J. Rakuno Gakuen Univ., **35** (2) : 33～43 (2011)

Remote Sensing Methods of Vegetation and Surface Run-off Change in Eastern Sudan Area

Buho HOSHINO[1)], Hiroshi NAWATA[2)], Ruichen Jia[2)],
Karamalla Abdelaziz[3)] and Kiyotsugu YODA[4)]

衛星リモートセンシング手法を用いた東部スーダン地区における植生と地表面流出変化の抽出

星　野　仏　方[1)]・縄　田　浩　志[2)]・Jia Ruichen[2)]・Karamalla Abdelaziz[3)]・依　田　清　胤[4)]

(Accepted 14 January 2011)

1. Introduction

Remote sensing technique is the science and art of acquiring information (multi-spectral, multi-spatial and multi-temporal) on material objects, an area, or a phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Remote sensing is therefore useful both at a global and local scale for land surface monitoring. However, remote sensing monitoring of surface run-off in arid land or semi-arid land is very difficult. This is because surface run-off occurs when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the ground, and any depression storage has already been filled. This more commonly occurs in arid and semi-arid regions, where rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing, or pavement. Soil moisture is a key parameter in different environmental assessment, such as hydrology and natural risk assessment. Remote sensing monitoring of soil moisture is more difficult. Because it is very difficult to extract the soil moisture signals in vegetated area. In many cases, classification of the plant and bare soil area is not simple, as well, because, the reflection of a plant is effected by the high reflection of background barren soil. Usually, two methods for estimating soil moisture by using remote sensing techniques are used. Such as one of them is based on microwave satellite (such as Synthetic Aperture Radar (SAR)) remote sensing and the other is using the optical multispectral remote sensing technique[1)].

Only spatial remote sensing allows monitoring of environmental problems over large areas at regular intervals. Moreover, radar sensors allow mapping regardless of meteorological conditions (clouds etc.), both day and night. This is not the case with optical sensors. Estimation of soil moisture by inversion of SAR data can be performed through using physical or semi-empirical approaches. The physical approach uses backscattering models capable of reproducing the radar backscattering coefficient from the sensor configuration (wavelength, polarization, and incidence angle) and soil parameters (soil moisture and surface roughness for bare soils). However, several studies have reported a low accuracy between measured radar signals and those predicted by the models. The second approach consists of establishing experimental calibration relationships linking the signal radar to soil parameters (surface roughness and soil moisture of bare soils) and to sensor parameters (frequency, polarization, and incidence). This approach requires an important experimental database, acquired from several study sites and representative of possible physical soil conditions.

[1)] Department of Biosphere and Environmental Sciences, Faculty of Environment Systems, Rakuno Gakuen University, 582 Bunkyodai-Midorimachi, Ebetsu, Hokkaido 069-8501, Japan
[2)] Research Institute for Humanity and Nature, 457-4 Motoyama, Kamigamo, Kita-ku, Kyoto 603-8047, Japan
[3)] Institute for Family and Community Development, Sudan University of Science and Technology, P.O. Box 407, Khartoum 11111, Sudan
[4)] Department of Basic Sciences, Faculty of Science and Engineering, Ishinomaki Senshu University, Shinmito Minamisakai Ishinomaki-shi, Miyagi 986-8580, Japan

In analyzing soil moisture, there is a great difference between specific inductive capacities of soil and water. As the amount of water contained in soil becomes greater, specific inductive capacity of the soil increases in proportion and as a result, backscatter strength increases. In this way, analysis of backscatter strength leads to an estimated amount of water content in the target land area. We therefore need to measure the leaf water content of the plant and must remove the ground surface roughness effect.

For bare soils, the radar backscattering coefficient (σ_o) in decibels can be written as the sum of two functions: the first one (linear), describes the dependence of the radar signal on volumetric surface soil moisture, while the second (exponential), illustrates the dependence of σ_o on surface roughness. To retrieve soil moisture (***mv***) from a single radar configuration, it is necessary to establish a relationship between the radar backscattering coefficient (σ_o and soil moisture (***mv***) alone, without having any knowledge of the (***rms***) surface height. As a first approximation, the radar backscattering coefficient may be expressed as follows: ($\sigma_o = \mathbf{a}^{*} mv + \mathbf{d}$). This simplified relationship ignores the surface roughness. The coefficient is dependent on both incidence angle and polarization. The coefficient d is primarily controlled by incidence angle, polarization and surface roughness. However, the coefficients describing the linear relationship between radar signal and soil moisture can be different from one catchment to another and also from one year to the next, and usually need to be calibration. This difference is mainly due to the effects of roughness variation.

While optical sensor is sometimes affected by meteorological conditions, it is very effective in the classification of the land cover. Using visible and near infrared (NIR), short wave infrared (SWIR) and thermal infrared (TIR) multispectral satellite data, developed the indirect estimation technique of the soil moisture by indices, such as NDVI, surface roughness and land surface temperature (LST), etc. In this case, {***Soil moisture*** = | ***(soil type, roughness, vegetation index, LST, rainfall)***}. We selected and for the intensive ground truth survey area the semi-arid area of China, succeeded in classifying the soil moisture distribution area in the oases and desert and also succeeded in the evaluating the "grain for green" effect.

The semi-arid tropics in Africa constitute 70% of the total semi arid areas in the world. These areas are subjected to more surface and water erosion compared with other areas with higher precipitation due to low vegetation cover. Surface run-off leads to soil erosion, soil degradation with a possibility of soil compaction, low organic matter, and loss of soil structure. In Sudan (largest African country 2.5 million sq. km) nearly 48% of the total land area is desert or semi-desert (see Fig. 1 and Fig. 2). Much of the original vegetation cover changed qualitatively and quantitatively by many factors such as low rainfall, overstocking and water erosion[2].

In many parts of semi arid the region of eastern Sudan including the Red Sea coastal zone, surface run-off and invasion of undesirable plant species are among the main challenges facing natural resources management. On the other hand, lack of water and its uneven distribution accompanied by intensive use in some areas, usually result in deterioration of agriculture land areas. In central Sudan vast areas have been affected by the unavailability of water and its uneven distribution which has been aggravated by excessive grazing pressure on available pasture which together led to intensive over- grazing, and consequently range deterioration and desertification[3].

The Nile river system provides irrigation for strips of agricultural settlement for much of its course in Sudan and also for the Al Gezira plain, situated between the White Nile and the Blue Nile, just south of their confluence at capital city Khartoum. In the extreme north, the Nile broadens into Lake Nasser, formed by the Aswan High Dam in Egypt.

Much of the rest of the country is made up of an undulating plateau, which rises to higher levels in the mountains located in the northeast near the

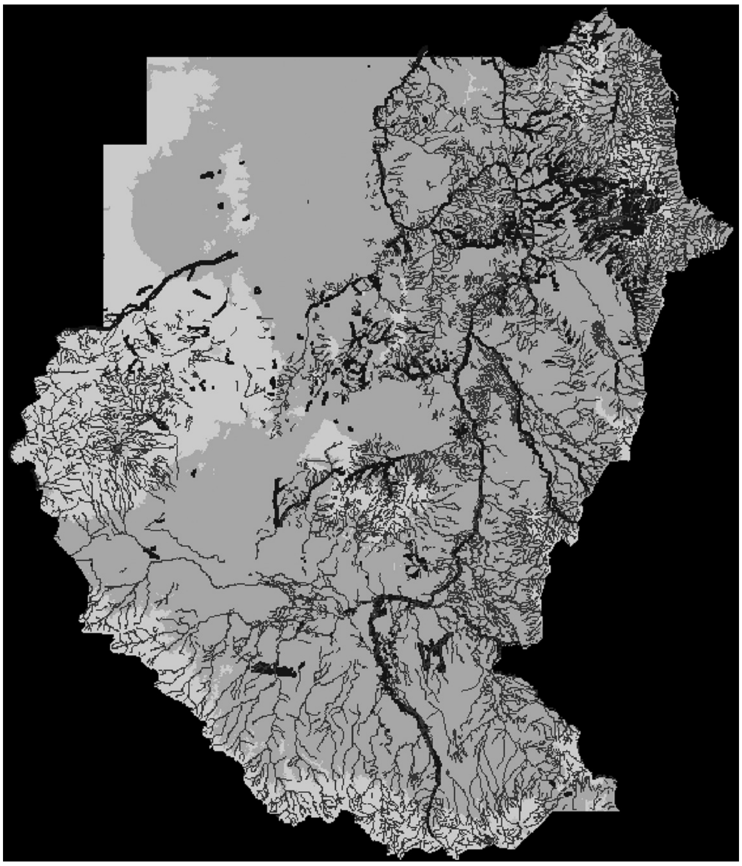


Fig. 1 The river systems of Sudan. (The main geographical feature of Sudan is the Nile River, which with its tributaries (including the Atbara, Blue Nile, and White Nile rivers) traverses the country from south to north (Where the dark blue line shows main streams; and light blue line shows the branch river, © The original data from DIVA-GIS: http://www.diva-gis.org/).

Red Sea, as well as in the central, western, and extreme southern portions of the country. The highest point in Sudan is Kinyeti in the southeast. Rainfall diminishes from south to north in Sudan; thus, the south is characterized by swampland (the Sudd region) and woodland; the center by savanna and grassland; and the north by desert and semi-desert. It is revealed that under different conditions of vegetation cover, slope gradient and slope length. Results revealed that soil loss from bare fallow soil per unit of rainfall and also per unit of run-off increased as the slope gradient increased. The associated run-off rainfall ratios were always high on the steep slopes. As slope length increased from 5 to 20 m, soil loss per unit of rainfall doubled and sediment concentration increased, five-fold, while run-off rainfall ratio decreased to one-half[4].

Invasive species mainly Mesquite (*Prosopis juliflora*) has been a problematic spreading in vast areas of eastern Sudan including Delta Tokar, Gash Delta and many sites along Red Sea area, a threatening agricultural activities.

According to Brown et al.[5], mesquite was introduced into Sudan in 1917 from South Africa and Egypt and planted in Khartoum (the capital). The tree had characteristics of high drought tolerate, fixing sand dunes, and could also be used as fodder for animals.

It was planted as shelterbelts at Port Sudan, Tokar area and Kassala between 1978–1981[6]. Its uncontrolled through out spreading Sudan but specifically in eastern Sudan led the government of Sudan to declare 1995 as "Mesquite eradication year".

In spite of its importance, data and information concerning specific sites in the semi arid areas are limited, because most of agricultural and ecologi-

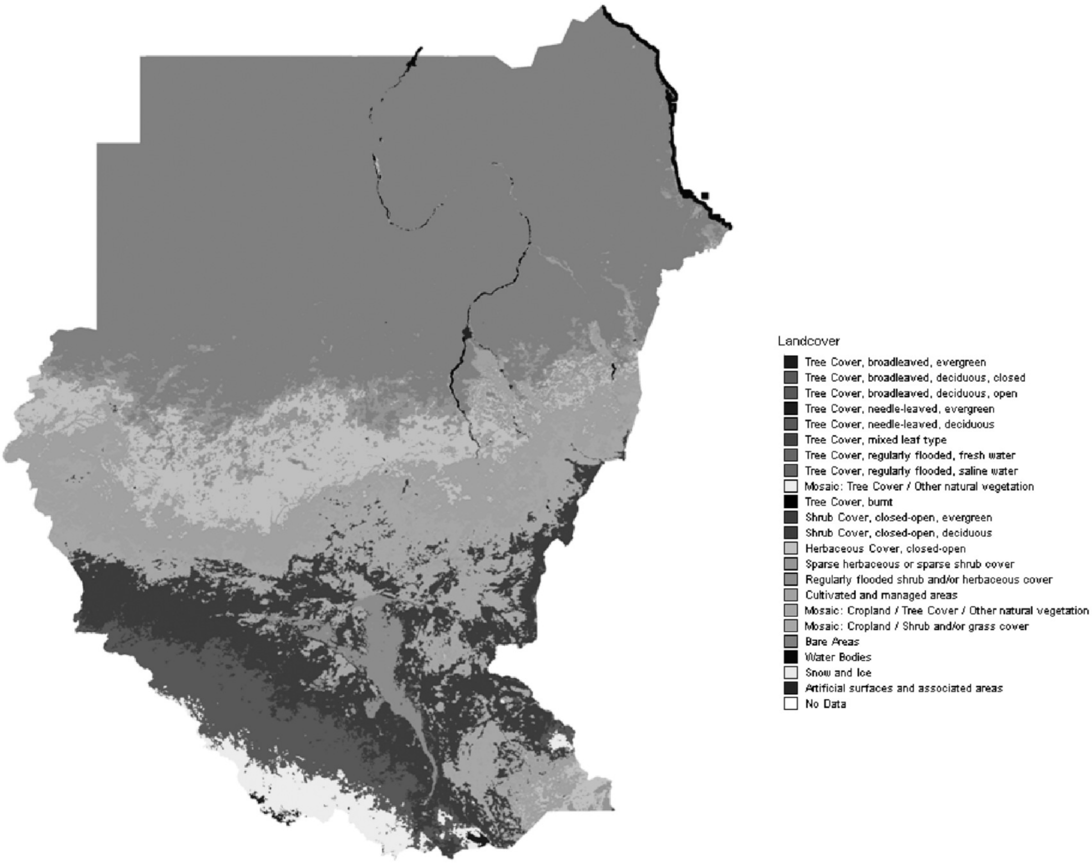


Fig. 2 The land-cover map of Sudan (© The original data from DIVA-GIS: http://www.diva-gis.org/).

cal research had been directed to words more productive areas. There is also a lack of technologies required to improve agriculture in semi arid regions and if technologies do exist, they are either limited or confined to certain research stations[7].

2. The scope of the problem

Although surface erosion is a serious problem the semi-arid region of Sudan, it is be considered more serious in the eastern parts due to its topography, which is characterized by slopes and existence of many small and medium sizes seasonal water ways.

Surface run-off causes serious loss of water, resulting in a significantly less sustainable environment for agriculture and livestock raising. Sudan run-off transports top soil decreasing soil fertility. When it is intensive, soil depth is reduced, leading to reduction of water stored in the soil.

Mesquite has been in eastern Sudan and in most parts of the country, where it has been introduced. Its use, beside sand dune fixation is limited to fuel wood and charcoal production[8]. More than 90% of mesquite is thought spread eastern Sudan, where livestock keeping and subsistence cultivation constitute the main source of income. Invasive mesquite tends to form dense and impenetrable thickets. Its highly competitive nature leads to reduce grass cover, stocking density, and threatens the livelihood of traditional pastoralists. Its invasion into agricultural land, along irrigation channels and water courses is also a major problem[6].

Surface run-off is linked to mesquite distribution, since there is a possibility that mesquite distribution and water and animal movement are related to the soil condition.

Efforts were made in Sudan, to eradicate mesquite[8]. However, the high cost and complexity of the problem, have made most of the efforts made not successful or sustainable. Costly eradication programs, using both mechanical and manual methods of uprooting mesquite, were implemented in various locations in the country with variable results[8]. Soil disturbance resulting from the uprooting causes mesquite seeds to be distributed on the surface soil and aids regeneration[9]

The expected high water table at the lower streams of Tokar and Gash seasonal river in addition to the fertile soil, contribute to the menacing of mesquite spread. Global experiences in other part of the world have shows clearly that eradication of mesquite is neither desirable nor tenable[10].

3. Case Studies

3.1 Remote sensing methods for surface run-off and mesquite control (Red sea area eastern Sudan)

Remote sensing methods for mesquite control in eastern Sudan come within a project of Human Subsistence Ecosystem in Arab countries to combat livelihood degradation for the post-oil Era. The project is implemented with the co-ordination and partnership between the Research Institute for Humanly and Nature (RIHN) in Japan and the College of Agricultural Studies at Sudan University of Since and Technology (SUST).

The work is conducted in the Red Sea area of eastern Sudan using different methods of remote sensing, aiming at setting a practical methodology that could effectively help in assessing mesquite distribution and its spreading patterns.

The assessment of mesquite distribution is main component of the project component, which includes:

Classification of the alien plant species mesquite and native plant species in the arid region of Sudan based on multi-sensors satellite data and ground measurements.

3.2 Estimation of soil moisture distribution and water stress of arid region plants using microwave satellite data

Estimation of ground biomass (DMP) of mesquite in wide areas of Sudan using?multi- spectral satellite data and ground measurements.

a) In order to mesquite distribution and spread using multi-sensor satellite data can is a potential method that can be used. The distinctive characteristics of mesquite (been green) growing thought all over the year is an opportunity to trace mesquite patches as indicated by selected vegetation indices mainly normalized difference vegetation index (NDVI) or soil adjusted vegetation index (SAVI).

The moderate Resolution Imaging Spectrometer (MODIS) sensor of Terra satellite of 250 m resolution NDVI product is used for large dense mesquite patches in the Kassala area in eastern Sudan close to Toteel Mountain (Fig. 3). In the Fig. 3, the mesquite area is shows very high NDVI, it is clear that existence of mesquite.

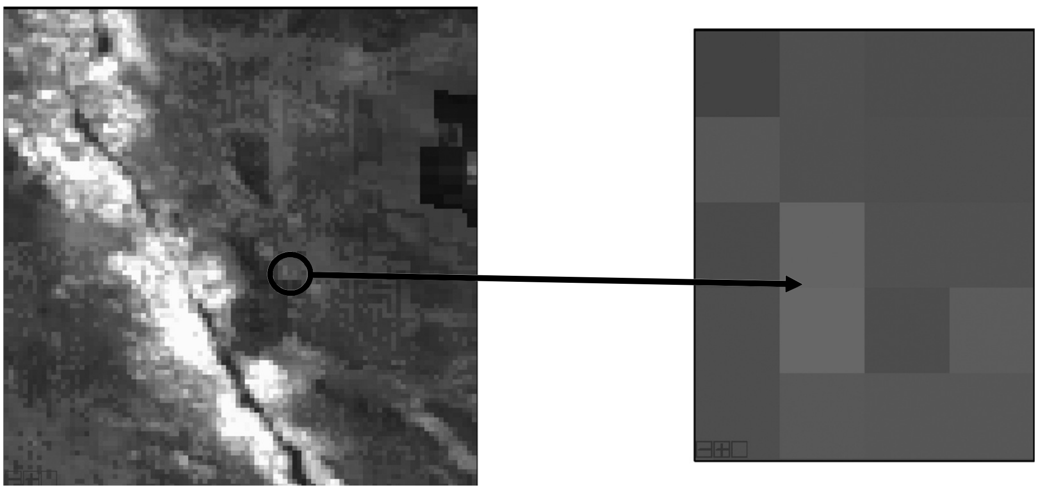


Fig. 3 MODIS NDVI product showing mequite area close to Toteel mountain (left), mequite area with higher NDVI value — brighter color (right).

This method could be effective in areas with dense patches of mesquite; however, area with few scattered trees may be difficult to trace.

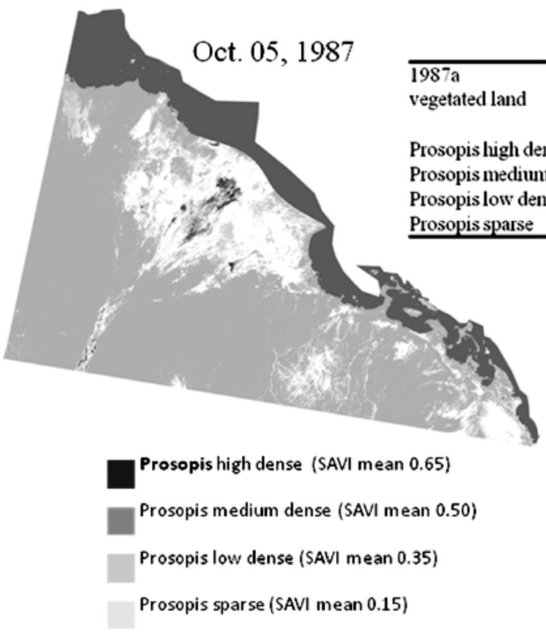
b) Another application was conducted using Landsat data to assess mesquite expansion within 13 years at the Tokar Delta. NDVI and SAVI were both used as indices for this reason, such as, the mesquite trees has a high photosynthetic activity, therefore, this trees all season very green and there is a high absorption of visible red light and high reflection of near-infrared light. Values for both indices were sliced and the area calculated. Results showed that mesquite area increased 10 times (see Fig. 4).

It is clear that the resolution of the images used is critical in identifying small mesquite patches, but the cost of the data in addition to the small coverage are the limiting factors.

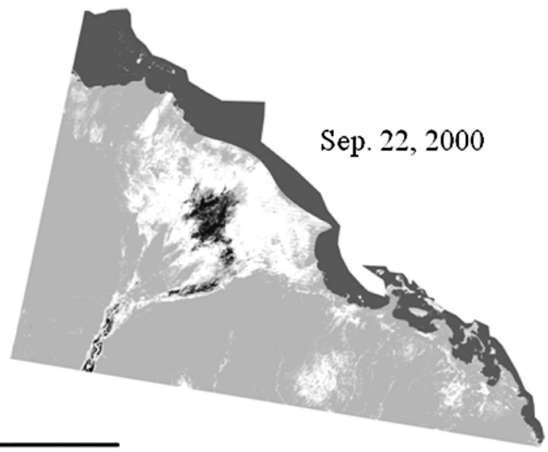
c) Experimental work within the project has also adopted to retrieve of the soil moisture from the Radar back scattering coefficient using ALOS/PALSAR polarization (HH/HV) data. The idea is that the to correlate soil moisture content can be correlated to the existences of mesquite patches. The project is progressing to develop models involving more than one variable including moisture and roughness.

Fig. 5 and Fig. 6 shows calculated backscattering coefficient (dB) of Tokar region of Eastern Sudan. The building (Tokar town) and mesquite trees show high backscattering coefficient values. This is because the reason why a building and a mesquite trees showed a high backscattering coefficient (dB), the microwave L-band signal was effected by surface roughness.

During the PALSAR L-band backscattering from the target i.e, the soil surface is adversely



1987a vegetated land	TM Pixels (30m*30m)	Area (Hectares)	SAVI Value mean
Prosopis high dense	1400	126	0.6594
Prosopis medium dense	4409	396.81	0.5193
Prosopis low dense	11643	1047.87	0.3611
Prosopis sparse	21802	1962.18	0.1763



2000a vegetated land	TM Pixels (30m*30m)	Area (Hectares)	SAVI Value mean
Prosopis high dense	7155	643.95	0.6735
Prosopis medium dense	13737	1236.33	0.5409
Prosopis low dense	17958	1616.22	0.3744
Prosopis sparse	30522	2746.98	0.18

Fig. 4 Extraction of mesquite trees distribution in Eastern Sudan by using satellite based SAVI index.

Fig. 5 Backscattering coefficient (dB) calculated from PALSAR L-band microwave data in Tokar region in Eastern Sudan: November, 2009). (Building and mesquite forest shows high dB; line: shows GPS tracking route)

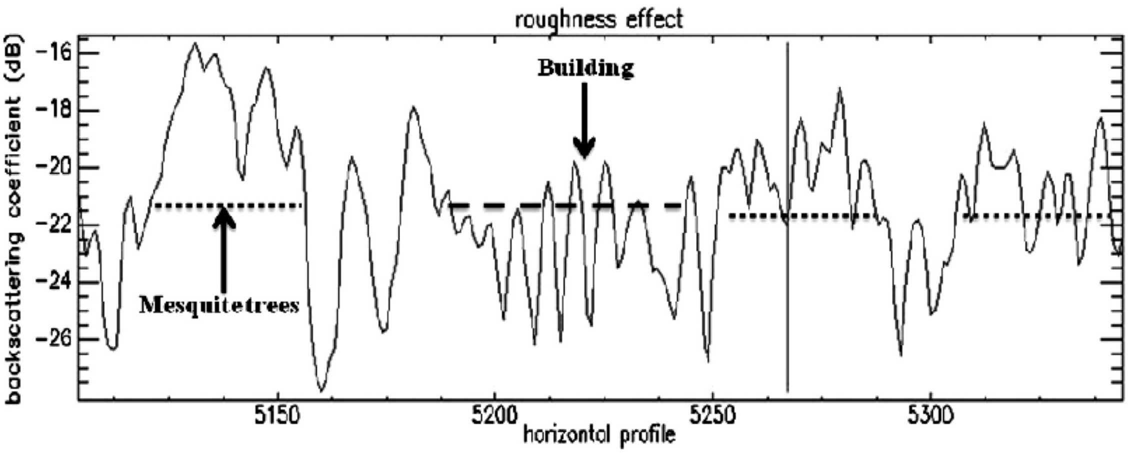


Fig. 6 Surface roughness effect of L-band Microwave backscattering coefficient (dB) in vegetated area (Tokar area: November, 2009).

affected by the overlaying vegetation, consequently, sending degraded signal back to the radar sensor. In this phenomena greatly compromise with the quality of soil moisture measurements. This study, we used visible band and short wave infrared bands of optical satellite (ASTER), and calculated NDWI (Normalized Difference Water Index) to made soil moisture distribution map (see Fig. 7), in order to estimate soil moisture distribution of vegetated area, where mesquite distribution is dense.

The result of change detection analysis based on time series satellite data shows that there is the areas where vegetation increases place and vegetation decreases place under the influence of farmland development and mesquite expansion during 1999a to 2006a. The green color is the place where an increase in vegetative growth and the pinkness color is the place where vegetation is stable shown in Fig. 8 (a) and 8(b) and Fig. 9.

4. Conclusion

Active remote sensing microwave PALSAR L-band is significantly interference with trunk and branches of shrubs (such as mesquite tree). L-band microwave data highly effective to estimating wide area soil moisture distribution in barren soil area, but microwave L-band also interfere with vegetation canopy (such as mesquite

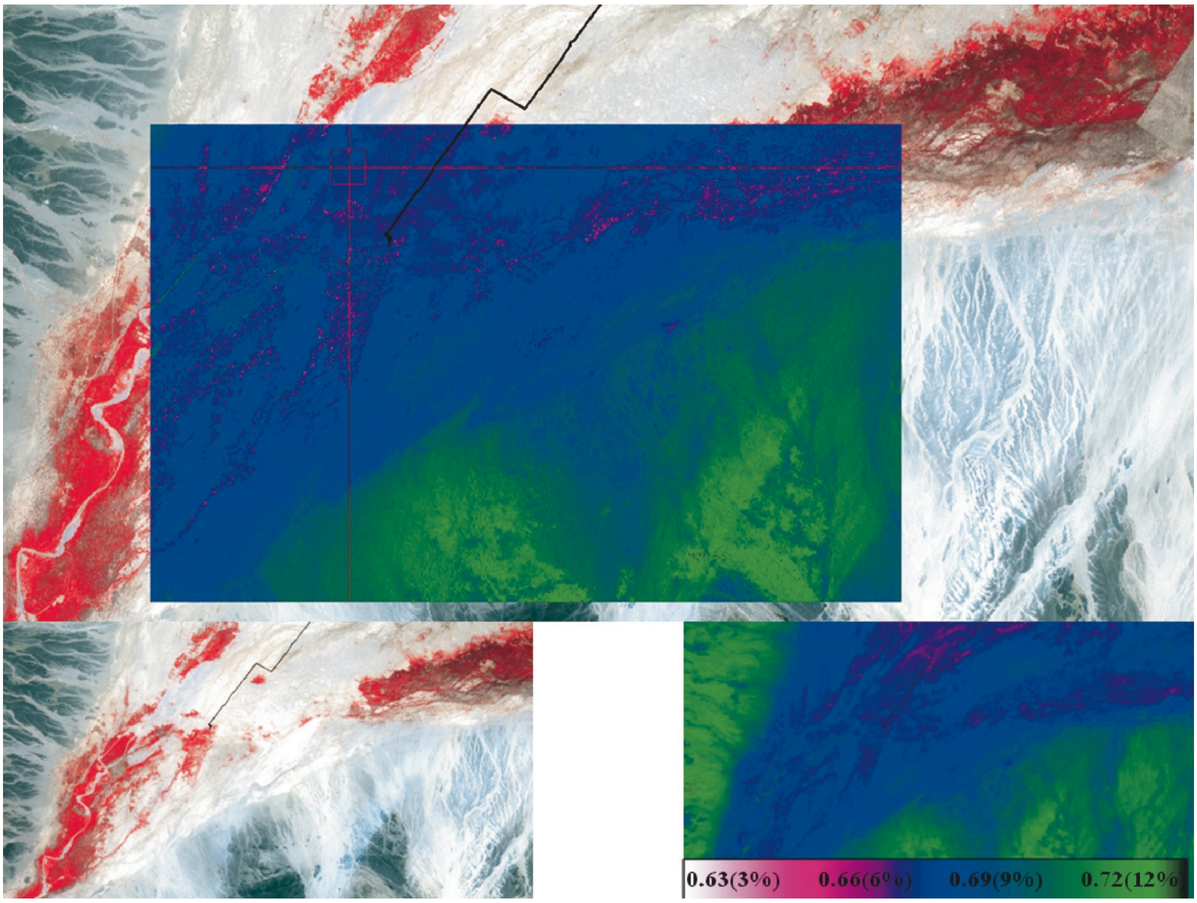


Fig. 7 Normalized Difference Water Index (NDWI) calculated from ASTER, VIS (Visible band-1), SWIR (Short Wave Infrared, band-4) data (front image) and RGB color combination image (RGB=ASTER band 3N-2-1) (back image) (where, the data 0.63 shows the NDWI values and (3%) shows the measurement volumetric soil moisture; and line shows GPS tracking route.)

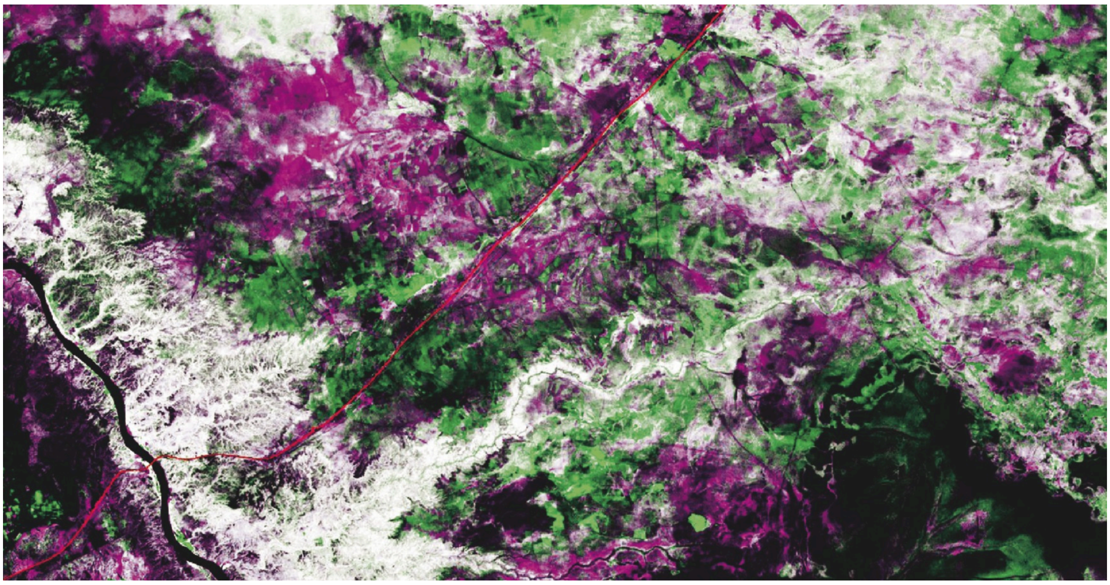
trees canopy). Linear statistical model (dB vs. VSM (volumetric soil moisture)) is simple and effective. To improve the estimation accuracy, it is necessary to remove the effects of surface roughness. We used Terra/ASTER visible and short wave infrared optical satellite data, success of estimating soil moisture distribution of high plants covered (mesquite trees) area in eastern Sudan. In this study, we also success of detection and extraction of mesquite trees expansion areas in Kassala area.

5. Acknowledgment

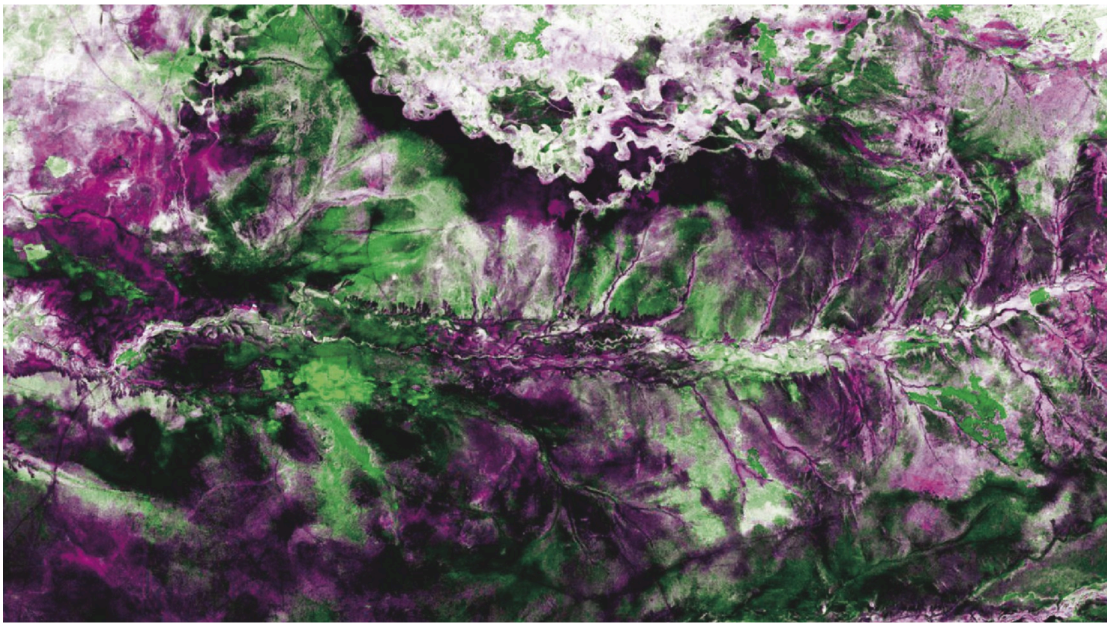
This study was supported by the research project "A study of Human Subsistence Ecosystems in Arab Societies: To Combat Livelihood Degradation for the Post-oil Era" (project leader: Dr. Hiroshi Nawata) of the Research Institute for Humanity and Nature (RIHN). We also thanks for Prof. Abdel Gabar Babiker and Sudan University of Sciences and Technology (SUST) supported all field investigation and arrangement.

References

1) Buhe Aosier, M. Kaneko, S. Shimada and K. Tsuchiya (2004) Estimating Soil Moisture in the Arid and Semi-Arid Region using Terra/ASTER Data, Participatory Strategy for Soil and Water Conservation (pp. 197-202), ERECON.
2) Yousef S. (1996) A warning of African droughts during the coming 35 year, Big Cities world conference on national disaster mitigation, Cairo, Egypt, Jan 5-9.
3) Abdelaziz K. Gaiballa and Gasim O. Elhag (2006) RELATIONSHIP BETWEEN GRAZ-



(a)



(b)

Fig. 8 Remote sensing change detection in Kassala area of eastern Sudan (where, in this (a) and (b) two images, green areas represent an increase in reflectance in Landsat TM channel 4 (NIR) in 2006 compared to 1999. It would be tempting to infer that this increase is all due to an increase in vegetative growth, but it must also be remembered that the 1999 image was acquired in November, and the 2006 image in October. We are then faced with the problem of deciding how much of the change is real increase in vegetated area, and how much is due to seasonal variations; The red line show GPS tracking route)

ING INTENSITY AND DISTANCE FROM WATER POINTS J. Sc. Tech, Vol. 7(1).

4) A.S. El-Hassanin, T.M. Labib and E.I. Gaber (2003) Effect of vegetation cover and land slope on run-off and soil losses from the watersheds of Burundi Agriculture, Eco-systems & Environment: Volume 43, Issues 3-4.

5) Brown, A.F., and Massey R.E. (1929) Flora of the Sudan Thomas Murby and CO, p. 376.

6) Elsidig NA, Abdelsalam AH, Abdelmagid TD (1998) Socio-Economic, Environmental and

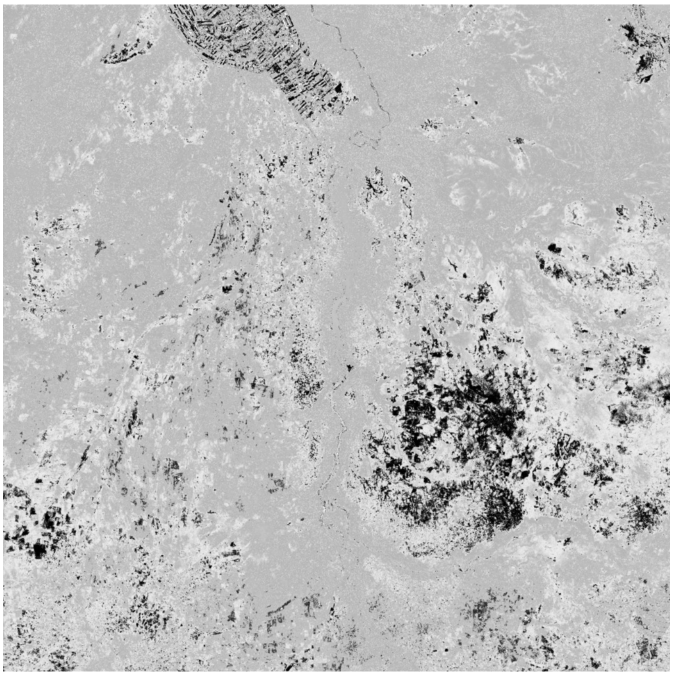


Fig. 9 Change detection result in Kassala area from different $NDVI_{(2009-1999)}$ (In this image, areas showing as dark red have a higher NDVI value in the 2006 image than in the 1999 image. Since strong visible red and NIR reflectance is often associated with exposed vegetated area, we might infer that these dark color areas have undergone an increase in mesquite expansion.)

Management Aspects of Mesquite in Kassala State (Sudan) Sudanese Social Forestry Society, pp 96.

7) Jones M.J. (1985) Conservation systems and crop production. Paper presented to Conf. on Agric. Development in Drought-prone Africa. Royal Commonwealth Society, London.
8) Babiker AG (2006) Mesquite (Prosopis spp.) in Sudan: history, distribution and control. In: Labrada R (ed.) Problems Posed by the Introduction of Prosopis spp. in Selected Countries, Plant Production and Protection Division, Food and Agricultural Organization of the United Nations Rome, pp 11-20.
9) Ahmed, E.A. (2009) Studies on Some Aspects of Mesquite Biology and Management, Ph.D Thesis Sudan Academy of Sciences, PP 162.
10) Pasiecznik, N.M. (1999) Prosopis ‘pest or providence’ ‘weed or wonder tree’ ETFRN news 28/29 39: 12-14.
11) DIVA-GIS: http://www.diva-gis.org/

和 文 要 約

スーダンの外来植物メスキート（*Prosopis juliflora*）のコントロール手法を提案した。メスキートはマメ科の常緑樹木である。現産地は南アメリカ大陸と北米大陸だが，ブラジルから 1917 年初めて首都のハルツームに植樹し，1978 年にエジプトから砂丘固定のためにスーダン北部・東部の乾燥・半乾燥地域に多量に輸入し，植樹した。しかし，その後コントロールが利かなくなり，スーダンの河川流域の農耕地や河沿いに広がり，毎年その分布を拡大し続けている。本研究はリモートセンシングの手法を用いて，メスキートの分布域を特定し，メスキートの拡大地域の特定や拡大規模の推定に成功した。

Abstract

This study reported about the alien species mesquite (*Prosopis juliflora*) control method. Mesquite is ever green leguminous trees or shrubs which grow in arrays of environments. Mesquite has ability tolerate drought, fix sand dunes, furnish shade, fuel, timber, fodder, edible pods. Mesquite was introduced into Sudan in 1917 and planted in Khartoum. More then 1978-1981 planted in many parts of the country (Sudan).

Constitutes a threat to agriculture, biodiversity and may lead to deterioration of natural vegetation and pastures and thus affecting livelihood. This study, we success to classify the mesquite trees area and other plants distribution area and success to change detection mesquite expansion areas in Eastern Sudan using optical multispectral satellite data and microwave backscattering coefficient.