

Christian Knieper

**Remote Sensing Based Analysis of
Land Cover and Land Cover Change
in Central Sulawesi, Indonesia**

ERDSICHT - EINBLICKE IN GEOGRAPHISCHE UND GEOINFORMATIONSTECHNISCHE ARBEITSWEISEN

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Christian Knieper

**REMOTE SENSING BASED ANALYSIS
OF LAND COVER AND
LAND COVER CHANGE IN
CENTRAL SULAWESI, INDONESIA**

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VORWORT DES HERAUSGEBERS

Die Reihe „Erdsicht – Einblicke in Geographische und Geoinformationstechnische Arbeitsweisen“ soll Forschungsergebnisse und Arbeiten im Bereich der Erdsystemforschung vorstellen. Die Betrachtung der Erde als System ist als Inhalt heutiger und zukünftiger Geowissenschaftlicher Gemeinschaftsforschung dringend gefordert. Die Herausforderungen liegen zum einen in der Erforschung der vielfältigen Interaktionen zwischen den verschiedenen Teilbereichen des Systems Erde. Hierzu zählen Wechselwirkungen zwischen fester Erde und Atmosphäre, zwischen der Landoberfläche und der Hydrosphäre oder zwischen Biosphäre, Hydrosphäre und Atmosphäre. Der Mensch steht dabei mit seinen zentralen Nutzungsansprüchen (Ernährung – landwirtschaftliche Nutzung – Ressourcennutzung) im Mittelpunkt eines vielfach vernetzten Erdsystems. Der Mensch verändert Landschaften und Atmosphäre und greift somit in alle Skalenbereiche des Erdsystems ein. Insofern müssen diese Veränderungen beobachtet und bewertet werden, damit Konzepte für ein nachhaltiges Erdsystemmanagement auf den unterschiedlichen Raum- und Zeitskalen entwickelt werden können. Die neuen Geoinformationstechniken (Geostatistik; Geographische Informationssysteme – GIS; luft- und Satellitengestützte Fernerkundungssysteme – Remote Sensing) helfen dabei das System Erde zu beobachten und zu begreifen. Ohne diese Techniken ist eine ganzheitliche Betrachtung der Erde und eine flächenhafte Bereitstellung von Informationen über das Erdsystem nicht möglich.

Die Arbeit von Christian Knieper beschäftigt sich mit der Thematik des Landschaftswandels vor dem Hintergrund des wachsenden und zum Teil dramatischen Verlustes der Artenvielfalt in den Tropen. Die Landnutzung und intensive Bewirtschaftung des Regenwaldrandbereichs durch den Menschen stellt einen wesentlichen Faktor dar, der - neben dem globalen Klimawandel - die Stabilität des Ökosystems „immergrüner tropischer Regenwald“ beeinflusst. Der Sonderforschungsbereich SFB-552 „Stability of Rainforest Margins in Indonesia“ (STORMA) untersucht in diesem Zusammenhang die Auswirkungen menschlicher Aktivitäten und anderer Faktoren und Prozesse auf den Zustand eines tropischen Ökosystems in einem Testgebiet in Zentral Sulawesi.

Die Studie von Herrn Knieper liefert im Rahmen dieses multi-disziplinären Forschungsprojekts wichtige Basisinformationen über den Zustand und die Dynamik der Landoberfläche in der Übergangszone zwischen Naturwald und Kulturlandschaft.

Martin Kappas

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LIST OF ABBREVIATIONS

A.	André
a.s.l.	above sea level
B	blue
BI	Bare Soil Index
BPS	Badan Pusat Statistik
BTNLL	Balai Taman Nasional Lore Lindu
CA	Tree Crop(s), Dominant Crop: Beverage - Cocoa (<i>Theobroma cacao</i> L.), Crop Cover: Plantation(s)
CCRS	Canada Centre for Remote Sensing
CF	Broadleaved Evergreen Trees: Cloud Forest
Classif.	Classification
CN	Tree Crop(s), Dominant Crop: Fruits & Nuts - Coconut (<i>Cocos nucifera</i> L.), Crop Cover: Plantation(s)
COH	Closed to Open Herbaceous Vegetation
CRF	Broadleaved Evergreen Trees: Closed Rain Forest
discrim.	discrimination
DJPHKA	Direktorat Jenderal Perlindungan Hutan dan Konservasi Alam
ed(s).	editor(s)
e.g.	exempli gratia
etc.	et cetera
ENVI	the Environment for Visualizing Images
ESRI	Environmental Systems Research Institute
et al.	et alii
ETM+	Enhanced Thematic Mapper Plus
f.	and the following page
FAO	Food and Agriculture Organization of the United Nations
fig.	figure

FWB	Natural Waterbodies (Flowing)
FWI	Forest Watch Indonesia
GFW	Global Forest Watch
GIS	geoinformation system
GLC2000	Global Land Cover 2000
GmbH	Gesellschaft mit beschränkter Haftung
GPS	Global Positioning System
HCO	Herbaceous Closed to Open Vegetation
HF	Broadleaved Evergreen Trees: Heath Forest
HRVIR	Haute Resolution Visible Infrarouge
i.e.	id est
IMPENSO	the Impact of El Niño Southern Oscillation
Inc.	Incorporated
iss.	issue
JRC	Joint Research Centre
LCCS	Land Cover Classification system
M	Graminoid Crop(s), Dominant Crop: Cereals - Maize (<i>Zea mays</i> L.)
MC	Mosaic of Cropland / Tree cover/ Other Natural Vegetation
MIR	middle-infrared
MSS	Multispectral Scanner
n.a.	no author(s) known
NASA	National Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NDVI _c	MIR corrected NDVI
NGO	non-governmental organisation
NIR	near-infrared
N.l.	No location(s) known
n.p.	no page(s) known
ORF	Broadleaved Evergreen Woodland: Open Rain Forest
p.	page

pp.	pages
p.a.	per annum
R	red
resp.	respectively
RGB	red, green, blue
RI	Graminoid Crops, Dominant Crop: Cereals - Rice (<i>Oryza</i> spp.)
SFB	Sonderforschungsbereich
SL	Broadleaved Evergreen Medium To High Shrubland
SPOT	Système Probatoire d'Obversation de la Terre
STORMA	Stability of Rainforest Margins in Indonesia
TC	Tasseled Cap
UTM	Universal Transverse Mercator
VMI	Vegetation Monitoring Instrument
vol.	volume
WRS-2	Worldwide Reference System 2

1 INTRODUCTION

1.1 Background

Tropical rain forests are regarded as the most complex, varied and species-rich terrestrial ecosystems on earth (BOHMAN 2004). Although tropical rain and moist forests cover only 7% of the planet's land surface, they are home for about 40% of all living species (WHITTEN, HENDERSON et al. 2002). However, earth is continually about to lose its vital 'green lung'. It is estimated, that about 146.000 km² of tropical forests have been lost each year between 1990 and 2000 (FAO 2001).

Indonesia has 10% of the world's remaining tropical rain forests (FAO 2001, in DECHERT 2003). This insular state was still densely forested in 1950, but about 40% of its forests have been cleared until the beginning of the 21st century (FWI and GFW 2002). The speed of forest destruction is accelerating: While on average 10.000 km² were cleared each year during the 1980s, this rate has increased to 17.000 km² in the early 1990s and has finally reached the level of 20.000 km² p.a. since 1996 (FWI and GWI 2002). About half of the remaining forests are strongly affected by degradation due to human activities (FWI and GWI 2002). The threat of the Indonesian rain forests is particularly tragic with regard to biodiversity, because the level of endemism is very high on many islands due to their geographic isolation for millennia (FWI and GWI 2002).

The island of Sulawesi constitutes a spatial centre of gravity for biodiversity in Indonesia, with a strongly above average share of endemic species (WHITTEN, HENDERSON et al. 2002). It has never been connected with the Asian nor the Australian continental landmass in its past (WEBER 2005), thus a unique fauna and flora could develop. However, even Sulawesi did not escape forest destruction. Its lowland forests, which are richest in biodiversity, have already been cleared for the most part (FWI and GWI 2002).

Vast areas of tropical rain forests are still intact in the province of Central Sulawesi (DECHERT 2003). The Lore Lindu National Park has been established in order to preserve a part of these unique ecosystems. However, the national park is currently undergoing a strong use pressure, which becomes manifest in increasing encroach-

ment by the local population (BTNLL, DJPHKA et al. 2001b; FAUST and MAPPA-TOBA CHAIRIL 2003; MERKER 2003). The STORMA research project has been founded in order to examine land cover and land use conflicts inside the national park and in its vicinity. Remote sensing plays an important role in these analyses, because current, overall information about land cover and land use is often not available in tropical states, such as Indonesia (ALLEWELT 1987).

This work was performed within the framework of the STORMA research activities. Its aim is to gain general information about land cover and its recent change in and around the Lore Lindu National Park on the basis of remotely sensed data.

1.2 The Research Project STORMA

The research project STORMA (Stability of Rainforest Margins in Indonesia) was launched in July 2000. It is a German-Indonesian cooperation between the University of Göttingen (Germany), the University of Kassel (Germany), the University of Palu (Indonesia) and the Bogor Institute of Agriculture (Indonesia). Main aims of STORMA are “to analyse the key factors and processes that lead to destabilisation and forest degradation, to identify social, economic, political and ecological conditions that are decisive for stability in the forest margin and to investigate the consequences of land use change” (BOHMAN 2004: 6). Research takes place in the Lore Lindu National Park on Central Sulawesi (Indonesia) and its vicinity. This area was chosen as research area, because large, partly undisturbed forests still exist, but have faced encroachments in the past few years. The project follows an interdisciplinary approach (FUEST and TJOA-BARTZ 2001): Landscape ecology, forestry, bio climatology, soil science, agrarian science, agrarian economy, remote sensing, cultural geography and sociology are involved in the research activities in order to detect relations between socio-economic and ecological processes. The surveys are performed by German-Indonesian researcher teams. STORMA is funded by the German Science Foundation DFG as *Sonderforschungsbereich* (SFB) 552.

This diploma thesis was created within STORMA sub-project D6, which works at the detection of land cover/use and its changes by means of remote sensing.

1.3 Framework of the Present Work

As already mentioned above, research activities of the STORMA project on the destabilisation of rain forest margins include analyses by means of remote sensing. Several attempts to classify the total survey region on the basis of remotely sensed data were undertaken. These activities dealt with Landsat 1/MSS data of 1972, as well as Landsat 7/ETM+ data of 1999, 2001 and 2002 (ERASMI, TWELE et al. 2004). The scenes of 1999 and 2001 were classified by traditional techniques based on statistical analyses of each pixel's spectral values. This method did not produce satisfying results due to strong spectral similarities, which caused a variety of misclassifications¹. The Landsat scenes of 1972 and 2002 were classified on the basis of an object-oriented approach, which allowed analysis techniques going beyond pure statistical analyses of spectral values. These classifications did not produce satisfying results either, because compromises had to be made due to the poor spatial² and radiometric³ resolution of the Landsat MSS sensor.

There were also non-STORMA activities concerning land cover classification in the survey area by means of satellite imagery. HADISUMARNO (1978) created a map of land use and land cover of Sulawesi on the basis of Landsat 1/MSS data. The JRC (2005) produced a land cover classification of total Sulawesi within the scope of its GLC2000 (Global Land Cover 2000) project, based on very low resolution data⁴ detected by the satellite SPOT 4 from 1999 to 2000. BTNLL, DJPHKA et al. (2001a) produced a very detailed land cover classification of the Lore Lindu National Park and its vicinity on the basis of Landsat 7/ETM+ data. However, it does not cover the total STORMA survey area and its classification system is hardly transferable, because it was accompanied by intensive field studies.

Overall, all existing land cover classifications of the total STORMA survey area are either inaccurate, outdated, too coarse or not transferable. This hampers the examination of land cover change and related deforestation.

¹ E.g. rice was classified on steep, dry slopes that were indeed covered with shrubland

² The spatial resolution identifies the spatial extent of the detected units on the earth surface. It corresponds to the rectangle that is represented by one pixel in the digital scene.

³ The radiometric resolution is a parameter that informs about the level of detail, by which the sensor detects radiation and translates it into saved grey values. It corresponds to the data depth, which determines how many possible grey values are in the data range.

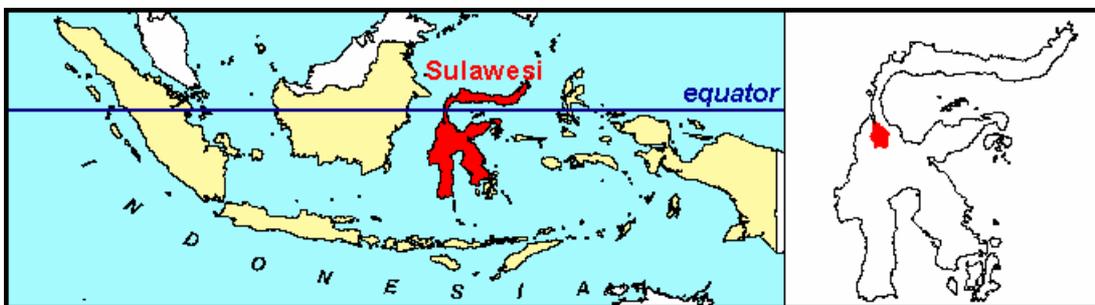
⁴ The spatial resolution is 1 x 1 km².

Against this background, the objective of this work is to find a way for the analysis of a recent Landsat time series⁵ on the basis of advanced, object-oriented classification techniques⁶. In addition, a classification system is to be used, which facilitates comparisons with other land cover classifications. The used classification techniques are to be transferable to other satellite data.

The classification results have a wide range of use within the scope of the research projects STORMA and IMPENSO⁷. It is intended to use this work's classification results for the validation of land use models, for hydrologic modelling, for the regionalisation of climate parameters and for examinations of relationships between census parameters and land use patterns. In addition, it is planned to transfer the techniques applied in this work to Landsat data of 1972 and 1983 in order to examine inner-tropical deforestation and land cover change in a longer space of time.

1.4 Survey Region

The survey region is situated in the Indonesian province Central Sulawesi (*Sulawesi Tengah*) on the island of Sulawesi (formerly *Celébes*), which is the fourth biggest landmass of the Indonesian archipelago.



Map 1: Geographic position of Sulawesi and the survey region (source: own illustration; data sources: STORMA database, STORMA D6 database)

⁵ It concerns the scenes of 1999, 2001 and 2002, of which classifications in the course of STORMA failed (see above).

⁶ According to JANOTH, EISL et al. (2002), the relatively new principle of object-oriented classification offers promising techniques that make an essential contribution to the analysis of remotely sensed data. This is particular important for the handling of spectral similarities, which constituted a major problem in earlier STORMA classification attempts.

⁷IMPENSO (The Impact of El Niño Southern Oscillation) is a German-Indonesian joint project that studies the impacts of the climate phenomenon El Niño on the watershed area of the Palu River in Central Sulawesi (IMPENSO 2005).

The survey area comprises a total area of 8,355 km² and consists of two parts:

(1) The research area of the German-Indonesian research project STORMA (7,257 km²), which is located between 0°50' - 2°04' southern latitude and 119°40' - 120°30' eastern longitude. It comprises the seven districts (*Kecamatan*) of Sigi-Biromaru, Palolo, Lore Utara, Lore Tengah, Lore Selatan⁸, Kulawi and Pipiorke⁹. The centre of the STORMA research area is formed by the Lore Lindu National Park (2,214 km²), which was established in 1993 by the union of three already existing conservation areas (MERKER 2003).

(2) An adjacent area in the northwest¹⁰ (1,098 km²), that was added to the survey region, because data about its land cover are needed for hydrological modelling in the context of the STORMA studies and other research activities in Central Sulawesi (IMPENSO project).

The island of Sulawesi has been formed by the collision of four different landmasses that met at the place of today's Lore Lindu National Park (BTNLL, DJPHKA et al. 2001c). Therefore, the relief of the survey region is very mountainous, ranging from 0 m a.s.l. (Palu) to 2526 m a.s.l. (Mount Buru Torenali).

According to the scheme of LAUER and FRANKENBERG (1987, in WESTERMANN SCHULBUCHVERLAG GMBH 1988: 220f., own translation), the climate of Central Sulawesi is classified as "humid warm tropic (A2h)" resp. "humid cold tropic (A1h)" higher up. The survey region is dominated by trade winds and the Australian-Asian monsoon system (KLEINHANS 2003), precipitation maxima are from March to April and in November. Because of its complex relief, the climate of Central Sulawesi is characterised by large spatial variation (DECHERT 2003): Whereas exposed settings may receive 2,500-3,000 mm of annual precipitation, the large Palu valley, which is enclosed in a rain shadow between two mountain ranges, may get only 600 mm per year, therefore being one of the driest places in Indonesia. Due to the position in the inner tropics, daily temperature means hardly vary throughout the

⁸ which was recently separated from the district of Lore Utara (SCHWARZE 2004)

⁹ which was separated from the district of Kulawi in 2002 (KREISEL, WEBER et al. 2004, in SCHWARZE 2004)

¹⁰ This sub chapter concentrates on the presentation of the actual STORMA research region in order to increase the usability of this work for further STORMA research activities.

year (WEBER, R. 2005): In lower areas, they are between 25-31°C, whereas they often do not exceed 16-22 °C on plateaus.

Under the conditions of a mostly humid tropical climate and the circumstance that Sulawesi has been isolated from other major landmasses for a long time, a unique fauna with a high level of endemism has developed on this island (PANGAU-ADAM 2003). This is one of the reasons why Lore Lindu National Park has been declared by the UNESCO to be a Man and Biosphere Reserve (WHITTEN, HENDERSON et al. 2002).

Sulawesi was originally almost entirely forested (MACKINNON 1997, in FWI and GFW 2002), but the forest area has declined by about 50% until 1997 (HOLMES 2002, in FWI and GDW 2002). A remote-sensing based vegetation classification published by the JRC in 2000 reveals, that there are still large areas of natural forest in the mountainous areas of the survey region, whereas its valleys have been mostly deforested and are now used for agriculture.

The STORMA survey region is only sparsely populated. In 2000, 130,835 inhabitants were living here (BPS 2005a; BPS 2005b). This corresponds to a population density of 18 inhabitants per km². There is no urban settlement in the STORMA survey region. The only city in the vicinity of Lore Lindu National Park is the provincial capital Palu, which is situated in the north of this work's extension area. Villages are concentrated along the main roads that are passing through the valleys of the survey region, only few settlements can be found in the uplands. Population is increasing rapidly, and a high proportion of its growth rate is caused by migration (WEBER 2005).

Migration plays a large role in the survey region. At the beginning of the 20th century, the Dutch colonial power resettled inhabitants of mountainous areas into the valleys (WEBER 2005) and thereby set the basis of today's settlement structure. Since the 1960s, Central Sulawesi has been destination area for migrants of *Transmigrasi*, an inter-island resettlement program by the Indonesian central government (HOPPE and FAUST 2004). In addition, local authorities have performed resettlement schemes several times. Apart from state-planned resettlement, there is a high level of spontaneous migration into the area around the Lore Lindu National Park. FAUST, MAERTENS et al. (2003) state that the area around the Lore Lindu National Park is very attractive for migrants because of its low population density and high availabil-

ity of land, that is suitable for agriculture. In total, the share of migrant¹¹ households in the STORMA research area accounts for 21%, with highest values in the eastern districts Lore Utara and Palolo (MAERTENS, ZELLER et al. 2002).

The population of the survey region is ethnically and culturally diverse. This is due to the high level of immigration as well as to the fact that local communities have been isolated from each other for a long time because of the mountainous relief (KRUYT 1935, in WEBER 2005).

The regional economy is dominated by agriculture. Off-farm employment opportunities are limited; a survey revealed that the share of farmer households in the STORMA research area is 87%, whereas the remaining 13% are mainly owners of small shops, traders, rattan collectors or wage labourers (MAERTENS, ZELLER et al. 2002).

The most dominant crops of the STORMA survey region are rice, cocoa, coffee, and maize (DECHERT 2003). In addition, coconut is cultivated on arable land in the south of Palu. Whereas rice is used as staple food and large amounts of it are usually used for own consumption by the producer household, maize is mainly sold and perennial crops are destined for export (DECHERT 2003). According to MAERTENS, ZELLER et al. (2002), all agricultural land is owned by smallholders. Traditional forms of shifting cultivation have almost entirely disappeared and can only be found in peripheral areas (WEBER 2005).

Cocoa has been introduced by migrants from South Sulawesi in the early 1980s. In the 1990s, there has been a large increase in cocoa production, since more and more local farmers switched to cocoa cultivation in view of good profit opportunities (FAUST, MAERTENS, et al. 2003). WEBER (2005: 194, own translation) states that “cocoa has turned to be a real prosperity motor in the Lore Lindu area”. A. Twele, a researcher of the STORMA project, who visited the survey region in 2003, 2004 and 2005, reported that another development has occurred in recent years: Area under maize cultivation has been expanding enormously because this is promising profit within a shorter period of time than cocoa production.

¹¹ defined as ‘coming from another province’; if the definition is extended to ‘coming from another settlement’, even half of the people living in villages around Lore Lindu National Park are migrants or descents of recent migrants (BTNLL, DJPHKA et al. 2001a)

The expansion of arable land often does not stop at the national park's boundary, several locations inside the park have been converted to agricultural fields and cocoa plantations (PANGAU-ADAM 2003). EBERSBERGER (2002) points out, that smallholders are the main cause for deforestation in the survey area, whereas commercial wood exploitation is of minor importance. Local farmers often rely on traditional law (*Adat* law), which regards forested areas as open for encroachment if the need for arable land arises (PANGAU-ADAM 2003; EBERSBERGER 2002). When the national park was established, its borders were not defined in agreement with the local population (WEBER 2005). The park administration admits that there are people "[...] who feel that the Park has been imposed by a central government that has appropriated land from traditional communities in violation of *Adat* law" (BTNLL, DJPHKA et al. 2001b: 81, emphasis in the original version). To solve this problem, a strategy of collaborative park management is now pursued, which means that local actors, especially village communities, are to participate in consultations, decision making and the initiation of actions (BTNLL, DJPHKA et al. 2001a). However, the self-assertation of the park administration has declined after large scale clearings took place in the Dongi-Dongi valley in the north-eastern area of the national park in 2001 (EBERSBERGER 2002).

Excursus: The Dongi-Dongi incidence

As the situation in the Dongi-Dongi valley is jointly responsible for recent land use conflicts around the Lore Lindu National Park and its further handling is crucial to the park's future, the course of this incidence is illustrated in detail. The following summary is based on FAUST (2001), FAUST and MAPPATOBA CHAIRIL (2003) and WEBER (2005).

The Dongi-Dongi area is a valley in the north-eastern part of the Lore Lindu National Park. An asphalted road, connecting the valleys of Palolo and Napu, passes through this area. The roots of the Dongi-Dongi conflict date back to the 1970s. Between 1979 and 1983, the Department of Social Welfare and the Department of Forestry carried out the *Native Resettlement Program* in order to establish a watershed protection area. Inhabitants from the mountains of Donggala were resettled to the south-eastern area of the Palolo valley, close to the latter Lore Lindu National Park. 2 ha of land were promised to each family by the government. However, the resettled households actually received only 0.8-1 ha and the new land was re-

garded as not suitable for cultivation. The more valuable land in the proximity of the resettlements was sold to wealthy inhabitants of Palu. As a consequence, many families were faced with marginalisation. In 1996, 1998 and 2000, the resettled people requested a new resettlement that would give them access to more land. The government agreed, but never fulfilled its promises. NGOs advised the people, who were upset because of this situation, to occupy the Dongi-Dongi valley in order to make the government fulfil its promises. Encouraged by post-Suharto reforms and probably supported by wood processing companies, several hundred people, especially from Kamarora and Rachmat, left their villages in June 2001 and cleared about 1500 ha of forest in the Dongi-Dongi area within a few weeks. However, the government did not react to this action. Therefore, the people decided to stay. Two solid settlements were founded for about 600 households. Further families moved into this area. The police did not intervene. Instead, an approach by negotiations was started, but until today no solution has been found.

Inhabitants of villages on the eastern side of the national park noticed that the state power did not take actions against this massive encroachment and now started to clear forest inside the park on their own. They pointed out that, if people who had no *Adat* rights in the area, were tolerated to encroach far away from their original settlements, their own right to clear forest near their villages was even stronger.