REMOTE SENSING AND GIS TO ANALIZE THE VULNERABILITY TO MALARIA IN FACE OF DEFORESTATION PROCESSES HELD IN THE URBAN-FRINGE OF HUMAN SETTLEMENTS IN THE AMAZON FOREST

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Abstract

The causes explaining the spread of malaria in the world include climatic changes, healthy service breakdown and migration. Due to the threat of this endemic disease in the Amazon region, this research aims at understanding the relationship between land use and land cover change process, induced by the construction of the Hydro-Electric Power Station of Tucuruí, and the spatial distribution of malaria incidence in the region. LANDSAT5 and RADARSAT images were used respectively for land use mapping and for monitoring the seasonal variation of UHE Tucuruí reservoir flooded area. A historic series of malaria data was also used. It was determined that Novo Repartimento and Tucuruí with large areas bounded by the reservoir are more prone to malaria incidence and that the time change of the disease in this region is related to the hydrology and reservoir operation, as well as with the precipitation and population dynamic.

Key words: Vulnerability to Malaria, Remote sensing, Amazon, Deforestation.

I. Introduction

As of 1960, the Amazon region has been subjected to environmental impacts, related to the implementation of momentous government projects (agricultural, hydroelectric, and mining) conceived to its economical integration and development. These interventions caused an intense migratory flow into the region and large-scale deforestation processes. In the period between 1970 and 1980 the urban population of Amazon increased from 37.7% to 51.8% of the total[1].

At the same time that this population was encouraged to migrate, the government did not provide the infra-structure to cope with the immigrant needs. As a consequence a series of problems came up such as land ownership conflicts, chaotic city growth as well as disease spread.

Wandering crowds following job opportunities within and outside Amazon caused malaria to spread all over the region. For example, many infected persons moved from mining areas of north of Mato Grosso state to Pará searching for land as gold production decreased. The 1980 census showed that in the 70's, Pará state received more than 48% of the country migrant population that moved to the north region, which was equivalent to 440 thousand persons. The majority of the Para migrant population was from Brazil northeast region, mainly from Maranhão state. That population was attracted to Itaituba mining area, to construction jobs at Tucuruí dam and to agricultural projects. When the building of Tucuruí hydroelectric finished, some people returned to their homeland causing an increase in malaria incidence in Piauí and Maranhão states[2].

According to the authors these migratory fluxes make it difficulty to control malaria in the Amazon. The large number of malaria victims and its spreading rate prevent infected persons to receive adequate treatment. Moreover, the majority of migrants live in risk areas with poor infra-structure, remaining therefore exposed to disease vectors.

Another reason that makes malaria situation worse in Amazon is the large number of people susceptible to infection, due to nonexistent acquired resistance against the disease, since they come from areas where malaria has not existed for many years[3].

As malaria is a complex disease related to the interaction among parasites, vectors, human hosts and environment, it is fundamental to study these factors together to try to control it. The combination between human factors and relevant environmental information to the malaria biology might indicate a predominant epidemiologic situation, making the action of health services easier[4]. Thus, remote sensing and GIS techniques can help epidemiologists to identify vector focuses. These technologies, allow them to relate disease occurrence indexes and environmental characteristics, enabling the exact observation of geographic area and the determination of how some physical factors (rivers, mountains, vegetation) can influence the spreading or controlling of the disease[5]. Besides that, the use of these techniques can improve the ground data acquisition and information accuracy[6].

The proliferation of Anopheles mosquito differs in space and time. This variability is influenced by environmental conditions, such as the deforestation, which is ultimately a land use and land cover change (LUCC) process, detectable by orbital sensors systems[7].

However, cloud cover frequently makes remote sensing application for the Amazon monitoring difficult. Orbital data acquired from optical sensors, such as Landsat TM are limited to dry season. This problem can be overcome using microwave systems since this spectral region is not affected by meteorological conditions[8].
The use of radar images is important for monitoring the aquatic macrophyte cover in the Tucuruí reservoir, mainly in the wet season when there is not enough optical remote sensing images available due to large cloud cover.

Taking into consideration that the risk of acquiring malaria is related to environmental alterations caused by human activities, this paper aims at understanding: (i) the relation between patterns of malaria spatial distribution in Tucuruí hydroelectric region and patterns of land use induced by its implantation; (ii) the relation between seasonal variations of malaria spatial distribution and Tucuruí reservoir operation.

II. Materials and Methods

II.A. Study Site

The study area covers the Tucuruí reservoir region. The reservoir was formed by the construction of a dam across the Tocantins River, in Pará State, Brazil (Figure 1). It is located in an area of dense tropical forest and measures around 2800 km^2 (at 72 m height) yielding a total perimeter around 3700 km. The purpose of the reservoir is to generate hydropower. The study area includes three municipalities: Jacundá, Tucuruí and Novo Repartimento.

According to IBGE (2004)[9] data, the main activities in Jacundá municipality is cattle raising, with a herd of 50,000 animals and agriculture with temporary farming such as rice (3,000 hectares); corn (1,600 hectares); manioc (1,500 hectares); beans (40 hectares) and permanent cultures such as banana, orange, black pepper and others. The wood extraction is carried out in areas more and more distant from sawmills (near Jacundá city), because almost the entire forest of this municipality has been cleared since the reservoir installation.

Tucuruí municipality has a cattle herd of 36,300 and its main cultures are rice (3,000 hectares); corn (1,700 hectares); manioc (320 hectares); beans (200 hectares) and permanent cultures such as black pepper, orange, banana, coconut and urucum.

Novo Repartimento municipality has the largest cattle herd with 120,870 animals. This municipality has the greatest diversity of crops too, though they are not very meaningful. There is cacao, Indian tea, coffee, passion fruit, banana, orange and black pepper. As for temporary cultures, this municipality is the largest rice producer in relation to other municipalities with 10,000 hectares of farmed areas, producing 15,000 tons by harvest. There is also corn (5,000 hectares); beans (500 hectares) and manioc (100 hectares).

II.A.2. Optical and Radar Satellite Images Analysis

Information from Landsat/TM, during the dry season and RADARSAT/SAR (on April, Mai, August and December) images in digital format was used to produce land cover maps for 1996 and 2001 and to identify different classes inside the reservoir respectively. Both data set were geometrically corrected and co-registered[10]. The years 1996 and 2001 were chosen in this study because of the availability of malaria occurrence data (Health Agency of Pará State) in this period.

The interaction among green vegetation, bare soil and water, through time or across space is a key aspect to the ecological understanding and to the disease patterns using remote sensing[11]. But one of the problems that may arise when mapping land cover is a poor image classification due to mixed pixels. The pixels of remotely-sensed images normally contain a mixture of different cover type responses. This is aggravated with low spatial resolution.

Mixed pixels also occur when the scale of land cover variability is less than the size of the pixel considered[12]. The linear spectral mixing model[13] is one of the approaches proposed to solve the problem of mixed pixels. The relative proportion of the land cover, called component inside the pixels is estimated and new bands are created. In this work, the linear spectral mixing model was applied using bands 3, 4 and 5 of the Landsat/TM images. New bands – called fraction-images - representing the three main components of the images – vegetation, soil and shadow – were created. Advantages of using fraction-images instead of the original Landsat/TM bands include the enhanced discrimination between certain land covers, such as deforested areas and mature forest in the soil and shadow fraction-images. The vegetation, soil and shadow image-fractions were segmented and classified[14] by the methods described as follows.

First land cover classes relevant to the study were defined: (i) forest, (ii) regenerating forest, (iii) forest with selective logging (herein called selective logging), (iv) urban area, (v) agriculture/grazing activities, (vi) flooded area, (vii) water. The occurrence of these classes had either a direct or indirect relationship with the incidence of malaria in the study area. Then, training and test samples derived aerial photographs and ground data for each land use class were selected to feed a supervised classification based on the Battacharya distance algorithm[12].

The RADARSAT/SAR images were used to map the classes inside the reservoir in the dry and wet seasons. Frost filter was applied for speckle removal[15]. A multisensor composite (C band SAR and TM bands 3, 4, and 5) was used to enhance class discrimination within the reservoir. To prevent confusion among classes, a mask was generated to limit the segmentation and classification to the reservoir area. The classes mapped in this phase were: (i) open water, (ii) macrophyte stands, (iii) paliteiros (above-water dead trees) and (iv) islands.

The SAR/TM composites were also segmented and classified according to the classes above. Manual editing was carried out to reduce classification error for dry and wet season maps.

II.A.3. Field Surveys

The field work was performed in July 2001 in Tucuruí and Novo Repartimento municipalities and in July 2003 in Jacundá. These field works were designed to obtain geographical coordinates for each of reported malaria cases. According to the Health Agency list, these points were only specified by name or category (farm, village or city) and by municipality. To be integrated into a Geographical Data Base, the precise location was necessary. For that, a series of meetings with local health agents were carried out to optimize field visits. During the field work, an application form was filled at each site to gather relevant information on family health history. Each application form was then tied to a GPS coordinate.

II.A.4. Population Distribution and Vulnerability to Malaria

Population distribution maps for the study area were produced using the MAP algebra method[16]. This method allows that selected parameters derived from ground observation and remotely-sensed data, such as (i) distance from agricultural settlements, (ii) distance from roads and crossroads, (iii) distance from rivers and from Tucuruí reservoir and (iv) distance from urban areas. For each one of these parameters a distance grid was created. The grid was divided in probability levels (very-high, high, medium, low and very-low) of finding people living in the area, according to the distances from each parameter. Then, weights were attributed to the probability classes, so as all classes at a given probability and parameters have same weight. The resulting map was a weighed average of these grids.

The malaria risk map followed the same approach, using the following parameters as input: (i) population distribution maps, (ii) distance from rivers, (iii) distance from roads and crossroads, (iv) distance from the reservoir (v) distance from urban area, (vi) distance from macrophyte areas and (vii) land use. Twenty four malaria risk maps were produced for Jacundá, Tucuruí and Novo Repartimento, for April, May, August and December, in 1996 and 2001.

III. Results and Discussion

As shown in the 1996 and 2001 land use maps (Figure 2), Jacundá and Novo Repartimento municipalities underwent large deforestation. In a 5 year period, the loss of native vegetation increased around 100%.

Since the beginning of the 80's, when the Tucuruí dam started to be constructed, a heavy population increase occurred in this region. According to IBGE population data, in 1970, Tucuruí and Jacundá had 9,930 and 2,225 people respectively and, in 1989 these numbers went up to 61,140 and 14,868. The population of these municipalities increased six times in ten years. From this time on, forest areas lost space to settlements; roads; agricultural projects; reservoir water and logging activities. One of the consequences of this loss was the explosion of malaria cases in this period. The disease levels were low until the end of the 70's, but in 1982 malaria cases reached 7,000 in Tucuruí and 6,000 in Jacundá.. In Tucuruí, soon after 1975, the number of cases started to increase since this town was the headquarters of the hydroelectric company. Tucuruí at time draw a huge migrant population, which is the most susceptible to malaria.

The highest level of malaria occurred in Tucuruí in 1984 when the reservoir filling up started. The lake formation was the main reason for the increase of malaria cases, since stagnant lake waters are prone for the breeding of mosquitoes On top of that Tucuruí reservoir experienced a major macrophyte infestation related to the water eutrophication. The settlements near Tucuruí reservoir banks were also important to increase malaria incidence, because of the proximity to several Anopheles habitats.

The malaria cases continued very high in 2001 and 2002 in the three municipalities. In Novo Repartimento the number of cases reached more than 4,000 in January 2002. The main reason for this was the upgrade of the hydropower plant which caused a new wave of migration to the region.

Monthly average of malaria data from 1993 to 2002 showed the highest mean malaria occurrence for the dry season (June to September). Several factors can explain that. In those months reservoir water level reaches its highest level which is kept stable so as macrophyte stands spread over large areas near the banks. As macrophytes are keen habitats for malaria mosquitoes, in this period the amount of malaria vectors increase. Moreover in this reservoir banks remain stable what is also favorable to the expansion of breeding habitats for malaria vectors.

Those aquatic plants, however, almost vanish in December, when reservoir level drops and large areas of the bottom are exposed and burned killing large amounts of mosquitoes. Another important reason that could contribute to an increase of human vulnerability to malaria in dry seasons is the population mobility. That is harvest the period for the main crops in the region (rice, corn and beans) as well was winter school vacation, which increases the floating population in the rural area, mainly children.

A buffer of 1500 meters was defined around each site registering malaria incidence from 1996 to 2001. This buffer was defined taking into account the flying range of Anopheles mosquitoes[17].

In Jacundá, for 1996 and 2001, approximately 60% of those sites are in high risk zone or under their influence and the 40% of them in medium risk zone. The high risk class decreased from 83.75 Km^2 in April to 80.1 Km^2 in December, related to a decrease in macrophytes stands, but confined to the reservoir banks.

The malaria risk maps showed that high risk zone increased from 83.75 Km^2 in April 1996 to 161 Km^2 in April 2001, related to new roads, deforestation and urban expansion, arousing many health problems in rural urban fringe population. The difference between 1996 and 2001 in relation to malaria sites is that its increased in high risk areas. For Tucuruí municipality out of 22 points collected in the field, 21 were in high risk area. One of these points that occurs very near Tucuruí reservoir and that presents many cases of malaria had not been notified by Pará Health Agency as a high risk area, but the mapping was able to detect it, which was later confirmed on the ground.

The maps for Novo Repartimento municipality were consistent with ground data too. For this municipality 65 samples were collected. Analyzing these maps it was observed that in 1996, 3.7% of the sites were in high risk areas or at least 1.500 meters from them. In medium risk areas there were 49.2% of sites and 12.3% in low risk or very low risk areas The percentage of 12.3% in low risk and very low risk areas, occurs because the field work was done in 2001 and, in the period between 1996 and 2001, new areas were deforested to open new roads and settlements. For 2001, it was observed that many sites that were in low risk areas before moved to medium and high risk zones. So, 55.4% of the sites moved to high risk zones, 26% to medium risk and only 4.6% to low risk zones. The maps of malaria risk for Jacundá and Tucuruí in April 2001 are shown in Figure 3.

IV. Conclusions

The malaria distribution in this region is related to patterns of land use, induced by the Tucuruí dam implementation. High deforestation indexes, new roads and people migration were responsible for malaria increase. The temporal variation of this disease in the studied region is related to the reservoir operation, as well as to precipitation and population dynamic. Satellite images and GIS enable to create malaria risk maps. These maps indicated that in the places near the dam and where macrophyte banks are present, the risk is higher. During the months of April to August, when considerable changes in water level have not occurred yet, there are no important modifications on risk maps. However in December there is a reduction of these risk areas due to macrophyte decrease. Another important observed factor was that points close to the reservoir area, presented the highest API (Annual Parasitary Index) values.

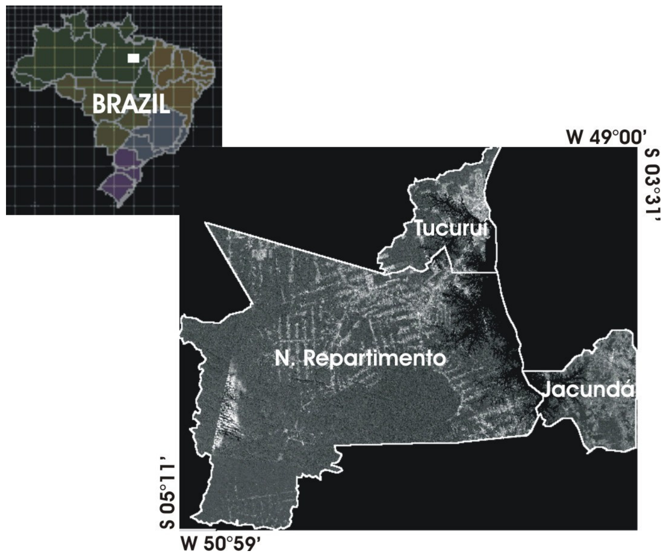

Figure 1- Study area location in Pará State, Brazil

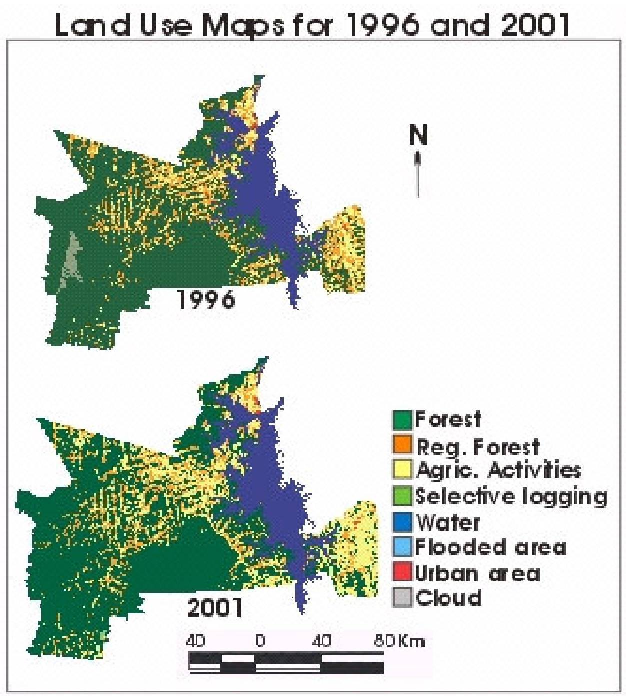

Figure 2- Maps of land use for the study area in 1996 and 2001.

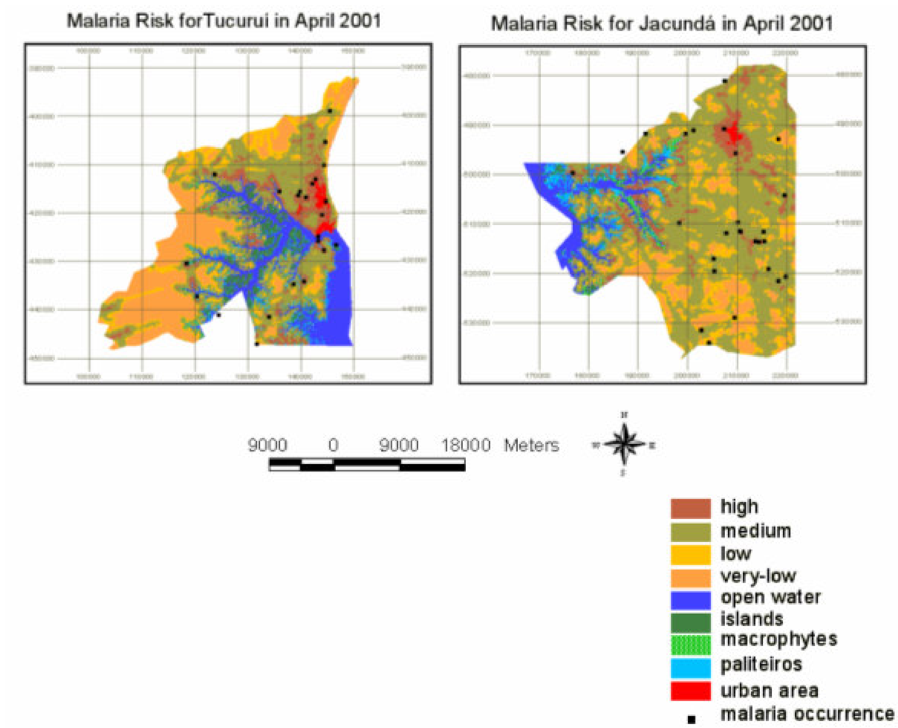

Figure 3- Maps of malaria risk for Tucuruí and Jacundá in April 2001.

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