Automatic stratification of priority areas for Dengue control using the QGIS Model Builder in multicriteria analysis

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Abstract

Objective: to present a methodological sequence resulting from multicriteria analysis indicating areas with different *Aedes aegypti* intervention priorities. **Methods**: a Female *Aedes* Displacement Index (IDF*Aedes*) was created, consolidated according to urban blocks, representing interaction between population densities, *Aedes aegypti* oviposition sites and dengue case notifications; a graphical model (Model Builder) was developed with QGIS software using the Kernel mapping algorithm and IDF*Aedes* as the weighting factor. **Results**: stratification for the evaluated example – Anápolis, GO, Brazil – indicated intervention priority levels for urban blocks – 17.5%, very low priority; 37.3%, low; 33.6%, medium; 10.2%, high; 1.4%, very high –; blocks with medium, high, and very high priority accounted for 22.53,% of the territory in the area. **Conclusion**: the spatial block method proposed in this article can be included in health surveillance programs for intensified targeting and planning of control actions.

Keywords: Spatial Analysis; Vector Control; Dengue.

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Introduction

Brazilian public practices for addressing *Aedes aegypti* have not achieved a satisfactory level of control. A literature review indicated dengue epidemic peaks in Brazil in 2002, 2008 and 2010.[1] Data retrieved from the Notifiable Health Conditions Information System (SINAN)[2] show that in 2013, 2015 and 2016 the threshold of 1.5 million cases nationwide was exceeded, resulting in incidence levels greatly above those considered to be risk levels by the World Health Organization (WHO), namely 300 cases/100,000 inhabitants.

> ***Structuring the planning of efficient health surveillance public policies is fundamental for compiling and analyzing a large amount of reliable and up to date information***

Repeated epidemics and marked seasonality require specific action strategies. Notwithstanding, much of the lack of success of these actions arises from the methodology involving universal and indiscriminate coverage of buildings, based on cycles, with the aim of controlling the immature form of the *Aedes aegypti* vector. Surveillance programs are completed by using the 'notified dengue cases' marker for adopting measures to combat the winged form of the vector. However, reality has shown that even when coverage targets are met, municipal environmental surveillance teams frequently find themselves overwhelmed by dengue transmission. As such, changes to current strategies are clearly needed and surveillance and control actions need to be enhanced.[3]

In view of the weaknesses of the current dengue combat model, studies aimed at defining strategic intervention areas have gained importance, using cluster analysis techniques from a spatial perspective.[4-8] The common stem of these studies consists of categorizing areas with known risk factors and identifying clusters, in order to target intensified control actions.

Structuring the planning of efficient health surveillance public policies is fundamental for compiling and analyzing a large amount of reliable and up to date information. Within this context, evaluation routines can be managed and automated in a competent manner using geoprocessing techniques.

By using Geographic Information System (GIS) software, the objective of this study was to present a practical and direct methodological sequence resulting from multicriteria analysis for automatic indication of priority areas for intervention and planning actions to combat *Aedes aegypti.*

Methods

When using multicriteria analysis to establish priority areas, factors were used that have already been scientifically explored and which interfere,[9] decisively, with biological behavior and with the prevalence of the female of the *Aedes aegypti* species in certain locations. These factors are population density and presence of oviposition sites. Dengue notification geoespatialization was also used to express the convergence of situations that lead to the occurrence of the disease.

An auxiliary index was created, referred to as the Female *Aedes* Displacement Index (IDF*Aedes*). This was based on the premise that areas with higher density of hosts and higher records of oviposition sites and dengue case notifications are most propitious to least displacement of *Aedes aegypti* females**.** Consequently, these regions are more vulnerable to dengue transmission, given that they are open to greater biological prevalence of the vector**.** A similar understanding was obtained in mark-release-recapture experiments in different urban arrangements in the state of Rio de Janeiro.[10]

Urban blocks were used as a primary unit of data inclusion and analysis. The urban block shapefile was imported from the State of Goiás Zero *Aedes* Monitoring System (SIMAZ).[11] When creating IDF*Aedes*, population density, history of *Aedes aegypti* breeding sites and dengue notifications were combined. The parameter values were grouped into quintiles and individually given scores ranging from 1 to 5. Each block was represented by the sum of its individual scores, totaling at least 3 and 15 at the most. The ranges were defined with the following segmentation: 3 to < 6 (very low priority), 6 to < 8 (low priority), 8 to <10 (medium priority), 10 to <12 (high priority) and above 12 (very high priority), as shown in Table 1. The levels of priority for intervention were divided into quintiles, according to the sum of the individual scores (Table 1). The analyses were performed using SIG *QGIS* 2.14 Essen and Excel® 2013. The database of the municipality of Anápolis, located in the state of

Goiás (GO), for the years 2016 and 2017, was used to exemplify the priority area automatic selection model.

Population information, by urban block, was obtained from the Ministry of Health's Primary Care Information System. This information is generated by Family Health Strategy teams and community health agents. History of Aedes aegypti breeding sites, also by urban block, was imported from the SIMAZ program. Dengue notifications were retrieved from the SINAN system and tabulated using Excel®. The QGIS Web Service Geocode algorithm was used to geocode 8,737 records of addresses of dengue notifications. In this stage, owing to erratic positions produced by the algorithm, some manual corrections and data removal were necessary (manual geocoding) and to this end support was provided by the municipal epidemiological surveillance team. Taking the 'count points in polygon' native algorithm, the sum of dengue notifications per georeferenced urban block was consolidated.

Excel® was used to calculate mean breeding sites between 2016 and 2017, segregated into two annual periods: October to March and May to September, which are the rainy season and the dry season in Goiás, respectively. In order to create IDF*Aedes* categories, each individual parameter was divided into quintiles, giving a score of 1 for least female *Aedes aegypti* displacement, reaching a score of 5 for greatest displacement. The sum of the scores of the individual parameters represented the IDF*Aedes* per urban block, whereby the IDF*Aedes* was greater when the trend of the female *Aedes aegypti* to displace itself in search of conditions favorable to its survival was greater. Ultimately, supported by a composite index, the IDF*Aedes* seeks to express the different levels of interaction between the parameters used, consolidated according to urban blocks.

A model was developed to be run on QGIS, along with the GRASS, GDAL/OGR and SAGA tools (Figure 1). This model is comprised of a series of computing routines, logically structured to incorporate, process and provide data. Basically, it is built on the territorial base and associated tabular data. These data are processed and prepared in order to run the 'kernel density curve' algorithm. Finally, class and style formatting is done, thus making the result more user-friendly. The detailed sequencing of the actions and the description of the algorithms and products obtained are listed in Table 2.

Results

The direct result of applying the graphical model that was built can be seen in Figure 2. Stratification indicated the following priority levels for intervention in the urban blocks: 17.5% very low priority; 37.3% low priority; 33.6% medium priority; 10.2% high priority; and 1.4% very high priority. The priority classes were shown in a cluster pattern, distributed over all regions of the municipality.

The technique used distinguished microregions with different dengue transmission predispositions. The classes with the highest priority for intervention had the highest values, among all the parameters used. According to Table 3, breeding site density (*Aedes aegypti* breeding sites per hectare [ha.], where 1ha. = 10,000 m^2]) increased 1600% between the very low priority class and the very high priority class. Population density and dengue case density also showed grading compatible with the level of priority proposed: variations of 13.2 inhab./ha. to 203.6 inhab./ha., and 0.03 dengue cases/ha to 3.96 dengue cases/ha., respectively.

Table 1 – Matrix of the composition of the Female *Aedes* Displacement Index, for intervention and planning actions against the *Aedes aegypti* vector

Percentile class	Parameters			IDF*Aedes*[a]	
	Population density	History of vector breeding sites	History of dengue case notification		
	Score			Range	Intervention priority
quintile 1	5	5	5	>12	Very high
quintile 2	4	4	4	10 to 12	High
quintile 3	3	3	3	8 to <10	Medium
quintile 4	2	2	2	6 to <8	Low
quintile 5	1	1	1	3 to <6	Very low

a) IDFAedes: Female Aedes Displacement Index.

Table 2 – Action sequencing, algorithm description and products obtained

Stage	Description	Algorithm/library used	Product obtained
1	Load municipal urban block layer	-/GDAL[b]	Polygon vector layer added to project
2	Load previously formatted table, indicating IDFAedes[a] per urban block	-/GDAL[b]	Table added to project
3	Table union to block layer	Union/GDAL[b]	Polygon vector layer linked to attribute table
4	Generate block layer centroid	Polygon centroids/GDAL[b]	Point vector layer linked polygon layer
5	Reproject centroid layer to UTM projection appropriate for the region (DATUM 31982)	Reproject Layer/GRASS[c]	Centroid layer with SRC 31982
6	Enveloping polygon on the block layer	Polygon from layer extent/GRAS[c]	Enveloping polygon created
7	Reproject enveloping polygon to UTM project appropriate for the region (DATUM 31982)	Reproject Layer/GRASS[c]	Centroid layer with SRC 31982
8	Boundaries of the enveloping polygon vector layer	Vector layer boundaries/GRASS[c]	Spatial delimitation of the reprojected enveloping polygon coordinates
9	Multi-weighted heatmap using the weight of the IDFAedes column and data of the delimitation produced in stage 8	Heatmap/SAGA[d]	Raster layer created
10	Migration of 'Mean' information on raster values consolidated per urban block	Zonal Statistical/GDAL[b]	Creation of 'mean' column on the block layer
11	Style applied to the layer produced in stage 10, categorizing 5 classes of the 'mean' column in equal intervals	Set style for vector layer/GDAL[b]	Blocks stratified in 5 categories

a) IDFAedes: Female Aedes Displacement Index .
b) GDAL: Geospatial Data Abstraction Library .
c) GRASS: Geographic Resources Analysis Support System.
d) SAGA: System for Automated Geoscientific Analyses.

Table 3 – Attributes of the priority areas for intervention and planning actions against the *Aedes aegypti* vector, selected for the annual dry period (May-September), Anápolis, Goiás, 2016-2017

Parameters	Intervention priority categories				
	Very low	Low	Medium	High	Very high
Quantity (number of blocks)	1,341	2,848	2,569	778	106
Area (ha.)	5,713	2,875	1,986	471	40
Breeding site density (number/ha.)	0.003	0.020	0.029	0.055	0.051
Population density (inhab./ha.)	13.2	89.4	128.6	144.8	203.6
Dengue case density (number/ha.)	0.03	0.42	1.67	2.56	3.96
Incidence (cases/100,000 inhab.)	359.9	749.9	2,045.5	2,785.5	3,054.6

Discussion

The model presented assumes accurate geocoding of the parameters used. Dengue breeding sites are input on SIMAZ, enabling geographic correspondence at the urban block level. However, dengue notifications can have certain conversion problems. The algorithm used has limitations with regard to interpretation of hierarchical levels, depending on input address variation. This fact is most serious for small cities where, generally, the addressing system is incomplete and/or out of date.

Detailed exploration of address geocoding nuances is beyond the objectives of this study, this being why the study stuck to commonly used systems (Web Service Geocode and Google Maps baseline). Notwithstanding, automatic geocoding error correction is possible, including correction of non-standardized input and correction of the geographic certainty indicator.[12]

It should be noted that address geocoding difficulties could be easily overcome on the national level, if the information input system (SINAN) migrated to or synchronized with the form of urban addressing for geographic addresses. Geocoding problems on the SINAN database may affect up to 16% of data, owing to database shortcomings.[13] On the state level, given the pre-existence of the SIMAZ system, the solution would be to integrate the notifying sector with this geographic information system.

The spatial block method proposed for this study differs from usual aggregation levels. They generally use political/administrative divisions (neighborhood, census tract, health district, municipality). Use of this

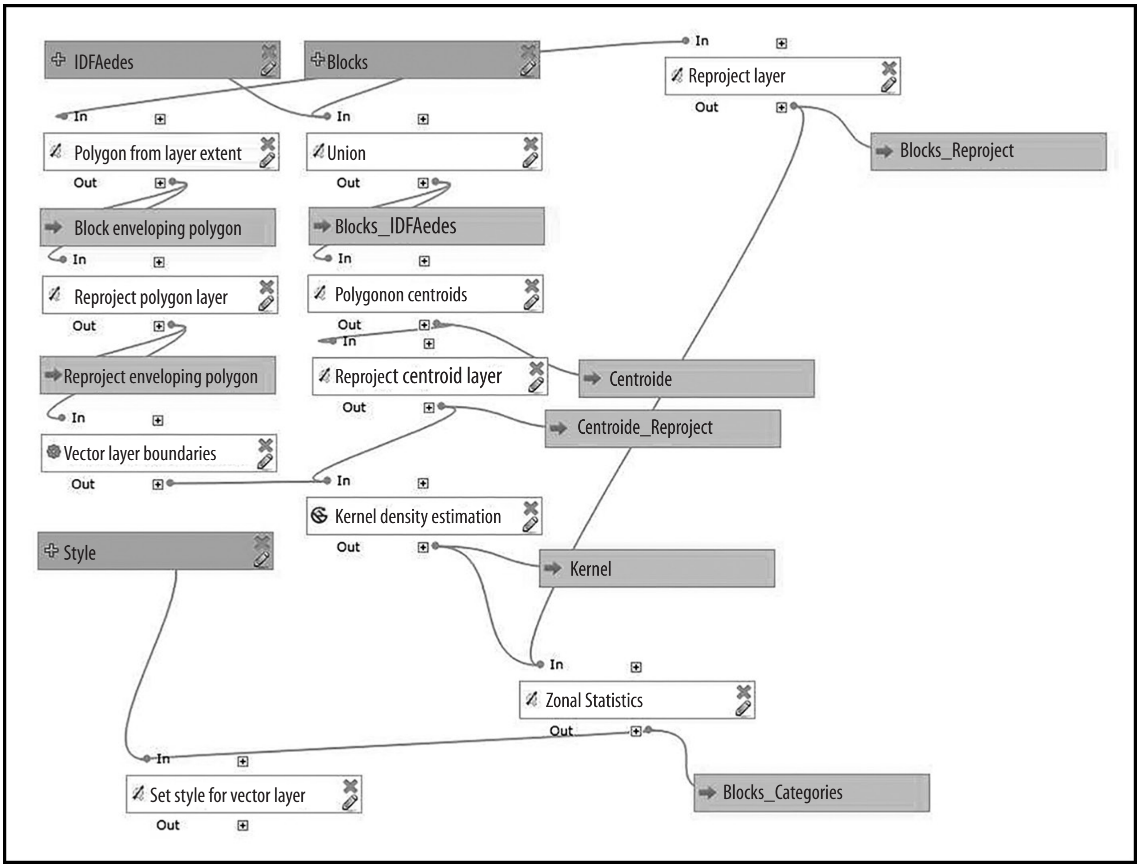

Figure 1 – Model built using the QGIS Model Builder

latter method persists owing to inertia, tradition or even because of indexation with current information systems. The processes, both environmental and social, that promote or restrict health risk situations are not limited to political/administrative boundaries.[4] It should be emphasized that the evolution of spatial analysis aggregation tools enables good interpretation of the environment-disease system, and breaking away from such divisions is fundamental for enhancing understanding of the modulation of this process.

Table 3 shows information segregated according to the level of stratification proposed in this study. It is important to emphasize that the areas taken to be a higher priority for intervention (very high and high) represented 11.6% of the blocks in the territory and just 4.61% of the extent of the urban area. However, in these clusters there was more intense convergence of interaction of the parameters that make them more vulnerable and, consequently, make them a priority as well. This interpretation of the territory represents an alternative for targeted intensification, which is promising for the model currently in force (universal and indistinct coverage).

The spatial block method used in this study is in accordance with the premises of the heterogeneous model of dengue transmission, according to which the probability of the vector contaminating a host differs between the different regions of the municipality.[14] This difference emanates from the population structure, and the graphical model proposed seeks to make this distinction.

Based on analysis of secondary data and application of the k-means and the kernel density curve methods for evaluating clusters, an instrument was proposed for planning *Aedes aegypti* control actions in Niterói, RJ,[4] and Natal, RN,[7] respectively.

Using kernel density curves in the multicriteria evaluation provided territorial stratification applied to health surveillance with neighborhood analysis and its influence on the production of risk factors in the different parts of the municipality. This is an interpretative gain, to the extent that each cell of the grid pre-established

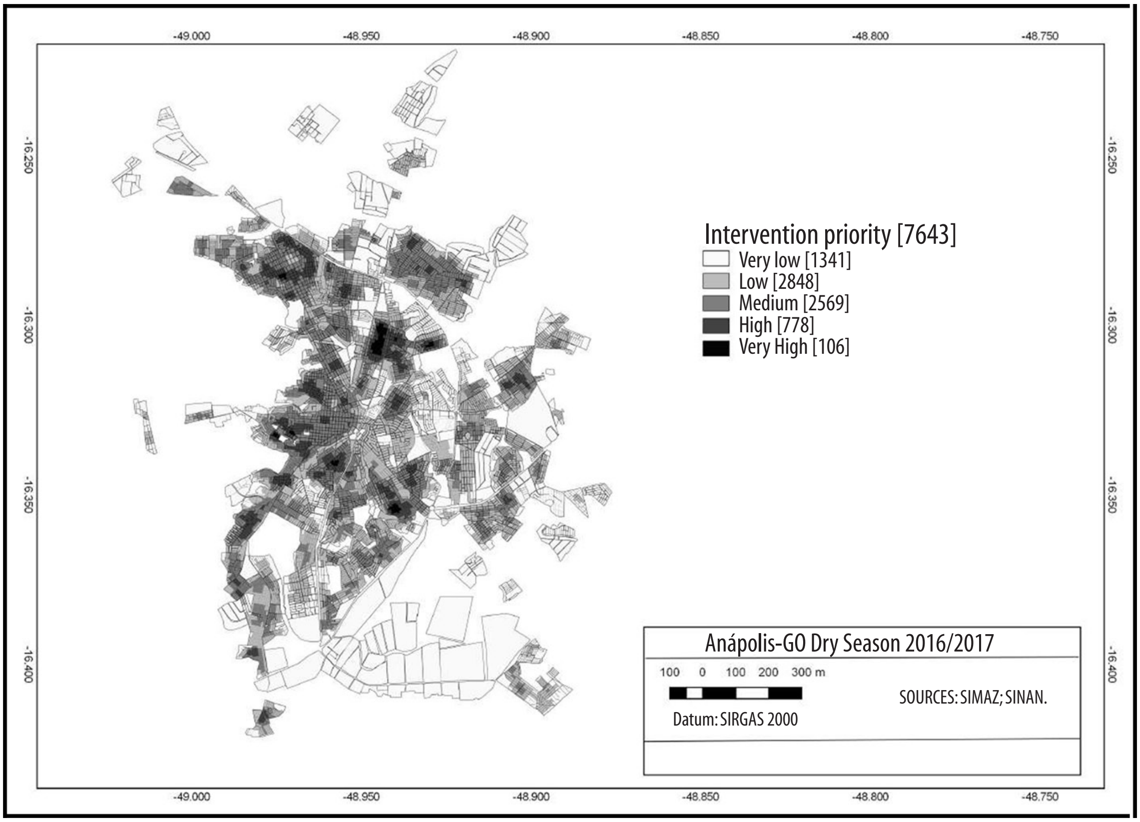

Figure 2 – Product obtained by applying the graphical model of automatic selection of priority areas for intervention and planning actions against the *Aedes aegypti* vector, Anápolis, Goiás, 2016-2017

in the input algorithm receives a score resulting from the weighted influence of the factors evaluated in the neighborhood (dengue cases, population density and presence of *Aedes aegypti* breeding sites).

Neighborhood analysis techniques and spatial dependence in the dynamics of dengue transmission have been investigated. A study conducted in the year 2006 in 157 of the 160 neighborhoods existing in the municipality of Rio de Janeiro, RJ, evaluated the spatial correlation between different indicators: the Gini index, the rainfall index and the Breteau index, and total dengue cases. Positive spatial correlation was found for all cases indicated by the global Moran's index in a temporal / spatial sample.[14] This signifies that there was a general spatial dependence pattern in the distribution of these indicators, i.e. adjacent neighborhoods had greater similarity than neighborhoods distant from each other.[13] It must be emphasized that positive spatial correlation of dengue notifications, as demonstrated by the authors of the cited article, as well as of the other parameters assessed, reveals the importance of including neighborhood analysis in area stratification.

Various different control protocols ('National Guidelines for Dengue Epidemic Prevention and Control', at federal level; and 'Goiás against ***Aedes***', at state level) adopt household visits in 100% of the urban grid with the same grading. In this work model, regardless of the social, environmental, entomological and epidemiological profile of the intervention areas, they receive the same treatment. The product proposed in this article (stratification in risk categories) can be included as a parameter for intensifying control actions in given areas, or for altering current intervention dynamics.

This article presented a proposal for parameters and for interaction between them, when building the matrix that informed the base table for the spatial areas considered. Notwithstanding, other criteria can be used but this in-depth discussion does not fall within the overriding objectives of the study in question, i.e., to present and discuss the results of an automatic area selection mechanism using GIS software.

We suggest that other area stratification methods be tested, such as including secondary data,[7-8] especially socio-economic data.[8] Other forms of series sequencing (percentile) can be tested, such as the use of natural breaks, standard deviation or equal interval. Other temporal clusters than the cluster used (2016 and 2017 dry season) can also be assessed. It should be emphasized that, regardless of the matrix that is built, the resulting table should be included in the graphic model proposed.

Including other entomological attributes, especially adult *Aedes aegypti* indices, will enable the model's sensitivity to be refined. Indicators such as the human development index (HDI) and the Gini index, schooling and income brackets, and degree of sanitation, can also be tested and validated. Moreover, it is of fundamental importance, to the extent that control actions are based on the stratification model proposed here, to modulate responses in stages,[7] in addition to mechanisms for evaluating the effectiveness and planning of feedback on the parameters used.

A graphical model was prepared using GIS open source software (QGIS 2.14 Essen), which involves simple inputs (table in .csv format, with usual current program parameters and shapefile of any inframunicipal geographic database). Despite the analytical complexity it includes (kernel density curves), the product of the model is intuitive and has a ramp user interface, with different colorimetric intensities. These are characteristics that make it easy for the model to integrate with current health information systems and, as such, they can assist with the generation of new health surveillance work routines.

Authors' contributions

Paiva-Júnior EF contributed to the conception and design of the study, data analysis and interpretation and writing the manuscript. Vaz TS, Rosa M and Garcia ILB contributed to data analysis and interpretation and relevant critical revision of the intellectual content of the manuscript. All the authors have approved the final version of the manuscript and are responsible for all aspects of the work, including guaranteeing its accuracy and integrity.

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