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Mapping of risk prone areas of kala-azar (*Visceral leishmaniasis*) in parts of Bihar state, India: an RS and GIS approach

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Abstract

Background & objectives: The kala-azar fever (*Visceral leishmaniasis*) is continuing unabated in India for over a century, now being largely confined to the eastern part of India mainly in Bihar state and to some extent in its bordering states like West Bengal and Uttar Pradesh. Two study sites namely Patepur block in Vaishali district with high endemicity in northern part and Lohardagga block in Lohardagga district with absolute non-endemicity in southern part of Bihar were selected for the study with the following objectives : (i) to study the macro-ecosystem in relation to distribution of vector —*Phlebotomus argentipes*; (ii) to identify/map the risk prone areas or villages in a block for quick remedial measures; and (iii) to make use of satellite remote sensing and GIS to demonstrate the utility for rapid assessment of landuse/landcover and their relation with the incidence of kala-azar leading to the mapping of risk prone areas.

Methods: Indian Remote Sensing (IRS)-1D LISS III satellite data for the periods of March and November 2000 were analysed in Silicon graphic image processing system using ERDAS software. False color composites (FCC) were generated and landuse/landcover was assessed using Maximum likelihood supervised classification techniques based on ground truth training sets. During the study the GIS functions are used to quantify the remotely sensed landscape proportions of 5 km^2 buffer surrounding each known group of villages of high occurrence of sandflies in endemic and non-endemic study sites. Instead of traditional ground based survey methods to vector surveillance, the present study used a combination of remote sensing (RS) and geographical information system (GIS) approach to develop landscape predictors of sandfly abundance—an indicator of human vector contact and as a measure of risk prone areas.

Results: Statistical analysis using the remotely sensed landscape variables showed that rural villages surrounded by higher proportion of transitional swamps with soft stemmed edible plants and banana, sugarcane plantations had higher sandfly abundance and would, therefore, be at higher risk prone areas for man-vector contact.

Interpretation & conclusion: The present study clearly brought out the usefulness of satellite remote sensing technology in generating the crucial information on spatial distribution of landuse/landcover classes with special emphasis on indicator landcover classes thereby helping in prioritising the area to identify risk prone areas of kala-azar through GIS application tools.

Key words Kala-azar vector – microfocus – remote sensing – sandfly

Introduction

The menace of kala-azar (*Visceral leishmaniasis*) is largely confined to the eastern part of India mainly in the Bihar state and to some extent in adjoining states like West Bengal and Uttar Pradesh. The epidemiological investigations on kala-azar further suggest that case multiplication/increasing trend is more pronounced in regions with a poor health infrastructure and areas under intense developmental activities related to agriculture. Further studies on kala-azar transmission dynamics highlighted the importance of local epidemiology of the disease.

Analysis of soil samples (positive for larval habitats of sandflies) in endemic focus point out that these are alluvial, dark coloured alkaline in nature (pH 7.2–8.5), calcareous with chief inorganic constituents of silicon, iron and aluminium. This nature of soil enhances its capability of retaining water as well as successful growth and abundance of edible shrubs, plants or agricultural crops. However, in non-endemic study sites, red and yellow laterite soils, with non-porous granular particles are not only acidic in nature (pH 5.9–6.1) but are also of less water retaining capacity. This does not assist the growth/propagation of shrub/soft-stemmed plants. So physical as well as chemical nature or soil supplemented with water retaining capacity can also be considered as an important factor contributing to much more positive sandflygenic conditions in endemic study sites in contrast to non-endemic study sites.

Peridomestic vegetation within 5 km radius of human settlements in endemic foci in favourable summer and monsoon months consist of edible shrubs and plants such as seem, pumpkin, chillies, carrot, beet, banana, *bhang*—agricultural plantations, orchards, etc. with very soft stems. This not only helps penetrate and imbibe plant sap by male sandfly population but may also serve as a source of sucrose for naturally infected vector population for development and multiplication of *Leishmania* spp within its gut. However, in non-endemic study sites, it was seen that hard and impregnable cacti, thorny plants, amorphophallus, kukrands, bonpatal, etc. consist of peridomestic vegetations within 5 km^2 periphery. So disposition of typical edible, pregnable, soft stemmed peridomestic vegetation vis-à-vis plant source of sandfly food in endemic sites may also help high vector abundance in contrast to non-endemic foci[1,2].

Housing patterns are also distinctly different in the two foci. While in endemic sites thatched, mud-plastered roof tops of housesholds with crack and crevices on it as well as on walls may serve as an effective day-resting habitats for these nocturnal feeder species, mainly tiled, dry, non-porous roof tops without any cracks/crevices in endemic foci cannot be a resting habitat for the adult population. Again loose, wet solid with rich organic debris, on house floors in endemic sites not only serve as a very good resting habitat/food source for thriving and probation of immature stages of vector sandfly, but also act as resting habitat of newly emerged adult population. Thereby, to some extent, factors in microfocus like housing pattern/house floors also determines vector abundance/resting place[3-5].

Upholding the limitations of available technology in establishing cause and relationship of spread of the disease, it has become imperative to address new vistas for possible risk prone areas of the disease. The increasing accessibility to new technologies—'Remote sensing' and 'Geographical information system', it has become possible to monitor landuse/landcover features on earth's surface over various time intervals to develop methods for rapid stratification of high susceptive risk prone areas and for the design of immediate remedial measures. However, considerable work on feasibility studies in delineating mosquito prone areas have been carried out in India and abroad using RS and GIS techniques and also observed that the spatial changes in the overall density of mosquitoes vis-à-vis changes in environmental variables revealed positive correlation with water bodies and vegetation cover. It has been proved that the RS and GIS could be a useful tool for surveillance of various arthropod vectors[6–9]. Hence, satellite remote sensing and GIS tools have been used to demonstrate the utility space technology for rapid assessment of landuse/landcover and their relation with the incidence of kala-azar leading to the mapping of risk prone areas.

Material & Methods

Study area: Two study sites representing different types of ecosystem have been selected in Bihar. The sites are in Vaishali district (longitude 85° 00' – 85° 45'N and latitude 25° 30' – 26° 00'E) of north Bihar with high endemicity and Lohardagga district of south Bihar with absolute non-endemicity. Considering the cost effectivity, the study has been limited to 'Block' level instead of entire district. 'Patepur block' (longitude 85°15' – 85° 40'N and latitude 25° 45' – 25° 55'E) in Vaishali district and 'Lohardagga block' in Lohardagga district with about 10 villages in each of the block were selected for field observation and correlation studies. Both the foci experiencing extreme climatic conditions with very hot in May–June and very cold in December–January.

Ten test villages were selected randomly from the pool of villages in each block using the centre point coordinate of a village to ensure that each village selected was atleast 2–3 km away from any village already selected. This distance requirement for minimum risk of non-unique observations due to overlap of surrounding. It was necessary, however, to include few more villages that did not cover more than the 2 km criterion due to problem with access to a few candidate villages during the wet season.

Data in respect of adult sandfly density in two study sites were collected in different seasons from preselected subsites for subsequent correlation with ecological data and satellite data as per date of satellite pass. Sampling of adult sandflies from human settlements and animal shelter was done from selected subsites of each study site from 0600–0900 hrs correlating sandfly sampling from different ecotypes, domestic and peridomestic ecosystem, vegetation, soil type, etc.

Satellite based information and extraction: During the present study IRS-1D LISS III of March and November 2000 of two test sites were used. The satellite data were geometrically and radiometrically corrected and registered with Survey of India toposheets on 1:50,000 scale. Further, the block boundary maps of Patepur and Lohardagga were scanned and registered with the satellite data. Village boundary layer was also digitised and vector layer was generated. The study block namely Patepur and Lohardagga were extracted from the satellite data of two seasoned passes—winter of November and summer of March for landuse/landcover analysis.

The satellite data were subjected to enhancement techniques like linear and histogram stretching and improved the quality of the image. Supervised maximum likelihood classification techniques were applied with the collected ground truth information of the study area. The study area has been segregated into different categories of landuse/landcover with special emphasis on type of crops like sugarcane, banana plantations, village orchards and fallows of very moist, moist and dry in nature. The satellite data pertaining to Patepur and Lohardagga blocks, were subjected to MXL classification techniques and segregated various classes namely deep water bodies (blue), high sediment water bodies (cyan), marshy areas with grass and weeds (mass green), orchards of banana/sugarcane (red), village orchards, an englomeration of fruit bearing and shade tree (green), agricultural fallows of varying degree of moist conditions like moist fallow (golden yellow) and less and dry fallow (yellow) also associated with hamlets (Fig. 1). The area statistics of all the classes pertaining to Patepur block is considered for discussion.

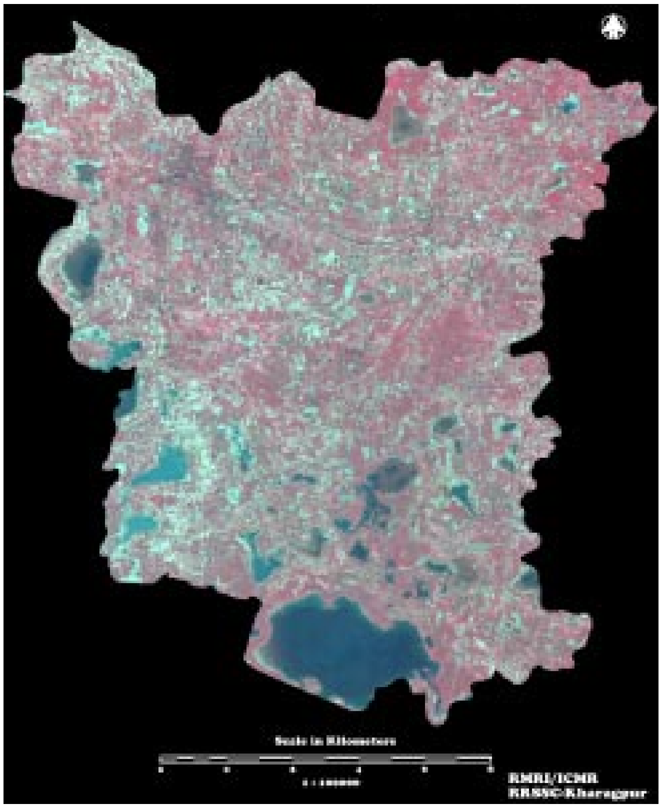

Fig. 1: False colour composite (FCC) of Patepur block, Vaishali district, Bihar (*Source: IRS 1D LISS III of March 2000*)

Correlation of sandfly population with spatial changes in landuse/landcover variables: The changes in sandflies density were analysed with seasons. Seasonal trend analysis of adult population density was correlated with eco-environmental parameters to understand influence of specific parameters, if any. Sandfly population changes were analysed with three main variables namely vegetation, water bodies and settlements. As vegetation and human settlements support the thriving of adult population by providing food and shelter, the adult densities were correlated with spatial changes in vegetation cover and human settlements.

During the study emphasis has been given to type of vegetation, water bodies and proximity to hamlets. The mapping of landuse/landcover with considerable emphasis on vegetation discrimination of agricultural crops, water bodies of various sizes and orchards using remote sensing satellite data has been accomplished, the distance of these variables from hamlets using GIS analysis through distance criteria and proximity analysis helped in prioritising the villages prone to high sandfly population.

Results & Discussion

It is observed that all the 10 sites (group of villages) chosen for the study support Genus *Phlebotomus* and their measured densities of vector species *P. argentipes* are summarised in Table 1. According to three predominant seasons (summer, rainy and winter) described earlier, density of *P. argentipes*, except winter season, almost maintained a steady pattern in endemic study sites in contrast to the non-endemic areas. Analysis of temporal fluctuations in vector densities in endemic sites indicated that it was generally very high in summer and rainy seasons (15–22 MHD) and low in winter seasons (4–5 MHD). However, in non-endemic sites irrespective of season,

Table 1. Summary of vector density of adult *P. argentipes* in different seasons

Block	Village	Season	MHD
Patepur block (Vaishali district)	Simarwara	Summer	15
		Rainy	16
		Winter	5
Patepur (Vaishali district)	Mahati Dharamchand	Summer	22
		Rainy	18
		Winter	4
Lohardagga block (Lohardagga district)	Gurhi	Summer	6
		Rainy	4
		Winter	1
Lohardagga	Jori	Summer	4
		Rainy	1
		Winter	–
Lohardagga	Kurse	Summer	5
		Rainy	3
		Winter	–

MHD varies from 1–6. Seasonal density of vector *P. argentipes*, as per Table 1 which showed almost a steady pattern in the endemic focus in contrast to the non-endemic focus. In summer and monsoon months its density ranged from 15–22/man hour. A study in predefined endemic focus in Patna pointed out that the optimal, critical density of 8/man hour or above was utmost essential for *P. argentipes* to enable it to transmit infection from one infected host to a new host.

In the present study preponderance of vector species (except winter months) was 2–3 times higher than the critical density in summer and monsoon months (from March–October) thereby suggesting probability of successful transmission subject to the presence of infective host and positive eco-environmental situation. In contrast to it, in non-endemic study sites, even in summer and monsoon months, when highest vector abundance is expected, its MHD ranged between 1 and 6, with an average of 3–4/man hour, thereby far below the requisite optimal density. Even in the presence of infective host, poor vector abundance will not assist in successful transmission, due to lesser chances of man-vector contact even in the most favourable seasons.

Field data collected in few villages of 10 numbers in Patepur—an endemic and Lohardagga—non-endemic blocks provided a prior knowledge of those villages that had high or low abundance of sandfly. Except winter season, density of *P. argentipes* almost maintained a steady pattern in endemic study sites in contrast to the non-endemic areas.

Analysis of landuse/landcover features, as per Table 2, which revealed that correlation of water bodies with adult density was positive for all study sites in endemic focus, wherein at least 25–30% land should have water bodies. The water bodies mainly consisted of ponds, irrigation canals or rivers/rivulets, etc. The importance of water bodies lies in the fact that these contribute to maintain moisture conditions in soil/subsoil level with an average humidity of 65–80% as varying from place-to-place, which in turn suits the breeding and propagation of immature stages of sandflies as well as suitable adult resting habitats in the microfocus (such as human habitations/animal shelters). This correlation is interestingly positive in the non-endemic focus also, where lesser number of water bodies (10% mean) contribute to dry, granular soil or subsoil (up to 1 cm or more) with low water level, which is in turn arrest

Table 2. Landuse categories and other eco-environmental factors

Features/landuse/soil	Endemic (Patepur)	Non-endemic (Lohardagga)
Land cover (approx.)	Water bodies (33%) Vegetation (18%) Agricultural fallow land (46%) Settlement (3%) Unclassified (Nil)	Water bodies (10%) Vegetation (15%) Agrricultural fallow land (62.5%) Settlement (2.5%) Unclassified (10%)
Soil type	Alluvial	Laterite
Soil chemistry	Inorganics, Fe, A1, Si Alkaline (pH 7.2–8.5)	Inorganics, A1, Mg, Ca Acidic (pH 5.9–6.1)
Peridomestic	Edible shurbs & plants — Cacti, thorny plants typical vegetation with very soft stems of hilly terrain	
Agricultural crops	Banana, sugarcane, maize, groundnut, barley, ragi (100 m radius), bamboo, rice, potato, etc.	
House flooring	Loose, wet soil with hard rocky bottom, organic debries	

breeding, resting or propagation of vector species. Organic debris, if any, an important source of larval food, also becomes hard and dry due to paucity of moisture soil condition. Therefore, presence/absence of water bodies can be considered as an important determinant of vector abundance vis-à-vis disease outbreak. Landuse/landcover trend and its correlation with sandfly density in the endemic block (Patepur) and non-endemic block (Lohardagga) are given in Table 2. During summer (March–June) and rainy season (July–October) there was increasing trend of irrigation as well as water areas, with edible shrubs or plants in and around peridomestic situations up to 5–10 km^2 radius (especially in monsoon months). Parallel increasing trend of adult population was observed in these seasons thus indicating the positive correlation. However, in the winter with fall of temperature in atmosphere as well as soil or subsoil level (up to 4.5 or 1.0 cm) diapauses sets in the immature stages of vector species and thereby irrespective of favourable peridomestic vegetation, the adult density was decreased, indicating negative correlation.

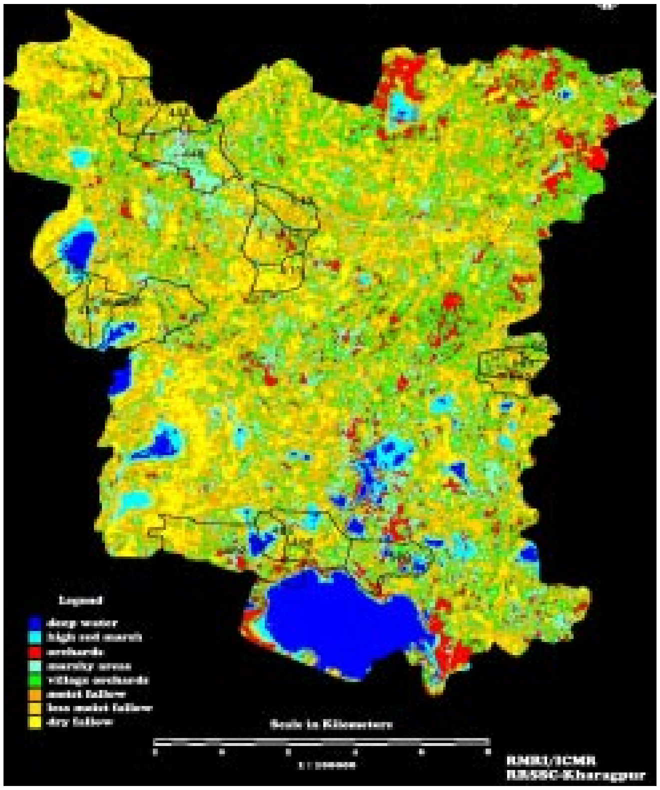

Fig. 2: Classified integrated landuse/landcover map of Patepur block, Vaishali district, Bihar, using IRS ID LISS III data of March 2000

The analysis of landuse/landcover variables through satellite remote sensing data in the Patepur block indicated varying composition depicting unique environment predominantly of high water bodies/moisture content in integrated March/November 2000 satellite data (Fig. 2). Patepur block consisted of big and small water bodies associated with weeds/marsh areas covering an area of about 8599 ha (33%). Vegetation consisting of agricultural plantations and orchards contributed to 4737 ha (18.3%) and agricultural fallow land of moist, less moist and dry fallow occupies an area of 12,598 ha (48.7 %) (Table 3). The present observation on the composition of vegetative cover especially edible plantations, predominant village orchards in association with human settlements coupled with marshy water bodies were the indicators of risk prone areas for the incidence of kala-azar disease. These variables might have supported the thriving of adult population of sandfly by providing food and shelter hence, the adult densities were correlated with the spatial distribution of vegetative cover and human settlements. However, in view of limitation of spatial resolution of satellite data used, all the settlements could not be mapped as such but identified those settlements from the Survey of India topographical maps and a rough estimate of the settlement areas had been made in two test sites.

Keeping these indicators in view, the villages having more of spatial area were prioritised and extracted using GIS tools. The villages with survey number namely Dharmchand–492, Matalya–495, Chokalya–496, Near Bhagwanpur– 560, 561, 562, Mardah–454, Near Lakhmlpur–455, 456, Shabpur Buzurg–443, Near Mohemmadpur–444 and Honachumpur–446 were prioritised and considered as risk prone villages for probable incidence of kala-azar fever.

Table 3. Landuse/landcover categories of Patepur block, Vaishali district, Bihar based on analysis of IRS-ID LISS III satellite data integrated for period of March and November 2000

Class	Area (ha)	Percentage
Water bodies—deep	2512	10
Water bodies with high sediment	2618	8
Marshy areas	1151	4.4
Water bodies with weeds/grasses	2768	10.6
Orchards (banana/sugarcane plantations)	841	3.3
Village orchards	3896	15
Fallow lands—moist areas	5185	20
Fallow lands—less moist	4447	17.2
Fallow lands—dry areas (includes settlement-hamlet)	2966	11.5
Total area	25902	100

Analysis of landcover features based on remotely sensed outputs and field data in endemic sites revealed that there was a positive correlation of abundant water bodies, marshy areas, edible soft stemmed shrubs, agriculture crops of banana, sugarcane, bamboo and paddy with occurrence of high sandfly density. In addition the alluvial soil with alkaline nature (pH 7–8,) settlement areas having house flooring of loose, wet soil with organic debris were also indications of high adult sandfly density occurrence. In case of non-endemic sites the land cover features were mostly devoid of water bodies and marshy areas with vegetation of hard stem with thorny plants and the soil was of lateritic with acidic of pH 5–6 with hard rocky house flooring.

The present study clearly brought out the usefulness of satellite remote sensing technology in generating the crucial information on spatial distribution of landuse/landcover classes with special emphasis on indicator landcover classes thereby helped in prioritising the area to identify risk prone areas of kala-azar through GIS application tools. The study clearly identified the risk prone villages in a block making it easy to Indian Council of Medical Research units to prioritise their visit to such interior village to take precautionary measures to control onset or spread of the disease in time.

It was significant that these habitats, although too small to be sensed, could be inferred from landscape elements mapped using IRS-1D LISS III data with ground resolution of 23 x 23 m. However, efforts are underway to study different seasons using IRS-1D (P+XS) data or the satellite from IRS-Resourcesat LISS IV MSS data with spatial resolution of 6 m to derive more landcover features with precision to identify different cropping parcels, small water bodies, marshy areas of even less than 0.5 ha size.

However, irrespective of favourable/unfavourable seasons, in non-endemic foci, no such definitive correlation could be established between sandfly density and landuse variables. So, it can be concluded that sandfly genic potential of an area arising due to specific environmental composition of water bodies, soil type, peridomestic vegetation, agricultural crops, etc. can be assessed for macrostratification for vector abundance/non-abundance vis-à-vis kala-azar occurrence/non-occurrence. These all are thereby the essential eco-environmental criteria or parameters which in conglomeration and supplemented with high vector density are thought to be determinant factors for occurrence and spread of the disease in endemic foci. On the contrary, low vector density and absence of these factors were contributor to near total absence of this disease in non-endemic foci. These parameters can also be effective ground truth validation factors in association prioritising the areas for possible disease outbreak as well as sandfly control programmes.

The study revealed that RS and GIS techniques helped in precisely identifying water bodies, marshy areas, weed prone water tanks and different crops like sugarcane, soft stemmed banana plantations including village orchards of areas even less than 0.5 ha. In addition the quantitative estimates of their spatial extent of indicators of landcover would benefit in prioritising the villages, which are prone to vector borne diseases than the other villages. It indicates that the environmental factors such as type and density of settlements, proximity to these with that of water bodies, marshy areas with succulent weed cover and also crops of high succulent in nature like sugarcane, bananas coupled with local prevailing conditions have definitely interactive influencing effect of vector density and also incidents of vector borne diseases. Further studies, may improve our understanding of the epidemiology and spread/arrest of the disease. It is also proposed to generate geomorphology, soil, slope map along with three season landuse/landcover of the two study areas and integrate in the GIS to derive useful information to further predict high risk zones of kala-azar in endemic Vaishali district in the northern part of Bihar.

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References

1. Elnaim DA, Connor SJ. Environmental determinants of the distribution of *Phlebotomus orientalis* in Sudan. *Ann Trop Med Parasitol* 1998; *92*(8): 877–87.
2. Sharma VP. Study on the feasibility of delineating mosquitogenic conditions in and around Delhi using Indian Remote Sensing Satellite data. *Indian J Malariol* 1996; *23:* 107–25.
3. Uriel K. Landscape ecology and epidemiology of vector borne diseases: tools for spatial analysis. *J Med Entomol* 1998; *35*(4): 435–77.
4. Wagner VE, Hill-Rowley R, Narlock SA, Newson HD. Remote sensing: a rapid and accurate method of data acquisition for a newly formed mosquito control district. *Mosq News* 1979; *39:* 283–7.
5. Washino RK, Byron LW. Application of remote sensing to arthropod vector surveillance and control. *Am J Trop Med Hyg* 1994; *50*(6): 134–44.
6. Sharma VP, Srivastava A. Role of geographic information system in malaria control. *Indian J Med Res* 1997; *106:* 198–204.
7. Pattanayak S, Sharma VP, Kalra NL, Orlov VS, Sharma RS. Malaria paradigms in India and control strategies. *Indian J Malariol* 1994; *31:* 141–59.
8. Barnes CM, Cibula WG. Some implications of remote sensing technology in insect control programs including mosquitoes. *Mosq News* 1979; *39:* 271–82.
9. Robert B. Possible remote sensing applications in the area of human and animal health, XIV UN/FAO/ Government of Italy training course on remote sensing applications to land resources. Rome, Italy 1989.

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