A multi-sensor approach for desertification monitoring in the coastal areas of Vietnam

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Abstract

This paper explores the use of a multi-sensor approach to monitor semi-arid areas of Vietnam, and represents the initial findings of a PhD project commenced in October 2003. Multitemporal data from optical systems, including ASTER and MODIS, have been employed to observe soil and vegetation at both large and small scale, and the thermal band of ASTER used to extract surface temperature data. ENVISAT ASAR (Advance Synthetic Aperture Radar) was used to estimate soil moisture using a data fusion approach. The relationship between vegetation density, soil moisture, and surface temperature, and the role of these parameters in the desertification process are under investigation. The final phase of the project will be to develop a desertification index based on three parameters: surface temperature, vegetation cover and soil moisture.

1 Introduction

1.1 Background

Desertification is a form of land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD, Article 1). Over 250 million people are directly affected by desertification and each year the about 42 billion US Dollars is lost due to desertification (UN, 2003). However, desertification is not only limited to extreme arid areas such as the Sahara desert in Africa or the Gobi desert in Mongolia. Desertification can result from inappropriate use of natural resources, such as deforestation, overgrazing and land degradation. Today we are also facing the problem of desertification in semi-arid and dry sub-tropical areas. If the ecological system is degraded beyond a threshold level, it can have negative effects on the micro-climate and render the temporary desertification problem permanent. It is thus important not only to study desertification in the arid areas, but also to carefully look at the problem outside of its traditional zones.

Vietnam is not designated as an arid or semi-arid country. However, some regions within the country are at risk from desertification. According to the latest inventory (UNCCD, 2002), there is more than 9 million ha of unused land, of which 4 million ha of barren hill have completely lost their biological productivity. Among 3.2 million hectares of coastal areas in Vietnam, 1.6 million are heavily affected by soil degradation and desertification. In the coastal area long dry seasons together with short-heavy rainfall in the rainy season have led to following types of degradation:

- Moving sand due to strong wind along the coastal area.
- Salinization in sandy soil, formation of salt crust on soil surface.
- Water erosion due to deforestation and overgrazing.
The net result of such land degradation is significant disturbance of ecosystems with loss of biological and economical productivity. Mapping and monitoring of degradation processes are thus essential for drafting and implementing a rational development plan for sustained use of semi-arid land resources of Vietnam.

1.2 Aim and Objective

The project aims to develop a desertification mapping methodology, transferable to other South East Asian regions. Specific objectives are:

- To quantify desertification problems in coastal areas of Vietnam.
- To develop operational methods for desertification mapping in semi-arid areas which combine the advantages of several types of readily available satellite imagery.

2 Study area

The study area is located in Binh Thuan province, in south central Vietnam. The area faces the Pacific Ocean to the east with a coastline of 192 km (Figure 1). The Truong Son mountain range, running from North-east to South-west, block most of the rain coming from the Thailand’s sea, thus created semi arid conditions for the area.

Binh Thuan province can be divided into 4 main landscapes:

- Sand dunes along the coast (18.2% of total area).
- Alluvial plains (9.4% of total area).
- Hilly areas, with the average elevation of 50 m asl (31.6% of total area).
- The Truong Son mountain range (40.8% of total area).

Binh Thuan is the driest and hottest region of Vietnam. The climate is a combination of tropical monsoon and dry and windy weather. The mean annual temperature is 27°C, with average minimum 20.8°C in the coldest months (December, January), and an average maximum of 32.3 °C in the hottest months (May and June). Binh Thuan also receives more solar radiation than any other area in Vietnam, with 2911 sunshine hour annually – or almost 8 hour per day.

Rainfall in this area is limited and irregular. Annual precipitation is 1024 mm, while evaporation in some years is equivalent to precipitation. At some locations annual rain fall can be as low as 550 mm. The dry season is from November to April, with 60 days of January and February having almost no rain. The rainy season is from May to October with heavy rain concentrated in a short periods with up to 200 mm/day.
Figure 1: Location of study area. On the right is ASTER image taken on 22 Jan 2003. In the image red colour represent vegetated areas, white and yellow represent sandy soil.

3 Data Resources

3.1 Parameters required for desertification monitoring.

Desertification is a complex process which involves both natural factor and human activities. Depending on the level and nature of management, such as decision making, economic policy, and land use management, different kinds of information are required. DESERTLINKS (a European commission funded project) have listed 150 indicators for desertification assessment which involve ecological, economic, social and institutional indicators (Brandt et al., 2002). However, for desertification mapping three parameters are of key importance – land surface temperature (LST), vegetation cover, and soil moisture. There have been several approaches adopted for desertification mapping. The first two are ground survey and image interpretation. Although different in scale and technique, both rely on expert knowledge and ability to visually analyse the landscape and group it to several predefined categories. The third, remote sensing based, approach is digital image classification based on a single image. The techniques and algorithms used can vary, but all are based on the spectral similarity of pixel value and a set of sample points with known characteristics. Class adjustment is based on local knowledge and ground observation.

The fourth approach is a group of techniques aiming at modelling the problem using physical parameters related to the land process, derived from Earth observation data. Using geophysical parameter make it possible to assess the problem as it happens, and produce results that are comparable among different geographic regions. As mentioned above there are many
indicators that can be used for desertification mapping, but not all are available or appropriate. However, in remote sensing we always need to generalize the problem to a few important factors that matter the most. To standardize the mapping method we develop a desertification index based on 3 parameters which are strongly reflect the changes in desertification environment. These parameters are: land surface temperature (LST); vegetation cover; and soil moisture.

Satellite-derive land surface temperature (LST) has a strong relationship with the thermal dynamic of land processes (Dash et al., 2002), and can be use to assist is assessment of vegetation condition. In dry conditions high leaf temperatures are a good indicator of plant moisture stress and precede the onset of drought (Mcvicar, 1998), and surface temperature can rise rapidly with water stress and reflect seasonal changes in vegetation cover and soil moisture (Goetz, 1997).

In arid conditions vegetation provides protection against degradation processes such as wind/water erosion. Vegetation reflects the hydrological and climate variation of the dry ecology. Decreasing vegetation cover, and changes in the species composition of vegetation are sensitive indicators of land degradation (Haboudane et al., 2002).

Soil moisture is an important variable in land surface hydrological processes such as infiltration, evaporation and runoff. Soil moisture is controlled by complex interactions involving soil, plant and climate (Puma et al., 2005). In arid and semi-arid areas, soil moisture can be use to monitor drought patterns and water availability for plant growth (Hymer et al., 2000). In an integrated mapping method, soil moisture can compensate for the weakness of vegetation indices in areas of sparse vegetation cover (Saatchi, 1994).

3.2 Extraction of parameters using RS data

Land surface temperature is a standard product that is either provided by remote sensing agencies or can be generated using standard methods. Land surface temperature can be estimated from thermal bands of remote sensing imagery by reverting Plank’s function using well established techniques such as the Split window and TES (Temperature and Emissivity separation) algorithm (Dash et al., 2002).

Vegetation cover can be extracted from remotely sensed data by mean of vegetation indices or digital image classification. Vegetation indices have been use for desertification monitoring since the early days of remote sensing (Rouse, 1973). Although, there are still problems to physically relate vegetation index to ground biomass or vegetation density, it is the most common method used to study the relationship between vegetation cover and dynamics of ecological systems. Careful interpretation, and good understanding of ground vegetation systems, however, is necessary to successfully apply VI for any local or regional monitoring application.

Estimation of soil moisture from remote sensing is still in the research stage and in need of improvement. However, it is already in use for several operation applications (Bartalis, 2004). Soil moisture content can be estimated from radar imagery because radar backscatter ($\sigma^0$) is related to target dielectric constant. An increase in soil moisture content changes the dielectric constant, resulting in a strong radar signal. In practice, backscatter is also highly influenced by topography, vegetation density and surface roughness. In many cases, the range of $\sigma^0$ response to variation in surface soil moisture is equal to the range of $\sigma^0$ response to variation in surface roughness. Thus it is a difficult task to convert a single-channel SAR image directly into a map of soil moisture content for heterogeneous terrain. Further discussion on soil moisture estimation from SAR data will be presented in the methodology section.
3.3 Scale issues

To combat desertification, we need to deal with the problem at different levels of detail and scale. A policy maker interested in the economical and social aspect of desertification will require generalised information for the whole country, whilst at a local level, a provincial department of agriculture will require more detailed and precisely located data. Therefore working with remote sensing data for desertification mapping, we need to take into account the scale issue.

In order to address the desertification problem at both national and local level, we follow a multistage approach wherein data are collected at multiple scales. At national scale we utilise medium resolution remote sensing data to map desertification for the whole coastal area of Vietnam. This offers a fast and cost efficient solution to continuously monitoring the desertification problem for a large area.

At local scale, high spatial resolution remote sensing data will be used. Some critical areas, identified from national scale mapping, have been selected for detailed assessment. Field observation are being carried out to quantify the desertification process and improve classification results. In this way, the detail observation can determine what the problems are on the ground, while the remote sensing analysis can quantify the spatial extent of the problems.

3.4 Remote Sensing data resources

3.4.1 Introduction

Currently, medium spatial resolution sensors offer data with spatial resolution higher than 1 km. The sensors listed in table 1 can be considered as the next generation of NOAA AVHRR or SPOT VGT, offering multiple scale data (250 -1000 m), improved spectral resolution (more band, better atmospheric calibration), and improved radiometric accuracy. At this resolution, a single scene can cover the entire coastal area of Vietnam.

<table>
<thead>
<tr>
<th>Platform</th>
<th>TERRA</th>
<th>ADEOS</th>
<th>ENVISAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>MODIS</td>
<td>GLI</td>
<td>MERIS</td>
</tr>
<tr>
<td>Resolution</td>
<td>250, 500, 1000 m</td>
<td>250,1000 m</td>
<td>250, 1000 m</td>
</tr>
<tr>
<td>Wavelength</td>
<td>VNIR, SWIR, TIR</td>
<td>VNIR, SWIR</td>
<td>VNIR</td>
</tr>
<tr>
<td>Number of Channels</td>
<td>36</td>
<td>36</td>
<td>16</td>
</tr>
<tr>
<td>Swath</td>
<td>10 x2330 km</td>
<td>1600 km</td>
<td>575,1150 x17500 km</td>
</tr>
<tr>
<td>Agency</td>
<td>NASA</td>
<td>NASA</td>
<td>ESA</td>
</tr>
</tbody>
</table>

Some of the new high spatial resolution sensors are listed in table 2. This group of sensor provide image with resolution between 10 to 100 m.
Another sensor technology that is important to desertification monitoring is SAR. The all-weather capability of spaceborne SAR sensors (table 3) is a major advantage over optical systems. SAR data can be used to estimate soil moisture content, which is important information in semi-arid land where vegetation growth is heavily dependent on water availability (Karnieli et al., 2002, Moran et al., 1998, Tansey and Millington, 2001, Wang et al., 2004).

<table>
<thead>
<tr>
<th>Platform</th>
<th>ERS-1/2</th>
<th>ENVISAT</th>
<th>Radarsat-1/2/3</th>
<th>JERS-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>SAR</td>
<td>ASAR</td>
<td>SAR</td>
<td>SAR</td>
</tr>
<tr>
<td>Resolution</td>
<td>25 m</td>
<td>30-150 m</td>
<td>30-150 m</td>
<td>25 m</td>
</tr>
<tr>
<td>Frequency</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>L</td>
</tr>
<tr>
<td>Polarisation</td>
<td>VV</td>
<td>HH/HV</td>
<td>HH/VV/HV/VH</td>
<td>HH</td>
</tr>
<tr>
<td>Swath</td>
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<td>50-500 km</td>
<td>10-500 km</td>
<td>75 km</td>
</tr>
<tr>
<td>Agency</td>
<td>ESA</td>
<td>ESA</td>
<td>CSA</td>
<td>NASA</td>
</tr>
</tbody>
</table>

### 3.4.2 Specific requirements

In the context of the case study, suitable remote sensing data sources are sensors which could provide all or some of the parameters discussed in section 3.1. It is important to note that the “value” of each sensor is not only dependent on high spatial resolution, but also the spectral resolution, cost, coverage, calibration standards, and availability. Desertification is a long-term process, so an operational desertification monitoring system must be based on a robust and reliable suite of satellite sensors that can guarantee data continuity, quality, and availability on a decadal scale. It is for these reasons that only sensors from government-supported non-commercial Earth observation programmes were considered for this project. Another issue that
needs to be considered is data cost. As most of desertification occurs in developing country, a relatively low cost monitoring solution is required.

The medium spatial resolution sensor selected for this project was MODIS, chosen because of its finer spectral resolution than MERIS (table 2). MODIS provides the following useful data for desertification modelling: surface reflectance, land surface temperature and emissivity, land cover change, and vegetation index. MODIS data is available free of charge from NASA and routinely archived back to 1999.

The high spatial resolution sensor selected was ASTER. ASTER offers several advantages over rival sensors. It provides more bands in SWIR and TIR (6 bands in SWIR and 5 bands in TIR) than Landsat 7 ETM+ while retaining adequate spatial resolution in visible bands. The 5 TIR bands offer better measurement of land surface temperature with accuracy of 0.3°C. Cost is an issue, with ASTER level 2 products available free of charge, while level 1 cost £50 per scene.

For radar imagery, we chose ENVISAT ASAR (Advance Synthetic Aperture Radar). ASAR provides multiple swath-widths with spatial resolutions ranging from 30 to 150 m. Thus it can be used for both national and local scale. Another advantage of ASAR is that the ENVISAT satellite also carries the MERIS sensor which can offer optical data simultaneously with SAR data.

A key feature of all the data sources listed above is the availability of standardised product formats and rigorous calibration, important for the development of long term quantitative monitoring.

### 3.4.3 RS data acquired

During the study period two sets of remote sensing data were collected representing dry season and wet season conditions. The dry season dataset (Table 4) was successfully acquired in January 2005.

<table>
<thead>
<tr>
<th>Date of acquisition</th>
<th>Sensor</th>
<th>Level/ Image mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Jan 2005</td>
<td>ENVISAT ASAR</td>
<td>Level 2B/ ASAR IMG</td>
</tr>
<tr>
<td>19 Jan 2005</td>
<td>ENVISAT ASAR</td>
<td>Level 2B/ ASAR IMP</td>
</tr>
<tr>
<td>22 Jan 2003</td>
<td>ASTER</td>
<td>Level 1B/ AST_1B</td>
</tr>
<tr>
<td>14 June 2005</td>
<td>ASTER</td>
<td>Level 1B/ AST_1B</td>
</tr>
<tr>
<td>14 June 2005</td>
<td>ASTER</td>
<td>Level 2/ ASTER_08</td>
</tr>
<tr>
<td>Jan 2005</td>
<td>MODIS</td>
<td>Level 3G/MOD09A1</td>
</tr>
<tr>
<td>Feb 2005</td>
<td>MODIS</td>
<td>Level 3G/MOD09A1</td>
</tr>
</tbody>
</table>

### 3.5 Other data sources

The following ancillary data are available:

- Topographic maps in digital format at 1:50,000 scale, with contour interval of 20 m.
Land cover map for the year 2000 at 1:50,000 scale.

- Soil map at scale 1:1,000,000.
- Climate data from 1995 to 2004.

Two fieldwork visits are required, in dry and wet seasons, to provide ancillary data and basic soil properties need to validate the image processing result. The first of these was successfully completed in January 2005.

4 Methods

4.1 Image processing

Level 2 ASTER data, atmospherically corrected using a radiative transfer model and atmospheric parameters derived from the National Centers for Environmental Prediction (NCEP) data (Abrams, 2000) was used for the initial analysis. Images were registered to topographic map using second order transformation with sub-pixel RMS and nearest neighbourhood resampling.

MODIS surface reflectance for the visible near infrared wavelengths were corrected for atmospheric effects at the data centre using a bidirectional reflectance distribution function (Huete, 1999). To conform with the national geo-database of Vietnam, we transformed MODIS images from ISIN to UTM WGS 84 coordinate system using the MODIS reprojection tool.

For ENVISAT ASAR imagery, first we applied a Lee filter to remove the noise, then carried out an image-to-image geometric correction using the previously georeferenced ASTER imagery. Raw ASAR image amplitude values were converted to backscatter using equation 1 (ESA, 2004). Corrections for the effect of slope on local incident angle were applied to all SAR backscatter image using a slope map derived from the 1:50,000 digital topographic maps.

\[
\delta_{i,j}^0 = \frac{DN_{i,j}^2}{K} \sin(\alpha_{i,j}) \quad \text{(Equation 1)}
\]

For \( i = 1 \ldots L \) and \( j = 1 \ldots M \)

Where \( K \) = absolute calibration constant

\( DN_{i,j}^2 \) = pixel intensity value at image line and column “i,j”

\( \delta_{i,j}^0 \) = sigma nought at image line and column “i,j”

\( \alpha_{i,j} \) = incident angle at image line and column “i,j”

4.1.1 Land surface temperature (LST)

LST is retrieved from two data sources. At small scale, we use MOD11A2, an 8 days average surface temperature product derived from the MODIS thermal bands at 1 km resolution using a generalized split-window based on a database of targets with known emissivity. This product has been validated to an accuracy of 1K degree under clear sky condition (Wan, 1999).
At medium scale we use AST_08, ASTER surface kinetic temperature. This product has a spatial resolution of 90 m and is generated from ASTER’s thermal band using the TES algorithm (Gillespie et al., 1998).

4.1.2 Vegetation Index

In this study we use MOD13A1, a standard product generated from MODIS imagery. MOD13A1 is a 16 day composite Enhanced Vegetation Index (EVI) at 500 m resolution. The enhanced vegetation index (EVI) was developed to optimize the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences (Huete, 1999). The equation takes the form

\[
VI = G \times \frac{NIR - Red}{NIR + C1 * Red - C2 * Blue + L} \quad \text{(equation 2)}
\]

where,

- \(NIR\) = NIR reflectance
- \(Red\) = Red reflectance
- \(Blue\) = Blue reflectance
- \(C1\) = Atmospheric resistance Red correction coefficient
- \(C2\) = Atmospheric resistance Blue correction coefficient
- \(L\) = Canopy background Brightness correction factor
- \(G\) = Gain factor

Using the standard EVI and LST have advantages that they are readily available products, therefore reduce the time and resources for further processing. The second advantage is that these products are generated and calibrated using standard algorithms, thus simplifying the mapping method and allowing us to compare the results over the time and space. However, for detail assessment at local level, a customized calibration may be needed to fit with local condition.

At medium scale vegetation cover has been estimated from ASTER imagery using NDVI and SAVI (Soil Adjusted Vegetation Index). SAVI is a modification of NDVI with an L factor to compensate for vegetation density. Several author recommend SAVI for sparsely vegetated areas (Huete, 1998, Terrill, 1994).

\[
SAVI = \frac{NIR - RED}{NIR - RED + L} (1 + L) \quad \text{(Equation 3)}
\]

4.1.3 Soil moisture

In this study we applied the data fusion approach proposed by (Sano, 1997), in which the effects of soil roughness are accounted for by differencing the SAR backscatter from a given image and the backscatter from a "dry season" image \((\sigma^0 - \sigma_{dry}^0)\). The vegetation influence was corrected by using an empirical relationship between \(\sigma^0 - \sigma_{dry}^0\) and the vegetation index.
Figure 2. A graphic illustration of the SAR/optical approach for evaluating surface soil moisture developed by (Sano, 1997). The vertical distance of points A–C from the solid line is related directly to soil moisture content.

Sano (1997) found that the vertical distance between a given point and the line defining the \((\sigma^-\sigma^0)_{dry}/GLAI\) relation was independent of surface roughness and vegetation density, and directly related to target’s surface soil moisture content. It is important to note that a given relationship, as illustrated in Fig. 2, would be valid only for a single SAR configuration (e.g., sensor polarization and frequency) and would need to be adjusted for the influence of topography on local incidence angle. This, however, should not be an issue for this study, as majority of land in the test site is relatively flat.

SAR processing will be completed in 2006, following the second data acquisition campaign in the 2005 wet season.

4.2 Field methodologies

Two field visits (dry and wet season) are required in order to gather the necessary field observations. The first field visit was conducted in January-February 2005 (dry season). 150 sample locations were selected using a stratified random sample method. This method is preferred over full random sample because stratified sampling allowed us to distribute sample plots over the entire range of land use/land cover types without bias (Congalton, 1991, Stehman, 1999).

Stratification was based on unsupervised classification of a January 2003 ASTER image. The classification results provided a general guide to the location, size and type of desertification. Seven land cover classes were generated by unsupervised classification, which corresponded to high sand dune, low sand dune, bare sandy soil, rice field, grazing land, scattered forest on low land, and dense forest on hilly area.

At each sample point the following parameters were measured:
- vegetation type & cover %
- Top soil texture (5 cm depth)
- pH
- EC
- Surface roughness: measured in the field with paper profile
- Soil moisture (0-10 cm, and 10-20 cm).
- Soil surface temperature

Soil samples were analysed for basic parameters at the Forest Science Institute of Vietnam, and dried samples retained for further analysis the UK.

4.3 Data integration

The flow of data processing and analysis is presented in Fig 3. The project involves 2 main steps. At small scale, MODIS data and ASAR wide swath are used to map desertification. A desertification index is being developed using 3 variables extracted from remotely sensed data. The result of the first step will be a medium scale desertification map for the whole coastal area of Vietnam. Based on expert knowledge, some critical area will be selected for detailed assessment.

In the second step a desertification index will be constructed using variables estimated from ASTER and ASAR imagery. The results will be verified from field data and used to improve the accuracy of the map at national scale. Further analysis and comparison with existing data will be used to assist the drafting of guidelines on land use management.

![Figure 3. Workflow of the study method](image-url)
5 Initial findings

5.1 Initial image processing results

In order to assess the relationship between surface temperature and vegetation index, a plot of LST vs. NDVI was constructed from a January 2003 ASTER image. The feature space (Fig. 4) shows that LST and NDVI have a linear relationship with \( R^2 = 0.7 \). Vegetated areas have overall high NDVI value (0.3 to 0.5) and low surface temperature (20 to 26°C). Sand dune areas along the coast have lowest NDVI (-0.15 to -0.20) and very high temperature (40 to 55°C). These general trends were confirmed by the 2005 field data which revealed that non-vegetated sand dunes can reach 65°C at noon.

![Figure 4. Relationship between surface temperature and NDVI from an ASTER image (22 Jan 2003)](image)

At national scale, unsupervised classification was applied to a MODIS MOD09A monthly average image for Jan 2005 (Figure 5). The white area along the coast is classified as deserted land, and corresponds closely to the position of sandy soil, and sand dune unit on the 1:1,000,000 soil map.

Initial results suggest that MODIS is a promising data source for desertification mapping at national and regional scale, although the suitability cannot be confirmed until the final desertification index is completed.

5.2 Post-fieldwork soil analysis

Of 46 soil sample collected in the 2005 dry season, 29 samples are sandy soil, 11 are sandy loam, 4 are loamy sand, 1 is loam, and only 1 sample is clay loam. In general the soil is very poor in nitrogen and humus content (all samples <0.2% and 70% of samples <2% humus respectively). In the 4 main landscape units (sand dune along the coast, abandoned sandy soil, agricultural land and deciduous dry open forest) sandy soil dominates.

Moisture content is very low with more than 75% of all samples having values lower than 2%. Even soils under plantation forest had moisture content of only 5-10%. All sand dune and sandy soil units had surface temperatures higher than 35°C.
Figure 5. (Left) Unsupervised classification from MODIS imagery on Jan 2005. (Right) Overlay by sandy soil polygon extracted from soil map. The size of this image subset is 200x200 km
6 Discussion

The result of initial analysis have show that MODIS imagery has potential for desertification mapping at small scales, clearly delineating the coastal sandy soil region. Until now we have only tested the classification on VNIR bands. Further analysis on the combination of vegetation index, surface temperature and soil moisture need to be investigated.

ASTER level 2 derived NDVI and land surface temperature are strongly correlated (R_square=0.7) and can explain the variety of desertification status. However, it was found that the difference in spatial resolution between the VNIR (15m) used for vegetation index and thermal band (90 m) used for LST generation, can contribute to uncertainty in the result. Accurate image registration is therefore very important.

The fieldwork data have show that most of the study area has sandy soil texture and low moisture content. However, discussions with local people revealed that much of the land can still produce high yield and good quality of agriculture produce if sufficient water and fertiliser are available, but that it necessary to limit grazing during the dry period to protect the vegetation cover and prevent soil compaction.

For the next year following work is proposed:
- Development of the desertification index for small scale mapping.
- Wet season field data collection.
- Soil moisture estimation from ASAR imagery at small and medium scale.
- Development and testing of the desertification index for the main study area: Binh Thuan province.
- Transferability testing.

7 Conclusion

It has been demonstrated that remote sensing at different resolution has potential for desertification monitoring. Combination of parameters extracted from different parts of the spectrum or different sensors give more information on different aspect of desertification process, therefore improve the mapping accuracy.

Quantitative assessment of the desertification problem at both national and local scale is an important input for Vietnam’s country action plan on desertification combat. A low cost mapping solution using remote sensing could be easily adopted for developing countries such as Vietnam.

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