An Alert System for Informing Environmental Risk of Dengue Infections

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ABSTRACT: Dengue is a mosquito-borne infection the incidence of which varies with the environment and climate. Knowingly, the reported incidence of dengue is an insensitive indicator of infection risk in a locality. Ovitrap Index has been in use in many countries. This is a measurement of mosquito eggs in specified geographic location, which in turn reflects the distribution of *Aedine* mosquitoes, the vector for dengue. Using GIS application, an alert system was created from a synthesis of geospatial data on Ovitrap indices in Hong Kong. The inter-relationship between Ovitrap indices and temperature was made. This forms the rationale for the generation of weighted overlays to define risk levels. The weighting could be controlled to set the sensitivity of the alert system. This system can be operated at two levels, one for the general public to assist the evaluation of dengue risk in the community, and the other for professionals and academia for supporting technical analysis. The alert system offers one objective means to define risk of dengue in a society, which would not be affected by the incidence of the infection itself.

KEYWORDS: Health, GIS, Dengue Alert System, Ovitrap Index, Weighted Overlay

1. INTRODUCTION

Dengue is a mosquito-borne infection the incidence of which varies with the climate and environment. Ovitrap Index is a measurement of mosquito eggs in specified geographic location, which in turn reflects the distribution of *Aedine* mosquitoes. The main objective of this paper is to discuss an alert system with aid of geographic information systems (GIS) to describe the risk level of dengue infection in Hong Kong districts.

Aedes albopictus is the local vector of dengue fever. It is a day biter (the most active times are within 2 hours after dawn and before sunset) and a weak flier (about 100 meters). The presence of adult *Aedine* mosquitoes in selected areas is detected by the Oviposition Trap (Ovitrap), which is a simple device made up of a black plastic container with brownish oviposition paddle placed diagonally (figure 1) (FEHD 2006).

Fig.1 Ovitrap

The Ovitrap Index is measured monthly with the distribution of 38 locations for vector surveillance in Hong Kong. It is formulated as:

$$OvitrapIndex = \frac{no.ofAedes - positiveOvitrpas}{no.ofOvitraps} X100\% \qquad (1)$$

There are the Area Ovitrap Index (AOI) and the Monthly Ovitrap Index (MOI). The Ovitrap Index in this paper refers to AOI. AOI indicates the extensiveness of the distribution of *Aedine* mosquitoes in that particular area surveyed (FEHD, 2006).

There are specific preventive and control measures recommended for each alert level:

Classification	Ovitrap Index	Action to be taken
Level 1	<5%	Closely monitor the hygienic condition to prevent breeding Conduct weekly inspection to identify breeding/potential breeding places and eliminate
Level 2	5%<=O.I<20%	Public are advised to check and eliminate possible breeding places within their premises at least once a week
Level 3	20%<=O.I<40%	Conduct special operations in addition to the regular weekly program to eliminate all breeding/potential breeding places
Level 4	O.I>=40%	Private pest control contractor might be employed to control the mosquito problem. Other control measures by using larvicides or adulticides might be feasible

Table 1 Level of Action to be taken (FEHD 2006)

2. System Design and Development

2.1. Assumption

The alert system is designed to predict the risk of dengue infection. It is assumed that the two factors used in the system, namely temperature and Ovitrap Index, are strongly associated with exposure to dengue fever infection and are of great geographic significance.

2.2. Data Source

Data on Ovitrap Index for 2004 and 2005 are available from the Food and Environmental Hygiene Department (FEHD), and the 2004 and 2005 monthly mean temperatures from the Hong Kong Observatory. The base map of Hong Kong is obtained from the Geography and Resource Management Department, the Chinese University of Hong Kong.

2.3. Conceptual Design

The alert system is divided into two modules, one on technical analysis and the other being the alert system proper. The system is designed for four levels of users. The first level is the general public with limited data access. The second level is for researchers with more data access who may not be familiar with GIS software operation. User interfaces are designed for the first two levels to allow limited usage of GIS tools without difficulty. The third level is meant for researchers familiar with GIS software operation who are able to conduct in-depth analysis with GIS tools. The fourth level users are those maintaining the system.

First level users can only have access to the current Ovitrap Index, risk level data and the corresponding measures by selecting the area concerned.

For second level users who only have little knowledge of GIS software usage, interfaces are designed to facilitate their access to advanced data such as Ovitrap Index from 2004 onwards and buffer area.

Third level users are those familiar with GIS. They have easy access to and can reach more data available for analysis. The data accessible for level two and level three users include past and current statistics on Ovitrap Index. A login system is set up for distinguishing the type of users. In addition, they can use different GIS function tools advised for undertaking analysis. For instance, the buffer function gives them a concept of affected and potentially affected area.

The last level is for data maintenance officers who have the right to access, change and update the database. User interfaces are also designed to simplify their work. They can either enter the data directly to the attribute table through the interface or by adding the table from other sources.

The alert level used in the dengue alert system is built according to the guidelines of the FEHD as listed in figure 2. There is only one factor, Ovitrap Index, affecting the risk level. However, the results of weighted overlay analysis offer another perspective for assessing the risk level. Thus, weighted overlay is recommended to researchers to investigate the feasibility and standardization of the new set of risk level.

2.4. Function and Software Requirement

The functions required are graduated color mapping for spatial distribution analysis, buffering for showing affected and potentially affected area, zoom-in for clearer view, raster calculator for raster data overlay, weighted overlay for controlling the sensitivity of alert system and Visual Basic Editor for user interface programming.

The hardware needed in the system is a computer and the software needed is GIS software ArcMap developed by ESRI. It enables users to go for spatial data building, modeling, analysis, and map display.

2.5. System Framework

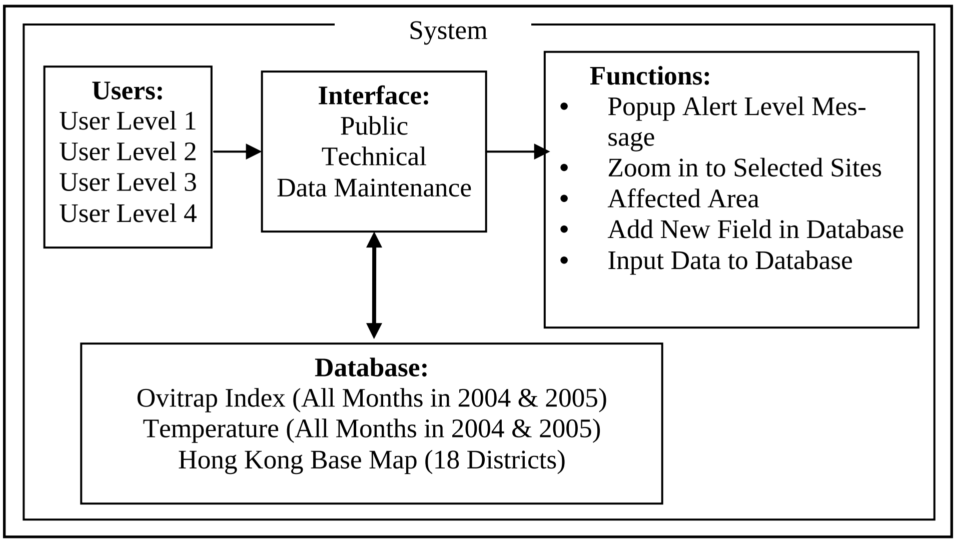


Fig. 2 System Framework

The system framework (figure 2) shows the components in the system. There are four user levels and three user interfaces providing easy of access data and functions to users. Level 1 users use the “Public” interface for knowing the alert level and action advised for them. Level 2, 3 and 4 users can also be level 1 users as no login is required. Level 2 and 3 users can find out the affected area through “Technical” interface. In addition, level 4 users have the right to change the data of the system through the “Data Maintenance” interface. These interfaces help the corresponding users access the functions and database of Ovitrap Index, temperature and Hong Kong base map in different extent.

2.6. System Development

To begin with, the project objectives are determined and user requirement is analyzed. Then, the flow charts are designed for the system. After data collection and processing, GIS functions are explored and processed. The alert system is then put in the testing stage and necessary modification is conducted. Finally, data maintenance methods and details are defined.

3. Application- Dengue Alert System

3.1. Documentation

First of all, raw monthly 2004 and 2005 temperature data and temperature station coordinates are stored in dbf file. Then, the station data are geo-referenced by GIS according to the X and Y coordinates. New raster layer (figure 3) is created by inverse distance weighted in spatial analyst extension, which generates an estimated surface from a scattered set of points, with means monthly temperature for each month.

Fig.3 Raster Layer of Temperature

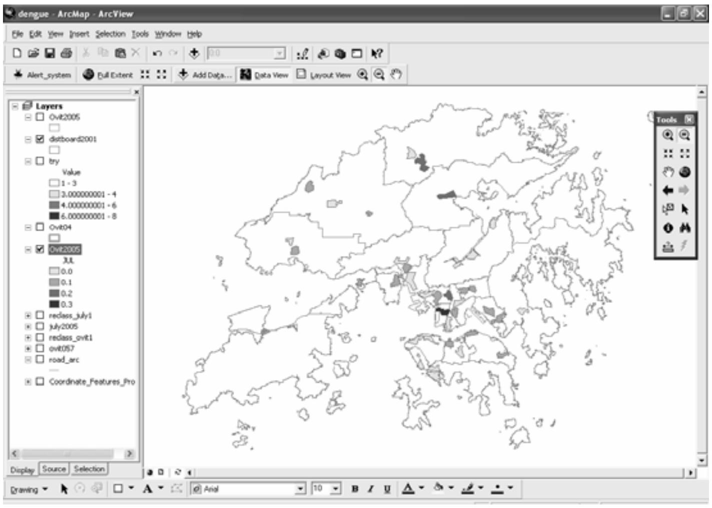


Fig.4 Ovitrap Index Site Polygon Layer

The raw data of Ovitrap Index 2004 and 2005 are stored in dbf file as well. The dbf file is joined with the attribute table of the geo-referenced Ovitrap Index site polygon layer (figure 4). Finally, the base map of Hong Kong is overlaid for visualization.

3.2. Spatial Query

The forms for interface are frm files, which have been designed under Visual Basic Editor. Users will be asked if he/she is “Public” or “Academic”.

After entering the system designed for public users, one can select to view the risk of Dengue in the whole territory of Hong Kong or go into different district in Hong Kong to obtain detailed information (figure 5).

Fig.5 Function Selection Box

Fig.6 Selection with Combo Box

If a user selects “District” (figure 5), he/she can go to the combo box shown in figure 6. One can select the site he/she is concerned with.

After the selection of district, logical operation will be carried out in the system, and relevant information will pop up in dialog box according to the result of logical operation, i.e. from no potential danger (Level 0) to alert level (Level 4).

Users can choose to exit the system by clicking the “Finish” Button or go back to select other operations by simply clicking “Back”.

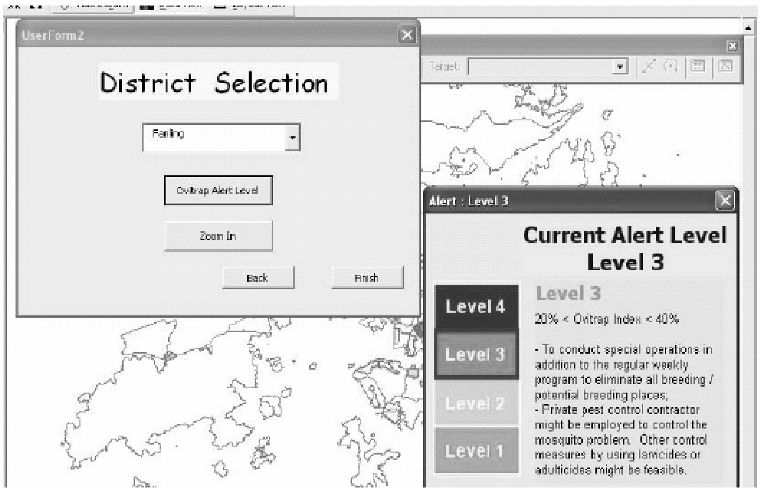


Fig.7 Alert Message Pop Up

For instance, by selecting the site area from the interface, such as Fanling, one can find out the alert level at that time, which is Level 3 in our example (figure 7). The user can also read the advice on preventing dengue infection in the message box.

Technical users are assigned an individual user ID and password. After choosing the user type as “Academic”, a login dialog box (figure 8) pop up and the user would be required to input the ID and password before one is allowed to retrieve detailed information. If user ID and password are inputted wrongly, an error message will pop up, and the user would be asked to input again until the correct one has been typed in. This mechanism serves to protect the security of data under research. A welcome message will pop up once the login is successful. If users do not have their ID and password, they can simply quit the system by clicking “Quit”.

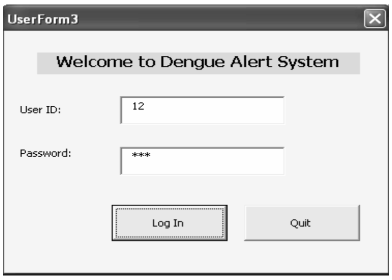


Fig.8 Login Dialog Box

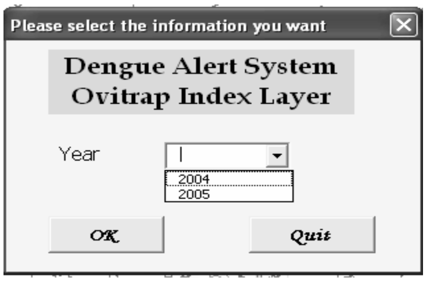


Fig.9 Selection of Temporal Data

Again, a combo box (figure 9) can be used by an academic (technical) user to make the selection. As a demonstration, the existing database has included only two years’ data. Both the contents of the database and selections could be increased in future.

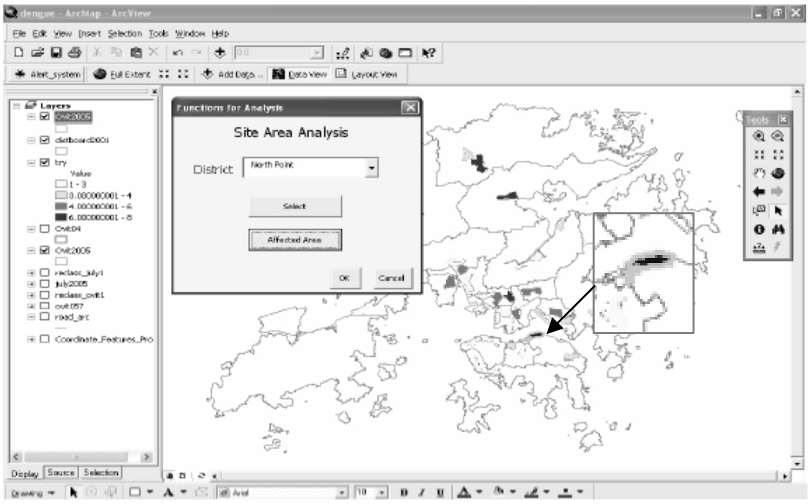


Fig.10 Site Area Analysis

Technical users can also determine the buffer zones of the areas concerned. This function enables them to have a general idea of the affected and potentially affected area (enlarged area in figure 10). Professionals responsible for control measures can expand the boundary to a wider area, 100 meters from the site area.

3.3. Analysis Process

3.3.1. Weighted Overlay

The weighted overlay is set up for Level 3 users who can perform analysis even without the aid of the alert system interface. They can use the data readily available for them, such as the database of temperature, Ovitrap Index and Hong Kong base map.

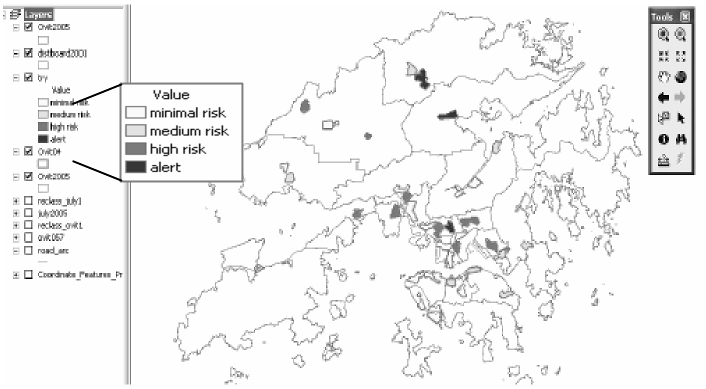


Fig.11 Results of Weighted Overlay

Figure 11 shows the result of weighted overlay of temperature (40% weighting) and Ovitrap Index (60% weighting) in July 2005. The darkest areas are defined as those with the highest risk, called alert level, the dark grey areas are high risk areas, the light grey areas are with medium risk and the white areas are with minimal risk. Thus, Tai Po and one site in Northern District are classified as highest risk area, as supported by the higher temperature and Ovitrap Index in July 2005. When overlaid with temperature (figure 12), the contribution of temperature on the result of weighted overlay can be evaluated. Temperature is not the main factor determining the risk level due to the weighting assigned and the use of multiplication in the formula. When the Ovitrap Index equals zero, the risk level will be zero as well, no matter how high the temperature is. For instance, though the temperature is similar for Kowloon Tong and Yau Tsim Mong, they have very different risk levels.

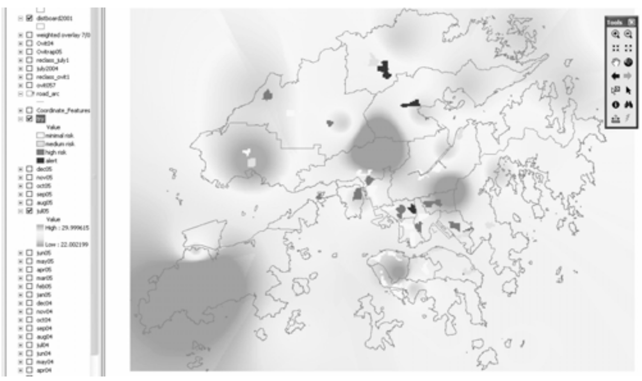
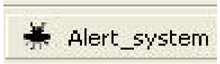


Fig.12 Overlay with Temperature and Result of Weighted Overlay

3.3.2. Alert System

All levels of users can access to the system by clicking 

to start the system.

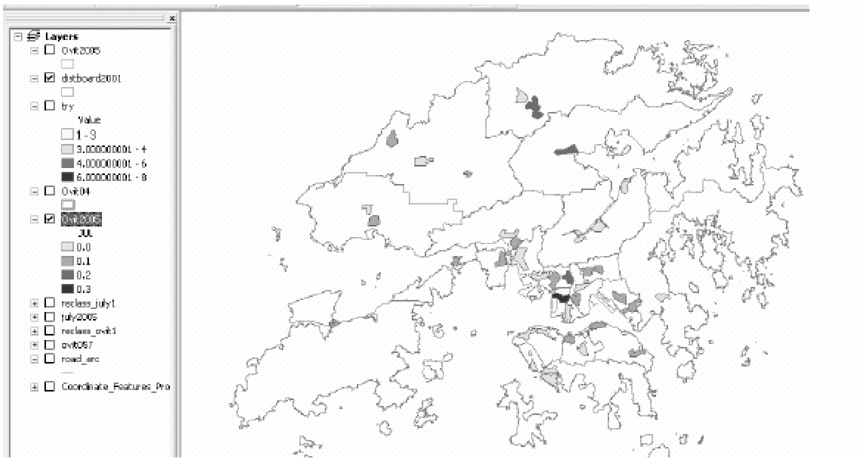


Fig.13 Ovitrap Index in July 2005

Besides what have been mentioned above (see Sect. 3.2), the users can also conduct analysis with the graduated colour map (figure 13). The site areas with different alert levels are shown. They can view the distribution of Ovitrap Index of a particular month, such as July 2005, in Hong Kong. From the distribution, for example, it is found that Eastern, Wong Tai Sin, Kwun Tong, Yau Tsim Mong and Tai Po are with higher Ovitrap Index. They can compare the situation with other months to determine the temporal change of Ovitrap Index in spatial scale.

4. Discussion

4.1. The Weighting of Factors

Two factors are used in the system, namely Ovitrap Index and temperature. From the temporal change of temperature and Ovitrap Index, a strong association between the two factors is found. Higher Ovitrap Index mostly concentrates in summer and autumn, the months with higher temperature.

Thus, it is believed that these two factors contribute significantly to the activity of *Aedes albopictus.* Spatially shown by GIS map, however, temperature variation is small at, for instance, around 2 ^{o}C, in July 2005. Geographic temperature variation is quite minimal in some months in Hong Kong due to the small area of the districts. It is advised to assign heavier weighting to Ovitrap Index at the weighted overlay analysis. Apparently, without the presence of *Aedine* mosquitoes, there is no risk even if the temperature is very high.

4.2. Other Possible Factors

In our system, the risk of dengue infection is assessed mainly by the favorable environment for *Aedine* mosquitoes breeding and the extent of protection against the *Aedine* mosquitoes. Other potential factors can be added to the system.

Vanwambeke et al. (2006) investigated the determinants of dengue infection in Thailand and discovered that the location of a person and the environment around the house were crucial. Density of human population can be an important factor, as a desert region with lots of *Aedine* mosquitoes can be regarded as not risky. Also, if the environment around the house is very favourable for *Aedine* mosquitoes breeding, there is a higher risk of dengue exposure. Thus, temperature, humidity, containers, vegetation and topology can be influential factors. Finally, the species of mosquitoes also plays a role, as it’s known that *Aedes albopitus* may not be the most efficient vector for the virus.

Currently, Ovitrap Index alone is used by the FEHD for the classification of risk levels. However, the 31 cases of dengue fever reported in 2004 and the same in 2005 in Hong Kong had a wide distribution over months, including January and February, when Ovitrap Index was almost zero (Table 2). Apparently many dengue infections were imported cases, the occurrence of which was unaffected by local risk levels.

Disease	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dengue Fever 2005		2	1	3		2	2	4	5	4	4	4	31
Dengue Fever 2004	5	3	1	1	2	2	3	5	4	1	2	2	31

Table 2 Dengue Fever Infection (Department of Health 2006)

4.3. Preventive Measures

The main aim of the alert system is raising public awareness for enhancing personal protection against dengue exposure. Knowledge of exposure risk and an advice on appropriate action is very important. For members of the public, this alert system must be user friendly, attractive and complete with geographic visualization. By selecting the site area concerned, a user can, in the same setting, find out the alert level at the point of time, learn about what to do, and may even zoom to the site area for a closer look.

The actions suggested in the website of FEHD are very thorough, including both elimination of *Aedine* mosquitoes and personal protection against *Aedine* mosquitoes. However, the personal protection advice is not included in conjunction with the level of action to be taken (see figure 2). It is advisable to include this as a reminder.

5. Limitations and Future Prospect of the System

Our system is not without limitations. In real life, many factors affect the risk of dengue infection, including those of the host, the virus, vector, and the environment. The combination of temperature and Ovitrap Index offers one aspect of risk assessment, focusing on the determination of exposure risk alone. Other factors could be explored and included for enhancing the robustness of the system. On the other hand, an alert system shall be viewed and used in perspective. Other information, for example, epidemiology of the infections in the region, vector characteristics, and the distinction between imported and local infections, would be important for interpreting the risk as defined by the alert level. The limitation of the alert system as a warning mechanism on the risk of local exposure should be made known to its users.

This pilot project has the potential of being expanded to become an ongoing programme that can be established in collaboration with the concerned government departments. In future, it would be meaningful to integrate the system with activities on the prevention and control of dengue fever; and to develop training to professionals on dengue vector control. Similar systems could be established and applied for supporting the assessment of exposure to other infections such as bird flu, for which environmental factors are important in propagation. Moreover, the alert system could be put on the Internet so that is can be widely accessible to the general public as a user-friendly risk assessment tool.

6. Conclusion

We have designed an alert system for users to visualize the spatial distribution of risk of exposure to *Aedine* mosquito in the local setting. The system complements information on the incidence of infection, and is a more objective way of defining risk level. Overall, the system helps to consolidate the spatial concept of risk level with the aid of GIS. Currently, statistics on the Ovitrap Index is displayed in the format of a table which is difficult for interpretation by general users. This project allows the visualization of Ovitrap Index information in a spatial pattern and in association with four risk levels, which serves to enhance public awareness. For researchers, dengue fever can be analyzed in a spatial and temporal manner using weighted overlay analysis tool in GIS, contributing to an integration of public health and geographic studies.

This project's significance is the introduction of a new method for expressing the alert system in spatial scale. Alert system should no longer be expressed in statistical and textual formats, but that spatial graphics could be incorporated. In addition, the weighted overlay allows the users to weigh the contribution of factors affecting the exposure risk to dengue. This is therefore both a more objective platform for informing risk, and an experimental tool for testing the influence of various factors on the distribution of risk level by changing the variable's weighting.

Finally, the alert system can contribute to the prevention of dengue infections in the real situation. The system raises the alertness of the public, and links users to personalised advice. Effective prevention requires the active participation by all sectors of the community including construction companies, property managers, architects and individual families aiming at source reduction. It is a complex problem requiring full community participation.

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