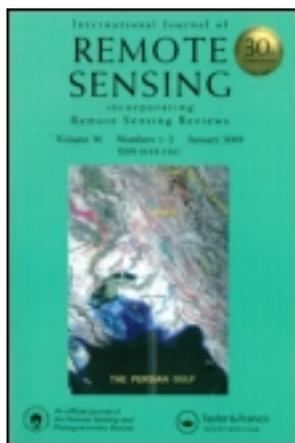


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## Using very high spatial resolution multispectral satellite sensor imagery to monitor refugee camps

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**Abstract.** Detailed geographic information is a key factor in decision making processes during refugee relief operations. The forthcoming commercial very high spatial resolution (VHSR) satellite sensors will be capable of acquiring multi-spectral (MS) images at spatial resolutions of 1 m (panchromatic) and 4 m (multispectral) of refugee camps and their environment. This work demonstrates how refugee camp environment, area and population can be analysed using a VHSR MS satellite sensor image from the Russian KVR-1000 sensor. This image, with a spatial resolution of 3.3 m, was used to study Thailand's Site 2 refugee camps, which were established to accommodate Khmer refugees on the Thai–Kampuchean border. At the time of image acquisition, the total population of Site 2's five refugee camps was close to 143 000. The VHSR MS image was found to be suitable for mapping the refugee camp environment and area. A statistically significant linear relationship between camp area and population was determined. Accordingly, the study suggests that VHSR MS images in general may be useful for refugee camp planning and management and points toward the utilization of forthcoming commercial VHSR MS satellite sensor images in humanitarian relief operations.

### 1. Introduction

Humanitarian organisations need reliable and up-to-date information about the situation on the ground for efficient planning and management of relief operations (Bouchardy 1995, Elo 1996). Satellite images can provide objective and updated information about the environment in which refugee camps are placed (Bouchardy 1995, Gupta 1995). Although satellite images have been used for regional-scale mapping (Lodhi *et al.* 1998), most relief agencies have not used this technology extensively. It is expected that images from the forthcoming very high spatial resolution (VHSR) satellite sensors, onboard polar-orbiting platforms such as Ikonos-2, QuickBird, Orbview-3, IRS-P6, and EROS A&B (as described by Aplin *et al.* 1997), will have less need for specialist interpretation and will thus be easier for non-specialist relief staff to analyse. VHSR satellite sensors are commonly defined by the remote sensing community to provide imagery below the 4 m spatial resolution limit. Single-channel, panchromatic VHSR images have proved useful for mapping and feature recognition (Gupta 1995). For vegetation assessment and change detection multispectral (MS) colour images are generally more suitable than panchromatic images (Tucker 1979).

This Letter demonstrates how VHRS MS satellite sensor imagery can be used to derive detailed information on refugee camp environment, area and population. It is based on analysing recently released archival VHRS MS satellite sensor imagery acquired from Russian satellites.

## 2. Study area and data

The now demolished refugee camp surveyed in this case study, Thailand's Site 2, was located approximately 80 km north of the town of Aranyaprathet in the Prachinburi province bordering Cambodia and peaked at a population of 143 000 refugees (Lynch 1990). Site 2 was selected for this case study because both *in situ* refugee camp information (Lynch 1990, Shook 1990, R. Burrows 1998, Personal communication), and a visible and near-infrared (NIR) VHRS MS image were available.

The United Nations High Commissioner for Refugees (UNHCR) Bangkok office provided the author with a 1:10 000 scale map of Site 2 settlement scheme dated 22 January 1990. This map was produced by the United Nations Border Relief Operation (UNBRO) Engineering Unit using Computer Assisted Design (CAD) software in combination with advanced field survey equipment (R. Burrows 1999, Personal communication). The map showed how Site 2 was organized into six camps, Ampil, Bantath (for administrative purposes only), Dang Rek, Nong Chan, Rithysen and San Ro. On the UNHCR map, detailed features such as administrative centres, water sites, hospitals and sanitation centres were mapped. In addition, the area coverage of all six camps were listed. Corresponding camp populations are listed in Lynch (1990).

The source of satellite data uniquely suitable for this study is Sovinformsputnik, an organisation that markets VHRS images derived from scanned photographs from the KVR-1000 intelligence sensor. The KVR-1000 sensor used in this study can acquire images with two light-sensitive film layers: a panchromatic layer and a NIR layer, with the NIR layer providing additional useful information for vegetation assessment (Tucker 1979). The MS spatial resolution of the image is 3.3 m, which is higher than the resolution available from other commercially available MS satellite images today. Table 1 lists the characteristics of the image used in this study.

## 3. Method

The VHRS MS image was geographically rectified based on image centre and corner coordinates as listed by the data provider. These ground control points (GCPs) were based on the satellite's position and listed as better than one minute-degree, i.e. better than 1.85 km by the data provider. This is a relatively low level

Table 1. Parameters of the original KVR-1000 image used in this study.

Date	Time	Satellite height (km)	Panchromatic wavelengths (nm)	Infrared wavelengths (nm)	Image dimensions (km × km)	Spatial resolution (m)
7 February 1989	04:35GMT	219.9	570–690	670–810	15 × 15	3.3

of horizontal accuracy compared to the 12 m horizontal accuracy listed for the forthcoming VHRS satellite sensors (Space Imaging 1999).

The true-coloured MS characteristics of the satellite image in combination with VHRS information facilitated visual interpretation of Site 2's environment and vegetation. A multi-layered digital space map of Site 2's infrastructure was created based on visual inspection (figure 1 and cover).

Individual camp areas were determined from polygon vector overlays representing camp borders from which the image analysis tool, ERMMapper, provided automatic area calculations. Based on VHRS satellite sensor data as well as *in situ* derived area and *in situ* population estimates for individual camps, a statistical linear regression

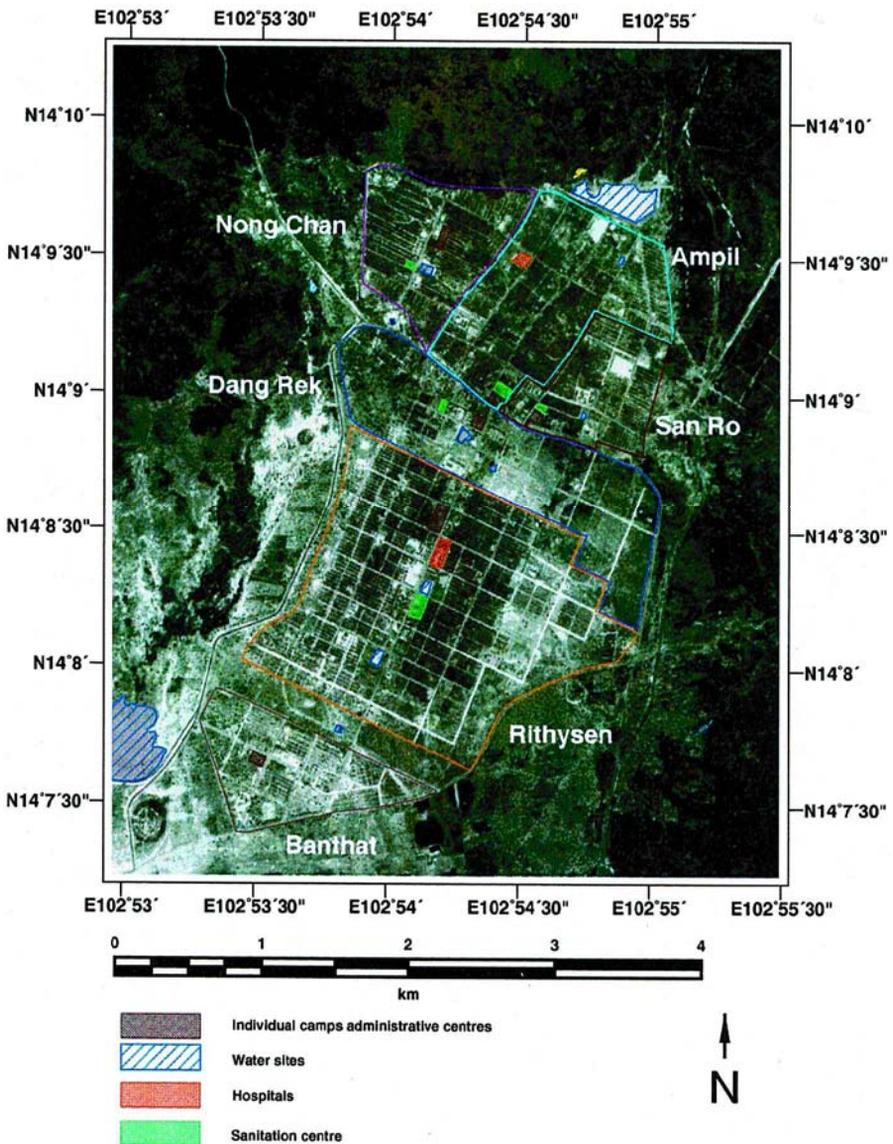


Figure 1. Multi-layered space map of Site 2. Image copyright Sovinformspnutnik, 1998.

analysis was carried out on the dataset in order to assess a potential relationship between area and population.

#### 4. Results

From figure 1 it is evident that the relatively dense vegetation in the north-west part of the image appears to have been altered due to the construction of the refugee camp. From *in situ* information it is known that housing was constructed from local materials such as bamboo and thatch (Lynch 1990). It is likely that these materials were collected from this previously forested area. From the infrastructure seen in the VHSR MS image, as well as information from *in situ* sources, it is evident that Site 2 was logistically a relatively well administered settlement (Lynch 1990, Shook 1990, R. Burrows 1999, Personal communication).

The VHSR MS characteristics of the satellite image in combination with the UNHCR map revealed eleven water sources scattered through the site (figure 1). The road network connecting Site 2 with neighbouring villages and main roads was also relatively well developed, as seen east of San Ro camp in figure 1.

Table 2 lists area and population characteristics of the individual camps. The total area of Site 2 derived from the polygon vector overlays of the satellite image is 8 189 848 m<sup>2</sup>, while the total camp area as listed on UNHCR's map is 8 095 000 m<sup>2</sup>—a difference of 94 848 m<sup>2</sup> (1.2%) (individual camp areas differed more). The total populated area of Site 2 was estimated to 4 851 388 m<sup>2</sup> based on visual analysis of the VHSR MS image. This resulted in an average population density estimate of 29 522 persons km<sup>-2</sup>, given the total population of 143 221 (Lynch 1990).

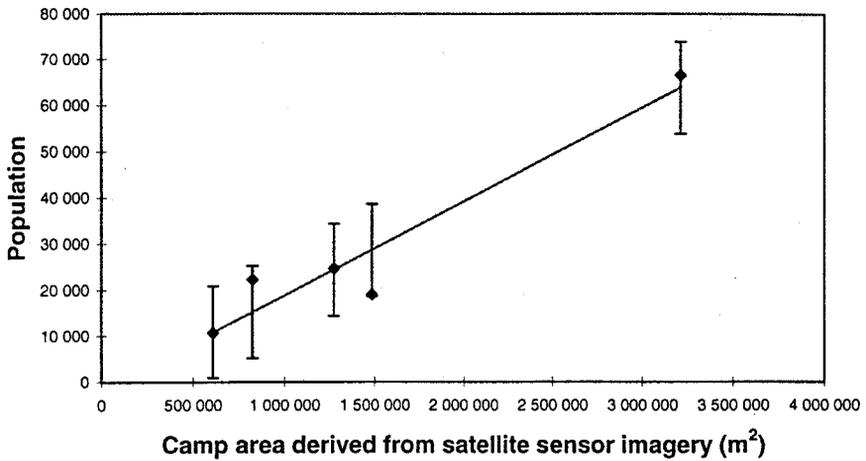
As may be seen from figure 2 and table 3, the statistical relationship between refugee population and camp area is linear and significant within a confidence level of 99%. The slope of the VHSR satellite sensor-derived population versus area and the *in situ* derived population versus area is 0.020 and 0.021 respectively.

#### 5. Discussion and conclusion

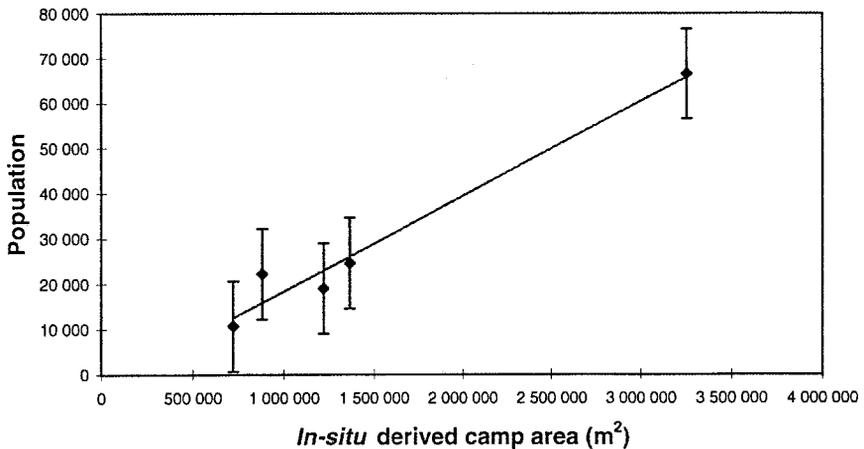
The combination of VHSR and MS information was found to be advantageous for an environmental analysis of Site 2 and its surrounding area, with the NIR information facilitating recognition of differences in vegetation. The detailed spatial

Table 2. Areas, populated areas, population and population density of Site 2's individual camps. The refugee population data are based on a census dated 24 August 1989 (Lynch 1990). Banthat is an administrative camp with no refugee settlement. The population density was computed from the ratio of refugee population to populated area.

Camp	Area (m <sup>2</sup> ) from satellite	Area (m <sup>2</sup> ) from <i>in situ</i> data	Satellite area— <i>in situ</i> area (m <sup>2</sup> )	Populated area (m <sup>2</sup> ) from satellite	Refugee population	Population density (persons km <sup>-2</sup> )
Ampil	1 274 727	1 365 000	- 90 273	948 986	24 658	25 984
Banthat	781 321	655 000	126 321	N/A	N/A	N/A
Dang Rek	1 485 999	1 220 000	265 999	580 910	19 069	32 826
Nong Chan	824 442	880 000	- 55 558	719 867	22 256	30 917
Rithysen	3 213 821	3 255 000	- 41 179	2 189 018	66 546	30 400
San Ro	609 538	720 000	- 110 462	412 607	10 692	25 913
Total	8 189 848	8 095 000	94 848	4 851 388	143 221	29 522



(a)



(b)

Figure 2. Linear regression analysis of (a) *in situ* derived refugee population versus satellite sensor-derived camp area and (b) *in situ* derived refugee population versus *in situ* derived camp area. The 95% confidence level error bars for population estimates are shown.

information added considerable value to infrastructure analysis. The overall difference of 1.2% between the satellite-derived area and UNBRO Engineering Unit field survey area suggests that VHSR MS images are suitable for area estimation. The statistically significant relationship between population and area derived here shows potential for use in planning and administering refugee camps with population densities similar to that of Site 2 (29 522 persons km<sup>-2</sup>).

A more complicated, but potentially more accurate, method of estimating population via remote sensing is through dwelling unit counts and corresponding *in situ*

Table 3. Results of linear regression statistical analysis on the relationships between VHSR satellite sensor-derived camp area and *in situ* derived population, and *in situ* derived camp area and *in situ* derived population (see also figure 2).

Parameter	VHSR satellite sensor-derived camp area versus <i>in situ</i> derived camp population	<i>In situ</i> derived camp area versus <i>in situ</i> derived camp population
Intercept	- 1541	- 2660
Slope	0.020	0.021
P-value	0.010	0.002
Confidence level (%)	99	99

information on the number of persons occupying each dwelling unit (Watkins and Morrow-Jones 1985). However, the spatial resolution of 3.3 m of the satellite image used here was too coarse for the detection of individual dwelling units in the dense settlement structure of Site 2.

Imagery of spatial resolution down to 1 m in panchromatic mode and 4 m in MS mode from forthcoming satellites, such as Ikonos-2, OrbView-3 and QuickBird, has potential for more efficient management of humanitarian relief operations, including dwelling unit counts in densely populated refugee camps.

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