Seen from above: how satellite technology can fill gaps in mosquito biology


Medical and Veterinary Entomology Unit
Institut Pasteur du Cambodge

GeoOneHealth 2022 – South East Asia
Symposium on Geospatial Approaches in One Health Studies
5 December 2022, Phnom Penh, Cambodia
Dengue is endemic in Cambodia (WHO)
The 4 DENV serotypes circulate (Vong et al. 2010)
Estimated 14,000 cases per year (WHO)
Regular outbreaks in Cambodia

* Aedes aegypti & Aedes albopictus
  Main DENV vectors

Vector control management:
  * Temephos (Abate) as larvicide
  * Deltamethrin and Permethrin as adulticide
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Context

- Dengue is endemic in Cambodia (WHO)
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Resistance of *Aedes aegypti* (Diptera: Culicidae) Populations to Deltamethrin, Permethrin, and Temephos in Cambodia

Published in 2018

Monitoring insecticide resistance of adult and larval *Aedes aegypti* (Diptera: Culicidae) in Phnom Penh, Cambodia

Published in 2022
ECOnomic development, ECOsystem MOdifications, and emerging infectious diseases Risk Evaluation

Evaluation of integrated vector method control management in schools

Do vector control in school lead to a community decrease of DENV transmission?
ECOnomic development, ECOsystem MOdifications, and emerging infectious diseases Risk Evaluation

Evaluation of integrated vector method control management in schools

Passive monitoring of dengue-like syndroms in Health centers

Do vector control in school lead to a community decrease of DENV transmission?

Serological monitoring for dengue with salivary test in school
Epidemiological Approach

Cluster Randomized Controlled Trial Study
Kampong Cham & Tbong Khmum Provinces
Epidemiological Approach

Cluster Randomized Controlled Trial Study
Kampong Cham & Tbong Khmum Provinces

- **24 clusters in 5 districts**
  - 71 villages (26 in urban/peri-urban)
  - 78,741 population
  - ~15,000 children aged 5-15 years old

- **One cluster**
  - **One SCHOOL** with primary grade
  - Several VILLAGES (300+ children aged 5-15 y.o.) surrounding and depending on that school
Entomological sampling

Sampling
- 24 hour per schools
- BG & CDC LT
- 4 times / year
- 3 years

Main entomo results
Mosquito species

HIGH BIODIVERSITY!

- ~ 60,000 mosquitoes
- 12 genus
- > 67 species
**Mosquito species**

- **Aedeomyia catasticta**
- **Aedes aegypti**
- **Aedes albopictus**
- **Aedes imprimens**
- **Aedes lineatopennis**
- **Aedes amalyensis**
- **Aedes mediolineatus**
- **Aedes vexans**
- **Aedes w-alba**
- **Aedes sp**
- **Armigeres magnus**
- **Armigeres subalbatus**
- **Armigeres theobaldi**
- **Armigeres sp**
- **Coquillettidia crassipes**
- **Coquillettidia ochracea**
- **Coquillettidae sp**
- **Anopheles aconitus**
- **Anopheles annularis**
- **Anopheles agyrops**
- **Anopheles barbicornis**
- **Anopheles barbumbrosus**
- **Anopheles campestris**
- **Anopheles crawfordi**
- **Anopheles hodgkinii**
- **Anopheles indefinitus**
- **Anopheles nigerrimus**
- **Anopheles nitidus**
- **Anopheles peditaeniatus**
- **Anopheles philippinensis**
- **Anopheles separatus**
- **Anopheles sinensis**
- **Anopheles subpictus**
- **Anopheles tessellatus**
- **Anopheles vagus**
- **Anopheles sp**
- **Culex bitaeniorynchus**
- **Culex brevipedis**
- **Culex fuscoccephala**
- **Culex gelidus**
- **Culex hutchinsoni**
- **Culex infantulus / minutissimus**
- **Culex malayi**
- **Culex nigropunctatus**
- **Culex quinquefasciatus**
- **Culex sinensis**
- **Culex sitiens**
- **Culex tritaeniorynchus**
- **Culex Vishnuii**
- **Culex whitmorei**
- **Culex wilfedi**
- **Culex sp**
- **Lutzia fuscana**
- **Lutzia halifaxii**
- **Lutzia vorax**
- **Lutzia sp**
- **Mansonia annulifera**
- **Mansonia indiana**
- **Mansonia uniformis**
- **Mansonia sp**
- **Mimomyia aurea**
- **Mimomyia elegans**
- **Mimomyia hybrida**
- **Mimomyia luzonensis**
- **Mimomyia sp**
- **Uranotaenia bimaculiala**
- **Uranotaenia lateralis/subnormalis**
- **Uranotaenia longirostris**
- **Uranotaenia micans**
- **Uranotaenia nivipleura**
- **Uranotaenia rampae**

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- **Culex whitmorei**
- **Culex wilfedi**
- **Culex sp**
- **Ochlerotatus vigilax**
- **Tripteroides sp**
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<th>Potential Vector Species</th>
<th>Number of Mosquitoes</th>
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<tr>
<td><strong>JEV</strong></td>
<td>12</td>
<td>39,900 (68%)</td>
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<td><strong>Malaria</strong></td>
<td>10</td>
<td>9,494 (16%)</td>
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<td><strong>RVFV</strong></td>
<td>7</td>
<td>10,441 (18%)</td>
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<td><strong>ZIKV</strong></td>
<td>5</td>
<td>8,349 (14%)</td>
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<td><strong>WNV</strong></td>
<td>4</td>
<td>9,123 (16%)</td>
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<tr>
<td><strong>CHIKV</strong></td>
<td>4</td>
<td>2,208 (4%)</td>
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<td><strong>DENV</strong></td>
<td>3</td>
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New Research objective

- Many mosquito species
- High proportion of vector species
- Randomized schools (=randomized environment)
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But an absence of spatial and temporal analysis

- How to link the distribution of mosquito species to environmental indicators?
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But an absence of spatial and temporal analysis

- How to link the distribution of mosquito species to environmental indicators?

-> Entomological data
-> Spatial data
-> Temporal / environmental data
-> Meteorological data
Entomological data
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24 schools
Kampong Cham province
Tbong Khmum province
aleatory chosen schools
all schools separated by at least 5 kms

12 samplings
every 3 months
during 3 years
Entomological data

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12 samplings
Every 3 months
during 3 years

6 school & demographic parameters
1. Presence of pagoda
2. Number of trap
3. Number of children in school
4. Number of children in the cluster
5. School area
6. Village population
Spatial data: OpenStreetMap
Spatial data: OpenStreetMap

- **Mapping**: 500m radius
- **Calculating length, areas, perimeters**
Spatial indicators
1. Number of houses
2. Roads
3. Forest
4. Road network
5. Water area
6. Wetland
7. Rivers
...

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Spatial data: OpenStreetMap

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Spatial data: OpenStreetMap

- Mapping: 500m radius
- Calculating length, areas, perimeters
- Creation of a mask

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Spatial data: OpenStreetMap

Mask creation

✓ Grey: school buffer area (500m radius)
✓ Blue: buildings, houses
✓ Red: permanent water areas
Temporal / Environmental data
Temporal / Environmental data

**Sentinel-2 satellites**

- Earth observation satellites (Copernicus program)
- Developed by European Space Agency
- 2 satellites in the same orbit
- 1 satellite image of the area / 5 days
- High resolution multi-spectral images: passive optical sensors
Temporal / Environmental data

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**From satellite image to database**
- 13 spectral bands
- from visible to invisible infrared
- 10,980 x 10,980 pixels
Different profiles for different spectral signatures

Temporal / Environmental data

Visible near infrared medium infrared
Different profiles for different spectral signatures

Environmental indices

**Vegetation Index (NDVI)**
- sensitive to the vigour and quantity of vegetation
- $\neq$ between read and near infrared bands

**Water index (NDWI)**
- *Gao*: changes related to leaf water content
  - $\neq$ between near-infrared and short-wave infrared bands
- *Mc Feeters*: water content related changes in water bodies (pond, pool, flood)
  - $\neq$ between green and near infrared bands
Temporal / Environmental data

NDVI

NDWI Gao

NDWI Mc Feeters
Temporal / Environmental data

- For each NDVI and NDWI:
  - Creation and application of a mask on the buffer zones
  - Extraction of environmental indices per image and for each buffer zone
  - Study on the quality of satellite images
  - Creation of prediction models
Temporal / Environmental data

Mask creation

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Temporal / Environmental data

Mask creation

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• Buffer zone with mask (NDVI):
  - Removal of buildings
  - Removal of permanent water areas
Temporal / Environmental data

Buffer area (500m radius)
Temporal / Environmental data

Quality of satellite images per school:

✓ ≤ 75% missing values

✓ Pre-processing problems: deletion of satellite images for several dates

✓ 95% correlation between NDVI and Mc Feeters’s NDWI
Temporal / Environmental data

Average NDVI with mask - only images with < 75% NAs

Date of observation of satellite images
Average NDWI Gao with mask - only images with < 75% NAs

Temporal / Environmental data
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Model calibration

• **Analysis on all schools** with 5 explanatory variables
Temporal / Environmental data

Model calibration

• **Analysis on all schools** with 5 explanatory variables

• **3 prediction models**
  GLM with stepwise method
  Random forests based on conditional inference trees
  SVM (Support Vector Machine) with linear, polynomial and Gaussian kernel
Temporal / Environmental data

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• **Deep learning** model on ¾ of the initial dataset
• **Cross-validation** K-fold repeated 5 times (K = 10)
• Determination of optimal parameters (train function of R caret module)
Temporal / Environmental data

Time average NDVI (observed and predicted)
Temporal / Environmental data

Time average Gao NDWI (observed and predicted)
Temporal / Environmental data

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⇒ **Best model**: Random forests on NDVI and Gao NDWI (lowest RMSE)
• 44 factors:

✓ 18 environmental indicators (Day 0, 5, 10, 15, 20, 30, 40, 50, 60 for NDVI & Gao NDWI)

✓ 13 spatial indicators (number of houses, rivers, roads ...)

✓ 6 school & demographic parameters (pagoda, nb of children, population...)

✓ 7 meteorological data (temperature, precipitation, humidity...)
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Model

- 44 factors
- IVM x Year

Correlation matrix (>90%)
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Model

44 factors

IVM x Year

Correlation matrix (>90%)

Fisher bivariate analysis with variables (10%)

• Biodiversity indices
• Relative abundance of species
• Presence of species
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- 7 variables for Shannon index
- 6 variables for *Ae. aegypti*
- 5 variables for *Ae. albopictus*
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Results

Example of Biodiversity with Shannon index

- NDWI (day – 5) *
- Minimal temperature **
- Total precipitation *
- Relative humidity *
- Treatment ***
- Year 1/Year 2 *
- Relative Humidity* Year 1/Year2 ***

1 environmental indicator (satellite)
3 meteorological data
2 automatic inclusion (IVM + Year)
See from above: how satellite technology can fill gaps in mosquito biology

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**Example with *Aedes albopictus***

- NDVI (day – 20) ***
- Forest perimeter **
- Number of school children ***
- Wind speed *
- Year 1/Year 2 ***

1 environmental indicator (satellite)
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1 environmental indicator (satellite)
1 spatial indicator
1 school & demographic parameter
1 meteorological data
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- Number of school children ***
- Wind speed *
- Year 1/Year 2 ***

1 environmental indicator (satellite)
1 spatial indicator
1 school & demographic parameter
1 meteorological data
1 automatic inclusion (IVM + Year)

Examples with *Aedes aegypti*

- Presence of small river ***
- Flooding area *
- Relative humidity **
- Max temperature ***
- Month of collect ***
- Treatment **

2 spatial indicators
2 meteorological data
2 automatic inclusion (IVM + Year)

**Results**

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Model

44 factors
IVM x Year

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Multivariate analysis on
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**Results**

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<th>N</th>
<th>N schools</th>
<th>N missions</th>
<th>Factors</th>
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<td>7894</td>
<td>24</td>
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<td>treatment NDVI.90</td>
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<td>5693</td>
<td>24</td>
<td>12</td>
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<tr>
<td><em>Anopheles barbumbrosus</em></td>
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**Understudied species**

**Coquillettidia crassipes**
**Results**

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Understudied species

Limit of relative abundance. Interest of presence/absence
### Results

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**Meteorological data**

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**Importance of environmental and spatial data**
Conclusion

• Diversity of environmental profiles with spatial and environmental indicators
• Very good estimation of NDVI and NDWI of Gao
• Mosquito species ↔ environmental data (vegetation and humidity)
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Application to one/several vector species: interest in generalizing models vs. *species/population* effect?
Reflection on the notion of *scale* for a mosquito population/species
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Reflection on the notion of scale for a mosquito population/species

Satellite image acquisition method and potential for high resolution monitoring compared to weather data

Disparity not related to weather but environments

Real impact of climate change? Only indirect?
Thank you for your attention