,000	64,000	108,800
Africa Sahel	49,72,800	428,800	5,932,800	275,200	940,800	12,550,400
Arabian Peninsula	64,000	89,600	0	6,400	249,600	409,600
Middle East	1,651,200	742,400	0	2,758,400	224,000	5,376,000
Caucasus	390,400	64,000	0	134,400	25,600	614,400
South Central Asia	83,200	32,000	0	1,433,600	320,000	1,868,800
North Central Asia	1,068,800	1,651,200	0	8,416,000	0	11,136,000
CWANA	8,736000	3,980,800	5,932,800	13,305,600	2,233,600	34,188,800

Notes: Rain: Rainfed croplands; For: Forests; Grass: Grasslands; Sav: Savannas

Table 12. Total area per sub-region for Change Trend 'Intensification Agriculture'

Sub-region	Total Intensification Agriculture
North-West Africa	5,081,600
North-East Africa	646,400
Africa Sahel	12,550,400
Arabian Peninsula	5,292,800
Middle East	13,708,800
Caucasus	1,184,000
South Central Asia	11,603,200
North Central Asia	14,752,000
CWANA	64,819,200

Table 13. Area per sub-region for Change Classes of 'Retrenchment Agriculture' from irrigated croplands

Sub-region	Irrig-Rain	Irrig-Grass	Irrig-Bare	Total from Irrigated
North-West Africa	121,600	19,200	1,260,800	1,401,600
North-East Africa	6,400	6,400	832,000	844,800
Africa Sahel	0	0	0	0
Arabian Peninsula	0	0	3,212,800	3,212,800
Middle East	467,200	576,000	1,484,800	2,528,000
Caucasus	326,400	70,400	12,800	409,600
South Central Asia	908,800	4,147,200	8,115,200	13,171,200
North Central Asia	544,000	2,432,000	1,452,800	4,428,800
CWANA	2,374,400	7,251,200	16,371,200	25,996,800

Notes: Irrig: Irrigated croplands; Rain: Rainfed croplands; Grass: Grassland; Sav: Savannah

Table 14. Area per sub-region for Change Classes of 'Retrenchment Agriculture' from rainfed croplands

Sub-region	Rain-Sav	Rain-Grass	Rain-Bare	Total from Rainfed	Total Retrenchment Agriculture
North-West Africa	0	134,400	704,000	838,400	2,240,000
North-East Africa	0	25,600	313,600	339,200	1,184,000
Africa Sahel	5,881,600	1,516,800	678,400	8,076,800	8,076,800
Arabian Peninsula	0	0	192,000	192,000	3,404,800
Middle East	0	3,398,400	422,400	3,8208,00	6,348,800
Caucasus	0	268,800	19,200	288,000	697,600
South Central Asia	0	2,707,200	89,600	2,796,800	15,968,000
North Central Asia	0	8,096,000	0	8,096,000	12,524,800
CWANA	5,881,600	16,147,200	2,419,200	2,4448,000	50,444,800

Notes: Rain: Rainfed croplands; Grass: Grasslands; Sav: Savannas

Table 15. Area per sub-region for Change Classes of 'Intensification natural vegetation'

Sub-region	Sav-For	Grass-For	Grass-Sav	Bare-Grass	Total Intensification Natural Vegetation
North-West Africa	0	0	0	704,000	704,000
North-East Africa	0	0	0	25,600	25,600
Africa Sahel	416,000	243,200	8,288,000	33,312,000	42,259,200
Arabian Peninsula	0	0	0	1,536,000	1,536,000
Middle East	0	147,200	0	992,000	1,139,200
Caucasus	0	0	0	6,400	6,400
South Central Asia	0	57,600	0	5,587,200	5,644,800
North Central Asia	0	134,400	0	10,969,600	11,104,000
CWANA	416,000	582,400	8,288,000	53,132,800	62,419,200

Notes: For: Forests; Grass: Grasslands; Sav: Savannas

Table 16 . Area per sub-region for Change Classes of 'Retrenchment natural vegetation'

Sub-region	For-Grass	Sav-Grass	Grass-Bare	Total Retrenchment Natural Vegetation
North-West Africa	12,800	0	332,800	345,600
North-East Africa	0	0	83,200	83,200
Africa Sahel	307,200	7,264,000	4,524,800	12,096,000
Arabian Peninsula	121,600	0	185,600	307,200
Middle East	19,200	0	595,200	614,400
Caucasus	0	0	64,000	64,000
South Central Asia	0	0	36,41,600	3,641,600
North Central Asia	179,200	0	4,627200	4,806,400
CWANA	640,000	7,264,000	14,054,400	21,958,400

Table 17. Areas per sub-region for the stable classes

	Sub-region								
Stable Class	**Maghreb**	**North-East Africa**	**Africa Sahel**	**Arabian Peninsula**	**West Asia**	**Caucasus**	**South Central Asia**	**North Central Asia**	***TOTAL CWANA***
Irrigated croplands	448,000	4,665,600	0	851,200	10,208,000	1,452,800	50,220,800	16,332,800	*84,179,200*
As above, low density	275,200	505,600	0	556,800	780,800	32,000	6,150,400	1,529,600	*9,830,400*
Irrigated croplands + Forests	1,913,600	6,400	0	0	5,920,000	1,555,200	595,200	57,600	*10,048,000*
Irrigated + Rainfed croplands	915,200	249,600	0	0	2,105,600	876,800	1,580,800	1,497,600	*7,225,600*
Forests	6,406,400	281,600	14,963,200	934,400	10,873,600	4,268,800	1,798,400	2,764,800	*42,291,200*
Forests + Rainfed croplands	1,926,400	134,400	3,308,800	128,000	2,073,600	876,800	128,000	2,784,000	*11,360,000*
Forests + Savannas	0	0	550,400	0	0	0	0	0	*550,400*
Forests, low density	44,800	0	403,200	326,400	57,600	12,800	57,600	358,400	*1,260,800*
Rainfed croplands	4,499,200	550,400	13,241,600	268,800	15,334,400	1,625,600	6,976,000	35,321,600	*77,817,600*
Rainfed croplands, low density	608,000	134,400	960,000	76,800	3,718,400	160,000	2,368,000	7,180,800	*15,206,400*
Rainfed croplands + Savannas	0	0	15,942,400	0	0	0	0	0	*15,942,400*
Savannas	0	0	21,484,800	0	0	0	0	0	*21,484,800*
Savannas, low density	0	0	18,880,000	0	0	0	0	0	*18,880,000*
Grasslands	128,000	44,800	66,483,200	57,600	10,745,600	364,800	21,740,800	128,710,400	*228,275,200*
Grasslands, low density	3,308,800	704,000	28,012,800	729,600	1,670,400	76,800	11,827,200	14,048,000	*60,377,600*
Barren	265,184,000	248,104,000	238,876,800	258,948,800	38,118,400	51,200	175,846,400	62,547,200	*1,287,676,800*
Lake	5,068,800	44,800	480,000	460,800	844,800	115,200	1,779,200	2,323,200	*11,116,800*
Total	**290,726,400**	**255,425,600**	**423,587,200**	**263,339,200**	**102,451,200**	**11,468,800**	**281,068,800**	**275,456,000**	***1,903,523,200***

Table 18. Change combinations per sub-region

ations	Africa	Africa					Asia	Asia	
1113	19,200	0	0	0	147,200	243,200	697,600	268,800	1,376,000
1115	12,800	6,400	0	0	358,400	32,000	3,078,400	1,516,800	5,004,800
1116	857,600	422,400	0	1,977,600	1,004,800	6,400	5,292,800	947,200	10,508,800
1133	19,200	6,400	0	0	102,400	57,600	64,000	108,800	358,400
1155	0	0	0	0	147,200	25,600	659,200	518,400	1,350,400
1166	256,000	384,000	0	966,400	345,600	6,400	1,331,200	339,200	3,628,800
1333	83,200	0	0	0	217,600	25,600	147,200	166,400	640,000
1555	6,400	0	0	0	70,400	12,800	409,600	396,800	896,000
1666	147,200	25,600	0	268,800	134,400	0	1,491,200	166,400	2,233,600
2111	243,200	0	0	0	1,548,800	134,400	288,000	44,800	2,259,200
2211	275,200	0	0	0	960,000	6,400	25,600	0	1,267,200
2221	768,000	0	0	0	1,094,400	70,400	32,000	0	1,964,800
2223	416,000	0	115,200	57,600	19,200	12,800	12,800	262,400	896,000
2233	38,400	12,800	89,600	19,200	76,800	19,200	0	268,800	524,800
2333	505,600	0	115,200	12,800	646,400	32,000	19,200	1,120,000	2,451,200
3111	89,600	19,200	0	0	441,600	243,200	614,400	454,400	1,862,400
3222	224,000	0	1,216,000	57,600	243,200	64,000	57,600	160,000	2,022,400
3311	160,000	12,800	0	0	396,800	57,600	268,800	160,000	1,056,000
3322	166,400	0	652,800	0	166,400	0	0	140,800	1,126,400
3331	300,800	0	0	0	1,030,400	32,000	313,600	192,000	1,868,800
3332	115,200	0	1,516,800	6,400	1,241,600	326,400	25,600	768,000	4,000,000

Table 18. Change combinations per sub-region (continued)

Change combinations	North-West Africa	North-East Africa	Africa Sahel	Arabian Peninsula	Middle East	Caucasus	South Central Asia	North Central Asia	Total
3334	0	0	1,164,800	0	0	0	0	0	1,164,800
3335	102,400	12,800	134,400	0	1,152,000	121,600	864,000	2,758,400	5,145,600
3336	198,400	108,800	25,600	51,200	166,400	12,800	64,000	0	627,200
3344	0	0	665,600	0	0	0	0	0	665,600
3355	25,600	12,800	83,200	0	1,075,200	70,400	972,800	3,232,000	5,472,000
3366	396,800	153,600	6,400	64,000	134,400	6,400	0	0	761,600
3444	0	0	1,344,000	0	0	0	0	0	1,344,000
3555	6,400	0	249,600	0	1,171,200	76,800	870,400	2,105,600	4,480,000
3666	108,800	51,200	0	76,800	121,600	0	25,600	0	384,000
4222	0	0	32,000	0	0	0	0	0	32,000
4333	0	0	998,400	0	0	0	0	0	998,400
4422	0	0	44,800	0	0	0	0	0	44,800
4433	0	0	576,000	0	0	0	0	0	576,000
4442	0	0	134,400	0	0	0	0	0	134,400
4443	0	0	915,200	0	0	0	0	0	915,200
4445	0	0	1,689,600	0	0	0	0	0	1,689,600
4455	0	0	710,400	0	0	0	0	0	710,400
4555	0	0	1,299,200	0	0	0	0	0	1,299,200
5111	12,800	0	0	0	153,600	19,200	1,132,800	908,800	2,227,200
5222	0	0	12,800	0	0	0	0	0	12,800
5333	134,400	25,600	19,200	0	1,222,400	76,800	665,600	3,596,800	5,740,800
5444	0	0	1,132,800	0	0	0	0	0	1,132,800
5511	12,800	0	0	0	25,600	0	505,600	409,600	953,600
5522	0	0	6,400	0	0	0	0	0	6,400
5533	83,200	0	19,200	0	697,600	19,200	313,600	2,067,200	3,200,000
5544	0	0	812,800	0	0	0	0	0	812,800

Table 18. Change combinations per sub-region (continued)

Change combinations	North-West Africa	North-East Africa	Africa Sahel	Arabian Peninsula	Middle East	Caucasus	South Central Asia	North Central Asia	Total
5551	0	0	0	0	121,600	6,400	742,400	345,600	1,216,000
5552	0	0	32,000	0	147,200	0	57,600	134,400	371,200
5553	32,000	6,400	96,000	6,400	838,400	38,400	454,400	2,752,000	4,224,000
5554	0	0	1,894,400	0	0	0	0	0	1,894,400
5556	32,000	25,600	1,356,800	0	211,200	32,000	1,644,800	1,504,000	4,806,400
5566	76,800	6,400	1,856,000	12,800	38,400	25,600	384,000	620,800	3,020,800
5666	224,000	51,200	908,800	172,800	345,600	6,400	1,612,800	2,502,400	5,824,000
6111	140,800	236,800	0	2,752,000	1,088,000	0	1,830,400	569,600	6,617,600
6333	256,000	19,200	115,200	64,000	179,200	19,200	121,600	0	774,400
6611	198,400	44,800	0	1,184,000	793,600	0	1,382,400	224,000	3,827,200
6633	51,200	25,600	6,400	19,200	19,200	0	57,600	0	179,200
6661	755,200	224,000	0	947,200	678,400	0	2,598,400	307,200	5,510,400
6663	102,400	19,200	6,400	166,400	25,600	6,400	140,800	0	467,200

Table 19. Area estimates for different change combinations per country (in hectares):
1. Afghanistan - Djibouti

Change combinations	Afghanistan	Algeria	Armenia	Azerbaijan	Bahrain	Cyprus	Djibouti
1113	57,600	6,400	0	192,000	0	0	0
1115	1,721,600	0	25,600	6,400	0	0	0
1116	422,400	236,800	0	6,400	6,400	0	0
1133	12,800	19,200	0	51,200	0	0	0
1155	371,200	0	25,600	0	0	12,800	0
1166	192,000	128,000	0	6,400	0	0	0
1333	19,200	51,200	0	19,200	0	0	0
1555	57,600	0	6,400	6,400	0	0	0
1666	128,000	19,200	0	0	0	0	0
2111	128,000	70,400	0	38,400	0	25,600	0
2211	0	70,400	0	0	0	44,800	0
2221	0	160,000	0	64,000	0	0	0
2223	0	102,400	0	12,800	0	0	0
2225	0	0	0	0	0	0	0
2233	0	32,000	6,400	12,800	0	0	0
2255	0	0	0	0	0	0	0
2333	0	441,600	0	12,800	0	0	0
2555	0	0	0	0	0	0	0
3111	185,600	64,000	6,400	44,800	0	0	0
3222	0	147,200	12,800	12,800	0	0	0
3311	44,800	57,600	0	12,800	0	0	0
3322	0	108,800	0	0	0	0	0
3331	89,600	121,600	0	19,200	0	19,200	0
3332	0	76,800	217,600	38,400	0	0	0
3334	0	0	0	0	0	0	0
3335	339,200	89,600	25,600	89,600	0	0	0
3336	25,600	96,000	0	12,800	0	0	0
3344	0	0	0	0	0	0	0
3355	364,800	0	25,600	38,400	0	0	0
3366	0	115,200	0	6,400	0	0	0
3444	0	0	0	0	0	0	0
3555	140,800	0	32,000	32,000	0	0	0
3666	0	108,800	0	0	0	0	0
4222	0	0	0	0	0	0	0
4333	0	0	0	0	0	0	0
4422	0	0	0	0	0	0	0
4433	0	0	0	0	0	0	0
4442	0	0	0	0	0	0	0
4443	0	0	0	0	0	0	0

Table 19. Area estimates for different change combinations per country (in hectares): (continued)

Change combinations	Afghani-stan	Algeria	Armenia	Azerbai-jan	Bahrain	Cyprus	Djibouti
4445	0	0	0	0	0	0	0
4455	0	0	0	0	0	0	0
4555	0	0	0	0	0	0	0
5111	710,400	6,400	6,400	0	0	25,600	0
5222	0	0	0	0	0	0	0
5333	140,800	44,800	38,400	19,200	0	57,600	0
5444	0	0	0	0	0	0	0
5511	236,800	0	0	0	0	0	0
5522	0	0	0	0	0	0	0
5533	57,600	6,400	12,800	0	0	12,800	0
5544	0	0	0	0	0	0	0
5551	89,600	0	0	0	0	0	0
5552	0	0	0	0	0	0	0
5553	89,600	0	19,200	12,800	0	0	0
5554	0	0	0	0	0	0	0
5556	300,800	0	19,200	12,800	0	0	0
5566	134,400	51,200	0	25,600	0	0	12,800
5666	793,600	89,600	0	6,400	0	0	19,200
6111	262,400	51,200	0	0	0	0	0
6333	6,400	108,800	0	19,200	0	0	0
6555	281,600	44,800	0	6,400	0	0	6,400
6611	160,000	25,600	0	0	0	0	0
6633	0	38,400	0	0	0	0	0
6655	288,000	64,000	0	0	0	0	70,400
6661	448,000	371,200	0	0	12,800	0	0
6663	0	96,000	0	6,400	0	0	0
6665	595,200	371,200	0	0	6,400	0	147,200

Table 20. Area estimates of change combinations for different countries (in hectares):
2. Egypt-Israel

Change combinations	Egypt	Eritrea	Ethiopia	Georgia	Iran	Iraq	Israel
1113	0	0	0	51,200	172,800	19,200	32,000
1115	0	0	0	0	1,152,000	0	0
1116	377,600	0	0	0	1,465,600	838,400	0
1133	0	0	0	6,400	32,000	0	6,400
1155	0	0	0	0	243,200	0	0
1166	326,400	0	0	0	300,800	288,000	6,400
1333	0	0	0	6,400	64,000	57,600	19,200
1555	0	0	0	0	326,400	6,400	0
1666	0	0	0	0	256,000	96,000	0
2111	0	0	0	96,000	108,800	0	0
2211	0	0	0	6,400	25,600	12,800	0
2221	0	0	0	6,400	25,600	6,400	0
2223	0	0	70,400	0	12,800	0	6,400
2225	0	0	0	0	0	0	0
2233	0	0	89,600	0	0	57,600	0
2255	0	0	0	0	0	0	0
2333	0	0	102,400	19,200	19,200	294,400	0
2555	0	0	25,600	0	0	0	0
3111	0	0	0	192,000	288,000	102,400	0
3222	0	0	1,184,000	38,400	57,600	0	6,400
3311	0	0	0	44,800	217,600	153,600	0
3322	0	0	620,800	0	0	0	0
3331	0	0	0	12,800	185,600	115,200	6,400
3332	0	0	1,491,200	70,400	25,600	44,800	6,400
3334	0	0	1,011,200	0	0	0	0
3335	0	6,400	12,800	6,400	480,000	140,800	19,200
3336	32,000	25,600	0	0	38,400	12,800	12,800
3344	0	0	620,800	0	0	0	0
3355	0	0	0	6,400	524,800	25,600	0
3366	0	6,400	0	0	0	19,200	6,400
3444	0	0	1,190,400	0	0	0	0
3555	0	0	6,400	12,800	531,200	0	0
3666	25,600	0	0	0	25,600	6,400	0
4222	0	0	6,400	0	0	0	0
4333	0	0	985,600	0	0	0	0
4422	0	0	12,800	0	0	0	0
4433	0	0	563,200	0	0	0	0
4442	0	0	102,400	0	0	0	0
4443	0	0	857,600	0	0	0	0

Table 20. Area estimates of change combinations for different countries (in hectares): (continued)

Change combinations	Egypt	Eritrea	Ethiopia	Georgia	Iran	Iraq	Israel
4445	0	6,400	1,107,200	0	0	0	0
4455	0	38,400	441,600	0	0	0	0
4555	0	96,000	857,600	0	0	0	0
5111	0	0	0	12,800	179,200	12,800	0
5222	0	0	0	0	0	0	0
5333	0	0	0	19,200	428,800	6,400	12,800
5444	0	6,400	800,000	0	0	0	0
5511	0	0	0	0	243,200	0	0
5522	0	0	6,400	0	0	0	0
5533	0	0	0	6,400	217,600	6,400	0
5544	0	6,400	441,600	0	0	0	0
5551	0	0	0	6,400	608,000	0	0
5552	0	0	32,000	0	57,600	0	0
5553	0	0	38,400	6,400	345,600	0	0
5554	0	25,600	1,132,800	0	0	0	0
5556	0	25,600	1,062,400	0	1,190,400	6,400	0
5566	0	38,400	1,363,200	0	211,200	12,800	0
5666	12,800	70,400	403,200	0	588,800	96,000	0
6111	230,400	0	0	0	652,800	1,011,200	0
6333	0	32,000	0	0	115,200	115,200	0
6555	0	768,000	2,828,800	0	1,126,400	0	19,200
6611	32,000	0	0	0	684,800	723,200	0
6633	0	6,400	0	0	57,600	0	0
6655	0	838,400	403,200	0	864,000	64,000	0
6661	204,800	0	0	0	1,459,200	512,000	0
6663	0	6,400	0	0	134,400	6,400	6,400
6665	0	448,000	723,200	0	1,760,000	262,400	0

Table 21. Area estimates of change combinations for different countries (in hectares): 3. Jordan-Mauritania

Change combinations	Jordan	Kazakh-stan	Kuwait	Kyrgiz-stan	Lebanon	Libya	Maurita-nia
1113	0	25,600	0	19,200	0	0	0
1115	0	659,200	0	198,400	0	6,400	0
1116	32,000	435,200	0	0	0	44,800	0
1133	0	12,800	0	19,200	0	6,400	0
1155	0	268,800	0	96,000	6,400	0	0
1166	19,200	256,000	0	0	6,400	57,600	0
1333	6,400	108,800	0	12,800	0	0	0
1555	0	288,000	0	25,600	0	0	0
1666	0	102,400	0	0	6,400	25,600	0
2111	0	0	0	0	0	0	0
2211	0	0	0	0	0	0	0
2221	0	0	0	0	6,400	0	0
2223	0	160,000	0	44,800	0	0	0
2225	0	12,800	0	0	0	0	0
2233	0	153,600	0	70,400	0	12,800	0
2255	0	0	0	0	0	0	0
2333	0	825,600	0	204,800	6,400	0	0
2555	0	166,400	0	0	0	0	0
3111	0	38,400	0	198,400	0	19,200	0
3222	0	83,200	0	64,000	6,400	0	0
3311	6,400	44,800	0	57,600	0	12,800	0
3322	0	115,200	0	6,400	12,800	0	0
3331	0	108,800	0	57,600	0	0	0
3332	0	659,200	0	102,400	32,000	0	0
3334	0	0	0	0	0	0	0
3335	25,600	2,374,400	0	236,800	19,200	12,800	115,200
3336	25,600	0	0	0	0	76,800	0
3344	0	0	0	0	0	0	0
3355	0	2,796,800	0	307,200	12,800	12,800	83,200
3366	0	0	0	0	0	153,600	0
3444	0	0	0	0	0	0	0
3555	0	1,830,400	0	134,400	0	0	243,200
3666	0	0	0	0	0	25,600	0
4222	0	0	0	0	0	0	0
4333	0	0	0	0	0	0	0
4422	0	0	0	0	0	0	0
4433	0	0	0	0	0	0	0
4442	0	0	0	0	0	0	0
4443	0	0	0	0	0	0	0

Table 21. Area estimates of change combinations for different countries (in hectares): (continued)

Change combinations	Jorda	Kazakh-stan	Kuwait	Kyrgiz stan	Lebanon	Libya	Maurita-nia
4445	0	0	0	0	0	0	0
4455	0	0	0	0	0	0	0
4555	0	0	0	0	0	0	0
5111	0	320,000	0	153,600	0	0	0
5222	0	0	0	0	0	0	0
5333	6,400	2,944,000	0	480,000	0	25,600	19,200
5444	0	0	0	0	0	0	0
5511	0	166,400	0	76,800	0	0	0
5522	0	0	0	0	0	0	0
5533	0	1,830,400	0	153,600	0	0	19,200
5544	0	0	0	0	0	0	0
5551	0	140,800	0	96,000	0	0	0
5552	0	134,400	0	0	0	0	0
5553	0	2,432,000	0	192,000	0	6,400	51,200
5554	0	0	0	0	0	0	0
5556	0	1,420,800	0	25,600	6,400	25,600	32,000
5566	0	576,000	0	12,800	0	6,400	6,400
5666	0	2,393,600	0	12,800	0	38,400	32,000
6111	19,200	275,200	0	6,400	0	6,400	0
6333	38,400	0	0	0	0	19,200	83,200
6555	6,400	4,819,200	0	422,400	0	12,800	3,955,200
6611	25,600	128,000	0	6,400	0	12,800	0
6633	0	0	0	0	0	25,600	0
6655	6,400	2,502,400	0	70,400	0	0	1,094,400
6661	0	198,400	0	0	0	19,200	0
6663	0	0	0	0	0	19,200	0
6665	0	2,611,200	0	32,000	12,800	12,800	832,000

Table 22. Area estimates of change combinations for different countries (in hectares):
4. Morocco-Tajikistan

Change combinations	Morocco	Oman	Pakistan	Saudi Arabia	Somalia	Syria	Tajikistan
1113	12,800	0	211,200	0	0	51,200	57,600
1115	12,800	0	153,600	0	0	0	288,000
1116	518,400	19,200	2,899,200	1,862,400	0	70,400	179,200
1133	0	0	12,800	0	0	44,800	19,200
1155	0	0	25,600	0	0	0	96,000
1166	96,000	32,000	620,800	832,000	0	6,400	38,400
1333	25,600	0	6,400	0	0	96,000	19,200
1555	6,400	0	25,600	0	0	0	38,400
1666	121,600	25,600	1,068,800	38,400	0	32,000	6,400
2111	147,200	0	51,200	0	0	89,600	19,200
2211	185,600	0	0	0	0	44,800	0
2221	467,200	0	6,400	0	0	38,400	0
2223	313,600	0	0	0	44,800	0	57,600
2225	12,800	0	0	0	38,400	0	0
2233	6,400	0	0	0	0	0	44,800
2255	0	0	0	0	0	0	0
2333	6,400	6,400	0	0	12,800	12,800	64,000
2555	0	0	0	96,000	6,400	0	0
3111	6,400	0	102,400	0	0	44,800	185,600
3222	64,000	44,800	0	6,400	32,000	19,200	0
3311	70,400	0	6,400	0	0	134,400	44,800
3322	51,200	0	0	0	32,000	19,200	6,400
3331	57,600	0	6,400	0	0	512,000	25,600
3332	25,600	6,400	0	0	25,600	12,800	0
3334	0	0	0	0	153,600	0	0
3335	6,400	0	0	0	0	6,400	64,000
3336	32,000	25,600	0	0	0	115,200	0
3344	0	0	0	0	44,800	0	0
3355	25,600	0	0	0	0	6,400	19,200
3366	281,600	25,600	0	6,400	0	96,000	0
3444	0	0	0	0	153,600	0	0
3555	6,400	0	0	0	0	0	38,400
3666	0	25,600	0	25,600	0	115,200	0
4222	0	0	0	0	25,600	0	0
4333	0	0	0	0	12,800	0	0
4422	0	0	0	0	32,000	0	0
4433	0	0	0	0	12,800	0	0
4442	0	0	0	0	32,000	0	0
4443	0	0	0	0	57,600	0	0

Table 22. Area estimates of change combinations for different countries (in hectares): (continued)

Change combinations	Morocco	Oman	Pakistan	Saudi Arabia	Somalia	Syria	Tajiki-stan
4445	0	0	0	0	576,000	0	0
4455	0	0	0	0	230,400	0	0
4555	0	0	0	0	345,600	0	0
5111	0	0	230,400	0	0	0	262,400
5222	0	0	0	0	12,800	0	0
5333	70,400	0	0	0	0	19,200	32,000
5444	0	0	0	0	326,400	0	0
5511	12,800	0	25,600	0	0	0	51,200
5522	0	0	0	0	0	0	0
5533	70,400	0	0	0	0	0	6,400
5544	0	0	0	0	364,800	0	0
5551	0	0	38,400	0	0	0	19,200
5552	0	0	0	0	0	0	0
5553	32,000	0	0	0	6,400	0	12,800
5554	0	0	0	0	736,000	0	0
5556	32,000	0	0	0	236,800	0	25,600
5566	25,600	0	12,800	6,400	435,200	0	32,000
5666	108,800	0	121,600	115,200	384,000	236,800	44,800
6111	57,600	32,000	499,200	2,700,800	0	38,400	134,400
6333	140,800	38,400	0	0	0	25,600	0
6555	64,000	0	32,000	0	1,004,800	0	108,800
6611	147,200	19,200	352,000	1,107,200	0	32,000	19,200
6633	6,400	0	0	6,400	0	19,200	0
6655	19,200	0	32,000	76,800	595,200	6,400	38,400
6661	236,800	192,000	409,600	614,400	0	115,200	25,600
6663	6,400	0	6,400	134,400	0	12,800	0
6665	128,000	25,600	115,200	633,600	2,822,400	160,000	38,400

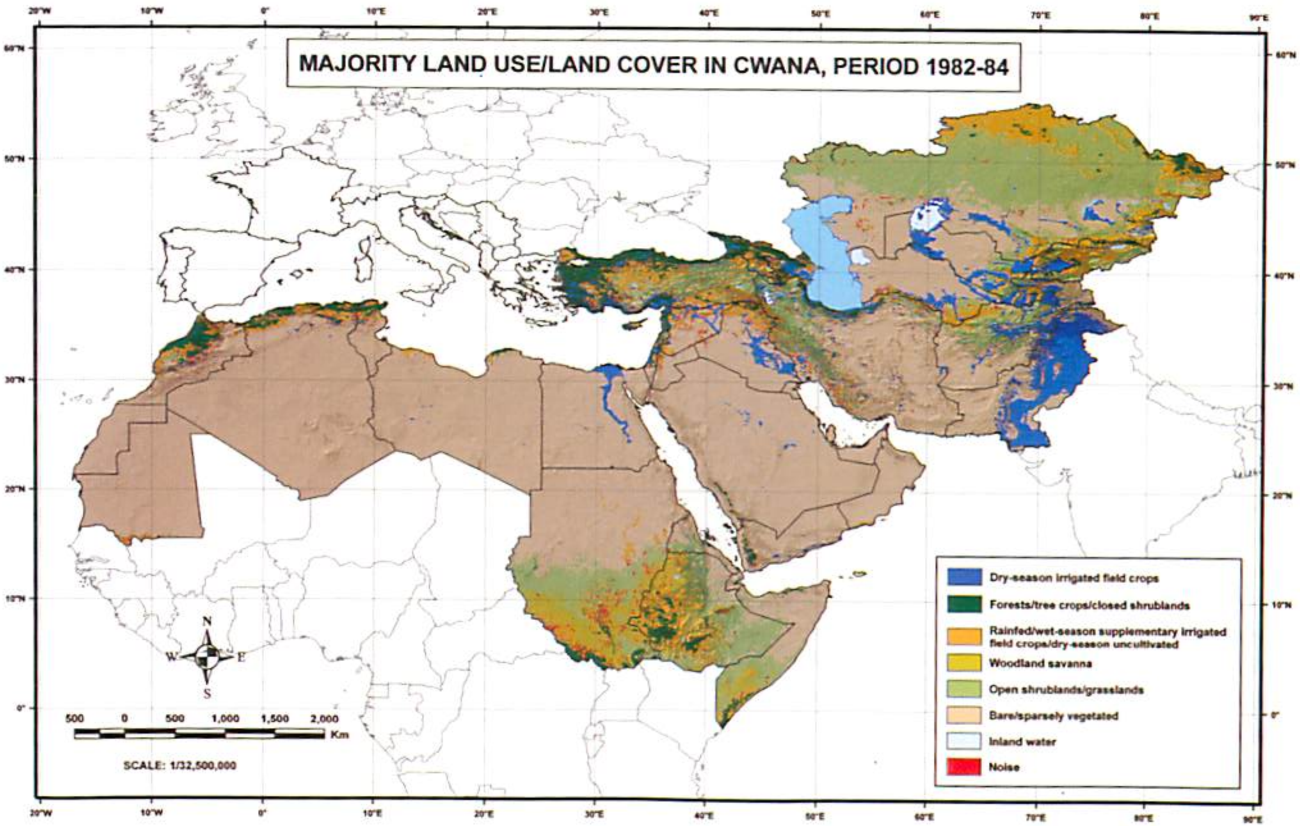
Table 23. Area estimates of change combinations for different countries (in hectares):
5. Tunisia-Yemen

Change combinations	Tunisia	Turkey	Turk-menistan	U.A.E.	Uzbeki-stan	West. Sahara	Yemen
1113	0	44,800	256,000	0	166,400	0	0
1115	0	358,400	51,200	0	371,200	0	0
1116	102,400	64,000	505,600	38,400	332,800	0	51,200
1133	0	51,200	6,400	0	57,600	0	0
1155	0	128,000	19,200	0	57,600	0	0
1166	32,000	19,200	217,600	32,000	44,800	0	70,400
1333	6,400	38,400	57,600	0	25,600	0	0
1555	0	64,000	0	0	44,800	0	0
1666	6,400	0	38,400	6,400	57,600	0	198,400
2111	25,600	1,433,600	0	0	25,600	0	0
2211	19,200	857,600	0	0	0	0	0
2221	140,800	1,043,200	0	0	0	0	0
2223	0	12,800	0	0	0	0	57,600
2225	0	0	0	0	0	0	6,400
2233	0	19,200	0	0	0	0	19,200
2255	0	0	0	0	0	0	12,800
2333	57,600	332,800	0	0	25,600	0	6,400
2555	0	19,200	0	0	0	0	6,400
3111	19,200	294,400	38,400	0	32,000	0	0
3222	12,800	211,200	0	0	12,800	0	6,400
3311	32,000	102,400	0	0	12,800	0	0
3322	6,400	134,400	0	0	12,800	0	0
3331	121,600	377,600	32,000	0	0	0	0
3332	12,800	1,145,600	0	0	6,400	0	0
3334	0	0	0	0	0	0	0
3335	6,400	940,800	44,800	0	83,200	0	0
3336	70,400	0	0	0	0	0	25,600
3344	0	0	0	0	0	0	0
3355	0	1,030,400	83,200	0	108,800	0	0
3366	0	12,800	0	0	0	0	32,000
3444	0	0	0	0	0	0	0
3555	0	1,171,200	198,400	0	102,400	0	0
3666	0	0	0	0	0	0	25,600
4222	0	0	0	0	0	0	0
4333	0	0	0	0	0	0	0
4422	0	0	0	0	0	0	0
4433	0	0	0	0	0	0	0
4442	0	0	0	0	0	0	0
4443	0	0	0	0	0	0	0

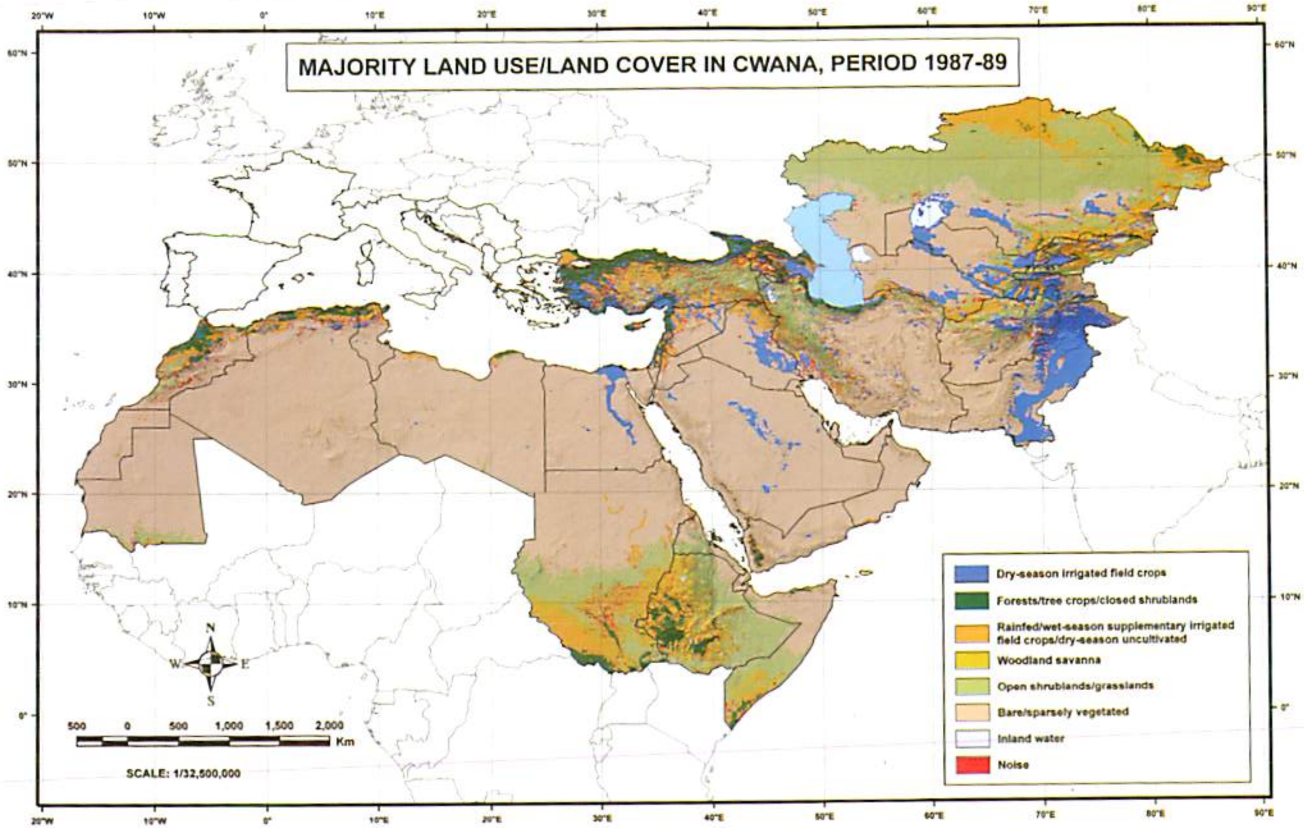
Table 23. Area estimates of change combinations for different countries (in hectares): (continued)

Change combinations	Tunisia	Turkey	Turk-menistan	U.A.E.	Uzbeki-stan	West. Sahara	Yemen
4445	0	0	0	0	0	0	0
4455	0	0	0	0	0	0	0
4555	0	0	0	0	0	0	0
5111	6,400	115,200	12,800	0	172,800	0	0
5222	0	0	0	0	0	0	0
5333	19,200	1,120,000	96,000	0	140,800	0	0
5444	0	0	0	0	0	0	0
5511	0	25,600	0	0	115,200	0	0
5522	0	0	0	0	0	0	0
5533	6,400	678,400	38,400	0	76,800	0	0
5544	0	0	0	0	0	0	0
5551	0	121,600	6,400	0	89,600	0	0
5552	0	147,200	0	0	0	0	0
5553	0	838,400	19,200	0	115,200	0	6,400
5554	0	0	0	0	0	0	0
5556	0	198,400	153,600	0	32,000	0	0
5566	0	25,600	25,600	0	0	0	6,400
5666	25,600	12,800	108,800	0	51,200	0	57,600
6111	32,000	19,200	416,000	6,400	153,600	0	12,800
6333	6,400	0	0	0	0	0	25,600
6555	6,400	320,000	108,800	0	121,600	0	83,200
6611	25,600	12,800	185,600	51,200	70,400	0	6,400
6633	6,400	0	0	0	0	0	12,800
6655	0	96,000	115,200	0	19,200	0	96,000
6661	147,200	51,200	281,600	121,600	83,200	0	6,400
6663	0	0	0	0	0	0	32,000
6665	6,400	38,400	268,800	0	185,600	0	614,400

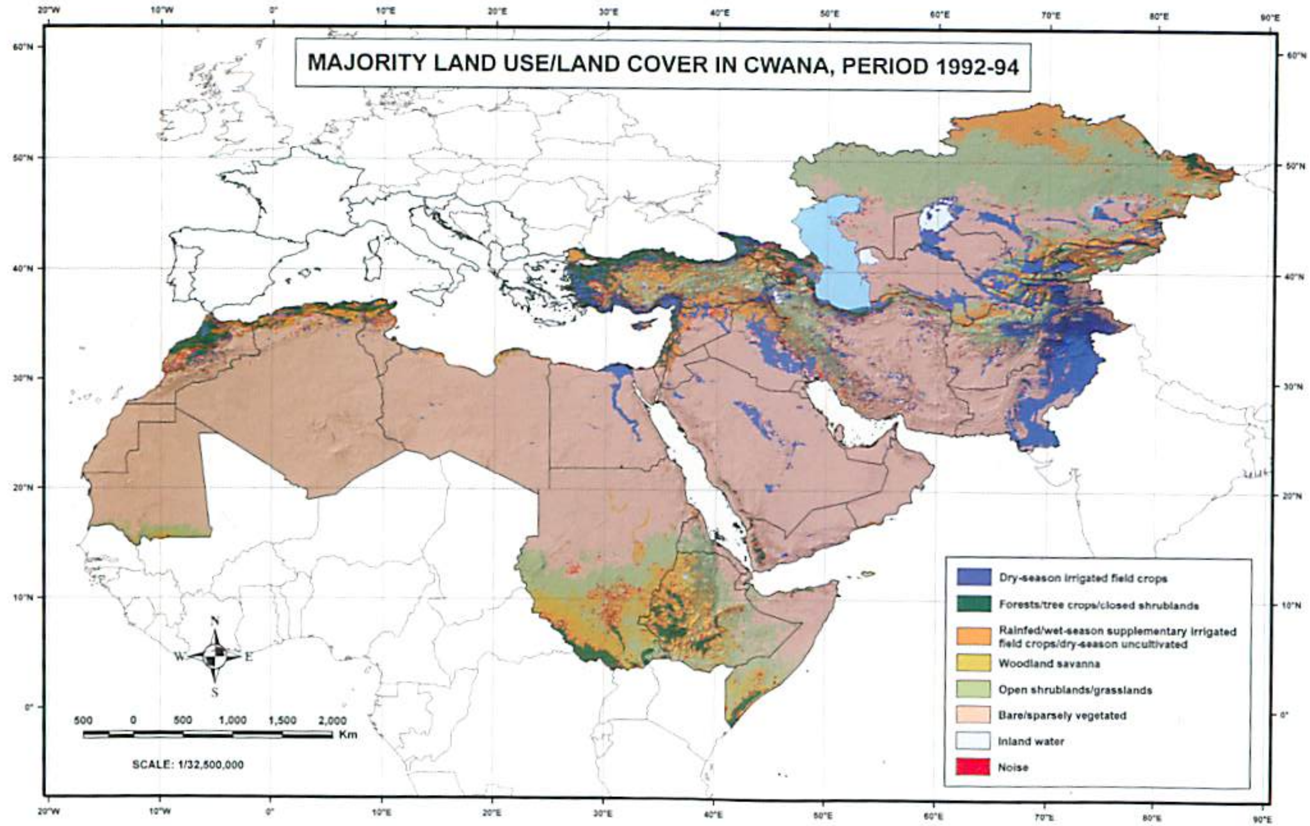
ANNEX 2


MAJORITY LAND USE/LAND COVER IN CWANA, PERIOD 1982-84
Dry-season irrigated field crops
Forests/tree crops/closed shrublands
Rainfed/wet-season supplementary irrigated field crops/dry-season uncultivated
Woodland savanna
Open shrublands/grasslands
Bare/sparsely vegetated
Inland water
Noise
N
W
E
S
500 0 500 1,000 1,500 2,000 Km
SCALE: 1/32,500,000

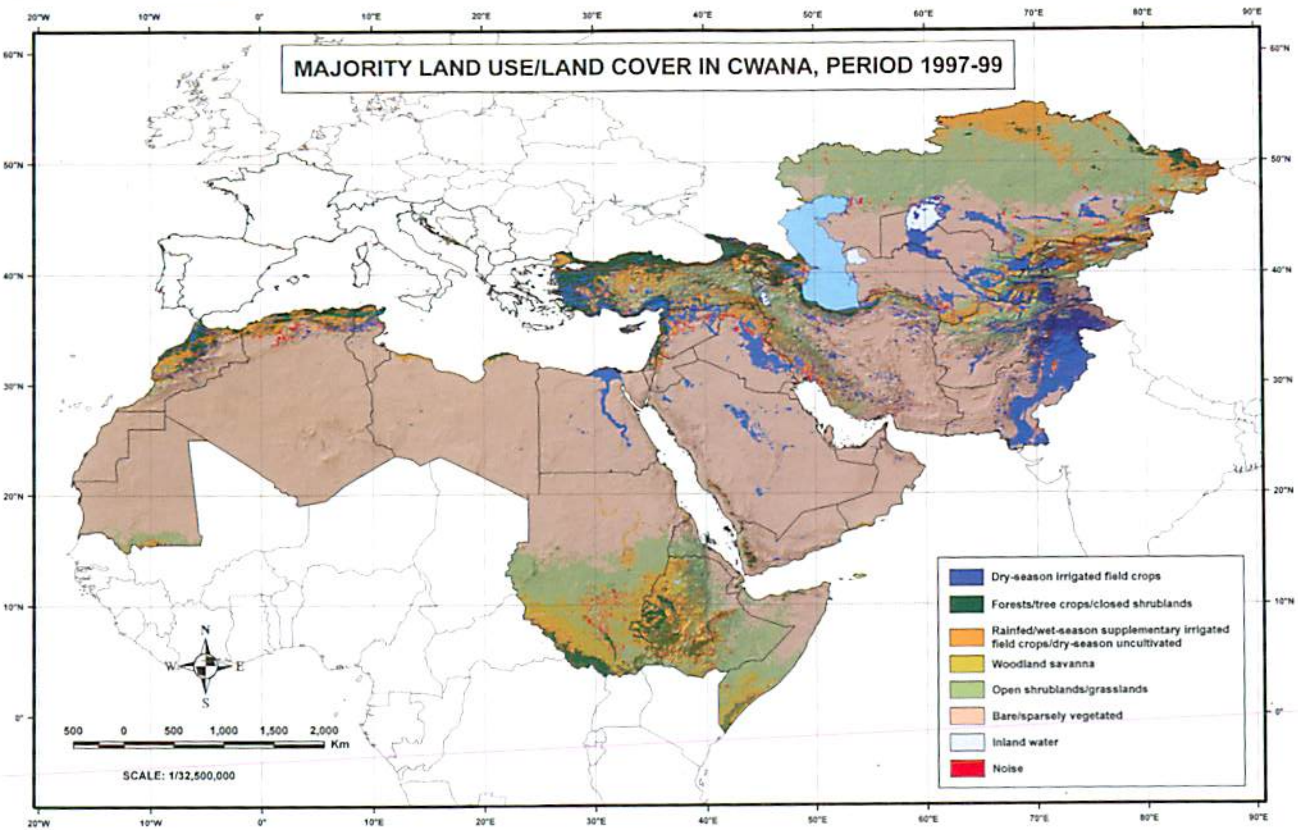
ANNEX 3


MAJORITY LAND USE/LAND COVER IN CWANA, PERIOD 1987-89
Dry-season irrigated field crops
Forests/tree crops/closed shrublands
Rainfed/wet-season supplementary irrigated field crops/dry-season uncultivated
Woodland savanna
Open shrublands/grasslands
Bare/sparsely vegetated
Inland water
Noise
N
W
E
S
500 0 500 1,000 1,500 2,000
Km
SCALE: 1/32,500,000
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
70°E
80°E
90°E
60°N
50°N
40°N
30°N
20°N
10°N
0°

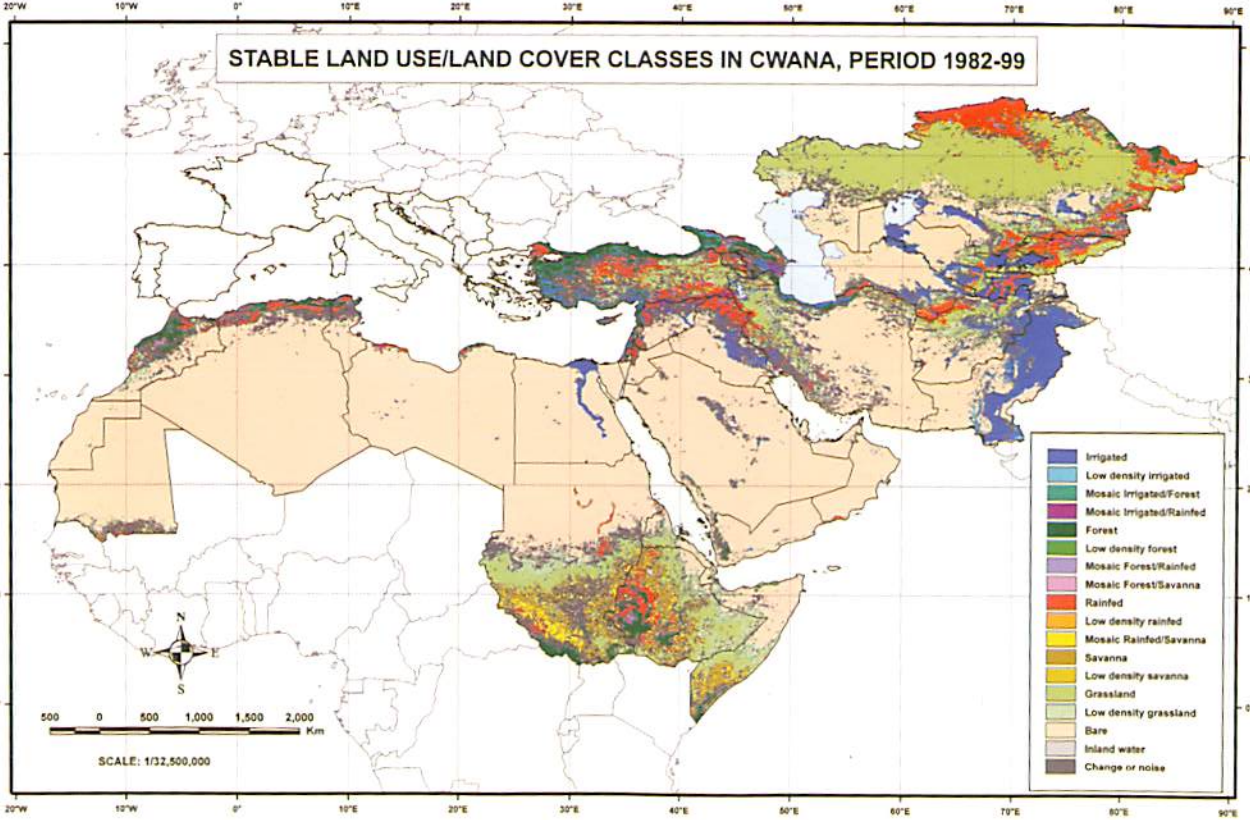
ANNEX 4


MAJORITY LAND USE/LAND COVER IN CWANA, PERIOD 1992-94
Dry-season irrigated field crops
Forests/tree crops/closed shrublands
Rainfed/wet-season supplementary irrigated field crops/dry-season uncultivated
Woodland savanna
Open shrublands/grasslands
Bare/sparsely vegetated
Inland water
Noise
N
W
E
S
500 0 500 1,000 1,500 2,000
Km
SCALE: 1/32,500,000

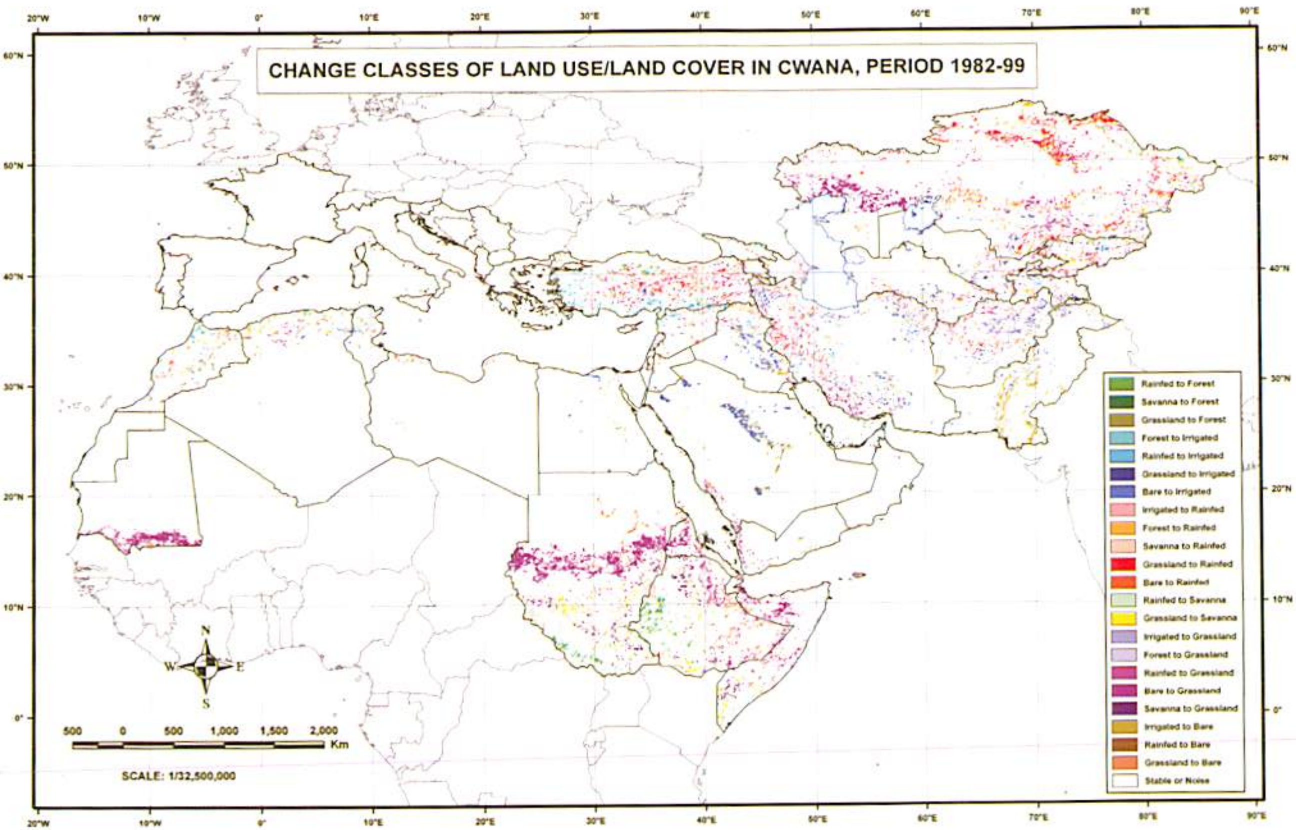
ANNEX 5


MAJORITY LAND USE/LAND COVER IN CWANA, PERIOD 1997-99
Dry-season irrigated field crops
Forests/tree crops/closed shrublands
Rainfed/wet-season supplementary irrigated field crops/dry-season uncultivated
Woodland savanna
Open shrublands/grasslands
Bare/sparsely vegetated
Inland water
Noise
500 0 500 1,000 1,500 2,000 Km
SCALE: 1/32,500,000
N
S
W
E
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
70°E
80°E
90°E
60°N
50°N
40°N
30°N
20°N
10°N

ANNEX 6

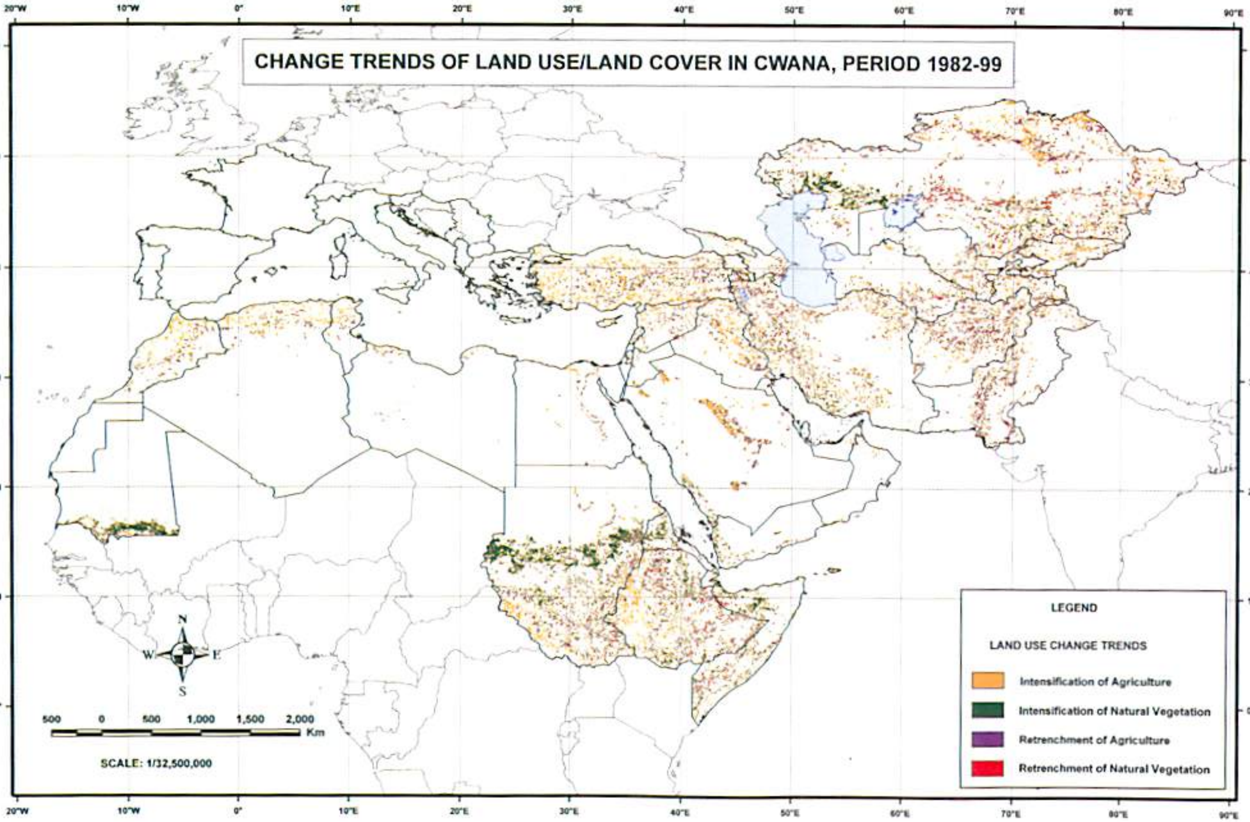

STABLE LAND USE/LAND COVER CLASSES IN CWANA, PERIOD 1982-99
Irrigated
Low density irrigated
Mosaic Irrigated/Forest
Mosaic Irrigated/Rainfed
Forest
Low density forest
Mosaic Forest/Rainfed
Mosaic Forest/Savanna
Rainfed
Low density rainfed
Mosaic Rainfed/Savanna
Savanna
Low density savanna
Grassland
Low density grassland
Bare
Inland water
Change or noise
N
S
W
E
500 0 500 1,000 1,500 2,000 Km
SCALE: 1/32,500,000

ANNEX 7

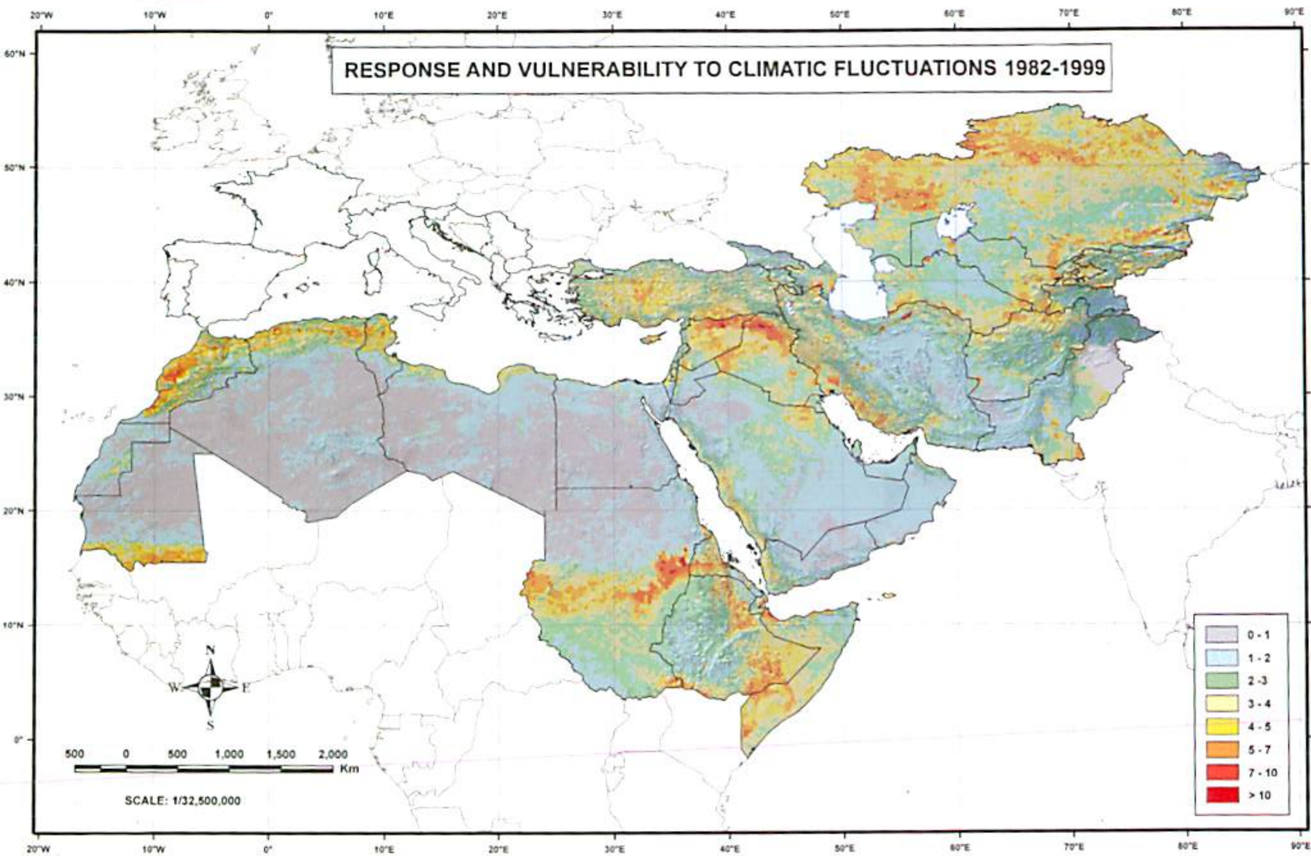


CHANGE CLASSES OF LAND USE/LAND COVER IN CWANA, PERIOD 1982-99
Rainfed to Forest
Savanna to Forest
Grassland to Forest
Forest to Irrigated
Rainfed to Irrigated
Grassland to Irrigated
Bare to Irrigated
Irrigated to Rainfed
Forest to Rainfed
Savanna to Rainfed
Grassland to Rainfed
Bare to Rainfed
Rainfed to Savanna
Grassland to Savanna
Irrigated to Grassland
Forest to Grassland
Rainfed to Grassland
Bare to Grassland
Savanna to Grassland
Irrigated to Bare
Rainfed to Bare
Grassland to Bare
Stable or Noise
N
W
E
S
500 0 500 1,000 1,500 2,000 Km
SCALE: 1/32,500,000

ANNEX 8

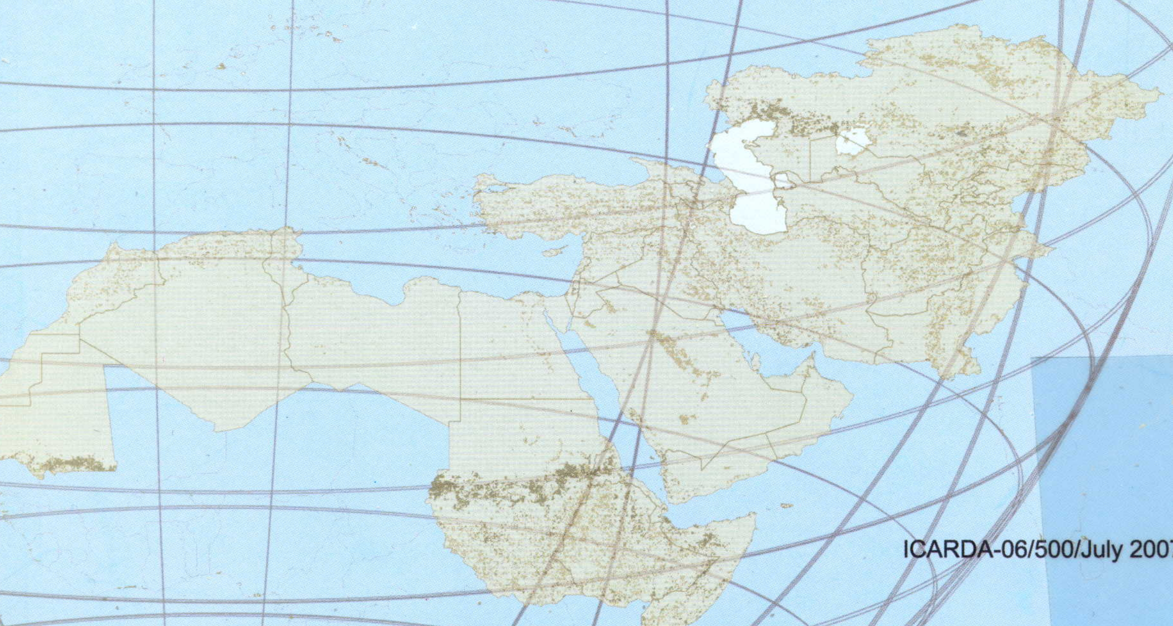

CHANGE TRENDS OF LAND USE/LAND COVER IN CWANA, PERIOD 1982-99
LEGEND
LAND USE CHANGE TRENDS
Intensification of Agriculture
Intensification of Natural Vegetation
Retrenchment of Agriculture
Retrenchment of Natural Vegetation
N
W
E
S
500 0 500 1,000 1,500 2,000
Km
SCALE: 1/32,500,000

ANNEX 9



RESPONSE AND VULNERABILITY TO CLIMATIC FLUCTUATIONS 1982-1999
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 7
7 - 10
> 10
500 0 500 1,000 1,500 2,000 Km
SCALE: 1/32,500,000
N
S
W
E

Assessment of Land Cover/Land Use in the CWANA Region Using AVHRR Imagery and Agroclimatic Data



ICARDA-06/500/July 2007