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Geostatistics Applied to the Study of Deforestation and Malaria in Rural Areas of Western Amazon

Carlos Alberto Paraguassú-Chaves[1], Carla Dolezel Trindade[2], Simão Aznar Filho[3], Fabrício Moraes de Almeida[4], Simão Dolezel Aznar[5], Carlos Alberto Dolezel Trindade[6], Levi Pereira Granja de Souza[7], Ricardo Guanabara[8], and Lenita Rodrigues Moreira Dantas[9]

[1]PhD in Health Sciences - University of Brasília - UnB, Brazil; PhD in Science - University of Havana (Cuba); Post-Doctor in Health Sciences - UnB and Degli Studi D'Aquila University - IT. Full Professor at the University Institute of Rio de Janeiro - IURJ, Brazil.
[2]PhD in Law - Universidad Nacional de Lomas de Zamora (Argentina). Post-doctorate - Universita deli Studi di Messina (Italy). Full Professor at the University Institute of Rio de Janeiro - IURJ, Brazil
[3]PhD in Law - Universidad Nacional de Lomas de Zamora (Argentina). Post-doctorate - Universita deli Studi di Messina (Italy). Full Professor at the University Institute of Rio de Janeiro - IURJ, Brazil
[4]PhD in Physics (UFC), with post-doctorate in Scientific Regional Development (DCR/CNPq). Researcher of the Doctoral and Master Program in Regional Development and Environment (PGDRA/UNIR). Leader of line 2 - Technological and Systemic Development, and Researcher of GEITEC — Federal University of Rondonia, Brazil.
[5]Graduated in Law. Master of Law Student, Specialist in Law. Professor at the University Institute of Rio de Janeiro, Brazil
[6]Graduated in Law and Psychology. Specialist in Higher Education Teaching. Professor at the University Institute of Rio de Janeiro, Brazil
[7]Master's Degree in Administration from Estácio de Sá University, Brazil. Professor at the University Institute of Rio de Janeiro, Brazil. Professor at the University Institute of Rio de Janeiro, Brazil
[8]PhD in Political Science from IUPERJ, Brazil. Professor at the University Institute of Rio de Janeiro, Brazil.
[9]Bacharel and Specialist in Geography. graduated in law. Researcher at the Higher Institute of Health Sciences and Environment of the Amazon - AICSA.

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***Keywords*— Geostatistics, semivariogram and kriging, deforestation, malaria, Western Amazon.**

***Abstract*— *Objective: To analyze the behavior of the spatial dispersion of deforestation and the number of malaria cases, in addition to providing integration of deforestation risk with epidemiological risk of malaria in Gleba União Bandeirantes, current União Bandeirantes District, in Porto Velho, Rondônia, Western Amazon, for a period of 3 years. Method: Two fundamental tools of statistical indicators were used: the semivariogram and the kriging. The semivariogram method is the mathematical modeling that allows studying the natural dispersion of the variable, and the Kriging method, used to analyze the spatial variability of the existing indicators in the area. Results: The indicative method of kriging showed that the occurrence of malaria cases is related to the growth of deforestation. With the advance of deforestation towards the north of the studied area, cases of malaria increased in the same direction. There was an increase in malaria cases east of the population concentration, converging with the area of advance of deforestation. Conclusion: The methods used are efficient to correlate and monitor deforestation and the social production of malaria. Public managers must develop means to implement a deforestation control strategy integrated with the malaria endemic in the União Bandeirantes District area.*

I. INTRODUCTION

Currently, there is much talk about human activities that cause pollution and environmental degradation in urban and rural areas, especially when these activities become a threat to health. In the Amazon, felling and burning is common, causing an increase in the incidence of diseases, especially malaria, putting the development of the region at risk. In view of the occurrence of deforestation and the proliferation of malaria, we sought to study the risk factors and perspectives for controlling malaria and deforestation in the current District of União Bandeirantes, belonging to the Municipality of Porto Velho, Rondônia, Brazil.

To obtain an understanding of the risk factors or protection against malaria, the implementation of alternative public health and environmental policies constitutes a powerful tool. Therefore, studies in different populations and geographic regions contribute to knowledge about malaria that do not necessarily apply to populations located in other areas of the world, subjected to plasmodium species with different genetic characteristics and different transmission conditions.

Studies show that infectious diseases are prominent in human history as they constitute major public health problems. Malaria, cholera, typhoid fever, leprosy, plague, among others, had a large incidence throughout the world throughout the last century. The improvement in the quality of life in the countries of the northern hemisphere, as well as the effects of the Industrial Revolution and, in particular, the phenomena of urbanization and technological acceleration, restricted these diseases to the "poor areas" of the world, including the tropical zones.

In Brazil, an epidemiological picture is currently characterized by the coexistence of endemic diseases and the return of old infectious diseases [1]. Malaria, leishmaniasis, leprosy, tuberculosis, among others, also represented major health problems, particularly in the Amazon Region.

For Tauil [2], factors that favor the transmission of malaria and hinder the application of traditional control measures were associated in the Amazon Basin Region. Among the first are: a) biological factors, such as the presence of high densities of vector mosquitoes, a migrant population without naturally acquired immunity against the disease and the prevalence of Plasmodium strains resistant to antimalarial drugs for safe use in the field; b) geographical ones, such as the prevailing low altitude, high temperatures, high relative humidity, high rainfall and forest-type vegetation cover, favorable to the proliferation of vectors; c) ecological, such as deforestation, keeping animals that mosquitoes feed on as an alternative to feeding human beings; such as the construction of hydroelectric plants and irrigation systems, increasing the number of mosquito breeding sites and d) social ones, such as the presence of numerous population groups living in houses with complete or partial absence of side walls and working near or inside forests, providing a very intense contact with the vector mosquito. And this association happens environmental changes as well as malaria transmission mainly in settlement populations, due to changes and alterations in the environment termed as the term border malaria. Alguns estudos corroboram com esse quadro, entre eles os estudos de Barata [3]; Bitencourt et al [4]; Marques e Cárdenas [5]; Alves [6]; Barbieri [7]; Carvalho [8].

And in the current District of União Bandeirantes, since its beginning in 1999, malaria has been a health problem for the local population, due to the large area of forest degraded by deforestation, causing environmental damage and the social production of endemic diseases.

In the late 1990s, Gleba Jorge Teixeira (later called União Bandeirantes) was predominantly a forest area, while it was configured with vacant land corresponding to the São Francisco, Janaiáco and Bom Futuro rubber plantations and adjacent areas, the rubber plantations represented by the intended land by Sebastião Conti Neto and others. Thus, one area resulted in the collection of Gleba Jorge Teixeira and part was regularized in favor of one of the applicants, in a fraction equivalent to about a third of his then claim, which was 99,000.00 ha. While most of those lands represented a pretense of private interest, it remained virtually free of invasion for many years. A Gleba is an unregulated area. When there is no type of land legalization, whether for subdivision, unification or construction.

However, after the incorporation of the União Bandeirantes area into public property, especially in the last 04 (four) years, the location was being modified with extreme speed and, unfortunately, being marked by predatory forms of human intervention, usually resulting from invasion by groups opportunistic social groups that use institutional passivity in order to promote disorderly occupation, combined with illegal logging.

Thus, real estate speculation is practiced in the region and, through this activity, unscrupulous people take the opportunity to "sell landmarks" (fractions of public land), in open use in bad faith, deceiving people who, out of ignorance, end up investing in the scarce economy in “invaded plots of land”, running the risk of losing the amounts invested. Furthermore, these people will be subject to penalties, both from agrarian legislation and from the environmental crimes Law.

With the absence of planning, on preventive and conservationist bases, the illegal occupations that proliferate within the Jorge Teixeira de Oliveira Gleba (current União Bandeirantes District) are depredating the forest, causing a vertiginous decline of forest species and, consequently, reducing, drastically, the volumetric potential of economically marketable woods and the local flora and fauna biodiversity. In addition, there is the inadequate use of soil resources, causing a rapid reduction of natural resources in the area, causing major social and political conflicts, in addition to enormous damage to the environment.

The main endemic diseases in the Amazon are closely linked to the destruction of Amazon ecosystems. These diseases are called focal diseases, which are rooted in the elements of fauna and flora. The dynamics of deforestation transforms the circulation of microbial agents such as viruses, bacteria and parasites. The intensity of deforestation will have an impact on the ecosystem. Due to several biological, behavioral and geographic factors, this population of União Bandeirantes is exposed to a greater or lesser incidence of malaria, with greater or lesser transmission instability.

According to Moraes [9], the environment is not homogenized in a single target of actions, but rather merges as an inherent facet to every act of producing space. In this approach, nature and space do not exchange only in a plea of complicity. In this approach, nature and space do not exchange only in a plea of complicity. The natural space does not exist only to be explored, it is much more than that. Man and nature coexist as synonyms [10]; [11]; [12]; [13] and [14]. However, phenomena such as hunger, thirst and epidemics are injunctions focused on what inhabits its core, which are the relationships maintained between man and the natural environment. Santos [13] called it hostile nature, through its catastrophic effects, with harm to the physical and mental health of populations, when nature ceases to be friendly to man. It is noticed that this unplanned human-environment interaction generates a conflict situation mainly on deforestation and endemic diseases.

Using the geostatistical method as a tool, the objective was to analyze the behavior of the spatial dispersion of deforestation and the number of cases of malaria, in addition to providing integration of deforestation risk with epidemiological risk of malaria in the current District of União Bandeirantes, in the municipality from Porto Velho, Rondônia, Western Amazon, for a period of 3 years.

II. METHOD

2.1 Geostatistics

The theoretical basis of geostatistics is centered on the theory of regionalized variables. One of the forerunners of this method was Georges Matheron, who began with the work of Daniel Krige, who aimed at solving mineral reserve estimation problems. As it is a probabilistic method, it uses a position of observations to understand the behavior of the variability of observed values [15].

Thus, the concern of geostatistical analysis is with natural phenomena. From the regionalized variable estimates, using some spatial characteristics of the sampling points of the discrete data set, evaluating the estimation errors, which establishes the degree of security in the forecasts and the optimal sampling patterns, so that the maximum errors estimates are not exceeded.

According to Landim [16], applied geostatistics deals with problems related to regionalized variables. The variables present an apparent spatial continuity, with the characteristic of presenting values very close to two neighbors, this makes the different measures increasingly distant, in addition to presenting their own location, anisotropy and transition.

In the behavior of regionalized variables there are two fundamental tools of statistical methods: the semivariogram and kriging [16].

2.1.1 Semivariogram

The semivariogram is the mathematical modeling that allows studying the natural dispersion of the regionalized variable [17], which, according to Landim [18], this modeling demonstrates the degree of dependence between the samples. The regionalized variable has spatial continuity evidenced in the moment of inertia designated by the variogram.

Huilbregts [19] states that the variogram is a basic tool to support kriging techniques, which allows to quantitatively represent the variation of a regionalized phenomenon in space. This phenomenon is due to the distance and direction between pairs of observations $[z(x_i), z(x_i + h)]$.

The variogram is translated as follows:

$$\gamma = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(x_i + h) - Z(x_i)]^2$$

Where:

γ (h) is the semi-variance;

n(h) is the number of pairs of values of the variable considered in a given direction;

z(xi), z(xi+h) are values of the variable at two distinct points, separated by a predetermined and constant distance in one direction;

h is the preset distance interval;

½ is half the mean of the squared differences and represents the perpendicular distance of the two points from line 45 of the spatial dispersion diagram.

The semivariogram is usually called a variogram, and the format of this graph describes the degree of autocorrelation present (Fig. 1).

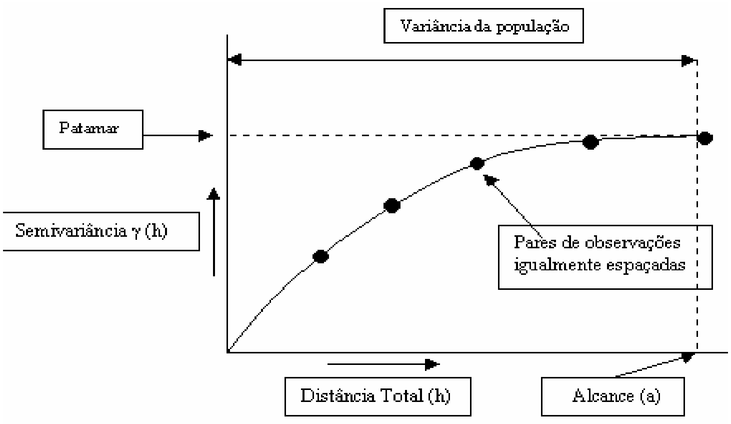

Fig.1: Semi-variogram model.

Where:

h: distance;

γ(h): semi-variance;

Range (a): indicates the distance where the samples no longer have spatial correlation, becoming random variation;

Level (C + C0): it is the value of the semivariogram corresponding to its range (a). Meaning that there is no longer any spatial dependence between the samples, hence null covariance.

C: is the contribution of the level.

C_0: called the "nugget effect" reveals the discontinuities of the semivariogram for distances smaller than the shortest distance between samples. According to Isaaks and Srivastava [20], this discontinuity may be due to measurement errors. Making it impossible to assess whether the greatest contribution comes from measurement errors or from small-scale variability not captured by sampling.

In practice, variographic models are not known and must be adjusted by a theoretical model that represents the different regionalizations that occur in nature, which can be classified into two categories: non-platform model and b) platform model.

According to Isaaks and Srivastava [20], these models are called isotropic. Models of the first type are referred to in geostatistics as transitive models. Since some of the transitives reach the level (C) asymptomatically. For these models, range (a) is arbitrarily defined as the distance corresponding to 95% threshold. The second type, on the other hand, does not reach the platform and continues to increase as the distance increases [21]. These models are used for modeling phenomena that have infinite dispersion capability.

According to Landim [18], in models with a platform, there are basically four theoretical functions that fit the empirical semivariogram models: linear, spherical, exponential and Gaussian.

For Camargo et. al [21],

> The semivariogram may or may not present structures of spatial variability in the study area, this can be seen by comparing the estimated semivariograms for the 0º, 45º, 90º and 135º directions. Therefore, this spatially dependent structure can occur in the same and in all directions, that is, in this case, h is considered as scalar, the phenomenon is called isotropic, otherwise, h

is considered as a vector and the phenomenon is called anisotropic.

Some natural phenomena are more likely to occur in anisotropic modeling, which can be geometric and zonal. The geometric anisotropy is adjusted in the same model, but there is variation in the range according to directions, with the maximum and minimum ranges being in orthogonal directions. In zonal anisotropy, there is more than one semivariogram model for the area [21].

The parameters found in the classic variogram models are related to scale, extension and continuity, where there is stability characterizing its form of spatial dependence, providing information necessary for the execution of kriging, allowing to find the optimal weights, related to the samples, still allowed estimate the unknown points [22].

2.1.2 Kriging

To obtain a more effective diagnosis of deforestation and malaria, the Kriging method was used to analyze the spatial variability of existing indicators in the area.

According to Fuks [23] and Fuks et al [24], kriging is a stochastic spatial inference procedure, whose variographic analysis model provides a spatial covariance structure. It is an elaborate statistical technique that estimates a spatial covariance matrix that determines weights assigned to different samples. A spatial dependence model is obtained, with the intention of predicting values at non-sampled points as well. This interpolator weights the neighbors of the point to be estimated, obeying the criteria of non-bias and minimum variance. There are several types of kriging: simple, ordinary, universal, indicative, among others.

Indicative Kriging basically consists of determining an average value in a non-sampled location. Other values can also be used as a basis for estimating values below or above a certain cut-off level [22]. This technique has the main advantage of being non-parametric, not requiring prior knowledge of the distribution for the random variable (VA).

Kriging by indication allows the estimation of the VA distribution function, allowing the determination of uncertainties and the inference of attribute values, in non-sampled spatial locations. Unlike linear kriging, the indication kriging procedure models attributes with high spatial variability, without the need to ignore sampled data whose values are very far from a trend [25]; [26]. To achieve these goals, the first step in Indicative Kriging is to transform the original data into indicators, that is, transform the values that are above a certain cut-off level into zero (0) and those below into one (1):

$$I(v_c) = \begin{cases} 1, \ldots se \ldots v_j \leq v_c \\ 0, \ldots se \ldots v_j \leq v_c \end{cases}$$

And, therefore, the expected value of the VA per referral, $E\{I(v_c)/(n)\}$, provides an F* estimate of the fdc of v_j at cutoff value v_c and conditioned to the n sample data of the attribute v_{j_i}

$$E\{I(v_c)/(n)\} =$$

$$1.\Pr ob\{I(v_c) = 1/(n)\} + 0.\Pr ob\{I(v_c) = 0/(n)\} =$$

$$1.\Pr ob\{I(v_c) = 1/(n)\} = F^*(v_c/(n))$$

According to Deutsch (1998), this technique allows the elaboration of the estimate by a kriging on the set of values per indication for the fdca of v_j at cutoff value v_c.

For Landim [16], the experimental semivariograms are calculated for certain cut-off levels and then the Indicative Kriging is applied, which provides maps of probability of occurrence. This aims to provide maps of occurrence of values, below and above the cut-off levels, providing the anomalies of the geoenvironmental research areas.

2.2. Study area

The area chosen to carry out the study and assess deforestation, as well as the number of cases of malaria, is located in the region of the municipality of Porto Velho, on the Gleba Jorge Teixeira known as União Bandeirante.

This is a colonization area monitored by the National Institute of Agrarian Reform (INCRA) in the vicinity of Highway BR-364, Km 9.5. It is an area of terra firme forest, which has a history of anthropogenic occupation. (Fig. 02). It is located 160 km from the city of Porto Velho.

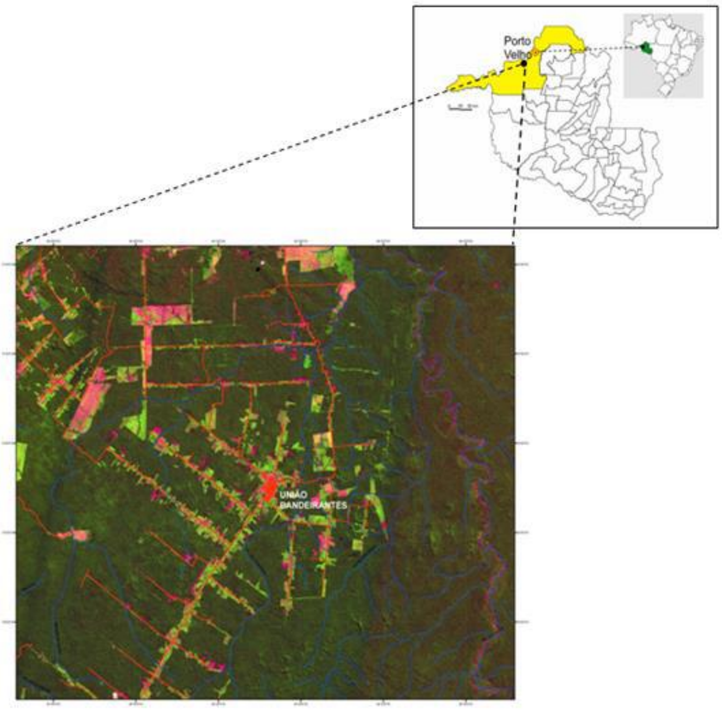

Fig.2: Location of the Gleba União Bandeirante study area.

2.3 Database

For the construction of the malaria incidence database in Gleba União Bandeirante over a period of 3 (three) years, data collected by the Surveillance and Epidemiological Information System - SIVEP were used, which were compiled into tables for analysis and identification of the standards of today.

The deforestation images were compiled from the satellite image database of the Rondônia Environmental Development Secretariat.

2.4. Statistical treatment

In the statistical treatment of the data, the geostatistical method of kriging was used as a tool for data analysis and geostatistical modeling to describe the spatial behavior of deforestation in Gleba União Bandeirante, current União Bandeirantes District – Municipality of Porto Velho, State of Rondônia, Western Amazon.

Descriptive statistics are often used with the purpose of describing the data and synthesizing the data series of the same nature, thus allowing an overall view of the variation of this set, that is, descriptive measures help to analyze the behavior of Dice.

The statistical measure used as a behavior parameter in this work was the median. This represented the best behavior as a measure that assessed the incidence of deforestation and its possible correspondence with the number of cases of malaria. This statistical parameter describes the measure of the data set as an evaluation that leaves 50% of the elements of the set [27].

This measure of tendency or central position describes the center of a distribution [28]. If the data set has outliers elements, these should not be discarded, since these elements do not affect the set, when using the median as an analysis measure [29].

III. RESULTS AND DISCUSSION

For the construction of the malaria incidence database in the current District of União Bandeirantes for a period of 3 years, data collected by the Surveillance and Epidemiological Information System - SIVEP were used, which were compiled in the tables below for analysis and identification of the standards of this study.

Table 1. Registration data on the incidence of malaria in the current District of União Bandeirantes (year 1).

	places	Pop.	Total Positives	IPA	IFA	F	V	F+V	M	O
610	LINHA 1		60	168	2.800,0	31,0	48	116	4	0
616	LINHA 15 DE NOVEMBRO		30	50	1.666,7	32,0	16	34	0	0
615	LINHA 1º DE MAIO		36	189	5.250,0	30,7	52	131	6	0
611	LINHA 2		50	125	2.500,0	28,8	34	89	2	0
708	LINHA 4 – SIT		102	228	2.235,3	28,1	62	164	2	0
241	LINHA DO BARRACO AZUL - SIT		10	68	6.800,0	38,2	25	42	1	0
312	LINHA F		145	232	1.600,0	24,1	53	176	3	0
614	LINHA P.O		35	118	3.371,4	24,6	27	89	2	0
613	LINHA TRIANGULO		900	161	178,9	39,8	63	97	1	0
612	LINHÃO – ACAM		100	240	2.400,0	27,9	65	173	2	0
600	RIO CONTRA – POVO		96	328	3.416,7	26,8	85	240	3	0
512	TRAVESSAO 10 – ACAM		23	382	16.608,7	32,7	123	257	2	0
307	TRAVESSAO 101 – SIT		9	103	11.444,4	10,7	11	92	0	0
518	TRAVESSAO 11 – ACAM		21	13	619,0	38,5	5	8	0	0
702	TRAVESSAO 4 – ACAM		8	9	1.125,0	22,2	1	7	1	0
405	TRAVESSAO 5 – ACAM		6	62	10.333,3	30,6	18	43	1	0
513	TRAVESSAO 6 – ACAM		8	12	1.500,0	25,0	3	9	0	0
514	TRAVESSAO 7 – ACAM		5	17	3.400,0	17,6	3	14	0	0
515	TRAVESSAO 8 – ACAM		7	30	4.285,7	40,0	12	18	0	0
516	TRAVESSAO 9 – ACAM		11	52	4.727,3	32,7	17	35	0	0
247	UNIÃO BANDEIRANTE - VILA		1250	1003	802,4	31,0	290	692	21	0
	Total	2912	3590	1.232,8	29,6	1013	2526	51	0	0

Subtitle: IPA – annual parasitic index. IFA – annual falciparum index. F – falciparum. V – vivax. M – malariae.

Table 2. Registration data on the incidence of malaria in the current District of União Bandeirantes (year II).

	places	Pop.	Total Positives	IPA	IFA	F	V	F+V	M	O
610	LINHA 1	60	190	3.166,7	28,4	46	136	8	0	0
616	LINHA 15 DE NOVEMBRO	30	50	1.666,7	16,0	7	42	1	0	0
615	LINHA 1º DE MAIO	36	75	2.083,3	30,7	22	52	1	0	0
611	LINHA 2	50	99	1.980,0	23,2	23	76	0	0	0

708	LINHA 4 - SIT	102	190	1.862,7	22,6	40	147	3	0	0
241	LINHA DO BARRACO AZUL - SIT	10	97	9.700,0	25,8	24	72	1	0	0
771	LINHA DO PAVÃO	142	21	147,9	19,0	4	17	0	0	0
772	LINHA DO TUCANO	53	50	943,4	28,0	14	36	0	0	0
312	LINHA F	145	249	1.717,2	19,3	47	201	1	0	0
614	LINHA P.O	35	126	3.600,0	24,6	31	95	0	0	0
613	LINHA TRIANGULO	900	101	112,2	16,8	17	84	0	0	0
612	LINHÃO - ACAM	100	279	2.790,0	18,3	48	228	3	0	0
600	RIO CONTRA - POVO	96	74	770,8	10,8	8	66	0	0	0
512	TRAVESSAO 10 - ACAM	23	284	12.347,8	25,4	68	212	4	0	0
307	TRAVESSAO 101 - SIT	9	594	66.000,0	18,2	103	486	5	0	0
518	TRAVESSAO 11- ACAM	21	45	2.142,9	26,7	12	33	0	0	0
702	TRAVESSAO 4 - ACAM	8	23	2.875,0	26,1	6	17	0	0	0
405	TRAVESSAO 5 - ACAM	6	79	13.166,7	19,0	15	64	0	0	0
513	TRAVESSAO 6 - ACAM	8	28	3.500,0	21,4	6	22	0	0	0
514	TRAVESSAO 7 - ACAM	5	117	23.400,0	12,0	14	103	0	0	0
515	TRAVESSAO 8 - ACAM	7	162	23.142,9	15,4	23	137	2	0	0
516	TRAVESSAO 9 - ACAM	11	137	12.454,5	13,9	19	118	0	0	0
786	TRAVESÃO DO TRIÂNGULO	35	10	285,7	20,0	2	8	0	0	0
247	UNIÃO BANDEIRANTE - VILA	1250	1728	1.382,4	19,4	317	1393	18	0	0
Total		3142	4808	1.530,2	20,0	916	3845	47	0	0

Subtitle: IPA – annual parasitic index. IFA – annual falciparum index. F – falciparum. V – vivax. M – malariae.

Table 3. Registration data on the incidence of malaria in the current District of União Bandeirantes (year III).

	places	Pop.	Total Positives	IPA	IFA	F	V	F+V	M	O
610	LINHA 1	60	198	3.300,0	29,8	57	139	2	0	0
616	LINHA 15 DE NOVEMBRO	30	85	2.833,3	25,9	18	63	4	0	0
615	LINHA 1º DE MAIO	36	52	1.444,4	15,4	8	44	0	0	0
611	LINHA 2	50	97	1.940,0	27,8	27	70	0	0	0

708	LINHA 4 – SIT	102	130	1.274,5	17,7	21	107	2	0	0
789	LINHA ABACAXI	79	91	1.151,9	40,7	34	54	3	0	0
241	LINHA DO BARRACO AZUL - SIT	10	43	4.300,0	41,9	17	25	1	0	0
790	LINHA DO FERRUGEM	68	215	3.161,8	38,6	81	132	2	0	0
771	LINHA DO PAVÃO	142	21	147,9	9,5	2	19	0	0	0
772	LINHA DO TUCANO	53	31	584,9	25,8	7	23	1	0	0
312	LINHA F	145	159	1.096,6	28,9	41	113	5	0	0
614	LINHA P.O	35	84	2.400,0	27,4	21	61	2	0	0
613	LINHA TRIANGULO	900	89	98,9	24,7	22	67	0	0	0
612	LINHÃO - ACAM	100	213	2.130,0	25,8	52	158	3	0	0
600	RIO CONTRA - POVO	96	24	250,0	41,7	10	14	0	0	0
512	TRAVESSAO 10 - ACAM	23	79	3.434,8	16,5	13	66	0	0	0
307	TRAVESSAO 101 - SIT	9	456	50.666,7	27,2	118	332	6	0	0
518	TRAVESSAO 11 - ACAM	21	21	1.000,0	38,1	8	13	0	0	0
702	TRAVESSAO 4 - ACAM	8	8	1.000,0	25,0	2	6	0	0	0
405	TRAVESSAO 5 - ACAM	6	27	4.500,0	18,5	5	22	0	0	0
513	TRAVESSAO 6 - ACAM	8	21	2.625,0	52,4	11	10	0	0	0
514	TRAVESSAO 7 - ACAM	5	63	12.600,0	44,4	28	35	0	0	0
515	TRAVESSAO 8 - ACAM	7	81	11.571,4	32,1	26	55	0	0	0
516	TRAVESSAO 9 - ACAM	11	101	9.181,8	32,7	31	68	2	0	0
786	TRAVESÃO DO TRIÂNGULO	35	21	600,0	19,0	4	17	0	0	0
247	UNIÃO BANDEIRANTE – VILA	1250	637	509,6	21,2	129	502	6	0	0
	Total	3289	3047	926,4	27,3	793	2215	39	0	0

Subtitle: IPA – annual parasitic index. IFA – annual falciparum index. F – falciparum. V – vivax. M – malariae.

Semivariogram Analysis

The first adjusted variographic model is Gaussian (Figure 3), whose direction is NE - SW. The parameters are: nugget effect (C0) = 20000, level is 1620,000 and range is 10500. This model describes the behavior of the deforestation variable. In this way, the map of figure 04 resulted.

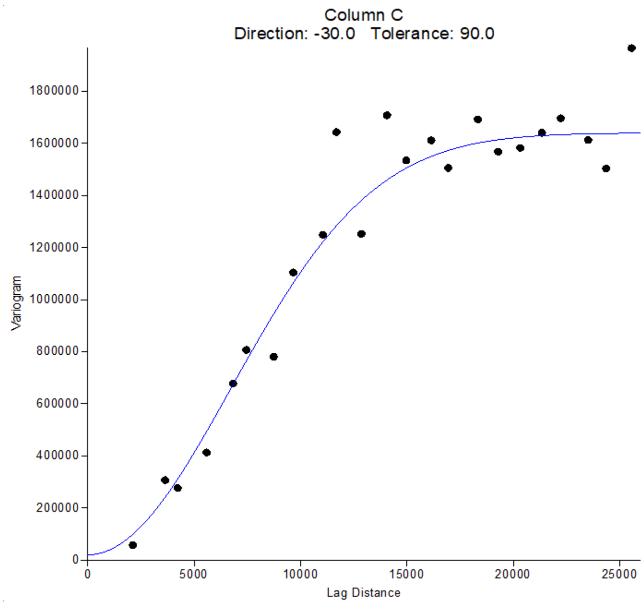

Figure 3. Experimental variogram of deforestation, adjusted for median (1410 ha). (year 1).

For the deforestation map (Figure 4), it is observed that it has a behavior of a large portion in the central region of Gleba União Bandeirante. This means that the occurrence of deforestation was highly prevalent in this area. In the southern and western parts of the tract, there is no deforestation, that is, it is not yet possible to make statements in relation to the portion, but it is clear that it may be an area that is or is not explored.

In the western portion of the Gleba are located the Karipunas indigenous reserve and the Bom Futuro reserve and the Jacy Paraná district, forming a deforestation control belt, thus reducing the rate of deforestation. As expressed in the clear part of the map, as the cut level approaches 0 (zero), deforestation is intense.

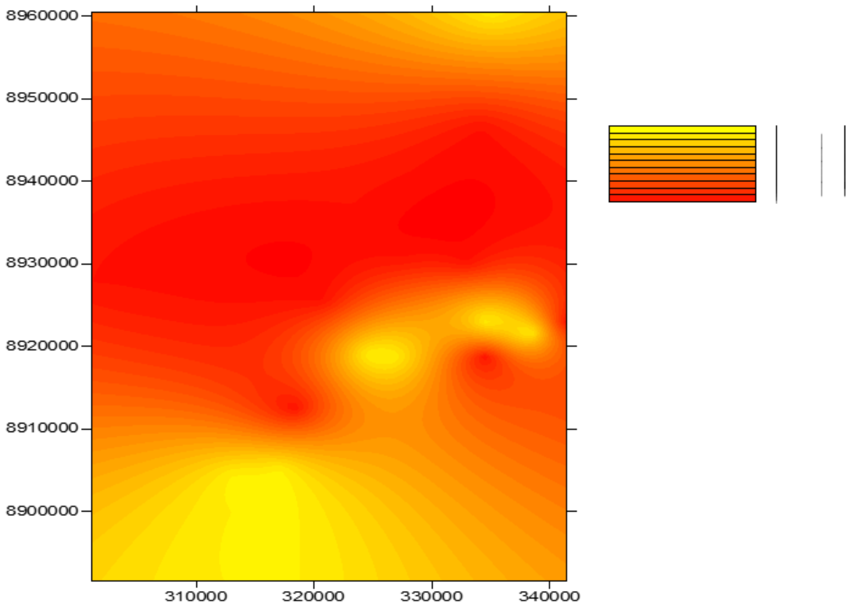

Fig.4: Probabilistic map of deforestation occurrence, median cut level (1410 ha).

The adjusted variographic model (Figure 5) is a Gaussian whose direction is NE – SW. Its parameters are: nugget effect (C_0) = 436, threshold is 21000 and range is 13000.

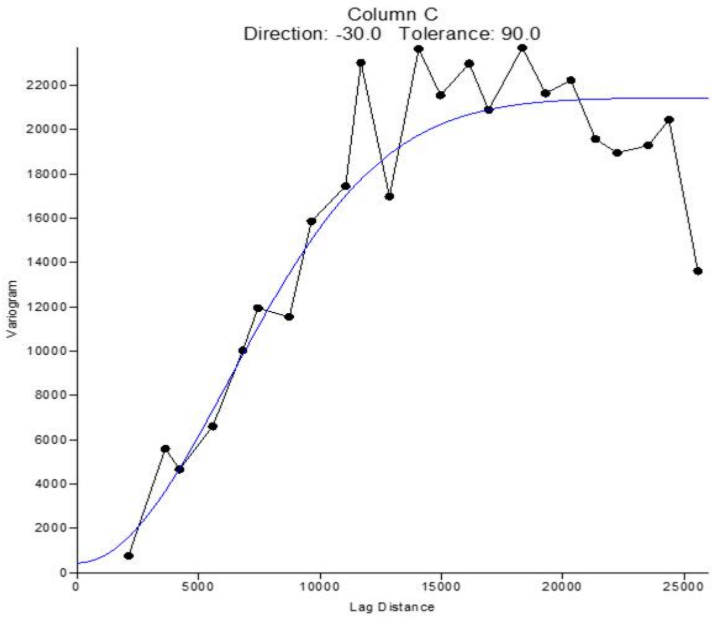

Fig.5: Experimental variogram for risk of malaria cases, adjusted for median (118 cases). (year one (1)

For the malaria risk map, it is observed that there was a great trend of occurrence of cases, in the entire northern portion of the glebe, demonstrating that this area has more than 118 cases. (Figure 6).

As for the combined occurrence map, in which the occurrence of deforestation and malaria is seen, the growth in cases of malaria occurs as deforestation advances to the north. This means that the growth of cases is due to human activity in an uninhabited field, leaving the population vulnerable to tropical endemics, especially malaria. (Figure 7).

The study by Paraguassu-Chaves [1] carried out in a subspace of Western Amazonia is another argument in favor of this interpretation. According to this author, the migrant population that lives in precarious housing conditions favors the expansion and development of a relevant environment for the social production of malaria.

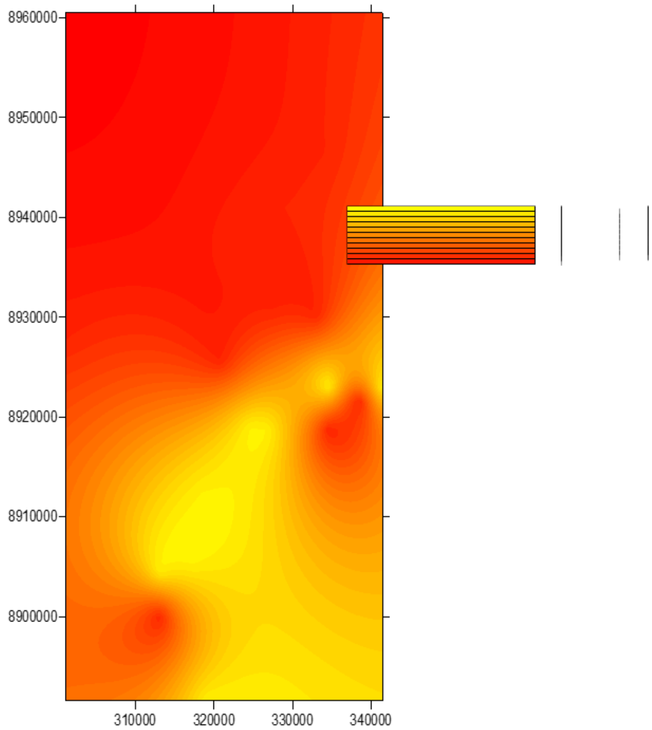

Fig.6: Map of probability of occurrence of malaria, median cut-off level (110 cases). (year 1).

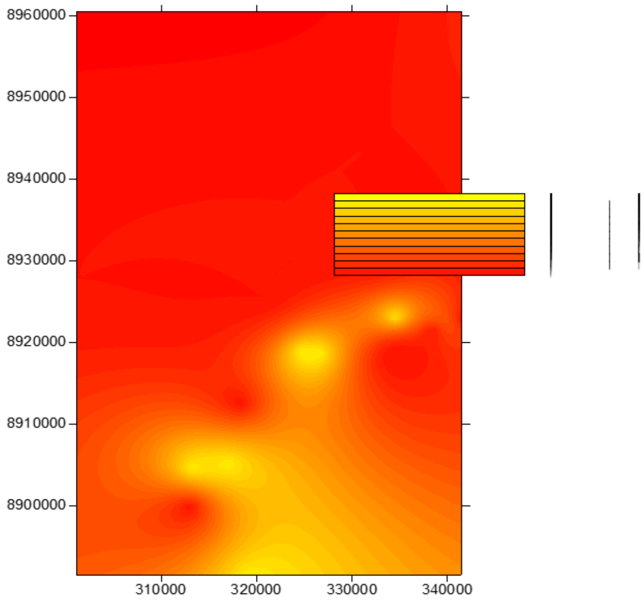

Fig.7: Combined occurrence probability map for the median cut-off level of deforestation (1410 ha) and malaria cases (110 cases).

The adjusted model (Figure 8) is Spherical whose direction NE – SW and follows the following behavioral characteristics of the variable. Its parameters are: nugget effect (C_0) = 0, threshold is 550000 and range is 15000.

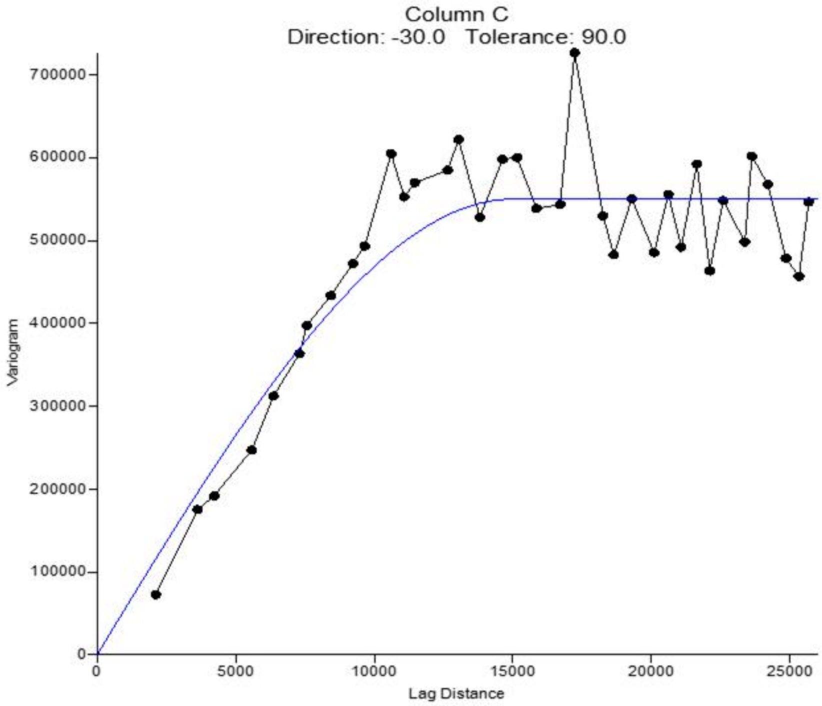

Fig.8: Experimental variogram of deforestation, adjusted for median (1317.5 ha). (year II).

The deforestation risk map (Figure 9) indicates that the incidence of deforestation occurred in the northwest of the region (year II). The other regions have a low incidence of deforestation, leading to believe that there was a strong influence of the public sector in managing deforestation that year.

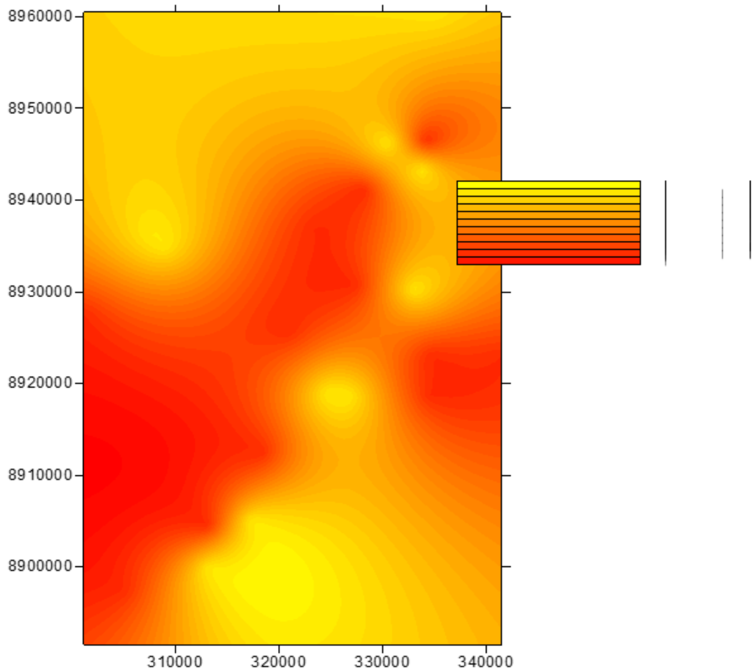

Fig.9: Probabilistic map of deforestation occurrence, median cut level (1317.5 ha). (year II).

The fitted model (Figure 10) is Gaussian whose direction and N - S parameters are: nugget effect (C_0) = 300, level is 7400 and range is 6800.

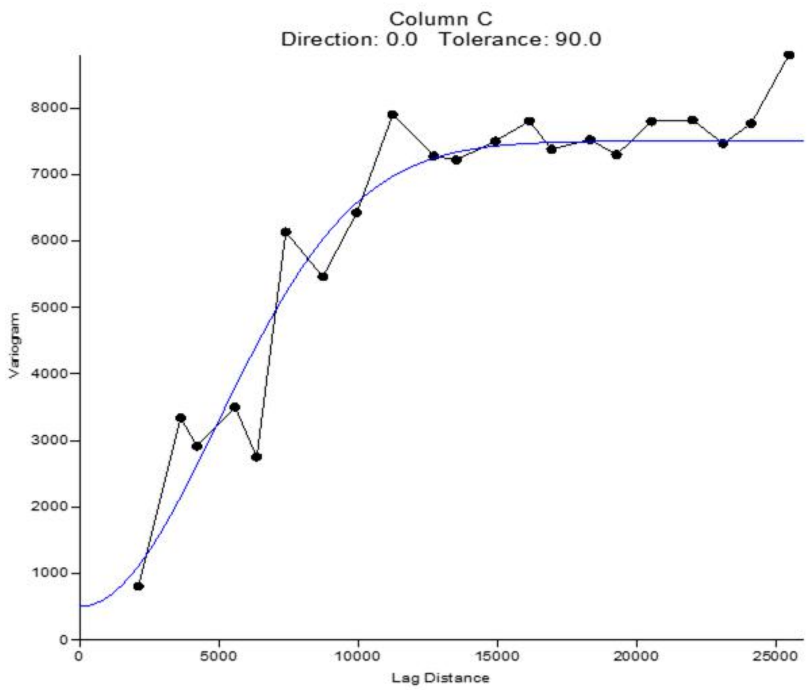

Fig.10: Experimental variogram for risk of malaria cases, adjusted for median (82.5 cases). (year II).

For the malaria risk occurrence map (Figure 11), there is a large concentration of cases above the median in the central portion of the Gleba, growing to the east, demonstrating convergence with the area of advance of deforestation. This convergence may probably be due to an area that is still difficult to access for inspection. Therefore, the number of cases in this sector is likely to increase.

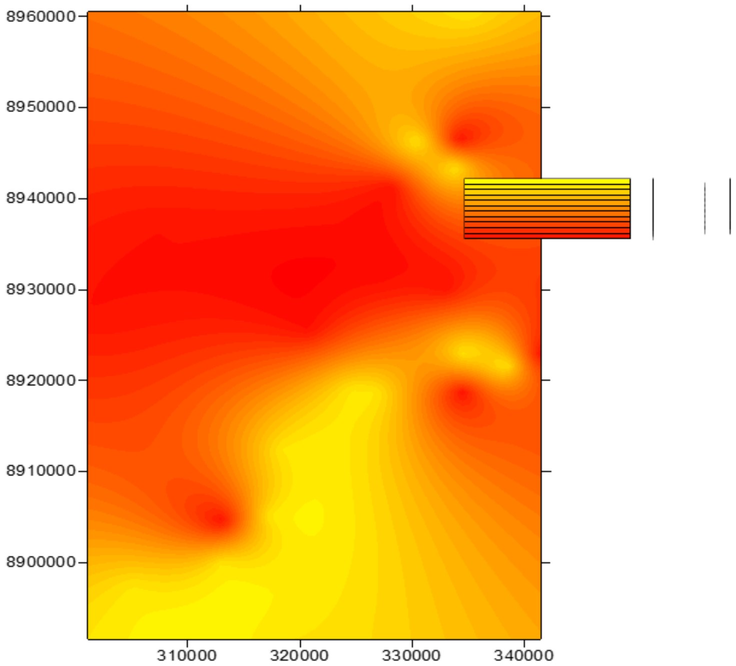

Fig.11: Probabilistic map of malaria occurrence, median cut-off level (82.5 cases). (year II).

As for the map (Figure 12), it shows a strong growth trend for the eastern sector both in terms of deforestation and malaria. Therefore, there is a low trend in deforestation growth. Furthermore, the occurrence of malaria will continue to exist in this area, as it is a very dense forest sector and the man who enters the region will run the risk of contracting some tropical disease.

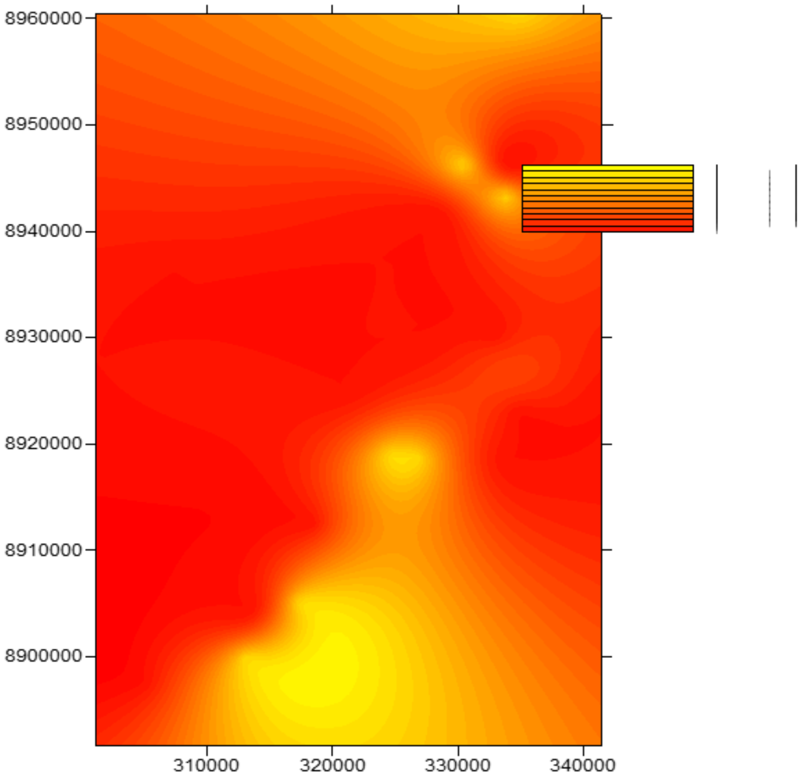

Fig.12: Combined occurrence probability map for the median cut-off level of deforestation (1410 ha) and malaria cases (82.5 cases). (year II).

The adjusted model (Figure 13) is Spherical whose direction NE - SW, whose parameters are: nugget effect (C_0) = 0, level is 211700 and range is 10000. (year III).

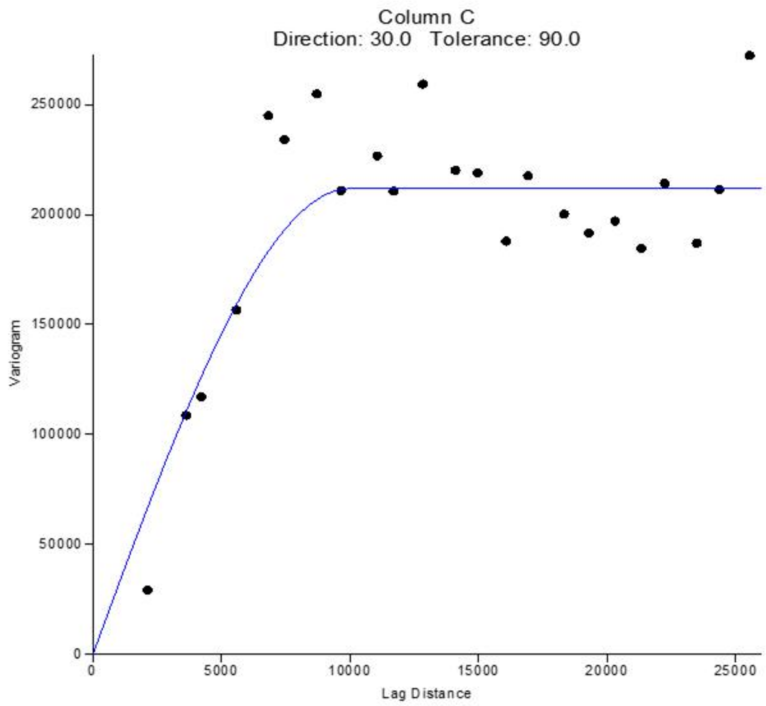

Fig.13: Experimental variogram of deforestation, adjusted for median (1019 ha). (year III).

The map (Figure 14) of deforestation occurrence demonstrates accommodation in all regions, that is, a decline in deforested areas, with deforestation outbreaks appearing in the central areas of Gleba União Bandeirante. Therefore, it is clear that this year was a year of great accommodation compared to previous years.

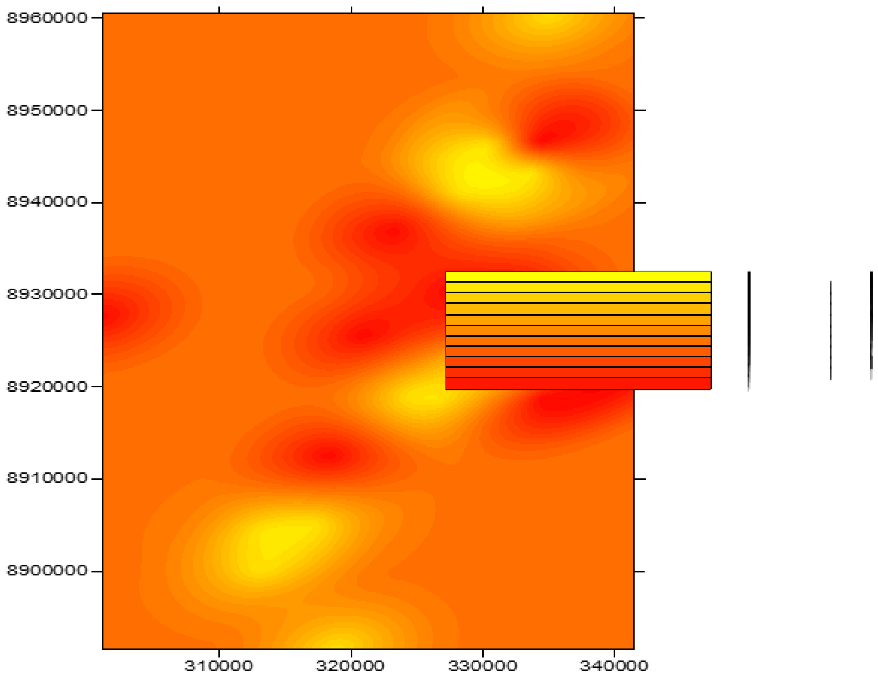

Fig.14: Deforestation occurrence map, median cut level (1019 ha). (year III).

The adjusted variogram model (Figure 15) is Spherical whose direction is NE – SW and its parameters are: nugget effect (C_0) = 679, threshold is 44690 and range is 11800.

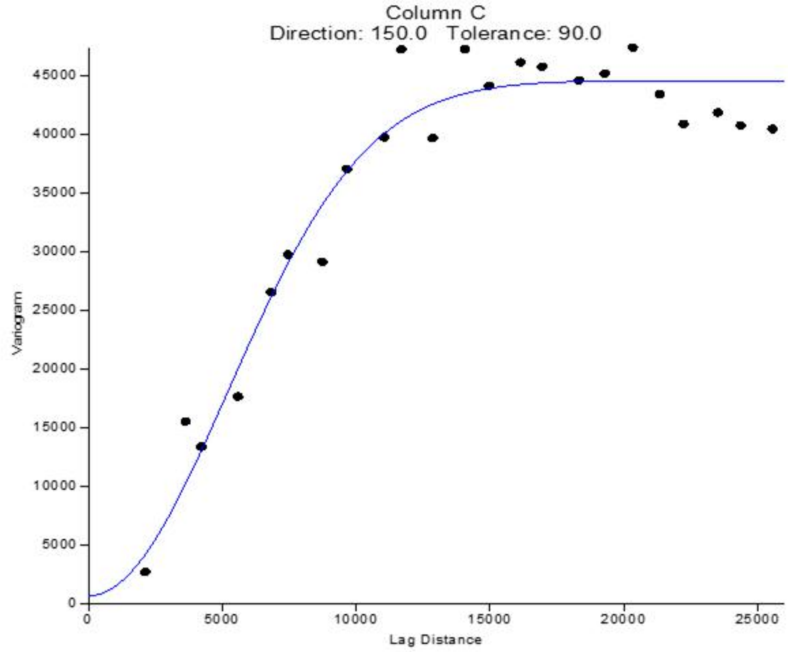

Fig.15: Experimental variogram for risk of malaria cases, adjusted for median (100 cases). (year III).

The map (Figure 16) shows practically the same trend of deforestation, that is, the areas with the highest concentration of malaria are in the northeast and southwest of the União Bandeirante gleba. (year III).

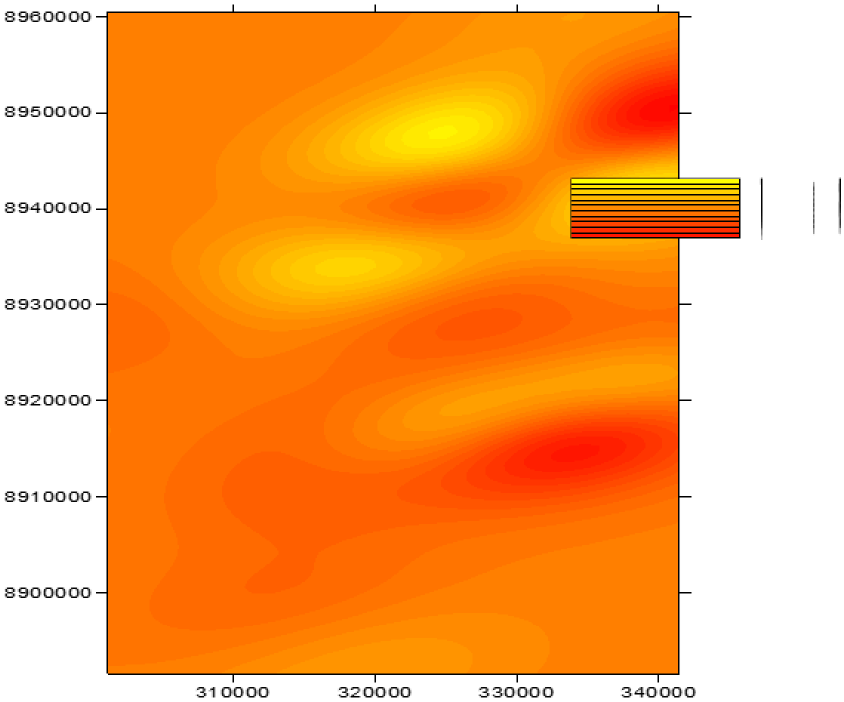

Fig.16: Probabilistic map of malaria occurrence, median cut-off level (100 cases). (year III).

For the occurrence of deforestation combined with the occurrence of malaria, it is observed that the map (Figure 17) shows a declining trend both in the trend of deforestation and cases of malaria, that is, the deforested areas were abandoned and the cases of malaria occurred only in the local population.

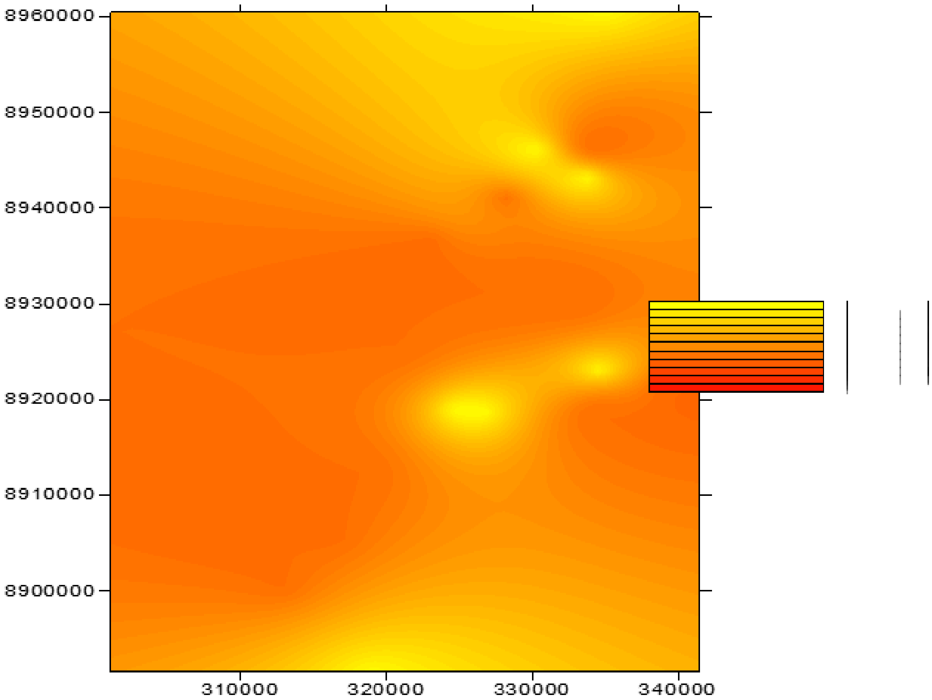

Fig.17: Combined occurrence probability map for median cut-off level of deforestation (1019 ha.) and malaria cases (100 cases).

IV. CONCLUSION

The present study was carried out in the current District of União Bandeirantes, in the municipality of Porto Velho, Rondônia, in which the rates of deforestation and incidence of malaria in the area were investigated.

The geostatistical method of kriging was used for statistical analysis and modeling, in which the behavior of the variables and their growth direction were observed both for cases of malaria and for local deforestation. The indicative kriging method proved to be satisfactory for presenting the occurrence of malaria cases in step with the growth of deforestation. In fact, it was noticed that, as deforestation advances towards the north of the studied area (Figure 7), the cases of malaria increased in the same direction.

The population in contact in the deforested region north of União Bandeirantes is vulnerable to contracting malaria. Likewise, there was an increase in malaria cases east of the population concentration studied, converging with the area of advance of deforestation. In fact, to the east of União Bandeirantes (Figure 12) there is a very dense forest sector, ideal habitat for malaria vectors.

From this perspective, the illegal occupations that proliferate in the União Bandeirantes area cause an expressive rate of local deforestation, which damages not only the environment, but also the fragile population structure of the sector. With the absence of planning and logistical guidance for the occupation of the area, the União Bandeirantes District is on a vertiginous path of decline in forest species and their biodiversity.

On the other hand, while the migrant population lives in precarious conditions of housing and basic sanitation, it will favor the emergence of an environment conducive to the emergence of endemic diseases.

Finally, at the study site, malaria transmission accompanies the process of occupation of the territory. It is pointed out that the incidence of malaria has a higher vector density on the outskirts of the Gleba, with a progressive reduction towards the more central areas of the urban core.

Therefore, by identifying the areas in which the highest levels of autochthonous transmission are concentrated, the possibility of the particularized area being the object of necessary intervention measures increases, enabling the right choice and targeting of control measures handled by program managers of endemic control.

Thus, managers must develop the means to implement a deforestation control strategy integrated with the malaria endemic in the area of the União Bandeirantes District. This necessarily implies creating conditions for coordinated multisectoral action, capable of facing up to local factors that make the transmission of malaria and the increase in deforestation in the District of União Bandeirantes heterogeneous and complex.

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