Satellite mapping of land cover and use

in relation to

Oil exploitation in concession block 5A

in Southern Sudan

1987–2006

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Content

Objective

To map human activity in oil concession area 5A in Southern Sudan based upon Landsat images, with particular focus on the changes in the period between 1999 and 2003 during the preliminary phase of oil exploration and development in this area.

The mapping includes the digitalization of new roads, pipelines and other infrastructure related to the oil industry, as well as a digital classification of land use and a change analysis of traditional farming patterns.

Study area

The study area (figure 1) covers the area west of the White Nile river overlapping oil concession area 5A and Landsat scene frame 174/54 in Southern Sudan. The focus area is south of the Bahr el Ghazal river to the town of Leer.

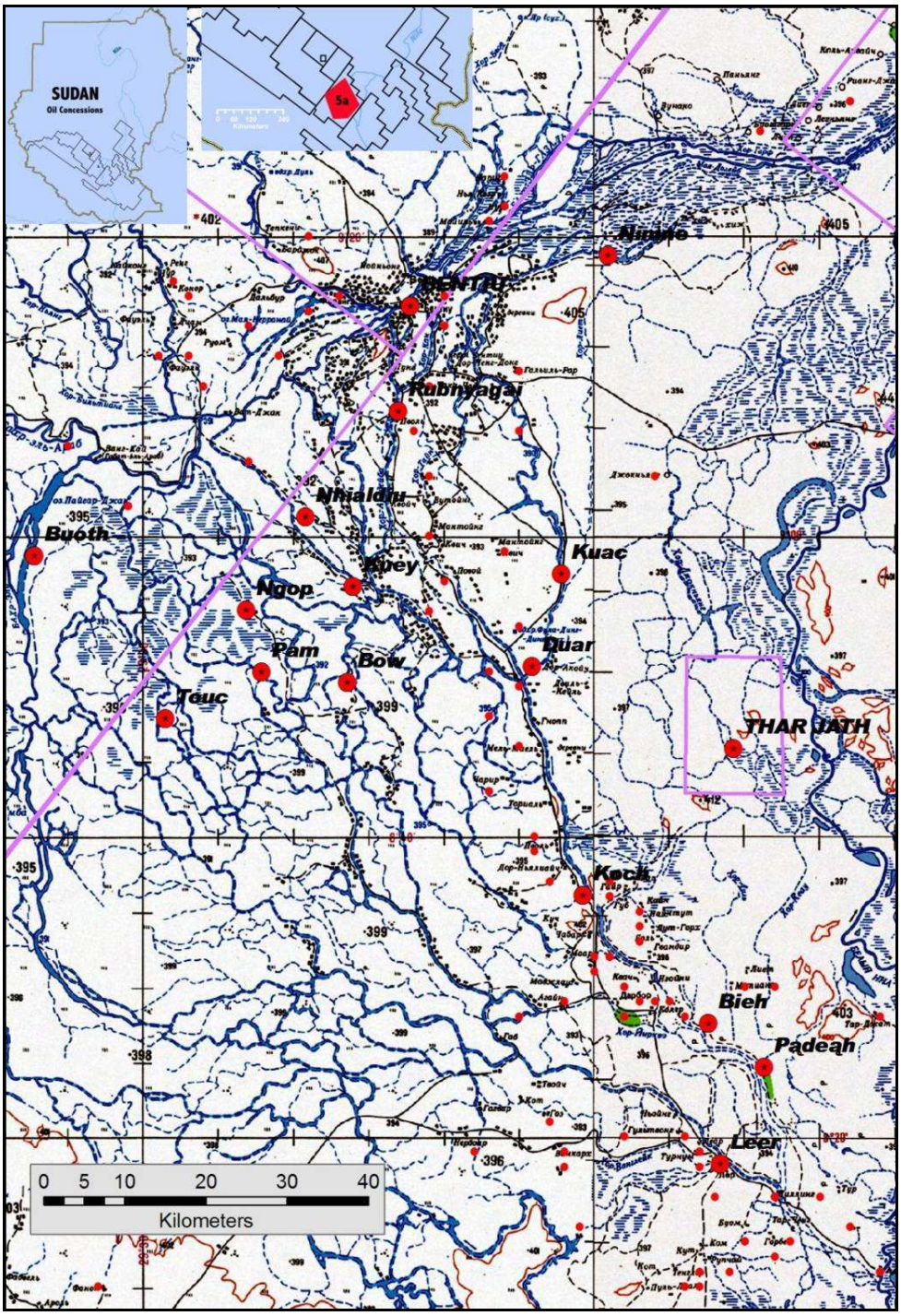

Figure 1. Russian (Soviet) map from the start of the 1980s (pre Sudanese civil war) giving village names in Western Upper Nile region, Southern Sudan. Towns and villages as red dots; other settled areas are indicated as small black dots located especially along streams.

The Traditional Land use in Block 5A

The Western Upper Nile of Sudan that includes oil concession block 5A is the home-land of primarily the Nuer[1] people and secondarily the Dinka people. Their agro-pastoral lifestyle has traditionally been adapted to the periodic flooding and drying out of the land they live in. Their transhumance way of life is driven by cattle migration where they move to the wet areas along the main rivers during the dry season to seek protein-rich fresh grass and water. During this period people camp in the wetland areas, but move back to drier areas when the wetlands flood.

Settlements

The permanent villages/settlements of the rural Nuer and Dinka are usually mud and thatch houses located above the maximum floodlevel, to which the Dinka and Nuer return annually during the rainy season and where they plant their crops typically located on sand banks along streams. These settlements include several extended family and/or other compounds. The compounds contain *tukuls*, circular single room mud huts with thatched roofs that last about five to ten years. The compound fence, of thatching or more permanent material, may encircle several *tukuls*, depending on family size. Other permanent structures such as cattle byres (known as *luaak*, plural of *luak*) and granaries are also made of mud and branches, in contrast to the impermanent "dry season" houses built of flimsy materials closer to the rivers, which are flooded during the rainy season.

Transhumance /seasonal movement

Movement from the permanent settlements to dry season grazing areas (*toic*[2]) starts in December–January at the beginning of the dry season. The return journey to the permanent settlements usually starts in May–June, during the early part of the rainy season.

These major migrations are planned not by individual families but by larger lineage groups. Some family members (particularly young men) accompany the cattle to the *toic*, and female family members go with them to milk cattle; these roles are traditionally assigned by gender. Other family members stay behind to cultivate.

Cultivation of sorghum and other crops begins on the higher ground or permanent settlement areas in the early rainy season and the harvest of crops begins when the rains are heavy in June–August. Rains drop off in September–November and cattle are driven to the *toic* again. This is the most socially active place and time, a period of fun, especially for the youth. The rains usually stop by early December, while the harvesting of crops is completed and the cattle graze on the stubble stalks

[1] The *Encyclopedia Britannica* defines the Nuer as a cattle-raising people "who live in the marshy and savannah country on both sides of the Nile River," spending the rainy season in permanent villages built on the higher ground and the dry season in riverside camps.

[2] Rich, green pastures of southern Sudan that emerge as the flood-waters of the Sudd recede after the rains

Materials and Methods

Map data
A number of digital maps have been used in the analysis of the area including Soviet government maps (1:200,000) published 1980–1989, on which a variety of more recent maps of the area are based i.e. the CDE maps (http://www.cde.unibe.ch/sudan/maps) established in 2006 but containing outdated information on village locations. Similar maps are under construction by Infoterra Ltd.. These maps are not used by this study as they contain Landsat images from approximately 2000 as the backdrop together with not fully updated US database information on villages and locations (several mistakes can be observed in the interpretation of these images such as seismic cut-lines that have been interpreted as pipelines). Furthermore, various GIS data from UN ORCH (http://ochaonline.un.org/sudan) including villages, roads and rivers.

Satellite Data used
This analysis is based upon land use changes derived from Landsat 5 and 7 images. QuickBird 2 data have been used for detailed studies and verification of classification results.

Landsat TM and ETM+ data
The analysis has used three historical Landsat TM and ten Landsat ETM+ scenes with 6 spectral bands in 28.5 m spatial resolution and a thermal band, in addition the Landsat ETM+ sensor has a panchromatic band within the visible spectrum in 14.25 m resolution and a thermal band in 57 m resolution. Each scene covers 173 x 185 km (http://landsat.usgs.gov/).

Landsat TM

Landsat Path/Row: 174/54: 25Oct1987
174/54: 07Dec1994
174/54: 08Jan1995

Recent Landsat ETM+ data

Landsat Path/Row: 174/54: 27Nov1999
174/54: 29Nov2000
174/54: 02Jan2000
174/54: 08March2002
174/54: 24March2002
174/54: 03Nov2002
174/54: 21Dec2002
174/54: 23Jan2003
174/54: 08Nov2004 gap filled with 174/54: 03Nov2002
174/54: 11Oct2006 gap filled with 174/54: 08Nov2004

Landsat 7 has had a malfunction since May 2003 that has caused a partial data loss increasing from 0% in the centre of the scenes to 24 % at the outer edges of the scenes. Thus, a gap-filling product has been used, where data from other scenes are filled into the gaps. In this case, data have been filled in the 2004 and 2006 scenes which have comparatively limited effect on the

image product as most of the area of study is in the centre of scene 174/54.

QuickBird 2
A 5 x 5 km sample of pan-sharpened QuickBird 2™ data (0.6 m resolution in natural colour) has been used to verify farming patterns in the study area, specifically where the oil road from Bentiu to Leer passes the village of Kuac. The image is recorded on the 21st March 2003, which is during the dry season.

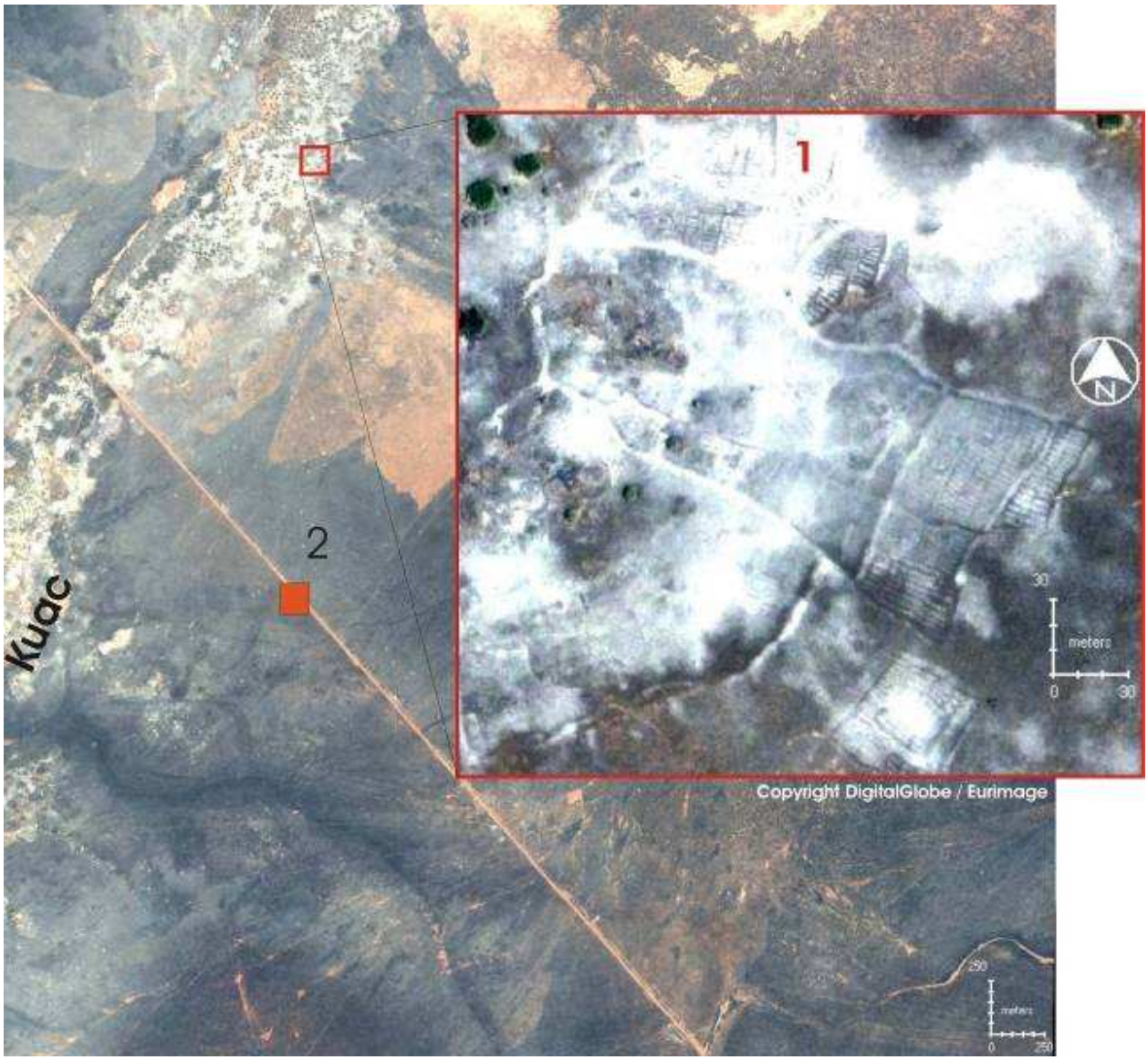

Figure 2. QuickBird 2 image 5 x 5 km close to Kuac recorded the 21st of March 2003 (dry season). The brightest areas refer to farming areas and dark areas to bush fire scars. Enlargement (1) illustrates an abandoned farm on a sandbank. Old cultivation patterns can be seen, where exposed sand is bright and dark areas refer to bush fire scars. The red square (2) along the all-weather road is shown in detail in figure 7.

Methodology

It is well-established in scientific literature that anthropogenic activity in the semi-arid regions of Africa can be traced by the use of space-borne sensors and can readily be used to detect changes in land use caused by humans and livestock (Hellden 1984 and 1988; Otterman 1974, 1977 and 1981; Otterman and Fraser 1976; Olsson 1985 and 1983; Prins 1997a+b and 2008; Tappan *et al*. 1992). During the dry season, human activity through cultivation and the introduction of livestock will break the soil crust leaving a surface with high reflectance (high albedo[3]) that can be detected relatively easily by standardised satellite image analysis methods (Crist and Kauth 1986; Jensen 1996 and Prins 2008). During the wet season, signs of human activity will be blurred as the bare soil will either be moist — which is especially evident in the Sudd — and/or partly overgrown by fresh vegetation growth, giving a surface pattern that is not significantly different from much of the surrounding area. Thus at this time of the year, crop fields provide the most evident pattern of recent human activity, albeit without any guarantee that people and livestock are actually present.

Satellite images for analysis have been chosen from the end of the cultivation season/start of the dry season when anthropogenic activity in terms of cultivated areas and the intensive presence of humans and livestock leave a clear bright soil signature. The selected images are primarily from November, but are also multi-temporal as other images from December until March have been used to confirm the observed patterns and to limit artefact errors such as bush fire scars that usually begin to appear at the beginning of the dry season. Recent bush fire scars leave a strong dark signature in the images that can obscure signs of human activity. This artefact is however temporary, as the permanent presence of man will override the bushfire artefact after a while, sometimes even within a month (see figure 2 for details). Late in the dry season, the analysis again becomes blurred as a mixture of burnt tissue and soil and other factors will leave a signature that is not significantly different from other surrounding land cover types.

Image enhancement for interpreting of data

The images covering the study area have been digitally enhanced by deriving albedo from satellite data and have been classified to separate areas where humans are active primarily by farming. In the following text farming will cover areas that have a high reflectance / albedo that indicates the presence of man and his livestock – this includes bare crop fields, villages, tracks, roads, farms and camps, heavily grazed areas and other areas where man and his cattle have been active and create a high reflectance by their presence.

[3] Albedo here refers to the ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it.

Elements of uncertainty

Fire scares
All Landsat satellite images used for the digital analysis have been acquired from the beginning of the dry season in November and well into the dry season (latest image 24th March). Bush fire scars are present in some of the images and will locally reduce the albedo reflection from these exposed areas. Thus, the detection of especially areas which are exposed to grazing can be temporally suppressed in the image analysis, giving a lower than actual area of farming activity. In the data set, there are a number of cases where fire scars, locally, can have affected the analysis, i.e. the area between Kuey, Pam, and Bow in the 2000 November image. In 2004 the area just south of Nhialdiu and in 1995 the area along the stream from Bentiu to Kuac are affected by fire scars to an extent that comparison with other images in these areas is not directly possible. The influence of fire scares is especially related to images recorded in the mid-late dry season (late December to May) and has highest influence on the more extensive used areas - such as grazing areas. Areas of permanent farming/human activity will rather quikly regain high albedo and thus, reveal where farming activity is concentrated at the time of satellite image aquistion.

Permanent sandy areas
Seasonal changes may also have an influence on the extent of the classified farming areas, i.e. if people and animals have just left an area the signs of environmental degradation caused by them will be maintained for a period before it will recover. This is especially evident along the sandy river banks where traditional housing and cultivation have taken place for years. An example of this effect can be seen in the early November 2002 image which shows a slight increase in the sandy bank areas compared to images taken some month before and after – this is interpreted as a result of the recent rainy season that has 'washed' the sandy degraded areas clean. Seasonal changes in the major river system are another example of bare surfaces that are changing without any connection to human presence.

Overall however, and considering the scale of the study and the multi-temporal annual approach, the above mentioned issues are not considered to have any significant influence on the observed general pattern of anthropogenic activities. I.e. the use of early dry-season satellite images with limited fires scares reveal the general change in land use in Block 5A during the observation period (HRW 2003). The additional dry season images (especially from 2002) further reveal the immediate concentration of farming activity in the area which again is described in literature (i.e. HRW 2003).

Satellite image processing
Image Geoprojection
All images have been projected to the UTM zone 35 North with WGS84 Datum and Spheroid.

Spatial resolution merge/enhancement
The Landsat data have been calibrated for reflectance.

To improve the interpretation the spectral bands have been pan-sharpened by the use of the panchromatic band to a spatial resolution of 14.25 m by the use of the Wavelet Resolution Merge technique (King *et al.* 2001).

Albedo and Tasselcap transformation (Crist and Kauth 1986) has been calculated and used to extract bright soil signatures.

Image classification
The digital image classification represents anthropogenic activity in terms of farming, thus the classification represents bare land surfaces and/or where anthropogenic activities have had a degrading impact on the natural environment during the latest season.

Images have been classified by the use of supervised and unsupervised classification procedures (Jensen 1996). An unsupervised 60 class ISO classification method was used on the individual images to extract areas with the highest albedo. Change detection has been made by the use of Boolean analysis in between annual classifications.

Oil industrial activities have been interpreted from pan-sharpened Landsat 7 data assisted by several map sources.

Verification
Given the local security situation where comprehensive field checks are not possible due to the civil war and the subsequent security cordon around the oilfields, the analysis of land use changes cannot be estimated exactly but is an expression of relative changes in anthropogenic land use. Several sources of verification have been used to assist self-explanatory image interpretation from Landsat images when they are put into natural colours (bands 1, 2 & 3), i.e. cultivated fields can be directly observed. In addition to this:

1) The pan-sharpened 60 cm resolution QuickBird 2 image has been used in natural colours. The image has been acquired for the 21st of March 2003 (late dry season) and has been used to confirm the cultivation pattern that could be observed in the Landsat images.
2) Aerial photos from February 2003 taken from an aircraft by the Civilian Protection Monitoring Team (Sharon Hutchinson) support the verification of derived cultivation and land use patterns.
3) A number of map sources, reports and geo-referenced information have been used to confirm the presence and movement of people in the area in the period between 1998–2003.
4) Comparing and relating information (primarily HRW 2003) on 41 attacks on villages and displacement of people with pattern of farming activity observed from the satellite data.

Findings

Documentation of land use and cover

Settlements
Villages were traditionally present along the raised sand banks of major streams (figure 3), with cultivation on the sandy soils leaving a bright signature in the satellite images. The smaller settlements in the study area are usually characterized by a few huts/houses close to each other or more commonly strung out in a line. They are in most cases visible by the degradation/bare areas surrounding them, with a bare core area, and in some cases by tracks leading to them, and/or cultivated fields surrounding them.

Land use
Small scale cultivation patterns are visible in the images which again are an indication of the farming activity of the population in the area. Figures 3 and 4 illustrate settlement areas where especially cultivation takes place on higher ground near the watercourses. The images are taken at the end of the cultivation season and reveal the bare fields which have been recently cropped. The presence of cattle also has a significant influence on the albedo. In figure 5, cattle tracks are clearly visible in the Landsat data although they only cover a minor fraction of the image elements. When cattle are concentrated in an area even for a shorter period the albedo increases significantly (Prins 1997 a + b) and the area is mapped as a farmed area.

Figure 3 and 4. Typical farming scenario from the area observed by an aerial photo (photo credit: Sharon Hutchinson ©) right and left Landsat TM (band 7, 5, 3. Cleared farm fields appear as bright whitish clearings.

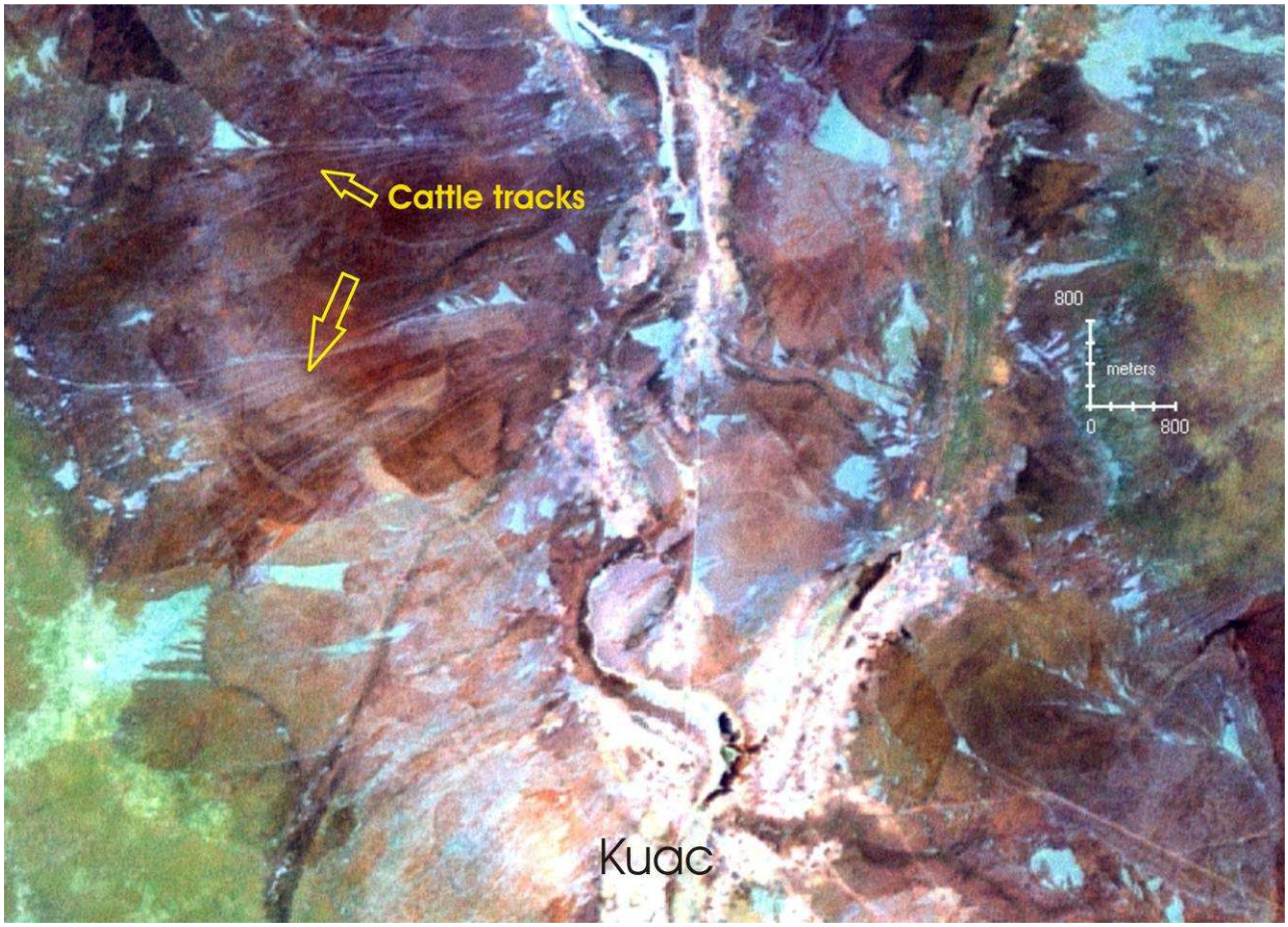

Figure 5. The presence of cattle in the dry season increases the albedo in populated areas. The above Landsat ETM+ image recorded in March 2000 illustrates a typical dry-season scenario — very bright areas refer to settlement/farmed areas along streams where cattle are also driven to. Cattle tracks are clearly visible although they cover only a minor part of the Landsat image elements.

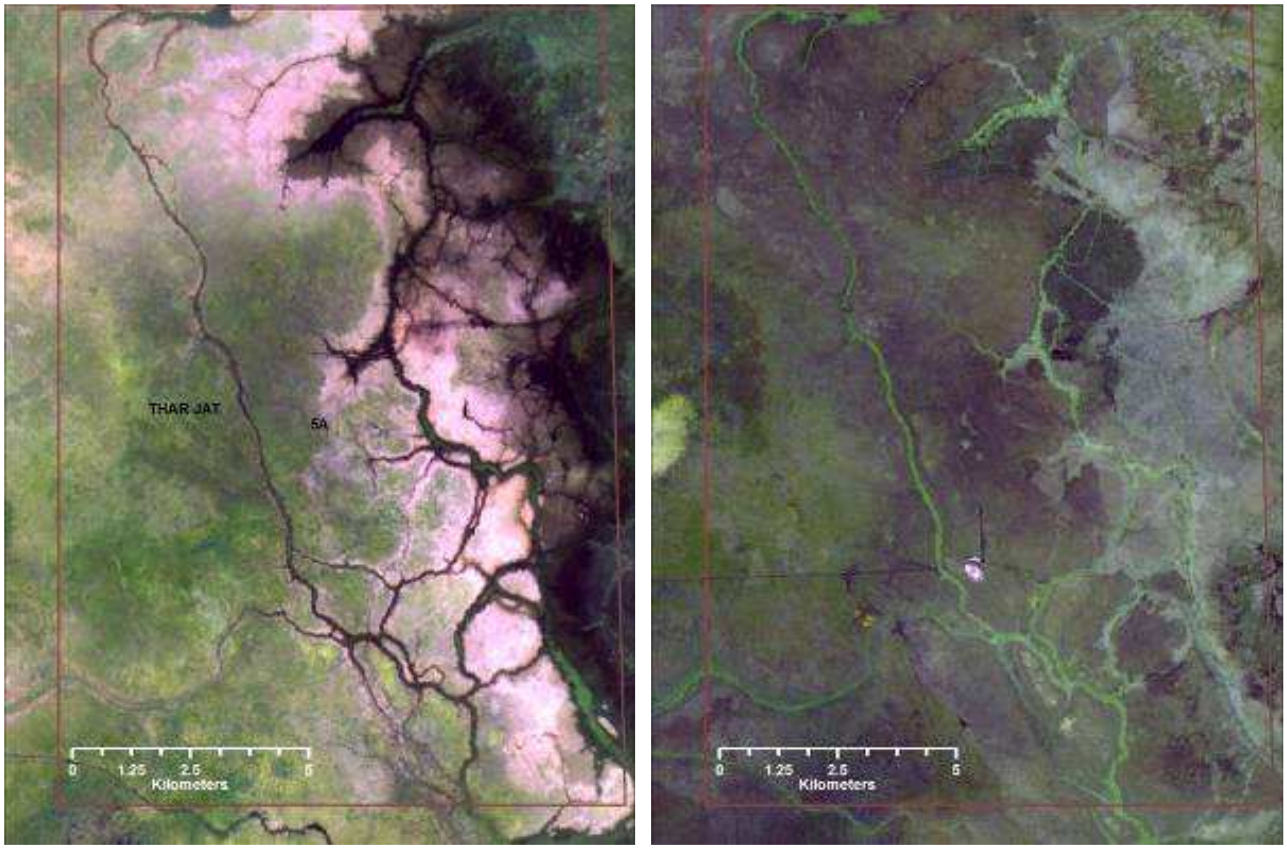

Figure 6. Thar Jath oil field. The 1987 image on the left indicates the Nuer dry season grazing (light pink colour) along the wetlands close to the White Nile river. In the 1999 image on the right, oil exploitation activities have started and the presence of Nuer dry season grazing is no longer visible, indicating that this farming practice had stopped in this area.

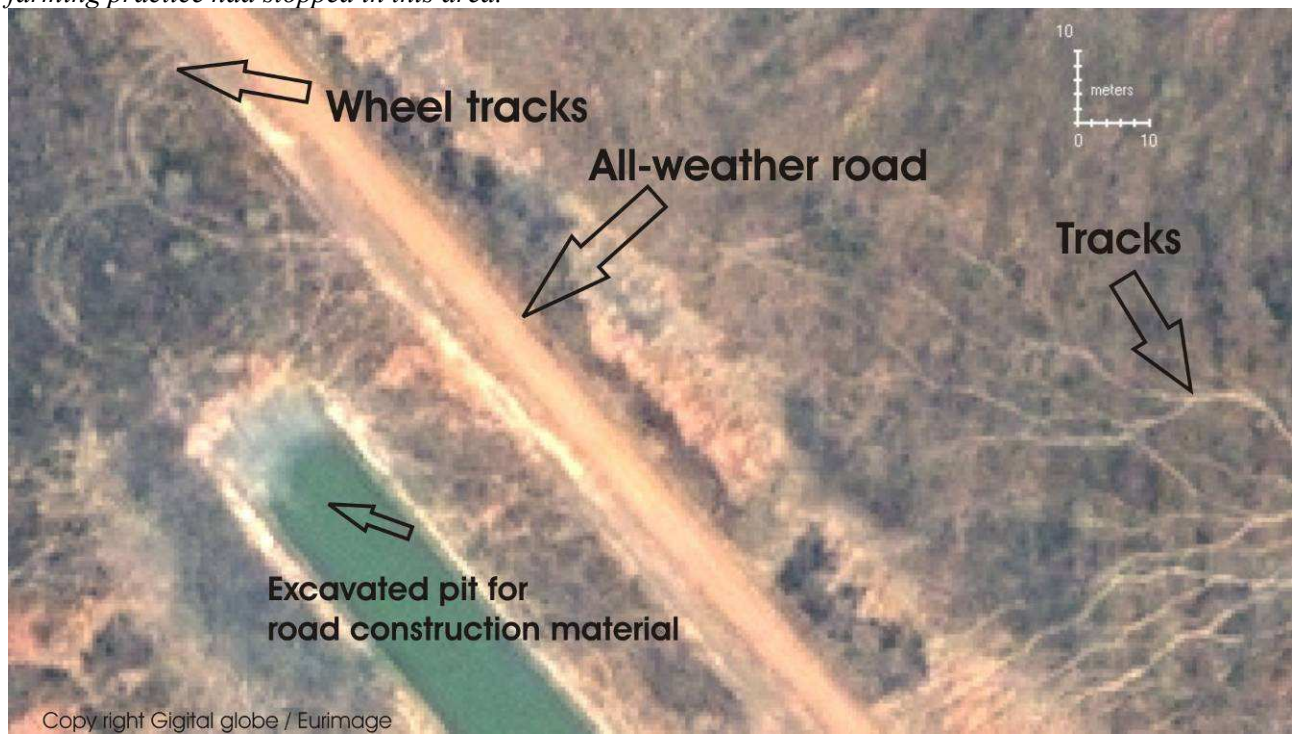

Figure 7. QuickBird 0.6 m resolution satellite image recorded the 21st of March 2003 on the oil road south of Kuac. Wheel and other tracks break the soil crust in the bush-fire affected environment.

Farming Activity 1994–2003
In order to avoid artefact errors and to cross-verify results, two sets of images were analysed for each annual scenario[4] at the beginning to the middle of the dry season (figure 8). The scenario of the 1994/5 situation[5] was used to indicate where farming activity would have been during the first part of the dry season. Further scenarios from 1999/2000 and 2002/3 were analysed to trace subsequent land use changes during the period of oil exploration and exploitation activities.

1994/5 Scenario
The 1994 /1995 scenario represents a stable situation at beginning of the dry season, a few years prior to the arrival of the oil industry in the area. The images are acquired approximately 1.5 months apart. Human activity is centred close to Ngop within an approximate radius of 20 km. The general pattern on the two images is similar — few changes can be seen and these are largely caused by the influence of recent bush fires in extensively used areas.

1999/2000 Scenario
The 1999/2000 scenario is based upon 2 images taken approximately 3 months apart. The general pattern is the same as the 1994/5 scenario, although the 1999 image shows less activity south of Pam and Touc which can be linked to fire scares and fighting (HRW 2003) in that area. It can be noted that a large area of anthropogenic activity is visible outside the study area north of Buoth on the northern banks of the Bahr el Ghazal river (which appears white in the images).

2002/2003 Scenario
Significant changes can be observed in the 2002/2003 images. The 2002 image is recorded on the 3rd of November which is the earliest in the overall analysis, however, it shows significantly less farming activity north of Ngop, Pam and Bow. The areas around Nhialdiu and Kuey show significantly lower farming activity — only the sandy banks along the streams show high reflectance. This may not be linked to active farming, but can be explained as sandy areas that have been used for years and therefore take more time to recover — a similar pattern can be observed in other places in the images and this pattern is confirmed by the very high resolution QuickBird image north east of Kuac (figure 2). A larger area of increased anthropogenic activity can also be observed between Bentiu and Nimne and additionally in the area north east of Leer. Furthermore, some traditional *toic* areas close to the White Nile appear to be populated.

Farming Activity 1999–2003
Given the scale of the observed changes in late 2002 and the beginning of 2003, a closer examination of the general changes in land use patterns was carried out for the period between 1999 and 2003 (figure 9). This was made possible as extraordinarily many satellite images are now publicly available from the United States Geological Survey for the study area within the desired time slot.

8th and 24th March 2002
Two images from the 8th and 24th March 2002 are available for the late dry season when bushfire frequency is high, and these images show an identical land use pattern. Compared to the situation

[4] Only the area south and east of Bahr el Ghazal river has been analysed in the mapped images.
[5] 1994/5 images were used as they are the closest cloud-free images that are available prior to 1999 for the study period. Much farming activity was observed in the area between Bentiu and Nimne and some population regrouping was observed in the area north of Leer.

in March 2000, the farming activity is considerably reduced in the wider area and nearly no farming activity could be observed in the areas between Rubnyagai and Nhialdiu down to Ngop, and around Kuey and Bow – This can be explained by people fled from this area in Feb. 2002 (i.e. HRW 2003). Furthermore, no activity could be observed along the new oil industry road south east of Bentiu and Kuac. Furthermore, a considerable increase in oil infrastructure can be observed.

3rd November 2002
Past the wet season and into the beginning of the new dry season an image was available for the 3rd of November 2002. The farming pattern here is similar to the March 2002 image, although the farming areas now stretch further south of Touc. There is also a decrease in farming activity on the northern part of the newly established all-weather road between Bentiu and Kuac (in the vicinity of the village area of Gwit). High reflectance or indication of farming can be observed in the areas between Bentiu and Nimne, and there are some *toic* grazed areas in the east close to the White Nile river. Furthermore, an increase in high reflectance areas can be found on the sandy banks in the Nhialdiu area where also a new all-weather road can be observed – this road is connected to the other new oil industry road that now extends beyond Thar Jath to Leer. There is uncertainty over how much of the high reflectance from the sandy banks is related to farming or is an artefact due to the recent rainy season where the very sandy areas around traditionally populated areas have been 'cleaned' by the rain. The latter interpretation is supported by the 0.6 m resolution QuickBird image from the 3rd of March 2003 in the Kuac area. Similar patterns have been observed by Prins (2008) in Darfur, where older burnt villages may turn from lower to higher albedo than the surroundings after a rainy season, despite not being re-occupied.

21st December 2002
In the Landsat image of the 21st of December 2002, farming activity can only be observed around and to the south of Touc. No farming activity can be observed in the triangle between Buoth, Thar Jath, and Bentiu. This area is affected by bushfire scars, however, largely no farming activity can be observed at all which suggest that close to non farming activity is present in the area.

23rd January 2003
The Landsat image of the 23rd January 2003 contains widespread bushfire scars, however shows a very similar pattern to the 21st December 2002 image, which again confirm ground reports (HRW 2003) of people presence in the Block 5A at that time, by refugee camps established in the Touc, Pam and Chotchara area and further south. A number of clouds were present and have been masked out but did not have any influence on the observed general pattern.

Verification of land use change against ground reports of attacks and displacement
Several reports have described attacks on villages and following displacement of people, most summarized in HRW 2003. I all 41 village attacks (1999-2002) were geo-located and plotted against the most severe changes between March 2000 and December 2002 (figure 22) – which can reflect the result of emptying the area around and south of Nhialdiu in late February 2002 (HRW 2003). The satellite study confirms the displacement of people in Block 5A - only 4 (less than 10%) of the 1998-9 attacks could not immediately be linked with substantial decrease in land use area (2000-2). However, a close examination of the maps (figure 8, - 18-21) gives a more complete description of the development of land use over the single years. Moreover, the refugee areas described in literature co-responded with the 2002-3 satellite observations of the remaining major anthropogenic activity in block 5A.

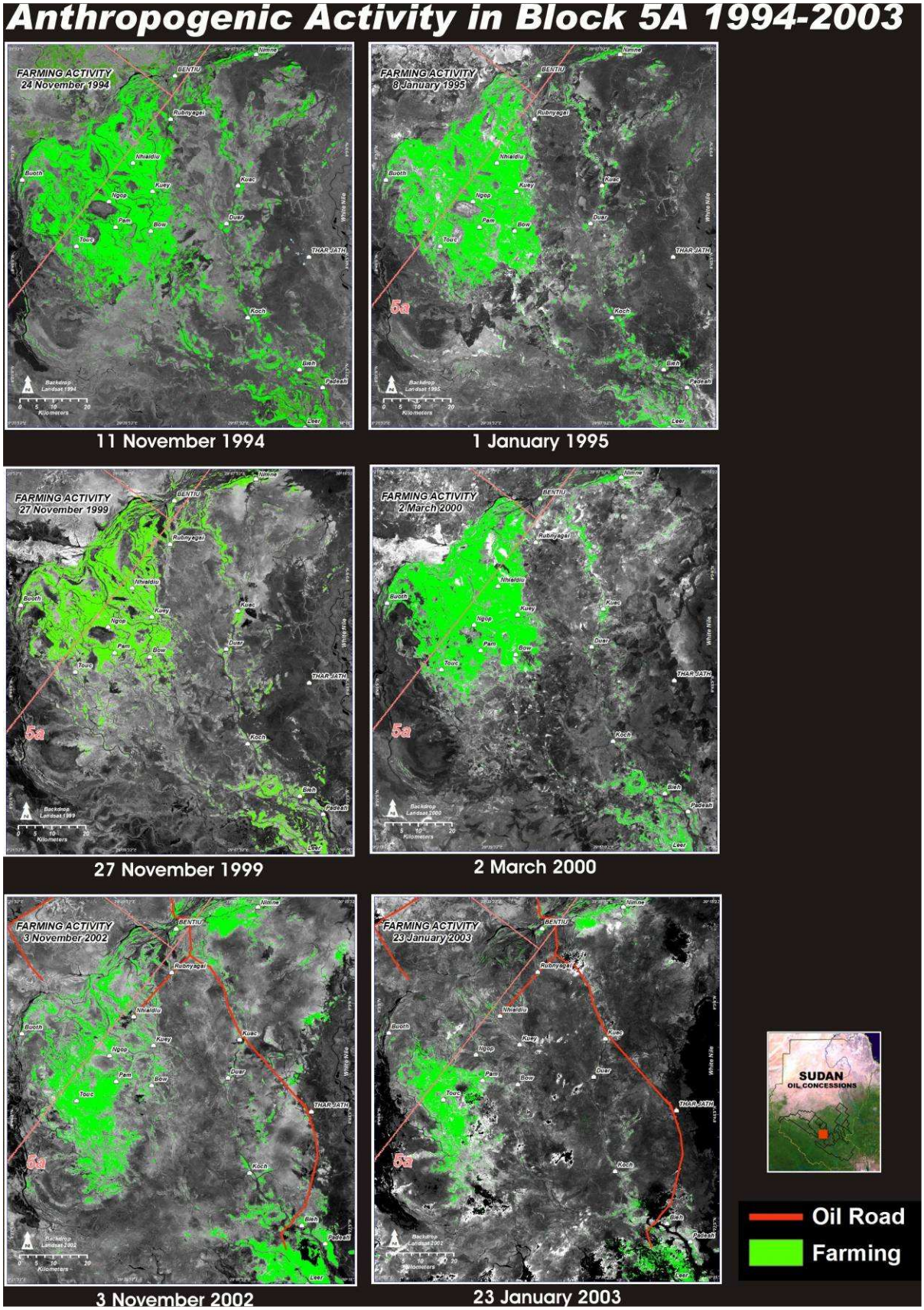

Figure 8. Multi-temporal dry season satellite image scenarios of the Block 5A concession in Sudan for 1994/5, 1999/2000 and 2002/3.

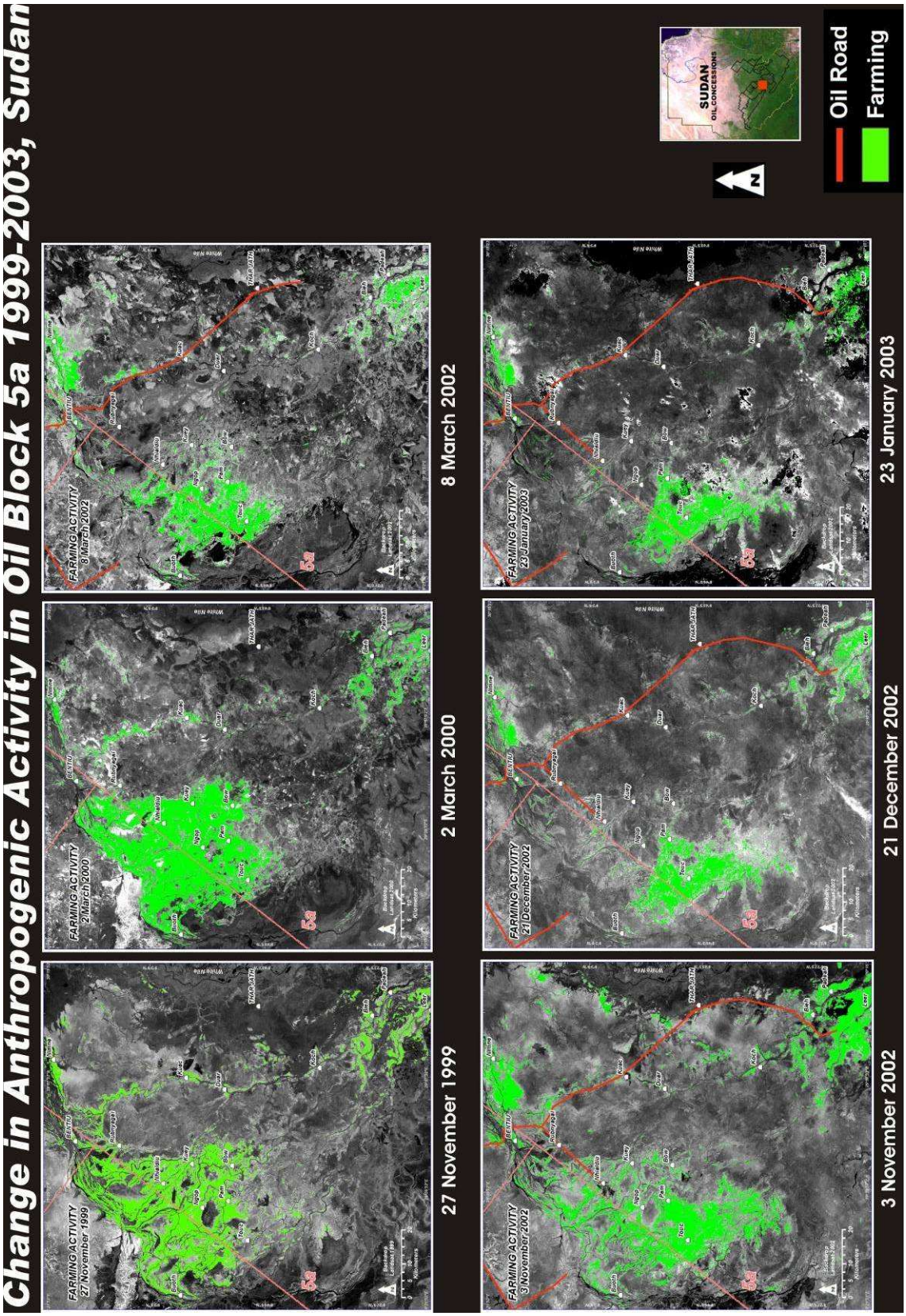

Figure 9. Multi-temporal dry season satellite image scenarios of the Block 5A concession in Sudan for the 1999–2003 period, which illustrates the massive changes that took place during 2002.

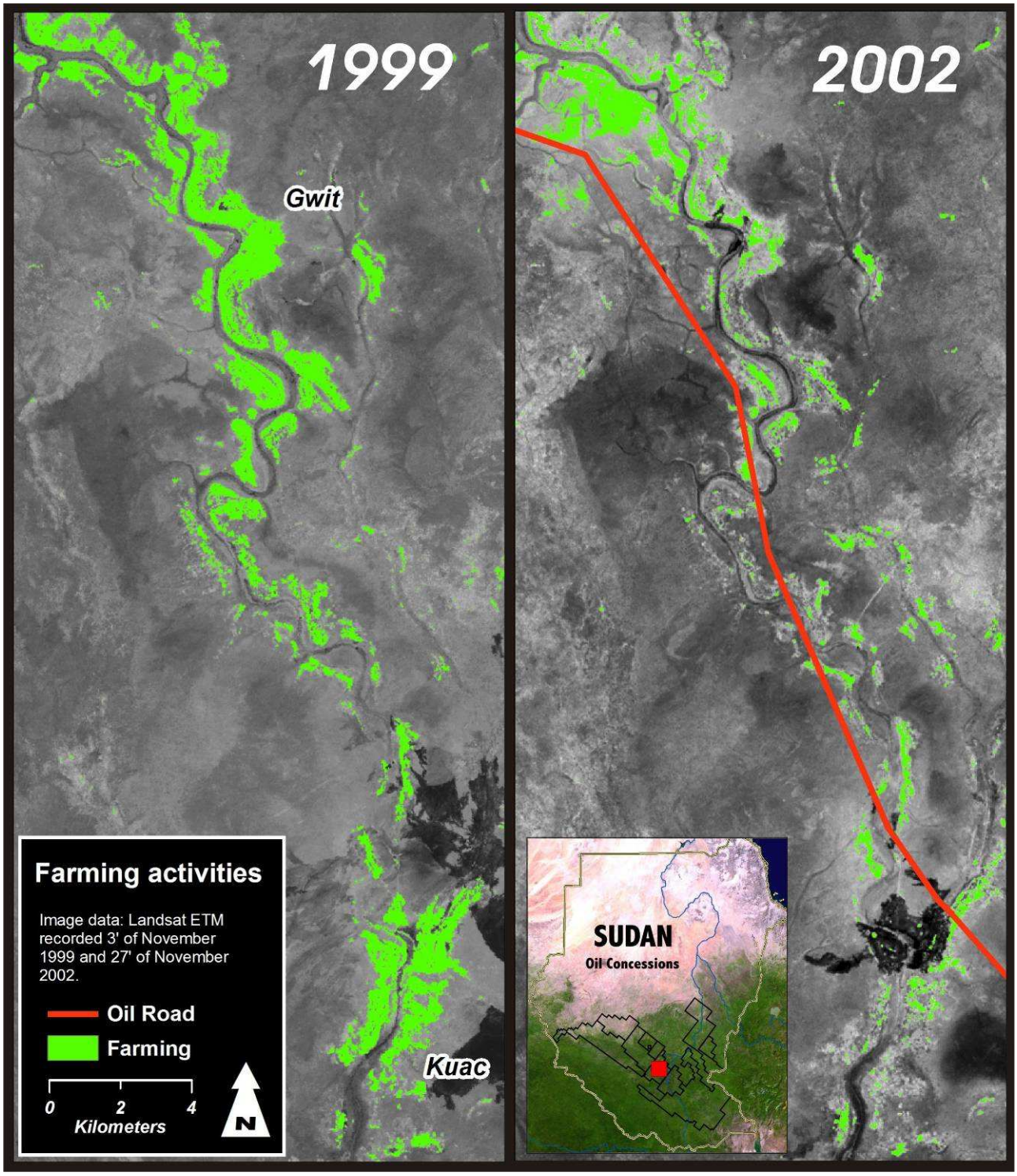

Figure 10. The situation in the area south of Bentiu before the construction of the oil industry road to Thar Jath (November 27, 1999) and after its completion (November 3, 2002). The images show that nearly all farming activity along the road has stopped between 1999 and 2002- this co-responds with ground reports that the villages Gwit/Guit and Kuac/Kuach where attacked several times during this period (HRW 2002). The indicated farmed areas in 2002 are primarily sand bank areas that may not actually indicate the presence of people, but are more likely the result of continuous bare sandy conditions after many years of human activity — see for an explanation of this condition the very high resolution image in fig 2 and text on uncertainty page 8.

Quantitative Changes in Farming activity

Two areas were statistically investigated for changes in farming activity during the period 1994–2003 (figure 11). The selection of the two areas was based upon reported areas of mass human displacement during 1999–2003 (i.e. HRW 2003) and their proximity to major road developments. The farmed areas under the two polygons in figure 11 have been calculated in hectares for each of the analysed images (figures 8–10) and their development is illustrated in Figures 12 and 13.

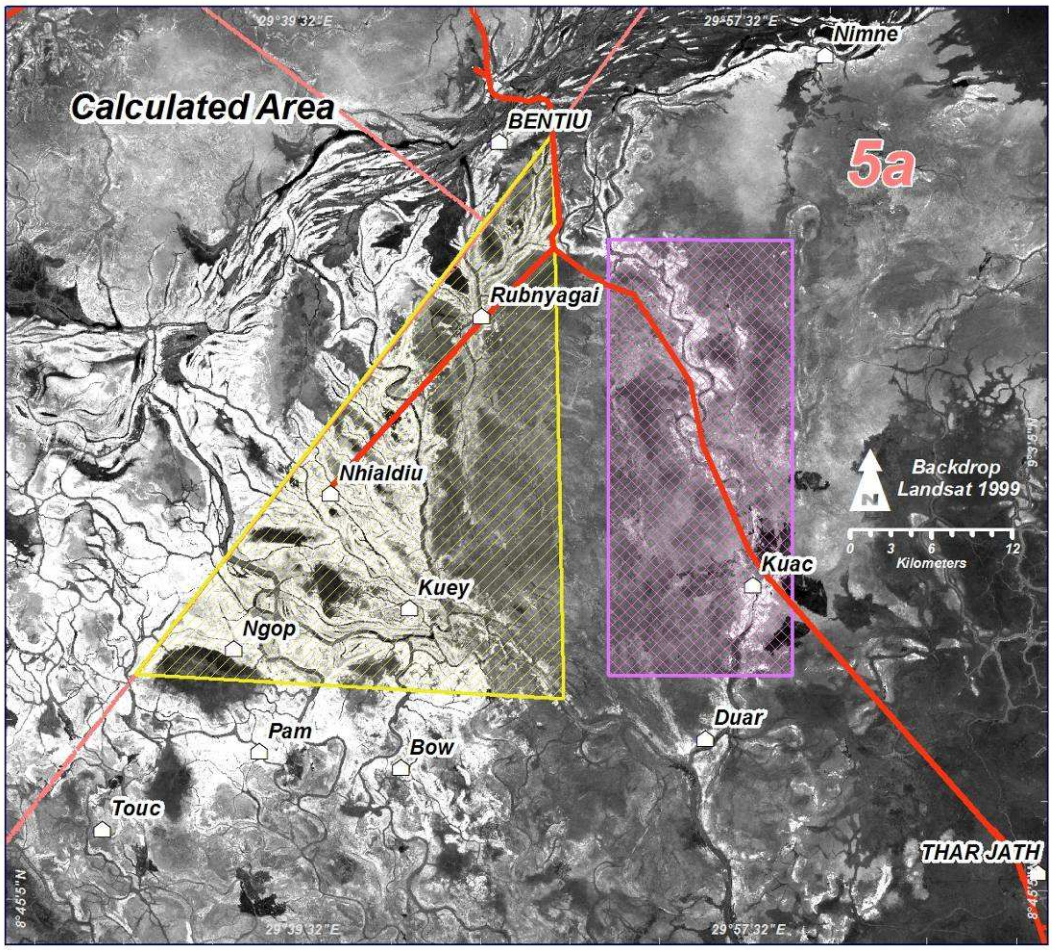

Figure 11. Two investigated areas inside oil Block 5A measured for changes in farming activity over the period 1994–2003. The yellow shaded area is centred on Nhialdiu and the magenta shaded area focuses on the northern part of the oil road from Bentiu to Thar Jath.

The land use changes in the Nhialdiu area (figure 12) show a striking decrease in farming activity down to approximately 1/8 of the former level. This was observed in March 2002 and continues to nearly vanish by the end of 2002. A small increase is observed in beginning of November 2002 which is interpreted as an artefact due to the early dry season image where the sandy banks appear more bright.

The significant reduction in farming activity in the area coincides with the establishment of the all-weather road to Thar Jath (figure 13) and at the end of 2002 farming has decreased down to a very low level. However, some variation can be observed during the monitored period which is primarily the result of variations in image acquisition dates, especially with regard to the onset of bushfires and the albedo signatures from along the stream areas. Thus, the November images of 1994, 1999,

and 2002 should be comparable with the latter being slightly over estimated (described above). The dry season images for 1995, 2000, 2002 (from March 8th, 24th and December 21st respectively) and 2003 show that farming activity stops around the area of Kuac village between March 2000 and March 2002, while no activity can be traced in the Gwit area from March 2002 – both villages reported burnt down.

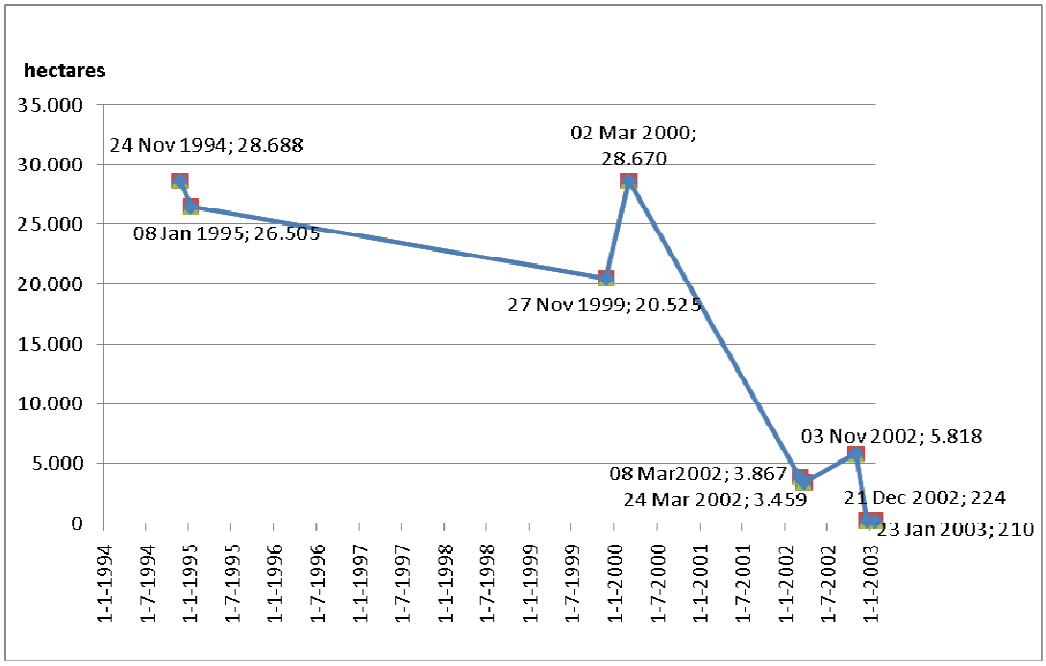

Figure 12. Observed changes to the area being farmed in the Nhialdiu area (see also figures 8, 9, and 10).

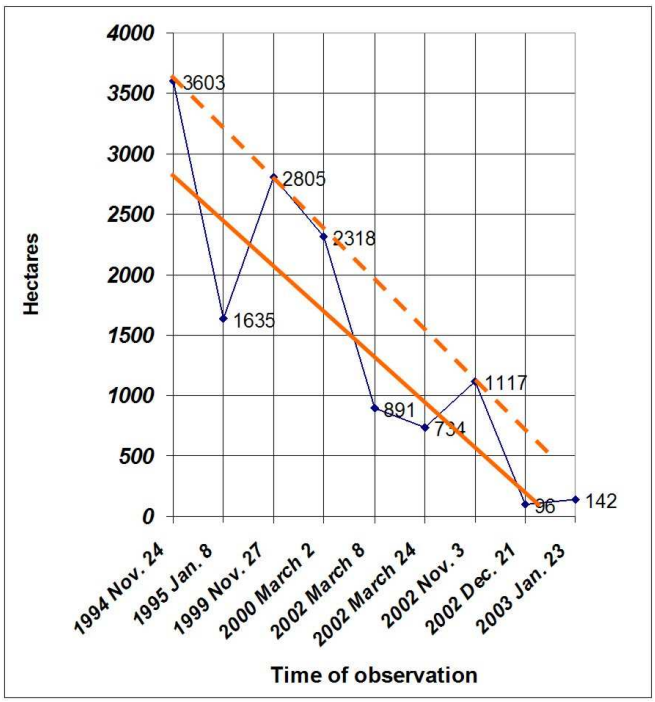

Figure 13. Observed changes to the area being farmed along the northern part of the oil road between Bentiu and Thar Jath (see figures 9 and 10 for specific area). Orange full line refers to trend in dry season images and dotted orange to early dry season images.

Construction of infrastructure in relation to oil exploration

Evidence of oil exploitation activities are directly visible in the Landsat images and more details can be derived from the pan-sharpened Landsat 7 images. This includes the construction of all-weather roads, secondary graded roads, vehicle tracks, as well as 200 x 300 m seismic grids for detailed oil exploration. Furthermore, drilling sites, pipelines, oil processing facilities, airports and other established facilities can be mapped. A scenario of the oil field developments carried out in concession Block 5A by 2006 can be seen in figure 17.

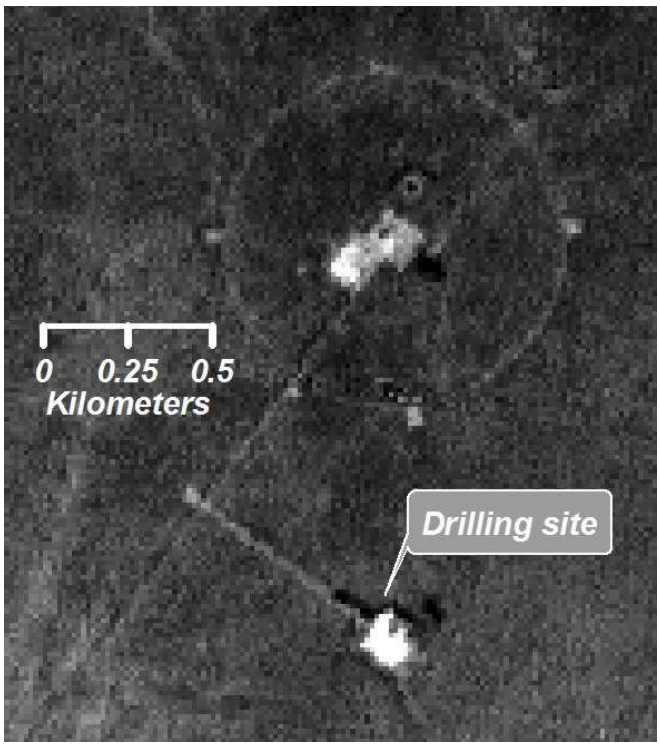

Figure 14. Example of oil facilities observed from a Landsat ETM+ panchromatic 14.5 m resolution image from oil concession area block 5A in Sudan — a drill site can be observed as a white square with a dark dot (drill tower), together with a circular object of unknown use.

Blocking of natural drainage

The construction of all-weather roads in connection with the oil exploration has had a visible effect on drainage patterns in the area. Several watercourse blockages can be spotted in the images in the form of moisture (low values in Landsat band 5 and Thermal band 6) that is trapped on one side of roads and thereby indicates disturbed natural drainage. The most severe case is north of the Thar Jath oil field where a blockage more than 8 km long was first observed in 2003 and has increased in 2004 through 2006 (figures 15 and 16).

It should be noted that the hydrological problems at Thar Jath were observed on satellite images 3 years after the all-weather road was constructed and the drilling/production started. It is also possible that the water may have been polluted due to oil production, which would be of serious environmental concern — especially as the White Nile river is only 5 km away. **Thus, a more detailed verification of the hydrological conditions should be made.** Further, an irregularity was observed in the oil field by Landsat on the 8th November 2004, when a thick black cloud with a 13 km black fan could be observed from one of the boreholes. No burning or hot temperatures were observed from the spot and an investigation for a ‘blowout’ and resultant oil spill should be made.

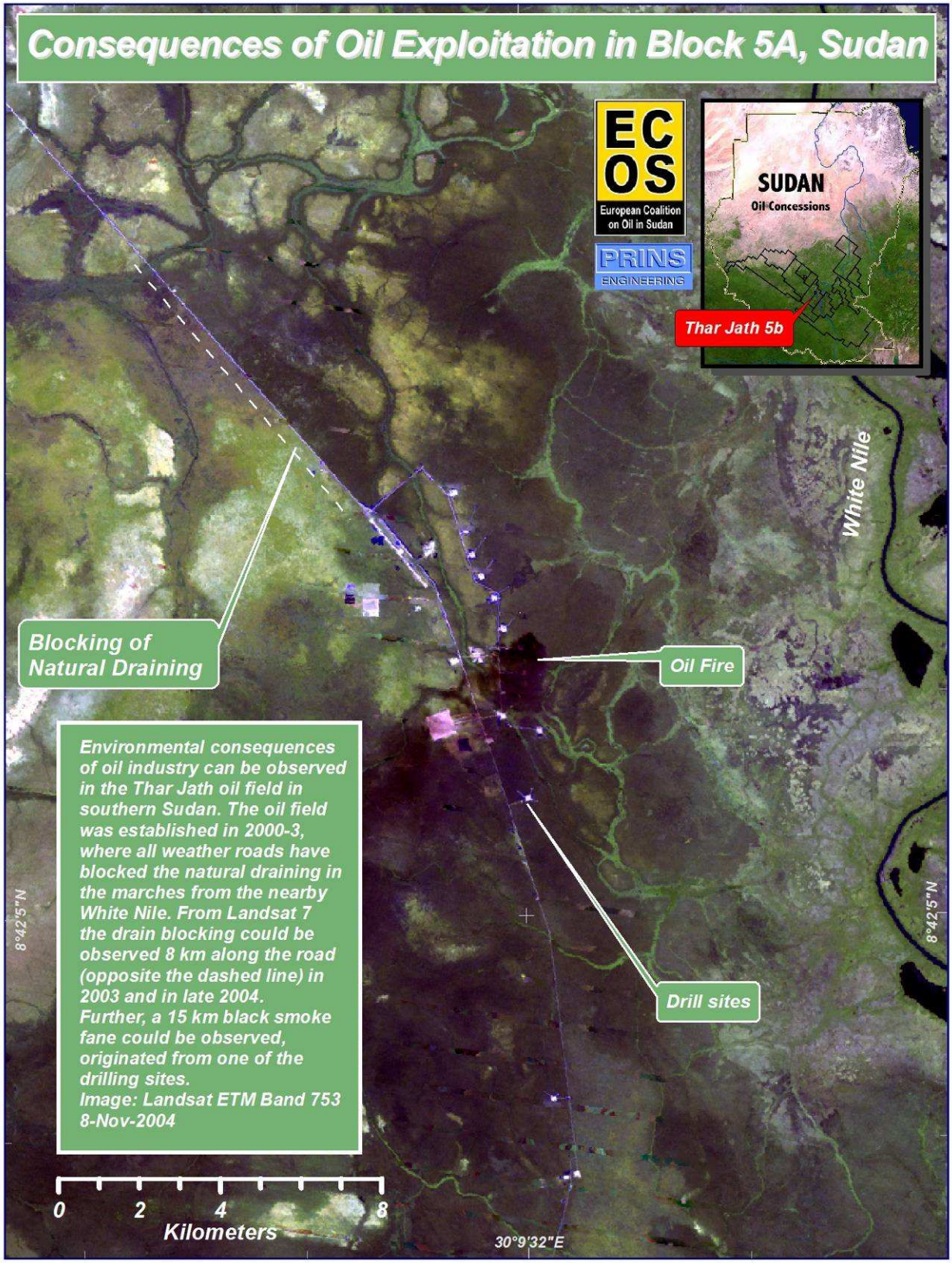

Figure 15. Thar Jath oil field recorded 8th November 2004. It can be observed that the all-weather road to Bentiu has disturbed the natural drainage in the area, resulting in an 8 km dam north of the oilfield. Further, a dark patch is emanating from the drilling site, leaving a black fan south west of the oil field.

Figure 16, Thar Jath oil field recorded 13th October 2006. It can be observed that the all-weather road to Bentiu has disturbed the natural drainage in the area resulting in an 8 km dam north of the oilfield. Further, considerable increased wetness (dark areas) is present south and south west of the oil field.

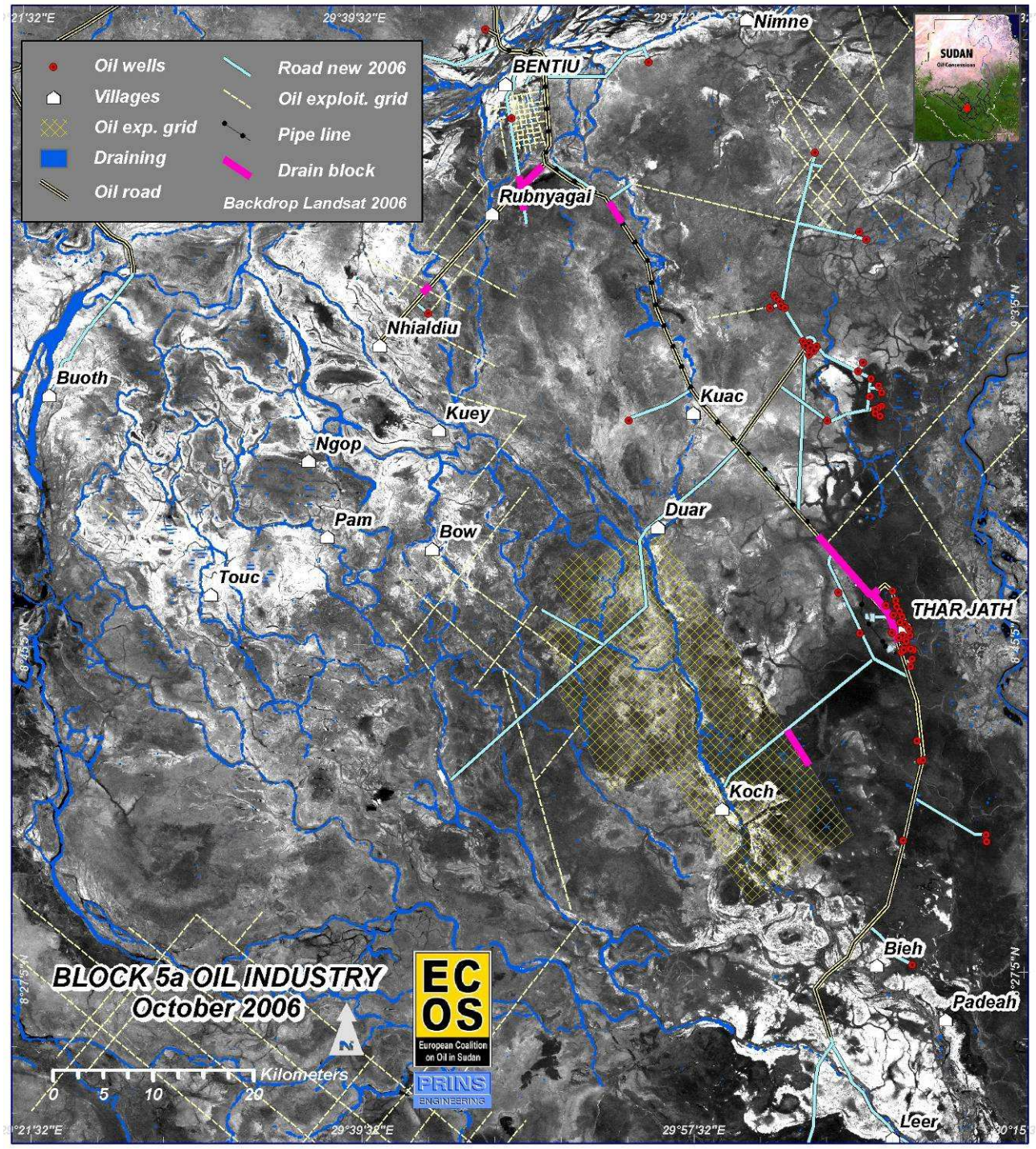

Figure 17. A Landsat scenario from October 2006. Development of the oil industry has stepped up since 2004, with the construction of several new all-weather roads attached to the Bentiu – Leer road. Drilling sites have tripled and a new oil field has opened west of Kuac, while extensive seismic grids have been established in the SW and NE of the area (including an intensive 200 x 300 m grid between Koch and Duar and south of Bentiu).
The background image is a panchromatic Landsat 7 image from 2006 where bright areas reflect farmed areas.

Changes in Land use.

The following maps illustrate changes in land use by comparing farming activities with developments in oil industry infrastructure.

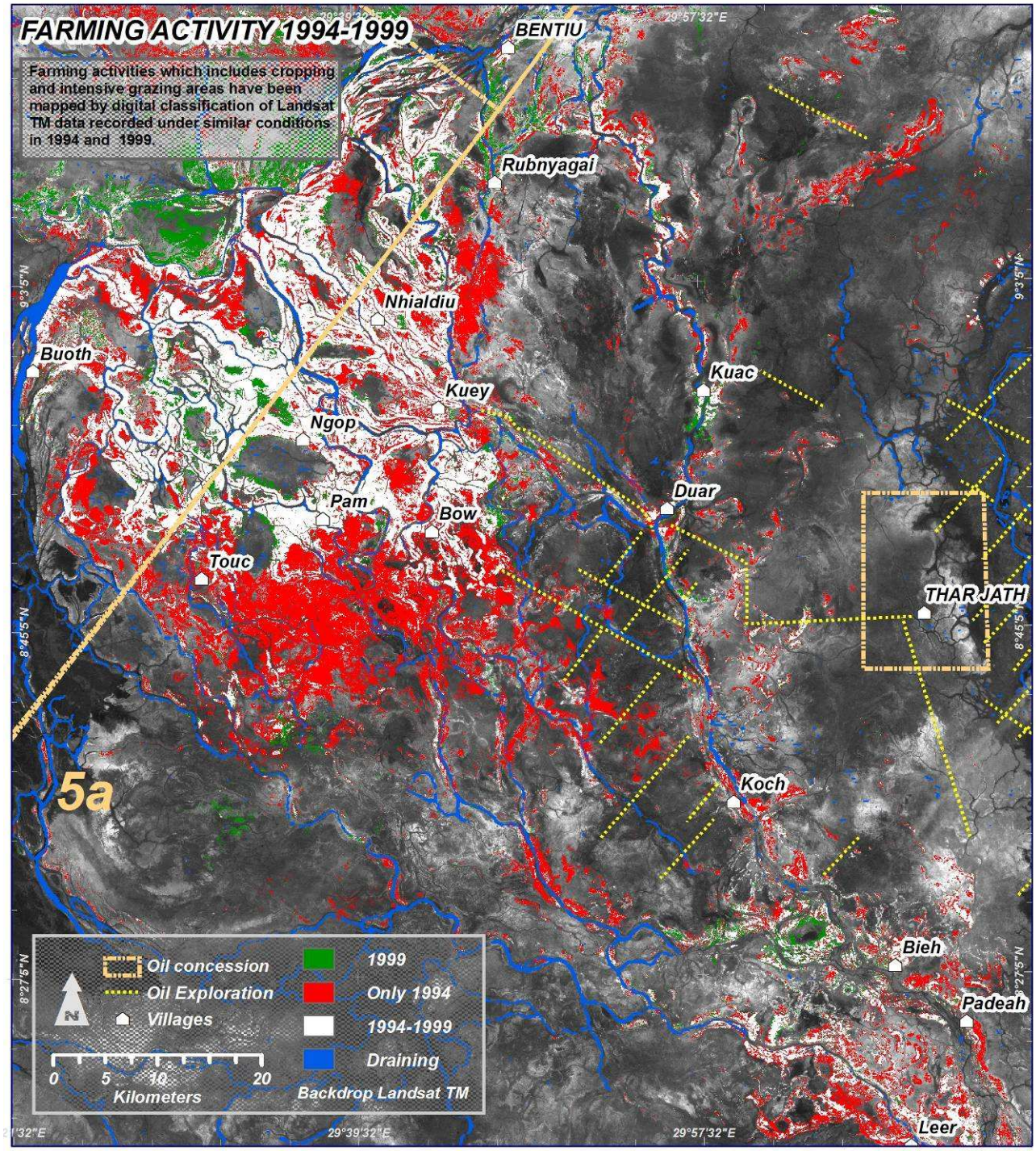

Figure 18. A comparison of the agricultural land use situation in 1994 and 1999 before the construction of the all weather road between Bentiu and Leer, however, with seismic oil exploitation grids visible in the 1999 image. In general agricultural land use has disappeared from the southern and eastern part of the area and is concentrated in the north western part of the area.

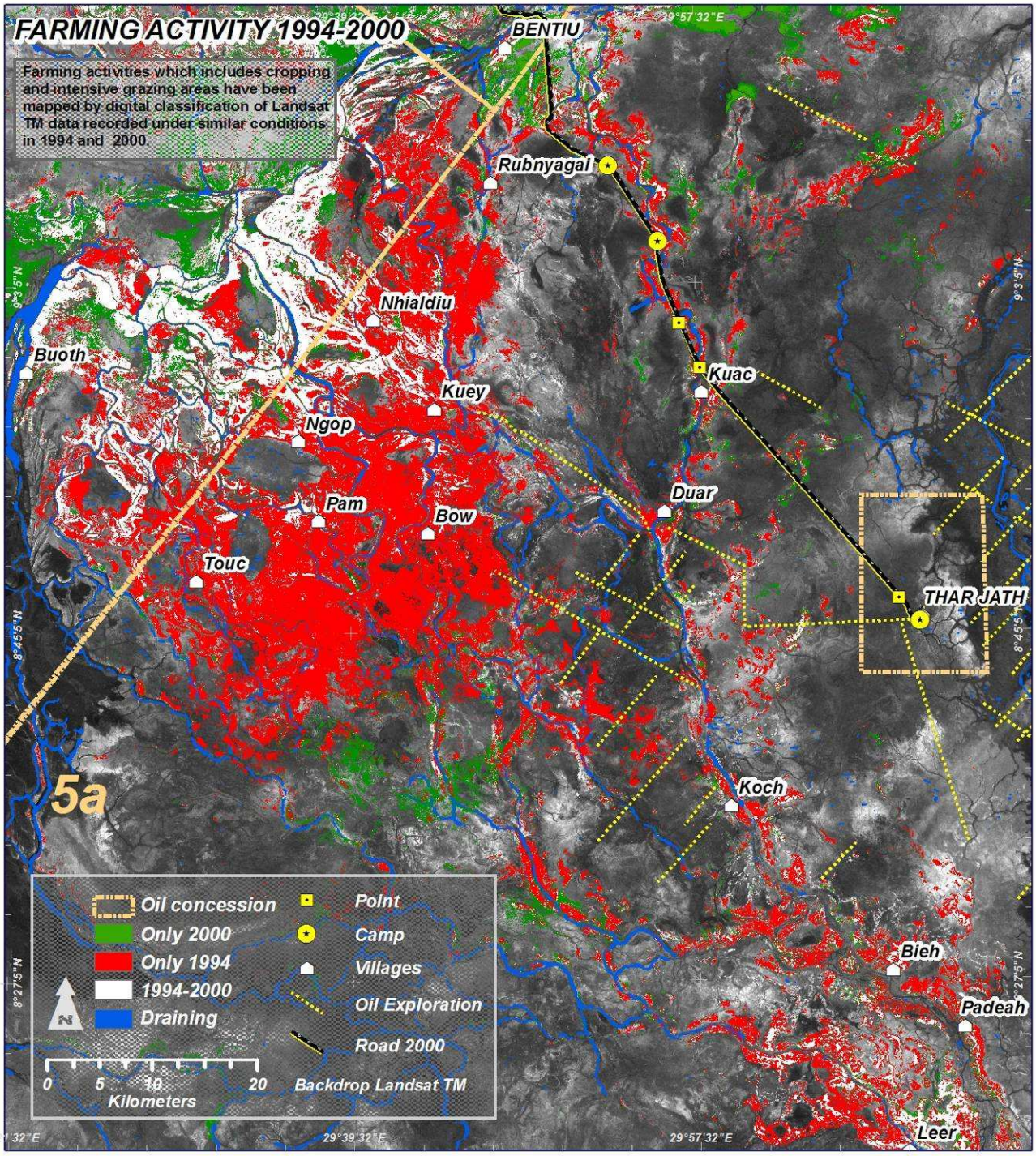

Figure 19. A comparison of 1994 and 2000 farming activity. The oil road between Bentiu and Thar Jath has been established and land use is concentrated in the NW part of the area and SE around Leer. Compared to the 1994 situation agricultural land use along the newly constructed road has in general disappeared and land use as such has decreased in Block 5A — especially the area between Pam, Bow, and Kuey. A number of camps were observed along the newly constructed road as well as a number of military check points (presence confirmed in a personal communication from Sharon Hutchinson).

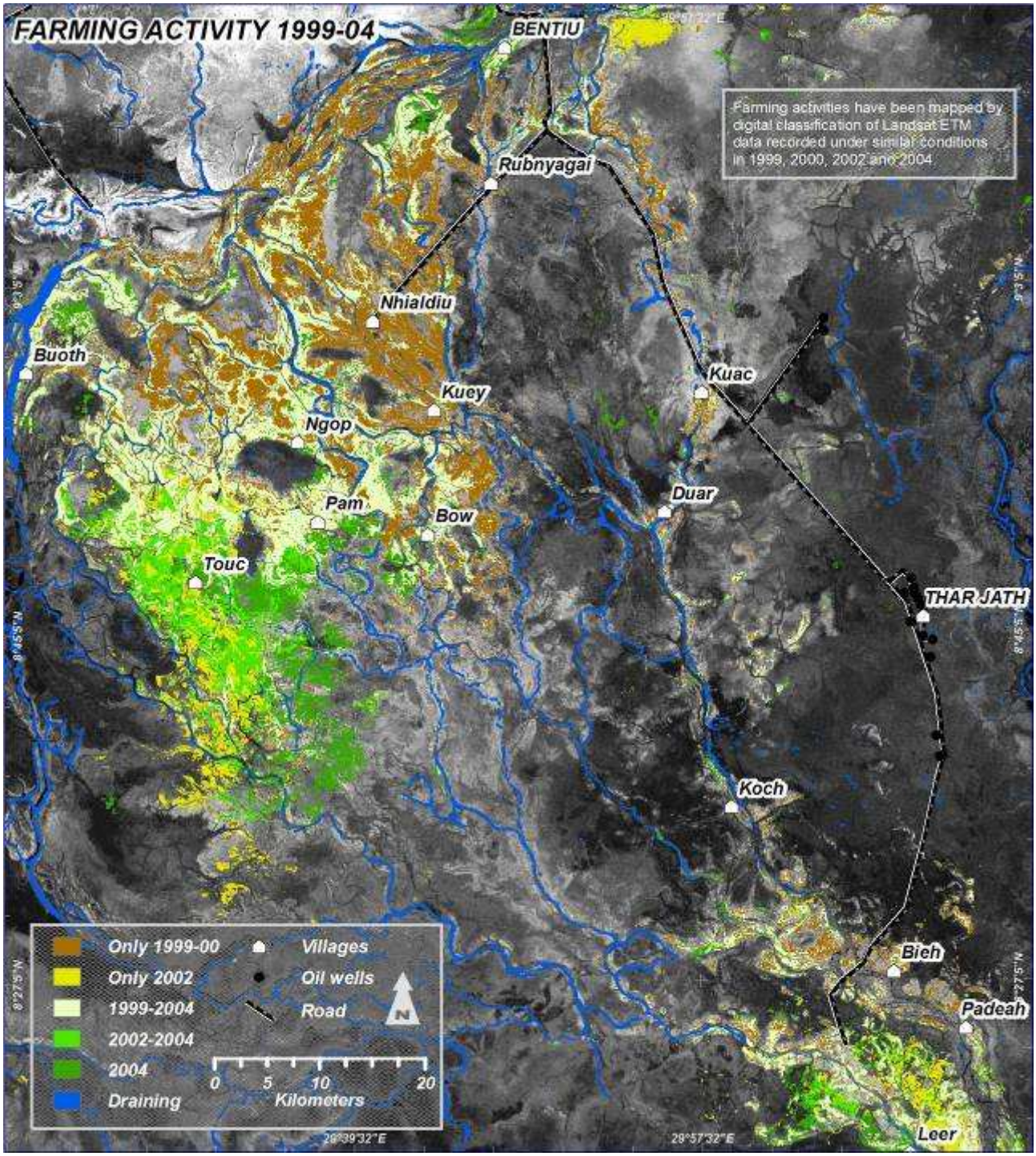

Figure 20. A combined scenario of the period between 1999 and 2004. All-weather roads have been constructed, the Bentiu–Leer road is completed and appendices to drilling sites are established. Furthermore an all-weather road to Nhialdiu has been constructed, while agricultural land use has disappeared from the area and new farming areas appear south of Touc–Pam –Bow. The increased land use south of Touc peaks in 2002, while land use activities along the Bentiu–Leer oil road remains limited through 2004. Land use may be underestimated in the area between Nhialdiu and Kuey due to the presence of bush fires in the area which may underestimate farmed areas.

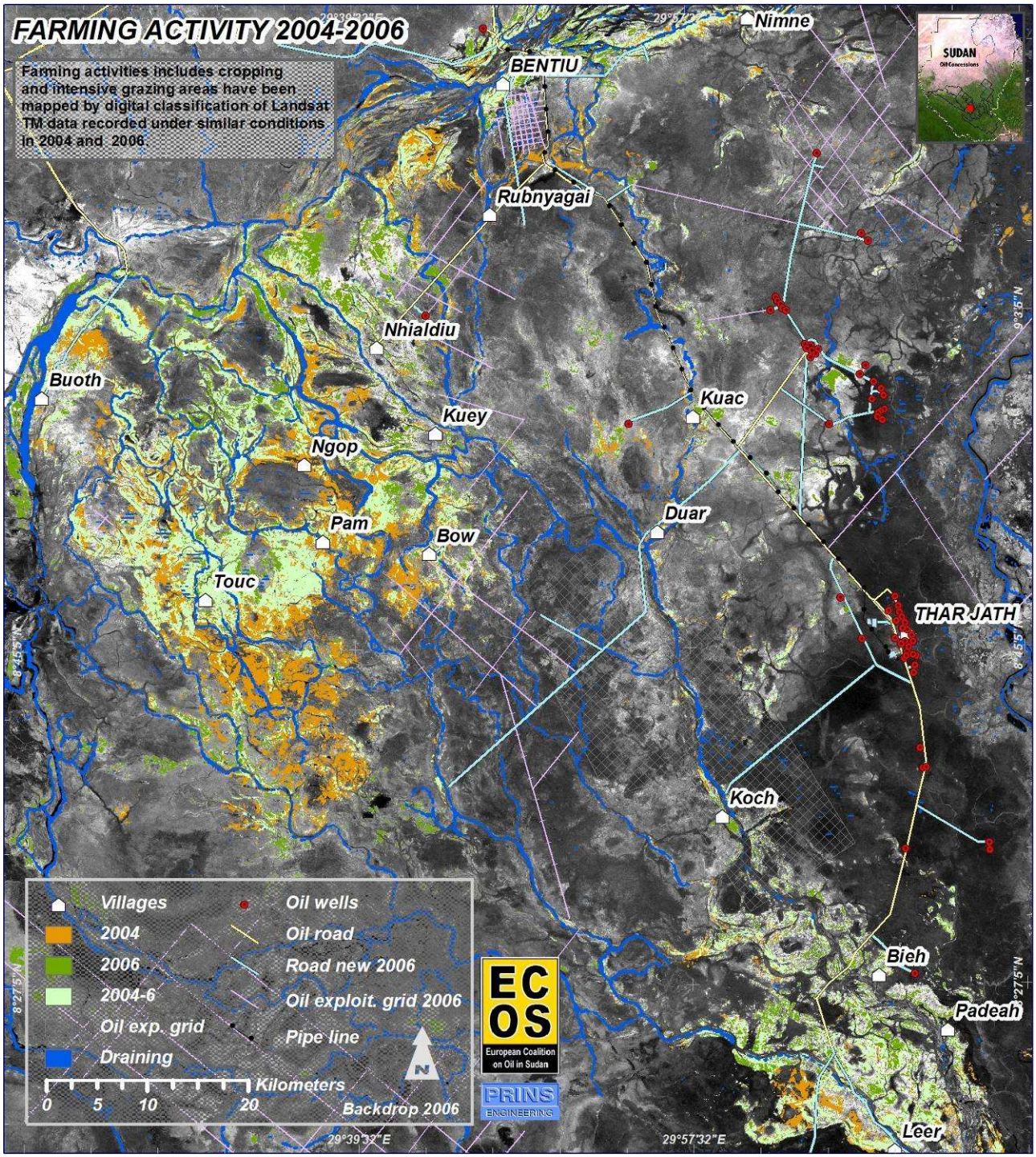

Figure 21. A combined scenario of the period between 2004 and 2006. Development of the oil industry has increased; several more all-weather roads have been constructed attached to the Bentiu – Leer road. Extensive seismic grids have been established in the area and drilling sites have been tripled. The agricultural land use concentration south of Touc is disappearing and some resettlement can be observed north of Nhialdiu and Leer. A pipeline has been constructed from Thar Jath to Bentiu.

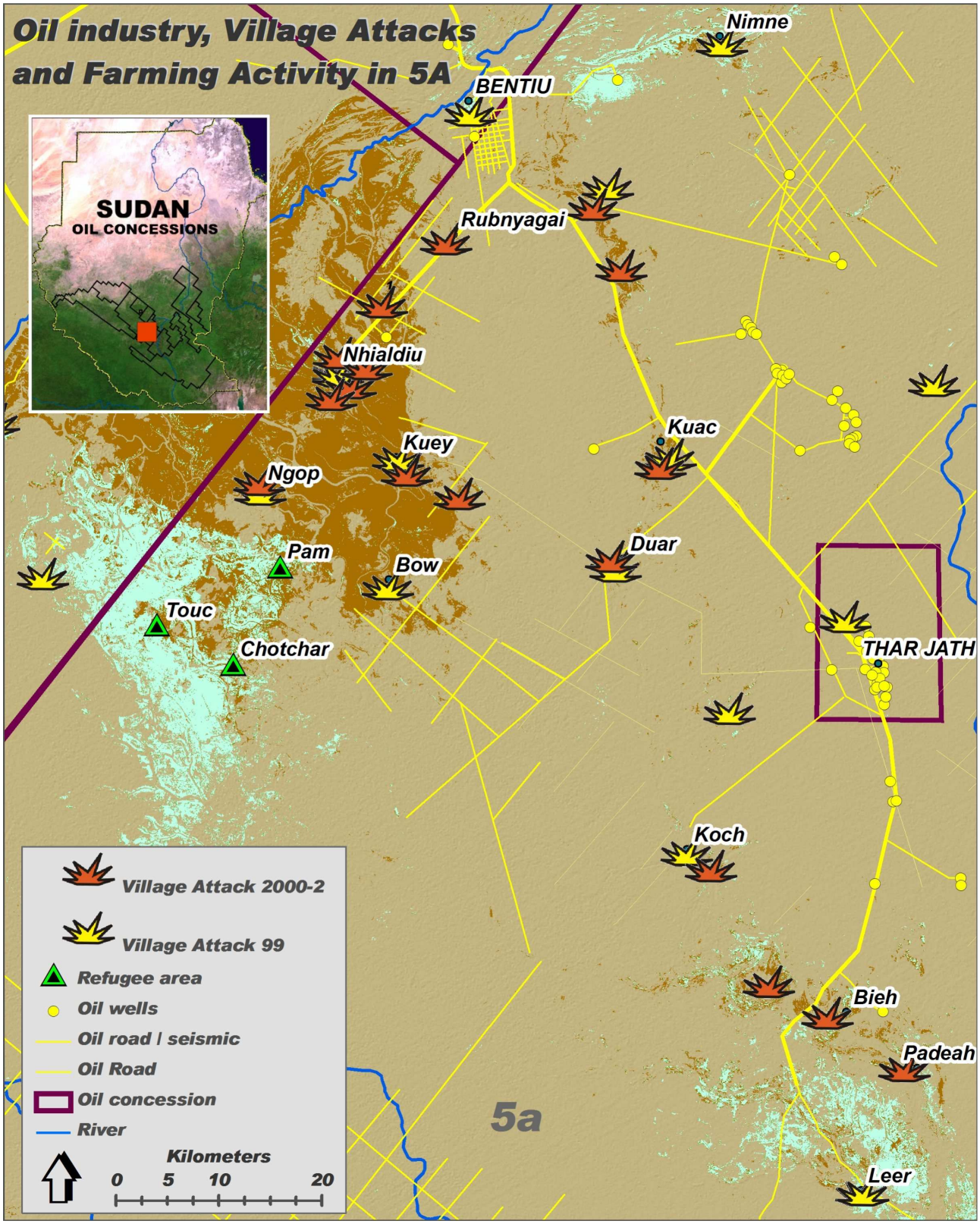

Figure 22. Changes in farming activity from March 2000 (brown) overlaid March 2002 (light green), attacks on villages, refugee villages and observed development of oil industry (yellow, updated until late 2006 - refer to figures 17 and 21 for exact oil industry legend).

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