Remote sensing as a tool to survey endemic diseases in Brazil

O sensoriamento remoto como ferramenta de vigilância em endemias brasileiras

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Abstract

The objective of this study, based on a systematic literature review, is to present the characteristics and potentialities of remote sensing as a useful environmental surveillance tool for applied research in the control of endemics in Brazil. Onboard satellite sensors allow for monitoring the territory, furnishing spatial and temporal information on various scales and regions in the electromagnetic spectrum. Based on the literature review on the application of this technology to the study of endemics and the identification of the potential of new sensors with better spectral, spatial, and temporal resolutions, this study highlights perspectives for the use of remote sensing in the study of important endemics for Brazil.

Communicable Diseases; Epidemiologic Surveillance; Review Literature

Introduction

Recent environmental and ecological changes within a context of widespread increased social vulnerability, associated with the persistence of inadequate living conditions, have caused an impact on the distribution pattern of diseases. These environmental, economic, and social changes increase the epidemiological complexity, favoring the emergence of new diseases and the reemergence of old endemics, traditionally related to rural areas and currently occurring in new environments, as in the case of visceral leishmaniasis [1,2,3]. These questions have motivated health-related organizations, and particularly international agencies like the World Health Organization (WHO), to pursue the development of new surveillance techniques and models in which the environmental issue is fundamental [4].

Remote sensing (RS) – a technology capable of acquiring information on the Earth's surface without any contact – allows systematic and regular monitoring of the Earth's environmental conditions, furnishing large amounts of spatial and temporal data and the possibility of extracting climatic and ecological information. Such information, together with appropriate field studies, can be used to identify and map the potential habitats of parasites and disease vectors; predict alterations in vector and parasite populations, monitoring quantitative and qualitative alterations in the respective habitats; and plan control programs, indicating areas of greater and lesser risk of the disease [5].

The environmental factors most closely related to vector-borne endemics and amenable to observation from spatial platforms include: temperature, water, soil moisture, plant cover conditions, deforestation, urban characteristics, ocean color, and topography [6].

Recognizing the potential of RS as well as its scarce utilization in Brazil, a review was conducted on the scientific knowledge acquired from applications of this technique to the study of endemic (and particularly vector-borne) diseases. The study attempts to identify possibilities for the use of this technology as a tool to support the study and control of the most frequent endemics in Brazil.

The article is developed along three main lines:

- Description of the main characteristics of sensors, seeking to provide the basis for discussing their use;
- The "state of the art" in the use of remote sensing applied to endemics;
- For each endemic, a description of its pattern, risk areas, information that the images can provide, and the satellites/sensors that can be utilized.

Principal sensors and their characteristics and applications

RS essentially measures the energy reflected or emitted in distinct and specific wavelengths in the electromagnetic spectrum, using sensors, usually on board satellites. When the objective of the monitoring is environmental, the visible, infrared, and microwave regions of the spectrum are used [7,8].

RS systems can be classified as active or passive. In *active* systems, for example radar, *Radio Detection and Ranging*, the sensor emits a flow of radiation in the microwave spectral range which interacts with targets on the Earth's surface, and the reflected portion is captured by the sensor. The principal advantages of radar are that: it operates both daytime and nighttime; cloud cover does not impede its use; and it detects different textures and slopes. *Passive* systems record environmental energy – light and heat – reflected and emitted, captured by the sensor. The TM (*Thematic Mapper*) sensor from the LANDSAT (*Land Satellites*) series and the HRV (*High Resolution Visible*) sensor from SPOT (*Satellite Pour l`Observation de la Terre*) are examples of passive sensor systems [7].

The different types of resolution that are characteristic of each sensor define the information content for each scene obtained.

Spectral resolution refers to the spectral range of each band in a given sensor and indicates the energy sample frequency. Since the targets display different responses in each of these spectral ranges, this information is used to identify such targets. For example, in an area of vegetation one observes a high reflectance value in the near-infrared region and a low value in the visible red band. *Spatial resolution* can be defined as the smallest possible area of terrain that can be individualized. *Temporal resolution* indicates the time interval between two satellite passes over the same point on Earth [9,10].

Table 1 shows the principal existing RS systems and their characteristics. The inclusion of the LANDSAT ETM+ sensor, out of operation since May 2003, is due to the large mass of data generated during its active period, from 1999 to 2003.

In the first contact with an RS image, the user utilizes such elements as tone, shape, size, pattern, texture, shadow, and association to interpret it. One can distinguish an urban area from a rural one, a more or less dense urban zone, crop areas from natural areas, and the rough texture of forest canopies from a smooth texture such as asphalt, crop fields, and pasture or grassy areas [7,11].

As for the choice of images, one should use those with the most adequate spatial, spectral, and temporal resolutions for the study. In relation to spatial resolution, what is essential is to evaluate the size of the object one wishes to map. In the identification of small agricultural areas, trees, buildings, rooftop characteristics, and distances between residences, one can use a maximum 5-meter resolution. A 15-meter resolution is capable of detailing forest areas or identifying city blocks, while 20 to 30-meter resolutions are ideal for identifying urban areas, roads, airports, and forest and agricultural areas, as well as characterizing land use. To detect floodable areas one can use spatial resolutions ranging from 10 to 100 meters, depending on the study area. A 1,000-meter resolution can be used to quantify vegetation and temperature [6].

The images furnished by LANDSAT and SPOT satellites provide a scale of details that is impossible to obtain from the NOAA (*National Oceanic and Atmospheric Administration*) weather satellite. However the latter has high temporal resolution, allowing the acquisition of images from the same region with a 12-hour

Table 1

Spectral, spatial, and temporal characteristics of some satellite sensors.

Satellite	Sensor	Bands	Spectral range (µm)	Spectral region	Resolution Spatial (m)	Resolution Temporal (days)	Scene (km)
NOAA							
	AVHRR	1	0.58–0.68	VIS	1100 (nadir)	0.5	833
		2	0.72-1.10	NIR			
		3	3.55–3.93	MIR			
		4	10.30–11.30	TIR			
		5	11.50–12.50	TIR			
Landsat							
	TM, ETM+	1	0.45–0.52	Blue	30	16	185
		2	0.52–0.60	Green			
		3	0.63–0.69	Red			
		4	0.76–0.90	NIR			
		5	1.55–1.75	MIR			
		6	10.40–12.50	TIR	120 Landsat5 60 Landsat7		
		7	2.08–2.35	MIR	30		
	ETM+	8	0.52–0.90	PAN	15		
Spot							
	VEGETATION	1	0.43–0.47	Blue	1000	1 a 2	2250
	HRV, HRVIR	1	0.50–0.59	Green	20-20	26, 26	60
	HRV,HRVIR,VEG	2	0.61–0.68	Red	20. 20.1000	26, 26, 1-2	60. 60. 2250
		3	0.79–0.89	NIR			
	HRV	PAN	0.51–0.73		10	26	60
	HRVIR	PAN	0.61–0.68	Red			
	HRVIR,VEG	4	1.58–1.75	MIR	20.1000	26, 1-2	60.2250
Cbers							
	CCD	1	0.45–0.52	Blue	20	26 (Nadir) 3 days (~32o)	120
		2	0.52–0.59	Green			
		3	0.63–0.69	Red			
		4	0.77–0.89	NIR			
		5	0.51–0.73	PAN			
	IR-MSS	1	0.50–1.10	PAN	80 e 160 (TIR)	26	120
		2	1.55–1.75	MIR			
		3	2.08–2.35	MIR			
		4	10.04–12.05	TIR			
	WFI	1	0.63–0.69	Red	260	3-5	900
		2	0.77–0.89	NIR			
Ikonos		1	0.45–0.52	Blue	4	1-3 (off nadir)	11(Nadir)
		2	0.52–0.61	Green			
		3	0.64–0.72	Red			
		4	0.77-0.88	NIR			
		5	0.45–0.90	PAN	1		

MIR = *Middle Infrared*; NIR = *Near Infrared*; PAN = panchromatic; TIR = *Thermal Infrared*; VNIR: *Visible Near Infrared*.
Lillesand & Kiefer [7].

frequency, while LANDSAT and SPOT have temporal resolutions of 16 and 26 days, respectively. When the study is done on a regional or continental scale, one normally uses images that cover larger areas. In this case, one can use NOAA or TERRA satellite images. The same area would require a larger number of LANDSAT images, involving an additional cost.

IKONOS and QUICKBIRD images, whose spatial resolution is better, can be interesting for the study of densely populated urban areas. In tropical areas with heavy cloud cover, radar images can be useful. In addition, active microwave sensors are particularly valuable for monitoring flooded areas.

In addition to the spatial and temporal resolution, one should be alert to the spectral range that best identifies the target. Flooded forests can be detected using the SAR-L band from JERS-1 radar [12]; for urban characteristics one can use the panchromatic band of SPOT or IKONOS [13]. Ecotones can be best identified using bands in the spectrum between 0.4 and 1.3μm, which includes visible and near-infrared, utilizing the LANDSAT, SPOT, or IKONOS satellite, depending on the desired detail [6].

Factors related to endemics, such as the effects of climatic variations on vegetation, urban growth, and deforestation, require temporal follow-up. A combination of sensors from different satellites, like a fusion of radar and optical images, can be used in complementary fashion [14].

Imaging processing techniques based on spectral responses can generate new information [8,9]. For example, using mixture modeling, one can create bands for the proportion of water, soil, and vegetation [15,16]. Operation of NDVI, *Normalized Difference Vegetation Index*, has also created a biomass information band that can indicate possible habitats of disease vectors and reservoirs. The operation, which transforms the spectral components represented in the RGB (Red, Green, Blue) color space into a system that furnishes information on intensity, hue, and saturation, can be useful for image fusion, thus allowing to use SPOT-PAN spatial resolution while keeping LANDSAT-TM spectral resolution [17].

TERRA, the Latin term for *"Land"*, a land observation satellite launched by NASA in 1999, has great potential for studying endemics. This satellite has various sensors, including MODIS (*Moderate Resolution Imaging Spectroradiometer*) and ASTER (*Advanced Spaceborne Thermal Emission and Reflection Radiometer*). The former has 36 spectral bands with 250, 500, and 1,000-meter resolutions and a 2-day temporal resolution. The latter has three 15-meter resolution bands in the 0.5-0.9μm region, six 30-meter resolution bands in the 1.6-2.5μm region, and five 90-meter bands in the 8-12μm region, with a 16-day temporal resolution These sensors are capable of monitoring land environmental factors in various resolutions [7,10].

In addition to the sensors already in operation, space agencies are expected to launch more than 80 missions by the year 2010, with instruments capable of measuring environmental change parameters with improved spectral, spatial, and temporal resolutions [6]. The literature related to RS application in the study of vector-borne diseases has grown, and new research perspectives are opening up with the emergence of sensors with improved resolutions.

Systematic review

The systematic literature review covered the period from 1996 to 2002, searching the following sources: MEDLINE (*Medical Literature, Analysis, and Retrieval System Online*), using "remote sensing" as the keyword; articles referred to in these publications when not indexed in MEDLINE; the Internet, especially the CDC website (*Centers for Disease Control and Prevention*) [18] and CHAART (*Center for Health Applications of Aerospace Related Technologies* – http://www.geo.arc.nasa.gov/sge/health); SciELO (*Scientific Electronic Library Online* – http://www.scielo.br); and the thesis/dissertation database of CAPES (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* – http://www.ged.capes.gov.br/agdw/silverstream/pages/frPesquisaTeses.html).

Table 2 provides a summary of the result of the systematic review, the reference for which was the pioneering work of Beck et al. [9]. Several contributions [19,20,21,22,23,24,25,26,27,28] were not included, since they were already reviews themselves.

Among the various sensors used, including in the Brazilian studies, there was a predominance of AVHRR (NOAA) and TM (LANDSAT), possibly because they are the oldest and with a broad historical series. There are still no studies applied to health using the high-resolution images from the QUICKBIRD or IKONOS satellites. As for radar images, no references were found, although they are mentioned in some articles as a potential resource for detecting floodable areas, possible habitats for mosquito larvae [25,28].

The review showed that most applications refer to the continental scale, with few on ur-

Table 2

Literature review.

Disease	Vector/reservoir	Location	Satellite/Sensor	Reference
Bartonellosis (Carrión disease)	*Lutzomyia verrucarum*	Caraz, Peru	LANDSAT (TM)	Masuoka et al. [45]
Cholera		Bangladesh	NOAA(AVHRR), TOPEX	Lobitz et al. [46]
Dracunculiasis	*Cyclops* spp.	Kwara, Nigeria/Africa	LANDSAT (TM)	Aheam & Rooy [47]
Ebola HF	Unknown	Sudan, Congo, Gabon/Africa	LANDSAT (TM) NOAA (AVHRR)	Tucker et al. [48]
EEE (Eastern equine enchephalitis)	*Culex salinarius, Culex melanura, Aedes canadensis, Aedes vexans*	Massachusett, USA	LANDSAT (TM)	Moncayo et al. [49]
Schistosomiasis	*Biomphalaria* spp.	Nile River Basin, Egypt	NOAA (AVHRR)	Malone et al. [50]
	Oncomelania spp.	Chuanxing, China		Gong et al. [51]
	Biomphalaria alexandrina	Kafr ElSheikh, Egypt	LANDSAT (TM) NOAA (AVHRR)	Abdel-Rahman et al. [52]*
	Biomphalaria spp.	Bahia, Brazil	NOAA (AVHRR)	Bavia et al. [32]
	Biomphalaria pfeifferi	Ethiopia/Africa	NOAA (AVHRR)	Malone et al. [53]
	Biomphalaria pfeifferi	Ethiopia/Africa	NOAA (AVHRR)	Kristensen et al. [54]
	Biomphalaria spp.	Tanzania/Africa	NOAA (AVHRR)	Brooker et al. [55]
	Oncomelania spp.	Yangtze River Basin, China	LANDSAT (TM) NOAA (AVHRR)	Zhou et al. [56]*
		Cameroon/Africa	NOAA (AVHRR)	Brooker et al. [57]**
		Africa	NOAA (AVHRR)	Brooker [58]**
Fascioliasis	*Lymnaea truncatula*	Highland between Lake Titicaca and La Paz, Bolivia	NOAA (AVHRR)	Fuentes et al. [59]
	Lymnaea truncatula	Ethiopia/Africa	NOAA (AVHRR)	Kristensen et al. [54]
Rift Valley Fever	*Culex, Aedes, mansonia*	Africa	NOAA (AVHRR)	Anyamba et al. [60]
Q Fever	*Direct transmission*	Cayenne, French Guiana	XS (SPOT)	Tran et al. [61]
Filariasis	*Culex pipiens*	Nile River Delta/Africa	NOAA (AVHRR)	Thompson et al. [62]
Hantavirus	*Peromyscus maniculatus*	Walker River Basin, Nevada, California/USA	LANDSAT (TM)	Boone et al. [63]
	Peromyscus maniculatus	Southwest USA	LANDSAT (TM)	Glass et al. [64]
	Peromyscus maniculatus	USA	LANDSAT (TM)	Khan & Young [65]*
Leishmaniasis	*Phlebotomus papatasi*	Saudi Arabia, Iran, Israel/Southeast Asia	NOAA (AVHRR)	Cross et al. [66]
	Lutzomyia spp.	Lagoinha, São Paulo, Brazil	LANDSAT (TM)	Miranda et al. [39]
	Lutzomyia spp.	Lagoinha, São Paulo, Brazil	LANDSAT (TM)	Miranda et al. [40]
	Phlebotomus orientalis	Sudan/Africa	NOAA (AVHRR)	Thompson et al. [33]
	Lutzomya longipalpis	Teresina, Piauí, Brazil	LANDSAT (TM)	Werneck & Maguire [31]
	Lutzomyia spp.	Itapira/São Paulo, Brazil	LANDSAT (TM)	Aparício & Dantas [67]

(continued)

Table 2 (continued)

Disease	Vector/reservoir	Location	Satellite/Sensor	Reference
Lyme disease	*Ixodes scapularis*	Chappaqua and Armonk, Westchester County, NY, USA	LANDSAT (TM)	Dister et al. [68]
	Ixodes scapularis	Wisconsin, USA	NOAA (AVHRR)	Kitron & Kazmierczak [69]
	Ixodes scapularis	Pennsylvania, New York, Wisconsin, Virginia, Northern California, Midwest USA	NOAA (AVHRR)	Estrada-Peña [70]
	Ixodes scapularis	Wisconsin, Illinois, Michigan, USA	LANDSAT (TM)	Guerra et al. [71]
	Ixodes scapularis	Northeast to Southeast USA	NOAA (AVHRR)	Estrada-Peña [72]
Malaria	*An. albimanus*	Central Belize	SPOT (XS)	Roberts et al. [73]
	An. albimanus	Chiapas, Mexico	Aerial photos	Rodriguez et al. [74]
	An.gambiae	Gambia/Africa	NOAA (AVHRR), METEOSAT	Thompson et al. [75]*
	Anopheles albimanus	Tapachula, Chiapas, Mexico	LANDSAT (TM)	Beck et al. [76]
	Anopheles spp.	Gambia	NOAA (AVHRR), METEOSAT	Thompson et al. [77]
	Anopheles spp.	USA, Mexico, Africa	LANDSAT (MSS), LANDSAT (TM) NOAA (AVHRR), METEOSAT	Hay et al. [78]*
	Anopheles spp.	Kilifi and Siaya, Kenya/Africa	NOAA (AVHRR), METEOSAT	Hay et al. [79]
	An. punctimaluca *An. vestitipennis*	Belize	SPOT (XS)	Rejmankova et al. [80]
	Anopheles spp.	Africa	NOAA (AVHRR), METEOSAT	Connor et al. [35]*
	An. gambiae	Gambia/Africa	NOAA (AVHRR)	Thompson et al. [81]
	An. subpictus	Lombok Island, Indonesia	JERS (optic)	Anno et al. [82]
	An. funestus	Ihosy and Ambalavao Districts, Madagascar/ Africa	LANDSAT (TM) SPOT (PAN)	Jeanne [83]
	Anopheles spp.	Africa	LANDSATMSS) LANDSAT (TM) SPOT, NOAA (AVHRR)	Hay et al. [84]
	An. gambiae	Gambia/Africa	SPOT (XS)	Thomas & Lindsay [85]
	Anopheles spp.	Kyunggi Province/Korea	LANDSAT (TM)	Claborn et al. [86]
	Anopheles spp.	Tanzania, Uganda, and Kenya/Africa	NOAA (AVHRR)	Omumbo et al.
	Anopheles spp.	Africa		Rogers et al. [88]*
RRV (Ross River Virus)	*Culex annulirostris*	Brisbane, Australia	Colored aerial photos	Dale & Morris [89]
Trypanosomiasis	*Glossina* spp.	Kenya/Africa	LANDSAT (TM)	Kitron et al. [69]
	Glossina spp.	Côte d'Ivoire and Burkina Faso/Africa	NOAA (AVHRR)	Rogers et al. [90]
	Glossina spp.	Southern Africa	NOAA (AVHRR)	Robinson et al. [91]
	Glossina spp.	Southern Africa	NOAA (AVHRR)	Robinson et al. [92]
	Glossina tachinoides	Togo/Africa	NOAA (AVHRR) METEOSAT	Hendrickx et al. [93]
	Glossina spp.	Africa	NOAA (AVHRR)	Rogers [94]
	Glossina spp.	Bukina Faso/Africa	LANDSAT (TM) SPOT	De La Rocque et al. [95]

TOPEX: http://topex-www.jpl.nasa.gov/science/science.html
METEOSAT: http://satelite.cptec.inpe.br/
* Review articles.
** Journal articles related to RS that do not specify the vector.

ban areas. Most information obtained by satellite is correlated to vegetation, utilizing NDVI, an index obtained from operations with spectral bands. For example, in the case of NOAA, utilizing bands 1 and 2 from the AVHRR sensor, one can highlight the vegetation through the following operations: band2/band1 or (band2-band1)/band2+band1. These operations can also be used based on LANDSAT, with the same objective, using bands TM4 and TM3. The enhancement of vegetation using these operations is due to the high spectral response of vegetation as compared to the soil in band 4 of the TM sensor and band 2 of AVHRR [29,30].

The methodologies correlating this measurement with target epidemiological indicators varied considerably in the studies. Werneck & Maguire [31] use NDVI as the independent variable in a mixture modeling in order to explain the incidence rate for visceral leishmaniasis in census tracts in the city of Teresina, Piauí. In the State of Bahia, Bávia et al. [32] use a multiple regression model in which NDVI is one of the explanatory variables. Thompson et al. [33] utilize NDVI as the dependent variable in a logistic regression to study the probability of occurrence of the vector *Plebotomus orientalis* in various locations in Sudan, Africa. Kitron & Kazmierczak [34] use the spatial autocorrelation measurement Moran's I to identify the degree of spatial grouping of cases of Lyme disease, ticks, and vegetation (NDVI) in Wisconsin, USA.

Considering the number of references (Table 2), malaria has been the most extensively studied endemic in this environmental context, utilizing a variety of high and low-resolution sensors. Risk of malaria infection, its spread, and seasonality are determined by the combination of human exposure, high vector density, the time the parasite takes to develop in the mosquito, vector survival rate, parameters influenced by meteorological variables such as temperature, precipitation, and relative humidity, deforestation, and bodies of water, which can be mapped by RS directly or using measures such as the vegetation index, surface temperature, and cloud temperature [35]. Despite this relevance of this endemic in Brazil, only three studies were located on RS and malaria [36,37,38].

Of the six articles found on leishmaniasis (Table 2), five apply to Brazilian regions. Three of these article refer to tegumentary leishmaniasis (TL) in Southeast Brazil [39,40,41] and the others to visceral leishmaniasis (VL) in the Northeast. Of the latter, one deals with climatic and demographic determinants of VL in the town of Canindé, Ceará [42]; another is an ecological study of VL in the city of Teresina, Piauí [31]. The CAPES thesis/dissertation database included three dissertations utilizing LANDSAT images to study tegumentary leishmaniasis [41,43,44].

Schistosomiasis is an important endemic in various tropical and subtropical countries and has been extensively studied, with a predominant utilization of the AVHRR sensor (Table 2). The number of references to schistosomiasis is due mainly to a special issue of *Acta Tropica*, dedicated to the study of the disease with a focus on the use of RS and GIS techniques. One of the articles presents an application in the State of Bahia [32] in which the authors used products derived from the AVHRR sensor, vegetation index, and diurnal temperature difference, to verify the relationship between the environment and density of schistosomiasis distribution. The authors go on to utilize these factors in a forecasting model to calculate the environmental risk of the disease in the municipalities in the State of Bahia. The authors used the SPRING-GIS software to develop and analyze maps for NDVI and dT (diurnal temperature difference).

Environment and endemics – challenges

Table 3, based on the description of possible ecological, socio-environmental, and soil-use characteristics related to the occurrence of endemics in Brazil, attempts to systematize the potential use of RS, discussing the variety of favorable environments. This table should be read as a challenge for researchers, raising hypotheses that orient this type of work, without the aim of exhausting the subject. In some cases the table categorizes the epidemiological pattern for the occurrence of the endemic in sub-groups in order to facilitate the characterization of environmental aspects detectable by RS. In all the references to specific sensors, the most accessible and lowest-cost sensor was prioritized, although it is possible to use finer resolutions. Each object of study has its specificities, and due to the diversity of factors involved, it is often necessary to use various sensors with different resolutions. In addition, complementary data from other sources included in a Geographic Information System may be necessary. Therefore, the objective is not to limit the applications to specific sensors, but to convey the idea of plurality, possibilities, and also limitations. The principal aspects of some of these endemics are listed below.

In mapping Chagas disease transmission areas, the land occupation pattern can be identified by using images with a resolution of up

Table 3

Principal transmissible diseases and some forms of occurrence in Brazil with associated environmental factors that can be tracked by remote sensing.

Disease (Parasite)	Vectors and Reservoirs	Region of Brazil	Pattern	Risk areas	What to map in the risk areas. RS factors.
Chagas disease (*Trypanosoma cruzi*)	Insects (triatomines or kissing bugs), of genera *Triatoma* and *Panstrongilus* Wild marsupials and rodents	North and Northeast	Domiciliary	Small towns and rural settlements with precarious housing.	Clusters of precarious housing at a short distance from the natural vegetation.
			Peridomiciliary	Traditional farming areas in the semi-arid region	Dry regions with, rocky outcroppings and domestic animal shelters in a semi-extensive regimen
Schistosomiasis (*Schistosoma mansoni*)	Snails of the *Biomphalaria* gender	Northeast and Southeast	Peri-urban	Small or medium-sized towns located in agricultural areas, permanent bodies of water used in domestic and recreational activities and contaminated with human feces	Bodies of water on urban peripheries and agricultural areas without sanitation. Urban expansion in agricultural regions. Permanent bodies of water with natural vegetation
Yellow fever (arbovirus of the *Flavivirus* gender)	Dípterans of the *Haemagogus* gender. Various species of monkeys, principally of the *Alouata* gender	Amazon Region and States of Goiás, Minas Gerais, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul	Sylvatic	Equatorial and tropical forests larges enough to maintain populations of monkeys; riparian forests, ecological integration corridors	Areas of deforestation and paths/ roads penetrating the forests. Markers of anthropic pressure in areas with forest cover. Riparian forests in settings with ecological tension. Housing settlements near forests, with large spots of vegetation
Hantavirus (various viruses from the *Buyanviridae* family)	Wild rodents of the genera *Akodon*, *Bolomys* and *Oligoryzomys*	Southeast, South, and Central-West	Rural	Rural areas with crops that produce large amounts of seeds, allowing the expansion of a population of wild rats	Agricultural areas with extensive grain crops, like soybeans, wheat, and corn. Proximity between households and crop areas. Stages of seed formation in the different crop cycles
Leptospirosis (bacteria of the *Leptospira* gender)	Rodents	Metropolises in the Northeast and Southeast	Urban	Urban areas with precarious sanitation, high density of human inhabitants and rodents, subject to occasional floods.	Precarious urban areas located in regions with little slope. Proximity of the urban areas to creeks and garbage dumps. Flooded areas in urban centers.
		Rice paddies in the State of Rio Grande do Sul	Rural	Grain crops in flooded areas	Flooded terrain in rice plantations

to 30 meters, allowing the identification of neighborhoods and estimated distances to breeding sites. In the case of schistosomiasis, mapping bodies of water in the middle of natural vegetation is of fundamental importance. Various sensors, including microwave sensors, can contribute to the study and choice of the sensor and should prioritize the size of these bodies of water. Imaging in this case helps detect risk areas and can support control measures by estimating the size of surfaces for use of molluscicide.

Sylvatic yellow fever is of great importance due to its high case fatality rate. One of the fundamental questions in this case is the risk of reaching populations in areas lacking vaccine coverage, which depends on the occurrence of monkey epizootics in these regions. Images can help detect forest corridors through which populations of infected monkeys can migrate. In this case, the images furnished by LANDSAT, SPOT, CBERS-CCD, and TERRA-ASTER sensors can be useful by identifying fragments of forests.

Leptospirosis occurs in Brazil with two distinct profiles: urban, related to areas with a high density of rats, with outbreaks following floods, and rural. The most susceptible locations are thus areas that concentrate water and mud. Although civil defense in cities has usually defined the potentially floodable areas, the definition is relatively gross. Images can help identify flooded areas and, together with slope information, more precisely map the risk areas. In this case the disease's seasonality also calls for periodic imaging. Radar images, although useful in slope identification and when there is cloud coverage, would contribute little to more detailed mapping of urban areas due to interference by the signal reflection on various other surfaces (European Space Agency – http://www.envisat.esa.int/dataproducts/asar). In this type of application, the images should display high spatial and temporal resolution and be available soon after the rain, in order to allow mapping of the wet flooded areas. Ideally, these images would be available as soon as they are acquired, like those used for weather forecasting, but this is not the case at present.

Visceral leishmaniasis was formerly transmitted mainly in forest areas or concentrated in small rural settlements, with the fox as the main reservoir. More recently VL has occurred in medium-sized Brazilian cities with low plant cover and the dog as the main reservoir, with the disease related to the organization and expansion of urban space [31]. LANDSAT, SPOT, and IKONOS sensors can be used to detect areas of vegetation, the limits between forests and urban areas, areas of vegetation within cities, the proximity between forests and residences, and the housing quality and pattern.

Two patterns of malaria occur in Brazil, and one can use images to detect deforested areas, bodies of water, expansion of the urban grid, areas of vegetation, and other characteristics that can point to possible resting and breeding sites for the mosquito vector. Radar images show promise for studying this endemic, complementing information in areas where the responses to optic sensors have limitations.

Tegumentary leishmaniasis, due to the complexity of its cycle, was not included in Table 3. This disease has occurred endemically and epidemically with different transmission patterns, which can be related to: human penetration of sylvatic foci, whether by the expansion of agricultural frontiers or other activities like ecotourism; the rural mosaic, with the interspersing of agricultural areas with secondary forests and scrub growth; areas of urban expansion with housing projects on the limits between the city and the forest or environmental preservation areas, with the adaptation of vectors, reservoirs, and parasites to modified environments. Various factors related to the scenarios described above can be detected by images: deforested areas, by the contrast between the vegetation and the soil; new rural settlements, using the irregular texture in the deforested areas; and the opening of roads, using the information on the contrast between the vegetation and the soil and the elongated and narrow shape. In the rural pattern, the risk areas are those involving agricultural use, which are normally identified with images due to their regular shape and their interspersing with secondary forests and scrub growth, giving the appearance of a mosaic. The areas occupied by the population can be identified by the irregular pattern in the geometric shapes of the dwellings. The paths used by people to circulate, when not identified, can be inferred by the distance between rural clusters in the agricultural areas. The urban pattern is observed when, due to population growth, new housing projects are built on the limits between the city and the forest, as in Manaus, or when transmission foci are located on the limits between urbanized and environmental preservation areas, as in Rio de Janeiro. Among many factors, images acquired on different dates can identify areas of urban growth, variation in plant cover, land use, and environmental preservation areas in urban spaces. Images provided by the TM sensor in the LANDSAT satellite can provide a good option for identifying these patterns, and SPOT can be used when finer resolution is necessary.

Other endemics can also be explored, like onchocerciasis, filariasis, and dengue. The latter, in which intradomiciliary transmission is decisive in maintaining what until recently was a scarcely "visible" endemic for remote sensors, has some environmental aspects which contribute substantially to reproduction of the vector (*Aedes aegypti*). Open-air storage of used tires, large open water tanks, and abandoned swimming pools account for the extensive proliferation of these insects after rain and can be located using high-resolution sensors.

Final remarks

An environmental context predisposing to the occurrence of various endemics can be captured by the spatial, temporal, and spectral resolutions of RS satellite onboard sensors. Remote sensing, combined with other technologies like GPS (*Global Positioning System*), capable of spatially locating the event, and GIS (*Geographic Information System*), add qualified information for the identification of vulnerable ecosystems, at a relatively low cost, thus providing an important ancillary (and previously little-explored) tool for studying certain endemics and supporting surveillance and control activities.

The use of statistical and computational methods and techniques, in addition to digital processing of satellite images, expands the prospects for research on the spatial distribution of diseases and the possibility of creating risk maps based on multivariate and hierarchical models. In addition, the role of this technology remains to be explored for supporting the implementation of endemic surveillance activities. Substantial improvements can be made in estimates of vector control inputs, based on calculations of the extension of settled areas; optimization of routes for visits by health agents; and identification of potential new foci, whether by expansion of urban areas or opening of trails in the forest.

Despite the opportunities this technology offers for studying endemics, its utilization is still limited by the cost and lack of knowledge of its potential. However, some images, like those from the NOAA and TERRA satellites, can be acquired free of cost (http://daac.gsfc.nasa.gov). The CBERS 2 images are also available, free of charge, at http://www.dpi.inpe.br/catalogo, having their use restricted by the license one can find at the same address. The LANDSAT, SPOT, IKONOS images and others can be ordered for any region of Brazil via internet (INPE – http://www.dgi.inpe.br, GISPLAN – http://www.gisplan.com.br, ENGESAT – http://www.engesat.com.br). Some of these images, for example LANDSAT, have quite affordable prices. Although commercial software programs for data processing currently available on the market are still expensive, there is a viable public-domain alternative, SPRING–GIS, which integrates image processing functions and statistical modeling algorithms for environmental data. The greatest limitation in our opinion is technical training in the health field, allowing for the gradual incorporation of this technology.

Resumo

O objetivo deste trabalho é, a partir de revisão bibliográfica sistemática, apresentar as características e potencialidades do remote sensing como ferramenta de vigilância ambiental útil para pesquisas aplicadas ao estudo e controle de endemias brasileiras. Os sensores a bordo dos satélites permitem monitorar o território fornecendo informação espacial e temporal em várias escalas e regiões do espectro eletromagnético. Baseado na revisão bibliográfica sobre a aplicação dessa tecnologia no estudo de endemias, e na identificação do potencial dos novos sensores, com melhores resoluções espectrais, espaciais e temporais, este trabalho aponta perspectivas para o uso do Sensoriamento Remoto no estudo de endemias importantes para o Brasil.

Doenças Transmissíveis; Vigilância Epidemiológica; Literatura de Revisão

Contributors

All the authors contributed to the concept, methodological development, discussion, and elaboration of the article.

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