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

Boyer S, Maquart PO, Jego S, Marcombe S, Revillion C, Hoeun S, Girond F, Herbreteau V

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

Context

- 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

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

Context

- 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


Resistance of *Aedes aegypti* (Diptera: Culicidae) Populations to Deltamethrin, Permethrin, and Temephos in Cambodia

Asia Pacific Journal of Public Health
1–9
© 2018 APJPH
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/1010539517753876
journals.sagepub.com/home/aph
SAGE

Sébastien Boyer, PhD[1], Sergio Lopes, Msc[2], Didot Prasetyo, PhD[3], John Hustedt, Msc[2], Ay Sao Sarady, Msc[2], Dyna Doum, Msc[2], Sony Yean, Msc[1], Borin Peng, Msc[1], Sam Bunleng, Msc[4], Rithea Leang, PhD[4], Didier Fontenille, PhD[1], and Jeffrey Hii, PhD[5]

Published in 2018


Boyer et al. Parasites & Vectors (2022) 15:44
https://doi.org/10.1186/s13071-022-05156-3

Parasites & Vectors

RESEARCH Open Access

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

Sebastien Boyer[1,2*], Pierre-Olivier Maquart[1], Kalyan Chhuoy[1], Kimhuor Suor[1], Moeun Chhum[1], Kimly Heng[1], Sokkeang Leng[1], Didier Fontenille[1,3] and Sebastien Marcombe[4]

Published in 2022

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

ECOnomic development, **ECO**system **MO**difications, and emerging infectious diseases **R**isk **E**valuation

Evaluation of integrated vector method control management in schools

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

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

ECOnomic development, **ECO**system **MO**difications, and emerging infectious diseases **R**isk **E**valuation

Evaluation of integrated vector method control management in schools

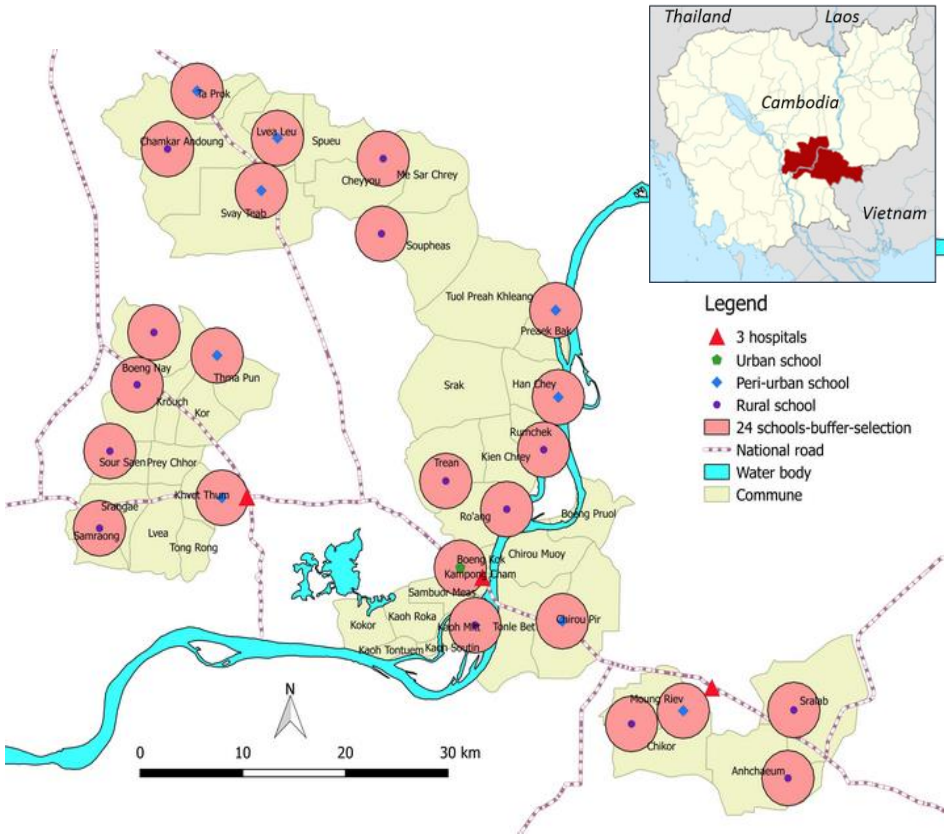
Passive monitoring of dengue-like syndroms in Health centers

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

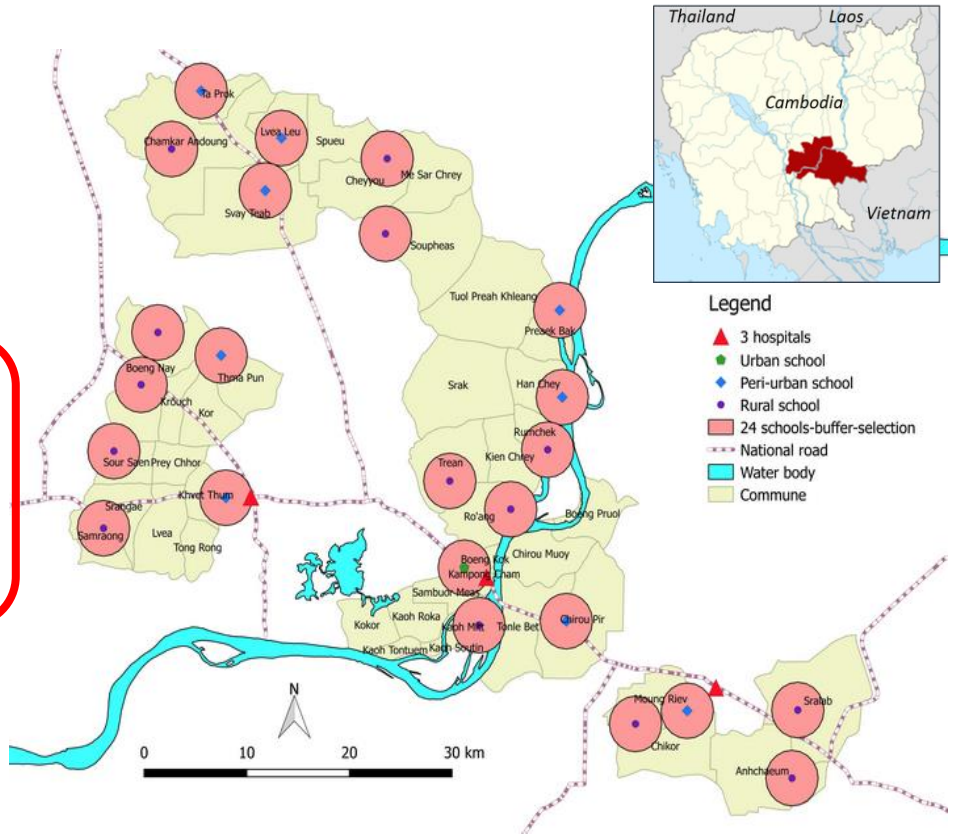


Epidemiological Approach

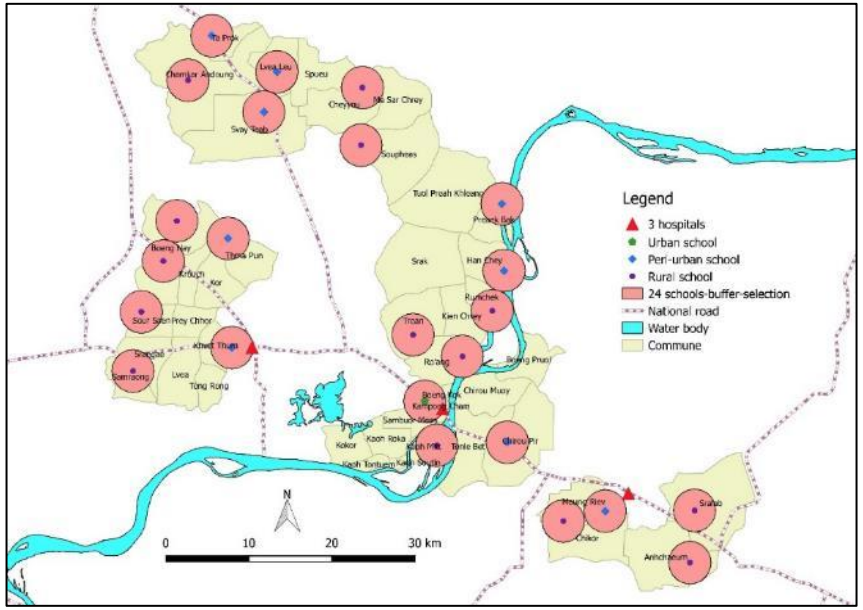
Cluster Randomized Controlled Trial Study
Kampong Cham & Tbong Khmum Provinces

- **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**
  - <u>One SCHOOL</u> 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

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

Mosquito species

HIGH BIODIVERSITY !

- ~ 60,000 mosquitoes
- 12 genus
- > 67 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
Coquillettidia sp

Anopheles aconitus
Anopheles annularis
Anopheles agyropus
Anopheles barbirostris.g
Anopheles barbumbrosus
Anopheles campestris
Anopheles crawfordi
Anopheles hodgkini
Anopheles indefinitus
Anopheles nigerrimus
Anopheles nitidus
Anopheles peditaeniatus
Anopheles phillippinensis
Anopheles separatus
Anopheles sinensis
Anopheles subpictus
Anopheles tessellatus
Anopheles vagus
Anopheles sp

Culex bitaeniorhynchus
Culex brevipalpis
Culex fuscocephala
Culex gelidus
Culex hutchinsoni
Culex infantulus / minutissimus
Culex malayi
Culex nigropunctatus
Culex quinquefasciatus
Culex sinensis
Culex sitiens
Culex tritaeniorhynchus
Culex vishnui.g
Culex whitmorei
Culex wilfedi.g
Culex sp

Ochlerotatus vigilax

Tripteroides 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

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

Mosquito species

HIGH BIODIVERSITY !

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

Aedeomyia catasticta

Aedes aegypti
Aedes albopictus
Aedes impri
Aedes lineat
Aedes amaly
Aedes medi
Aedes vexan
Aedes w-alb
Aedes sp

Armigeres ma
Armigeres subalbatus
Armigeres theobaldi
Armigeres sp

Coquillettidia crassipes
Coquillettidia ochracea
Coquillettidia sp

Anopheles aconitus
Anopheles annularis

Culex bitaeniorhynchus
Culex brevipalpis

Lutzia fuscana
Lutzia halifaxii

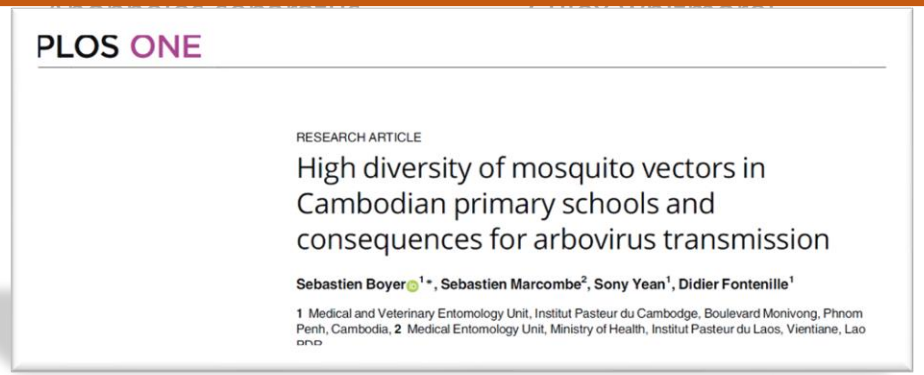
ulifera
ana
ormis

ea
gans
brida

Mimomyia luzonensis
Mimomyia sp

Uranotaenia bimaculiala
Uranotaenia lateralis/subnormalis
Uranotaenia longirostris
Uranotaenia micans
Uranotaenia nivipleura
Uranotaenia rampae

12 potential **JEV** vector species	39,900 mosquitoes (68%)
10 potential **malaria** vector species	9,494 mosquitoes (16%)
7 potential **RVFV** vector species	10,441 mosquitoes (18%)
5 potential **ZIKV** vector species	8,349 mosquitoes (14%)
4 potential **WNV** vector species	9,123 mosquitoes (16%)
4 potential **CHIKV** vector species	2,208 mosquitoes (4%)
3 potential **DENV** vector species	2,123 mosquitoes (4%)


PLOS ONE

RESEARCH ARTICLE

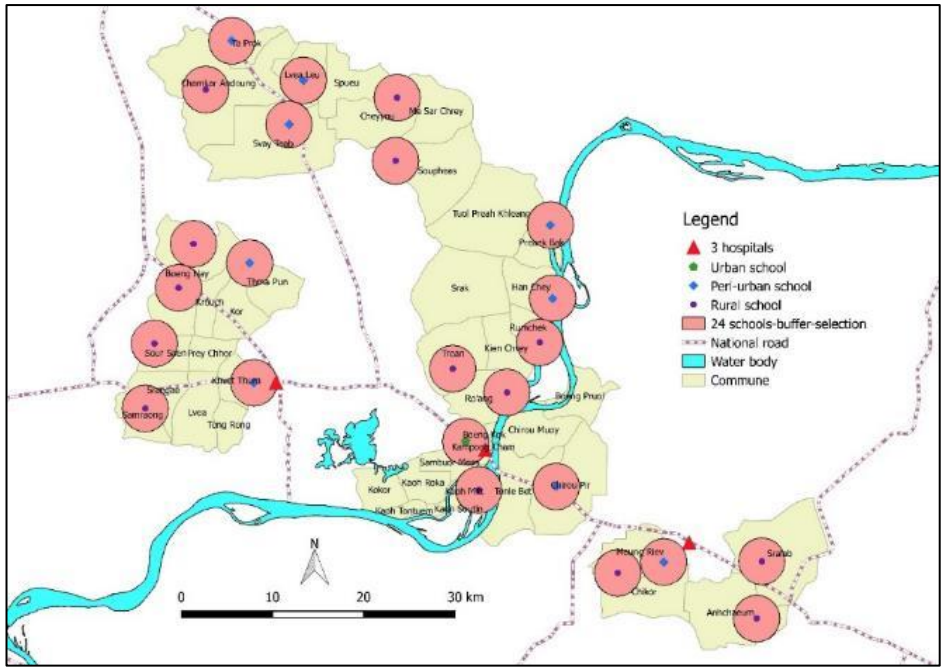
High diversity of mosquito vectors in Cambodian primary schools and consequences for arbovirus transmission

Sebastien Boyer[1]*, Sebastien Marcombe[2], Sony Yean[1], Didier Fontenille[1]

1 Medical and Veterinary Entomology Unit, Institut Pasteur du Cambodge, Boulevard Monivong, Phnom Penh, Cambodia, 2 Medical Entomology Unit, Ministry of Health, Institut Pasteur du Laos, Vientiane, Lao PDR

New Research objective

- Many mosquito species
- High proportion of vector species
- Randomized schools (=randomized environment)

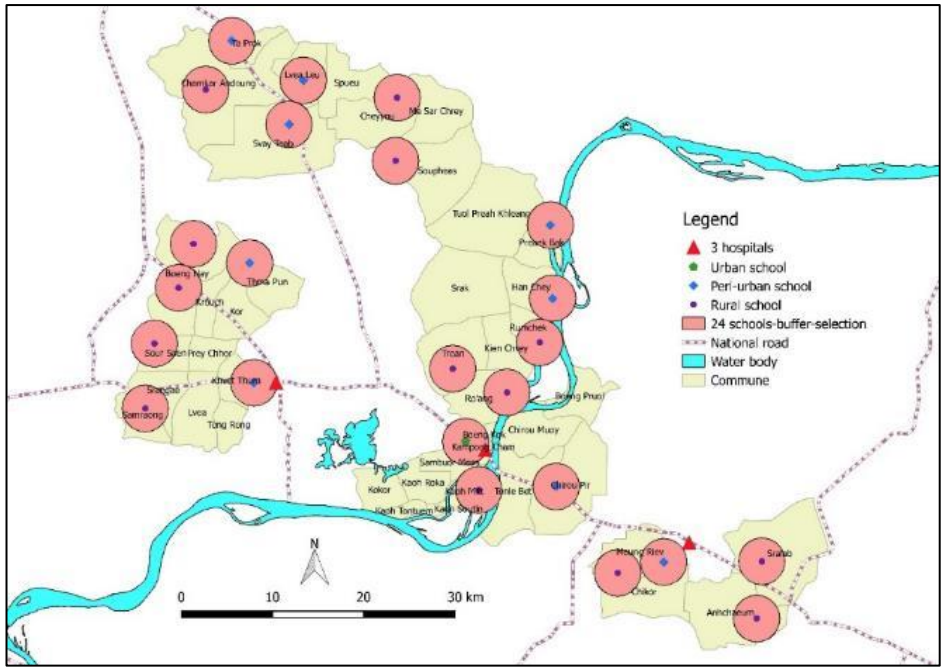


New Research objective

- Many mosquito species
- High proportion of vector species
- Randomized schools (=randomized environment)

But an absence of spatial and temporal analysis

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



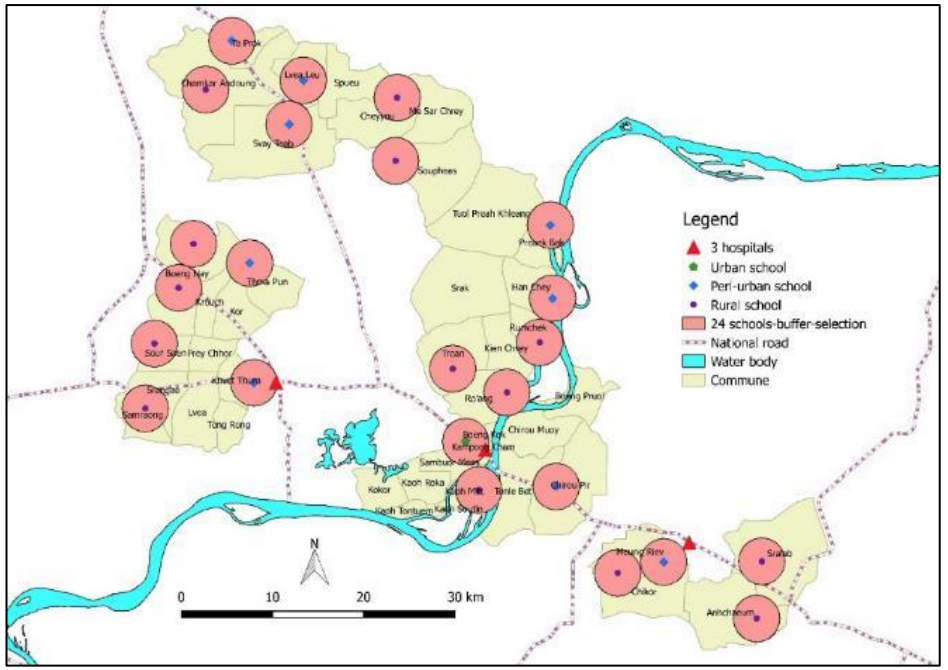
New Research objective

- Many mosquito species
- High proportion of vector species
- Randomized schools (=randomized environment)

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

Entomological data

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

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

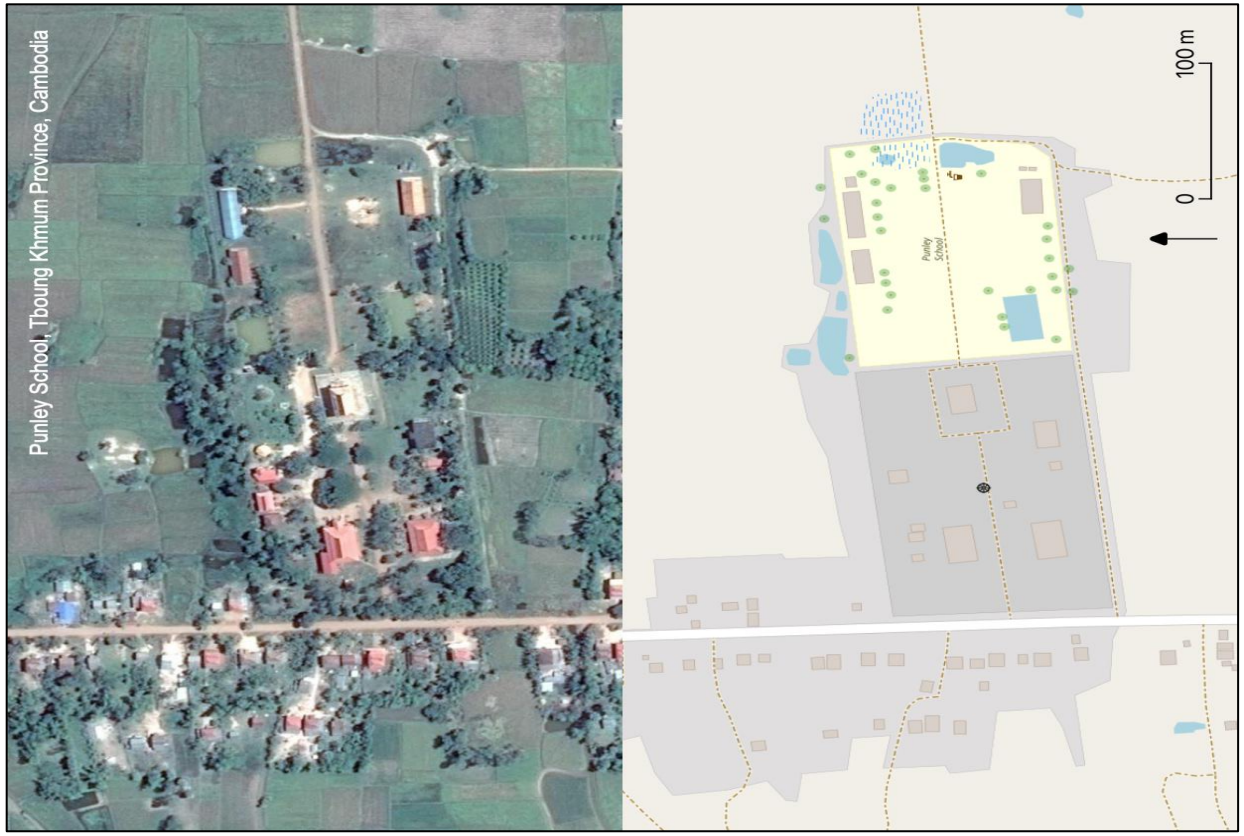
6 school & demographic parameters

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

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

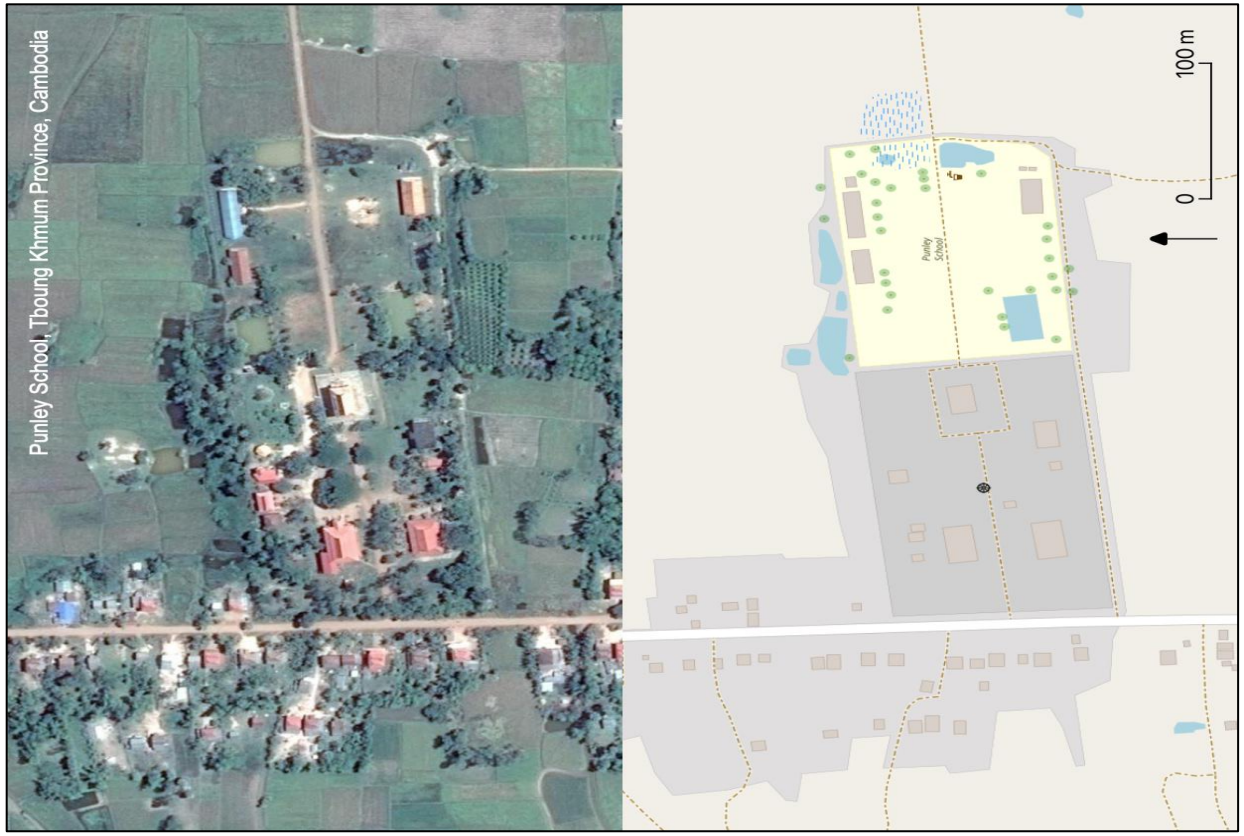
Spatial data : OpenStreetMap



- **Mapping : 500m radius**
- Calculating length, areas, perimeters

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

Spatial data : OpenStreetMap



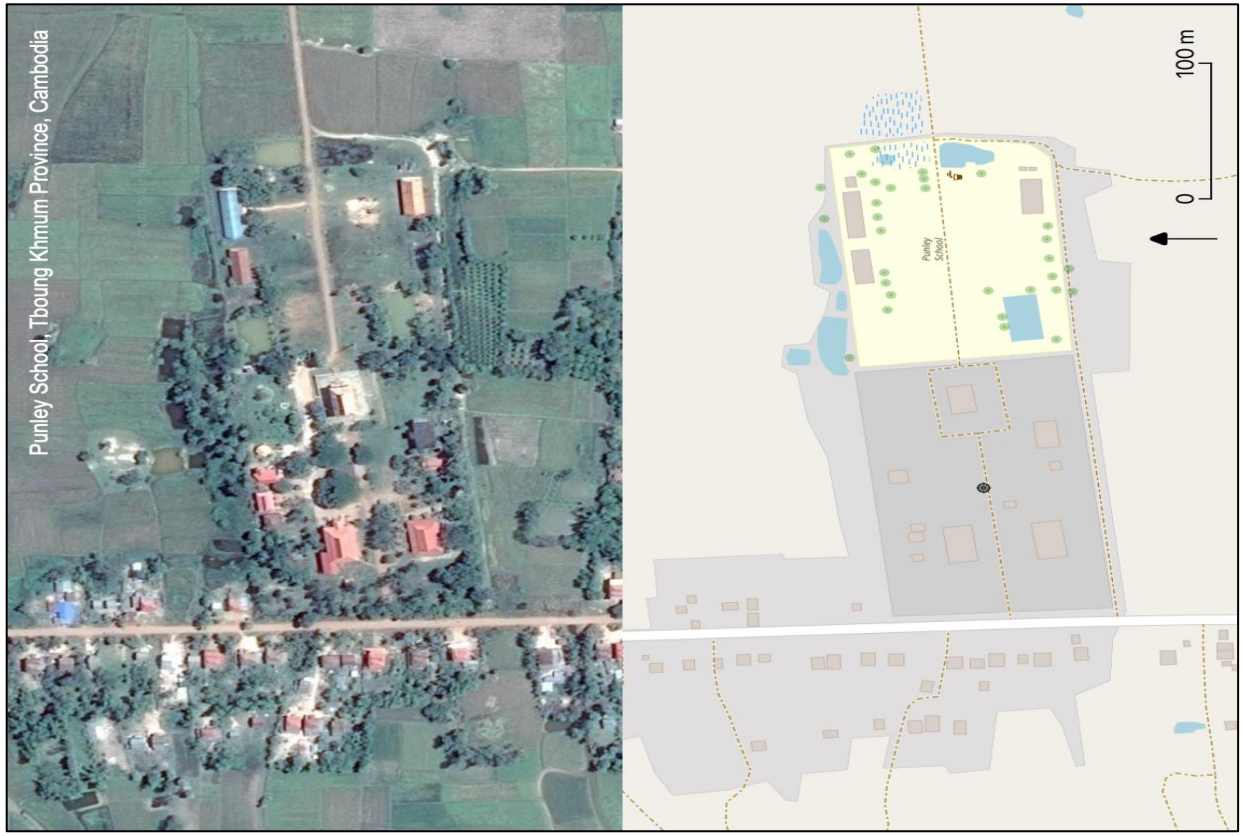
- **Mapping : 500m radius**
- Calculating length, areas, perimeters

Spatial indicators

1. Number of houses
2. Roads
3. Forest
4. Road network
5. Water area
6. Wetland
7. Rivers

…

Spatial data : OpenStreetMap



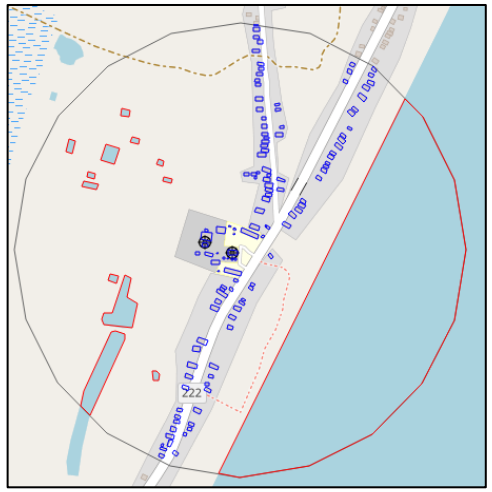
- **Mapping : 500m radius**
- Calculating length, areas, perimeters
- Creation of a mask

Spatial indicators

1. Number of houses
2. Roads
3. Forest
4. Road network
5. Water area
6. Wetland
7. Rivers

…

Spatial data : OpenStreetMap



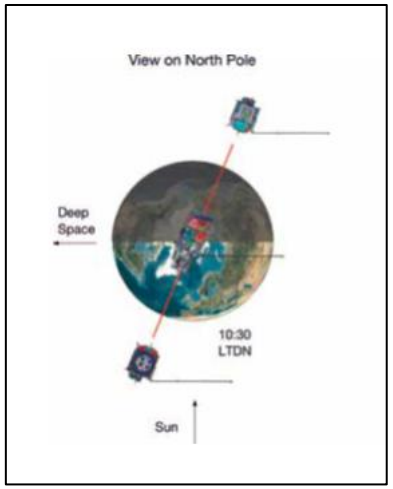
Mask creation

- ✓ Grey : school buffer are (500m radius)
- ✓ Blue : buildings, houses
- ✓ Red : permanent water areas

Temporal / Environmental data

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

Temporal / Environmental data



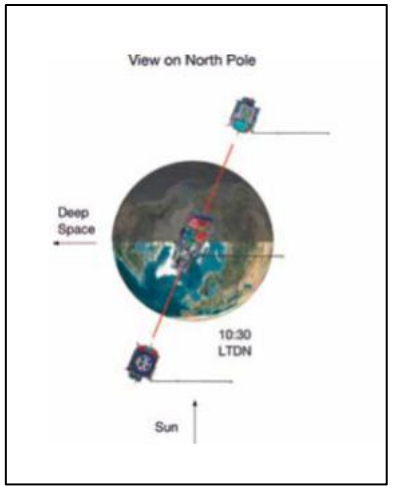
Sentinel-2

Sentinel-2 satelites

- 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

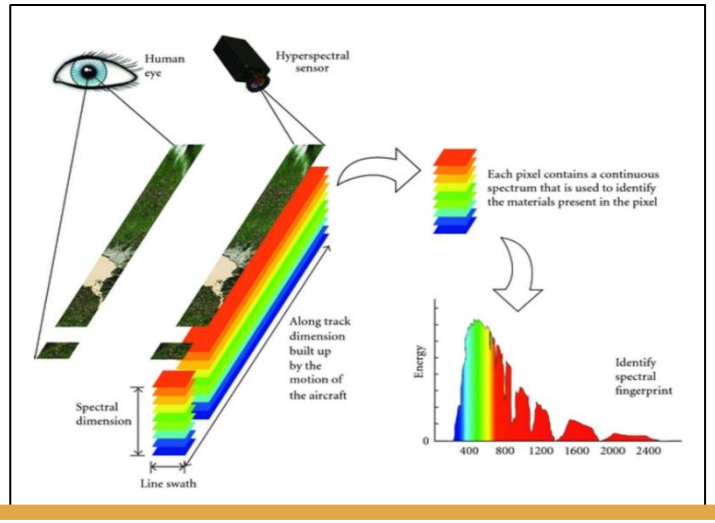
Seen from above: how satellite technology can fill gaps in mosquito biology

Temporal / Environmental data



Sentinel-2 satelites

- 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

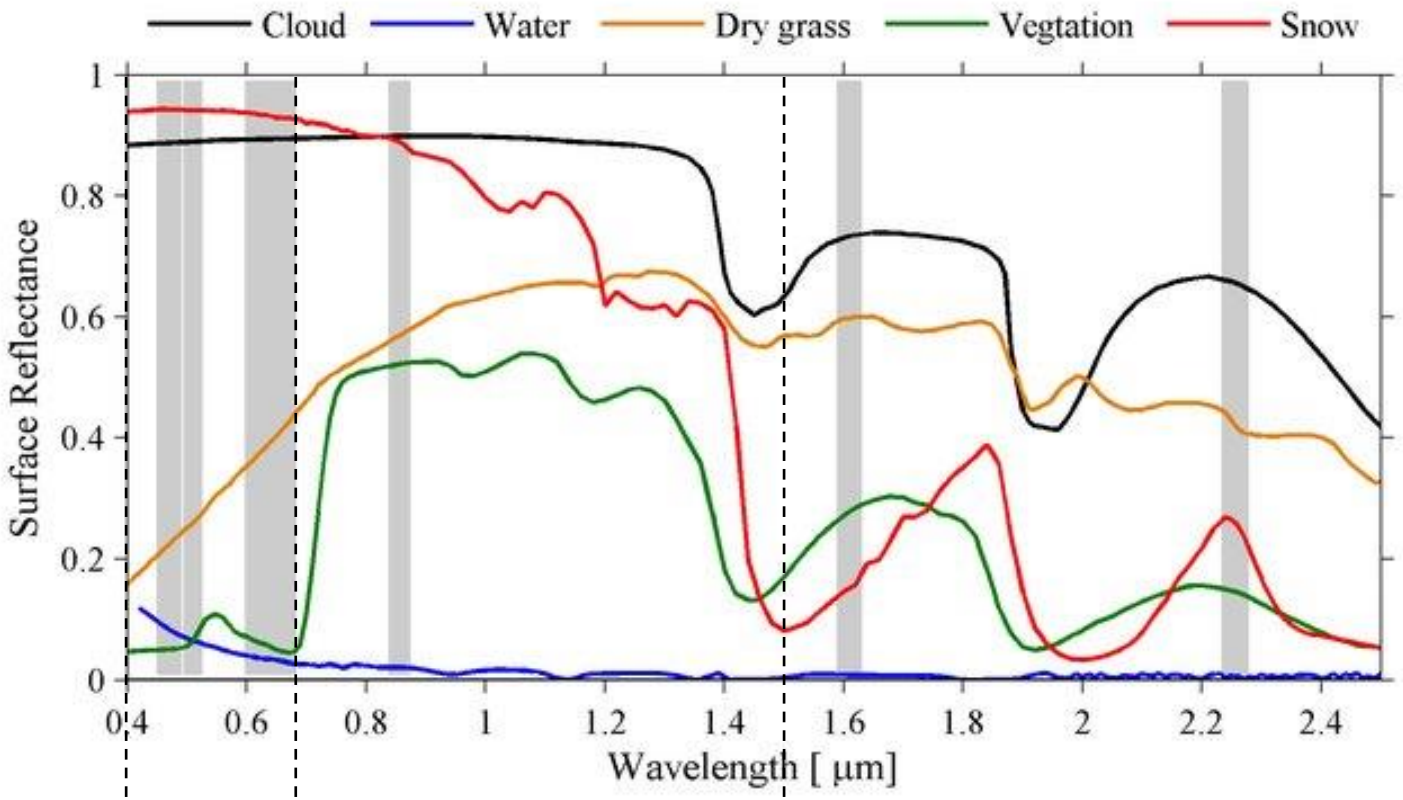


From satellite image to database

- 13 spectral bands
- from visible to invisible infrared
- 10,980 x 10,980 pixels

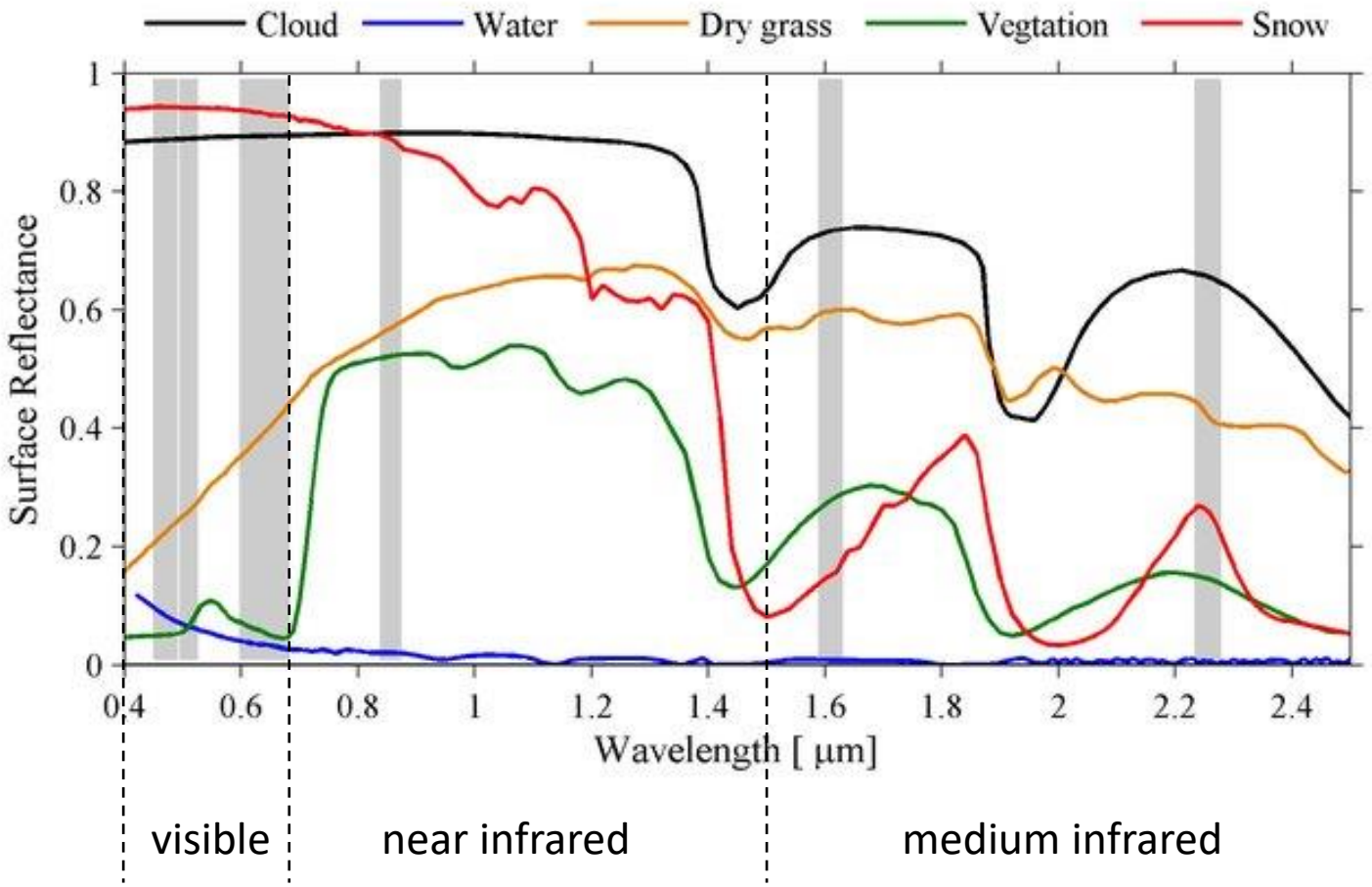
Temporal / Environmental data

Different profiles for different spectral signatures



Temporal / Environmental data

Different profiles for different spectral signatures



Environmental indices

Vegetation Index (NDVI)

sensitive to the vigour and quantity of vegetation

≠ between read and near infrared bands

Water index (NDWI)

Gao : changes related to leaf water content

≠ between near-infrared and short-wave infrared bands

Mc Feeters : water content related changes in water bodies (pond, pool, flood)

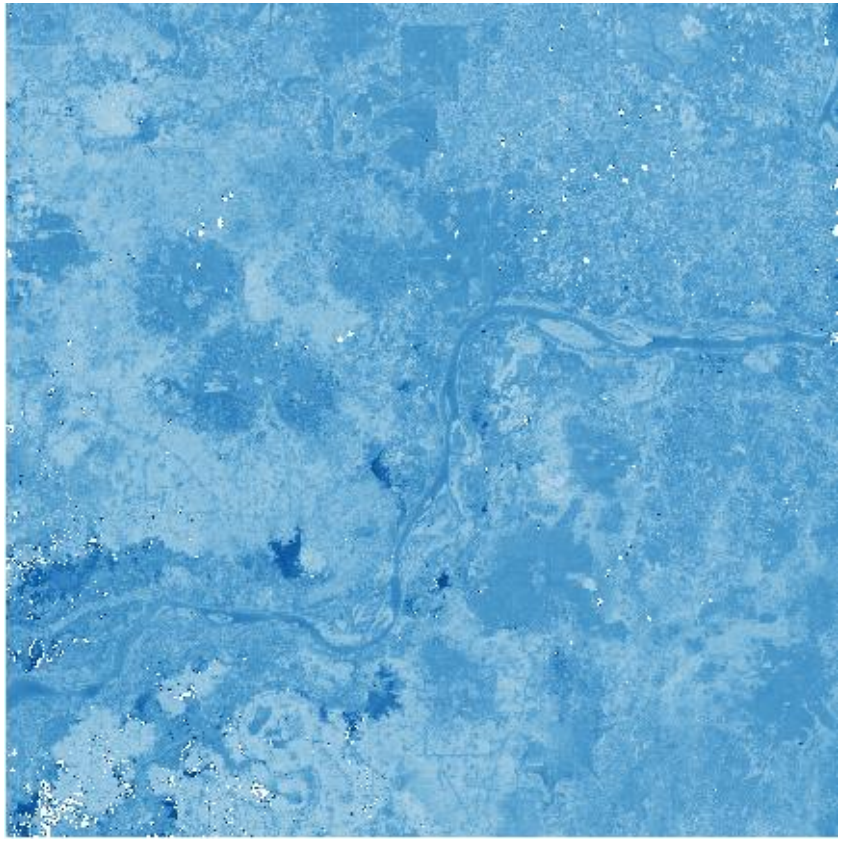
≠ between green and near infrared bands

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

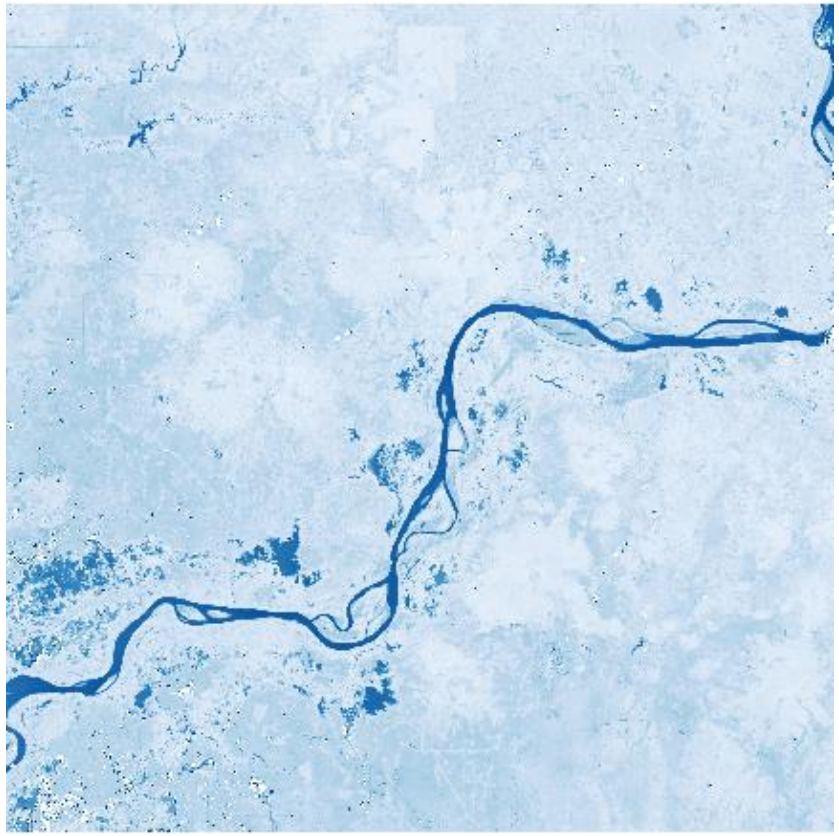
Temporal / Environmental data

NDVI

NDWI Gao



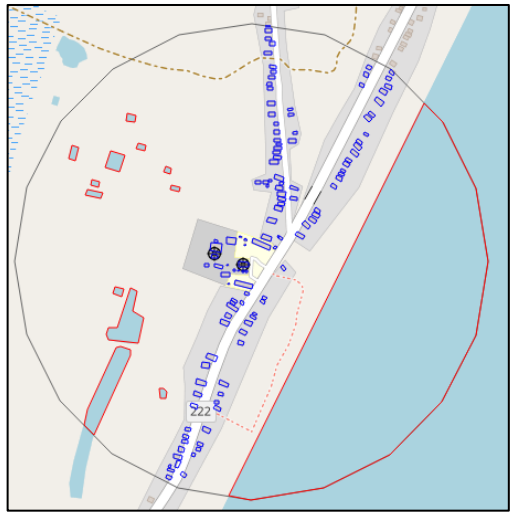
NDWI Mc Feeters



Temporal / Environmental data

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

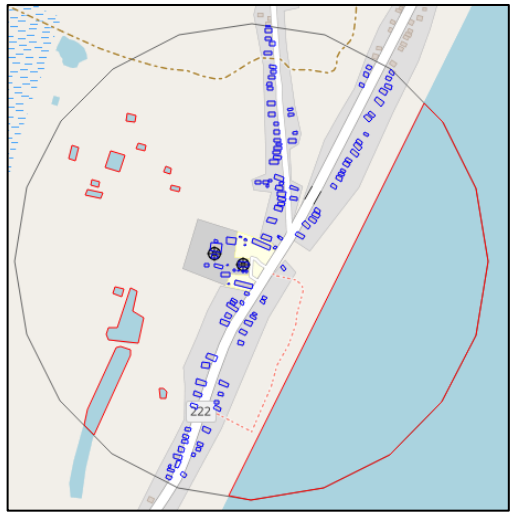
Temporal / Environmental data



Mask creation

- ✓ Grey : school buffer are (500m radius)
- ✓ Blue : buildings, houses
- ✓ Red : permanent water areas

Temporal / Environmental data



Mask creation

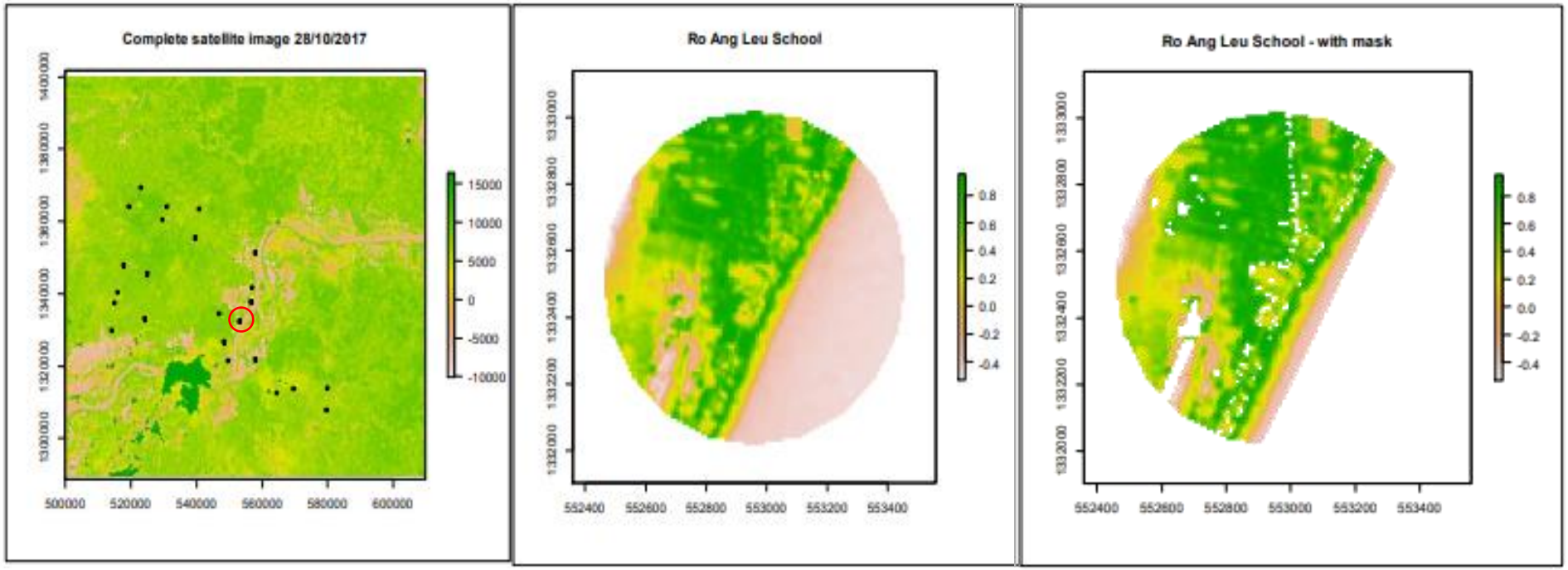
- ✓ Grey : school buffer are (500m radius)
- ✓ Blue : buildings, houses
- ✓ Red : permanent water areas

- Buffer zone with mask (NDVI) :
  - ✓ Removal of buildings
  - ✓ Removal of permanent water areas

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

Temporal / Environmental data

Buffer area (500m radius)



Temporal / Environmental data

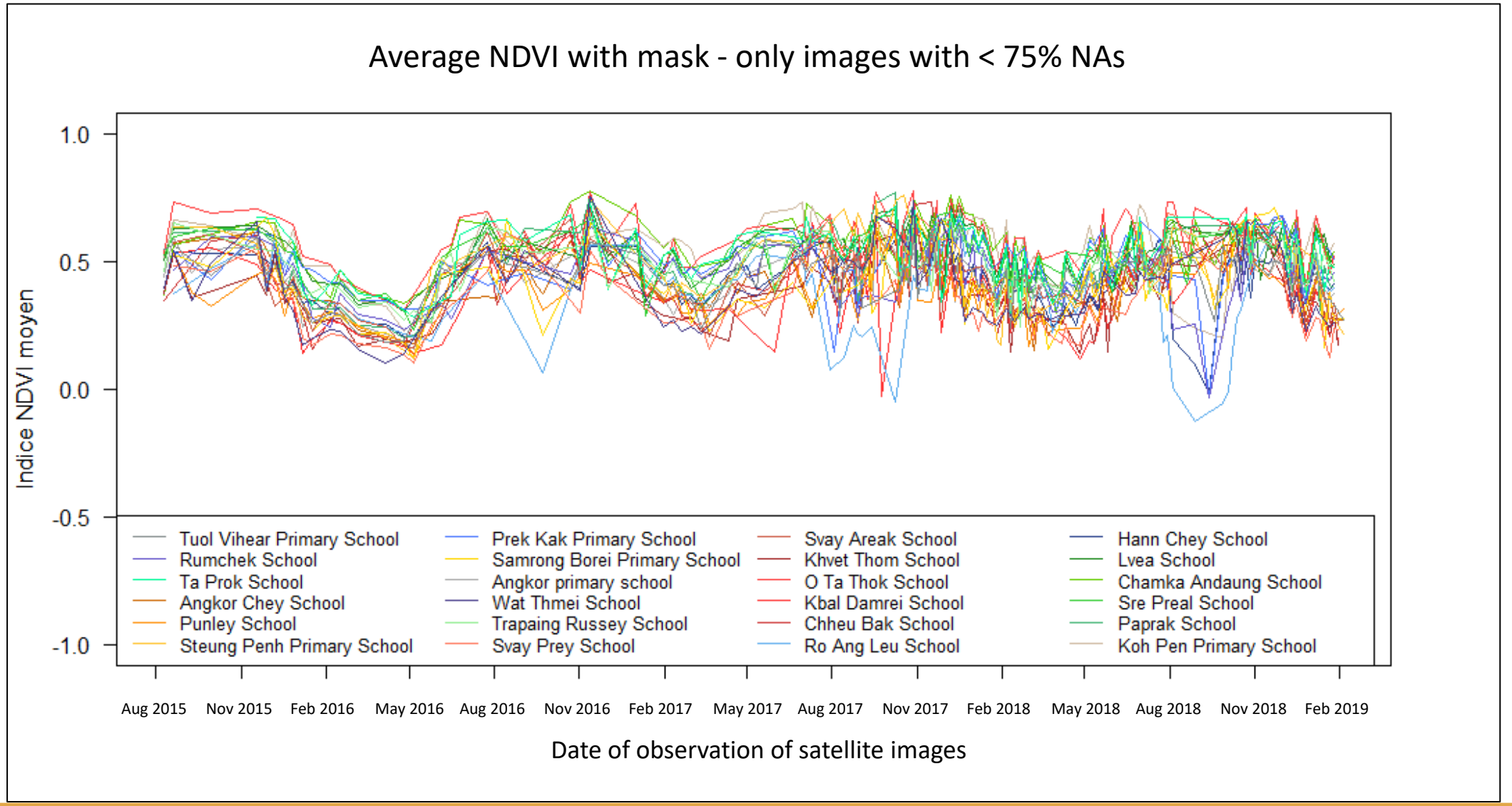
Quality of satellite images per school :

- ✓ ≤ 75% missing values
- ✓ Pre-processing problems: deletion of satellite images for several dates

- ✓ 95% correlation between NDVI and Mc Feeters's NDWI

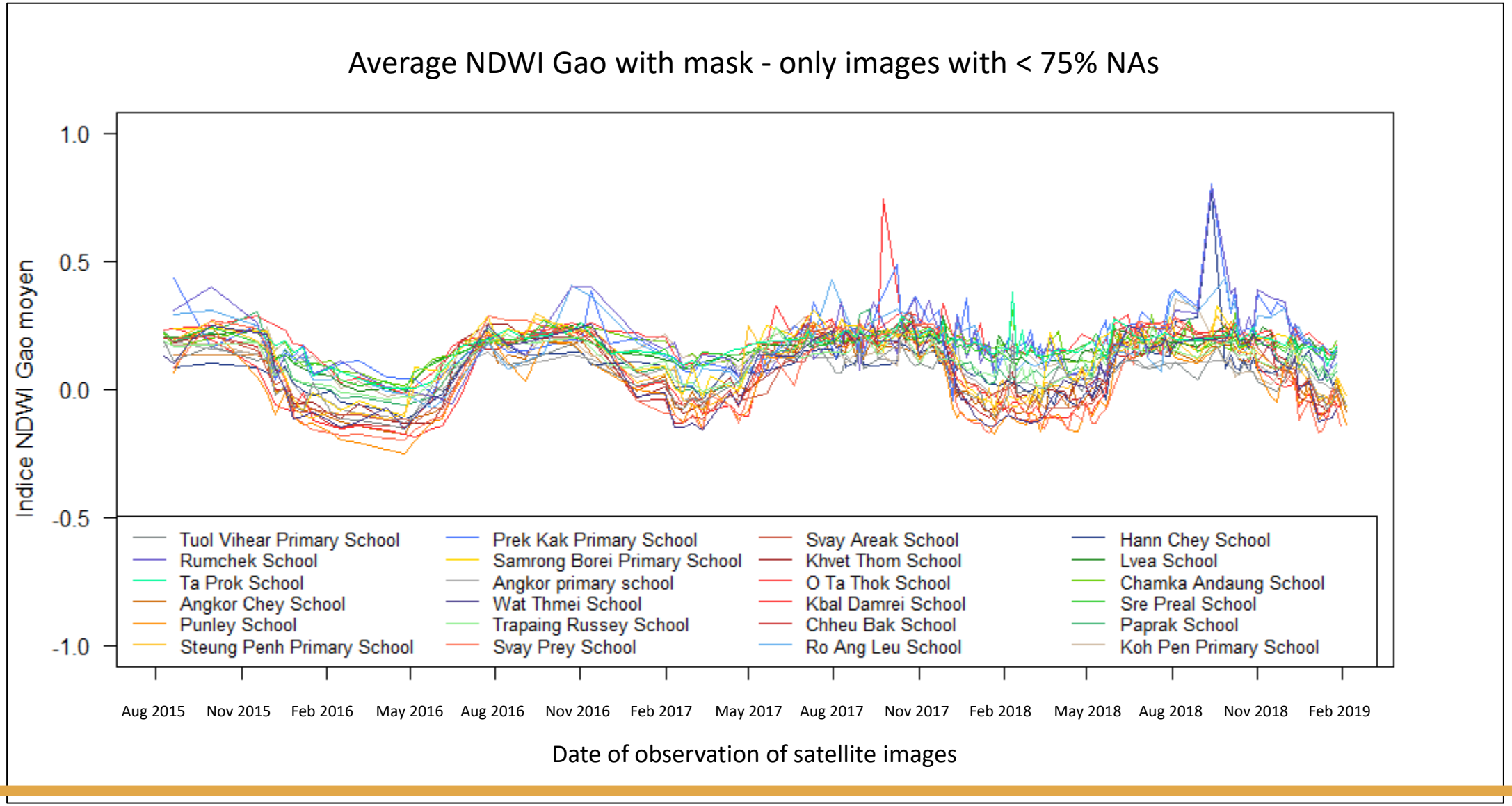
Seen from above: how satellite technology can fill gaps in mosquito biology

Temporal / Environmental data



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

Temporal / Environmental data



Temporal / Environmental data

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

Model calibration

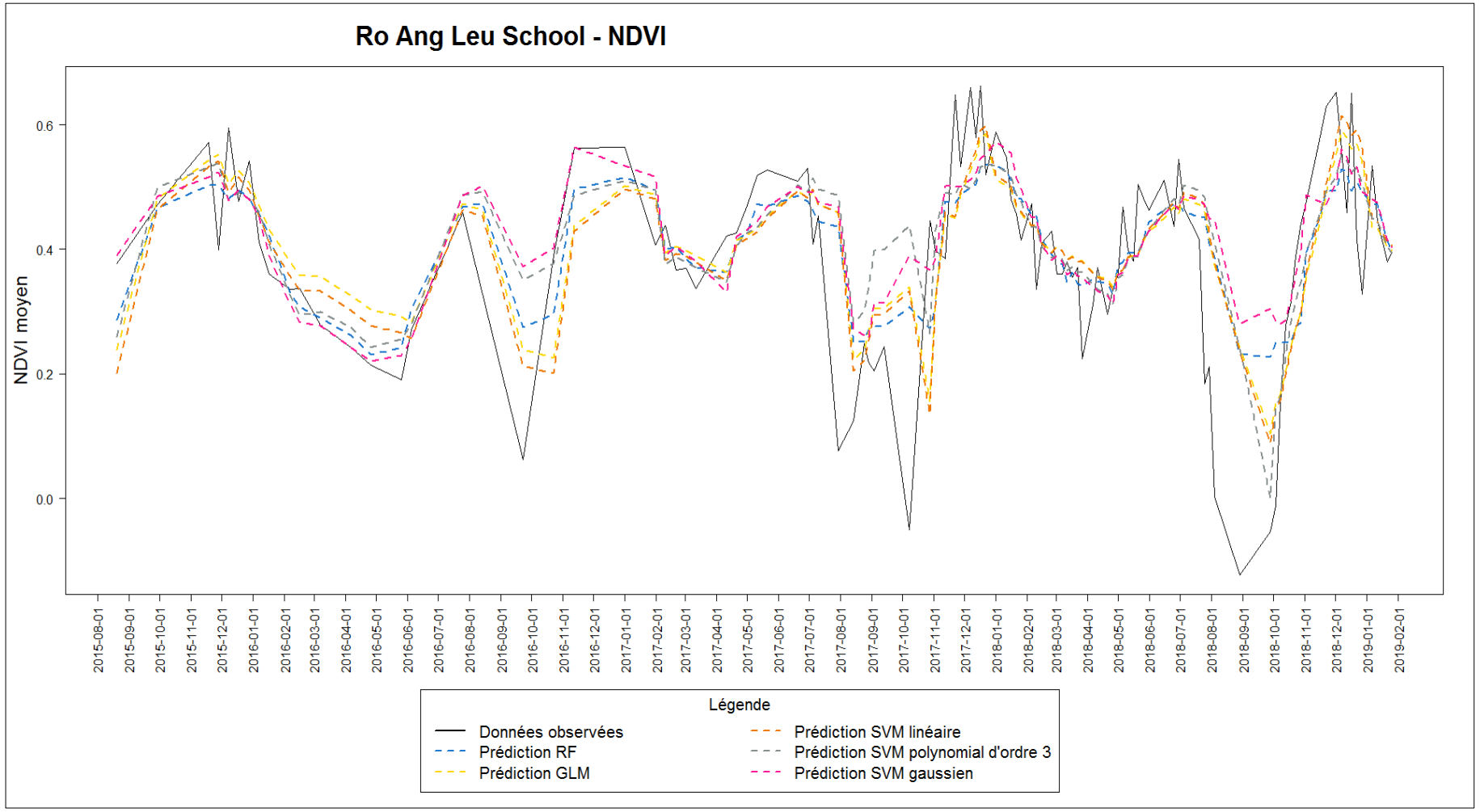
- **Analysis on all schools** with 5 explanatory variables

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

- **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)

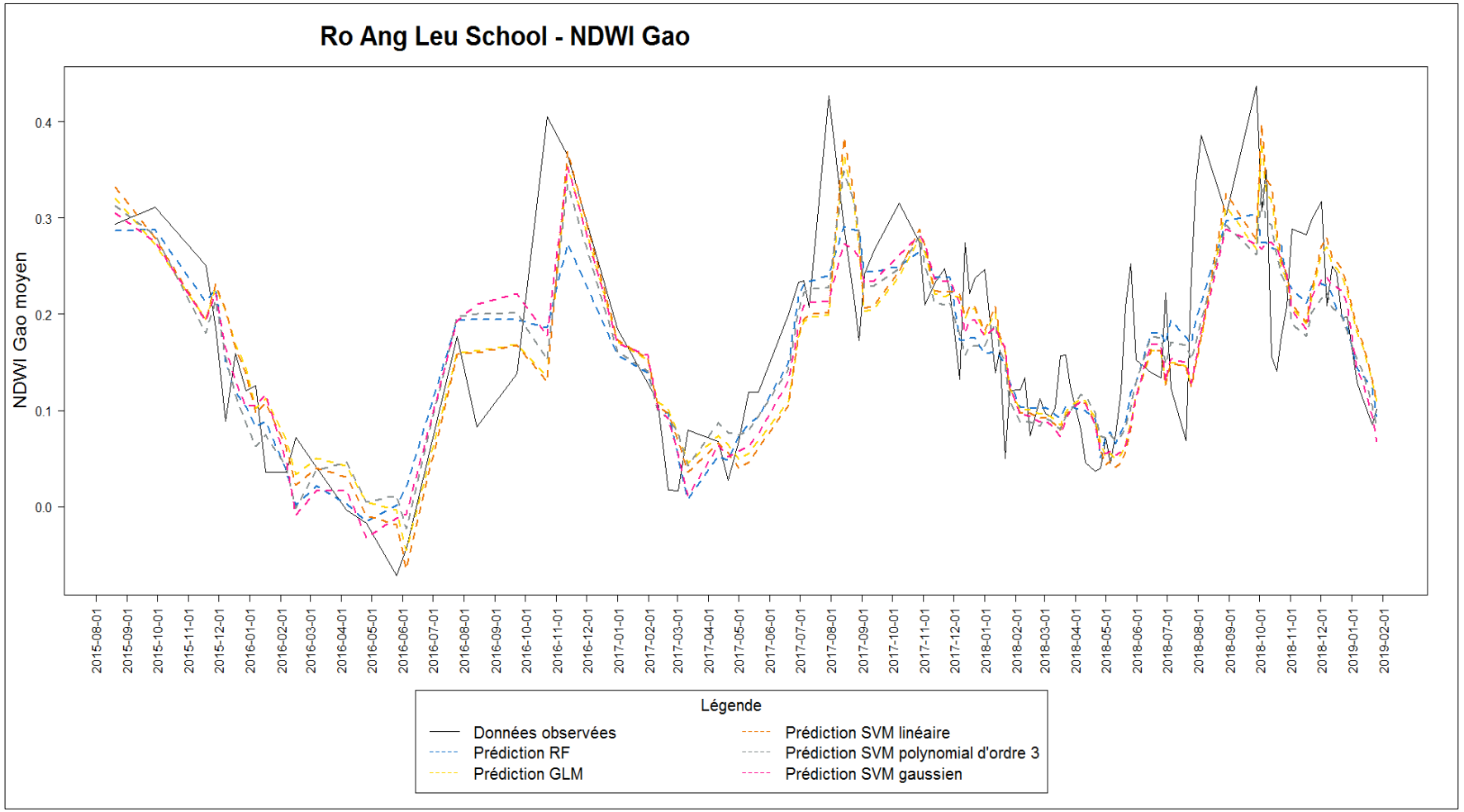
Temporal / Environmental data

Time average NDVI (observed and predicted)



Temporal / Environmental data

Time average Gao NDWI (observed and predicted)



Temporal / Environmental data

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

- **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)

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

Model

- **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…)

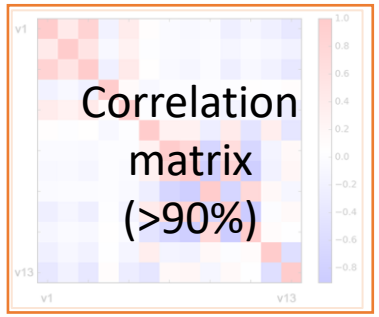
✓ **7 meteorological data** (temperature, precipitation, humidity…)

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

Model

44 factors

IVM x Year

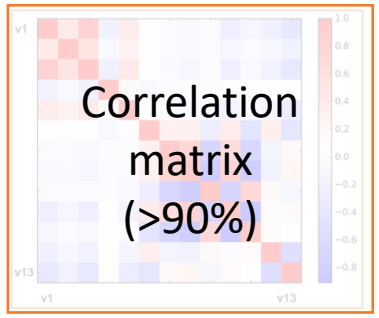


Seen from above: how satellite technology can fill gaps in mosquito biology

Model

44 factors

IVM x Year



Fisher bivariate analysis with variables (10%)

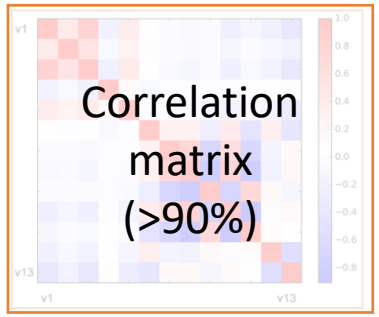
- Biodiversity indices
- Relative abundnace of species
- Presence of species

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

Model

44 factors

IVM x Year



Fisher bivariate analysis with variables (10%)

- Biodiversity indices
- Relative abundance of species
- Presence of species

- 7 variables for Shannon index
- 6 variables for *Ae. aegypti*
- 5 variables for *Ae. albopictus*

Results

Example of Biodiversity with Shannon index

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

1 environmental indicator (satellite)
3 meteorological data
2 automatic inclusion (IVM + Year)

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

Results

Example of Biodiversity with Shannon index

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

1 environmental indicator (satellite)
3 meteorological data
2 automatic inclusion (IVM + Year)

Example with *Aedes albopictus*

- NDVI (day – 20) ***
- Forest perimeter **
- 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)

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

Results

Example of Biodiversity with Shannon index

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

1 environmental indicator (satellite)
3 meteorological data
2 automatic inclusion (IVM + Year)

Example with *Aedes albopictus*

- NDVI (day – 20) ***
- Forest perimeter **
- 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)

Example with *Aedes aegypti*

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

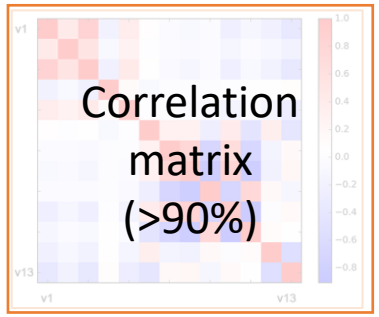
2 spatial indicators
2 meteorological data
2 automatic inclusion (IVM + Year)

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

Model

44 factors

IVM x Year



Fisher bivariate analysis with variables (10%)

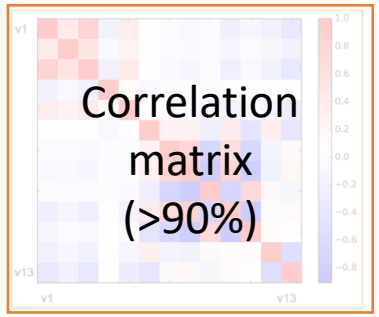
- Biodiversity indices
- Relative abundnace of species
- Presence of species

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

Model

44 factors

IVM x Year



Fisher bivariate analysis with variables (10%)

- Biodiversity indices
- Relative abundance of species
- Presence of species

Multivariate analysis on

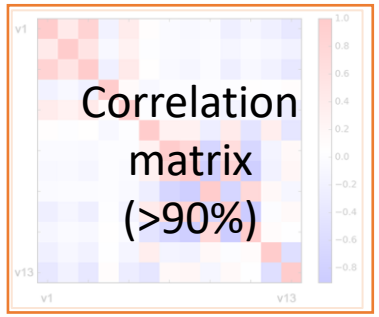
- Biodiversity indices
- Relative abundance of species
- Presence of species

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

Model

44 factors

IVM x Year



Fisher bivariate analysis with variables (10%)

- Biodiversity indices
- Relative abundance of species
- Presence of species

Multivariate analysis on

- Biodiversity indices
- **Relative abundance of species**
- Presence of species

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

Results

Species name	N	N schools	N missions	Factors
Anopheles indefinitus	7894	24	11	treatment NDVI.90
Culex quinquefasciatus	5693	24	12	perim.zone.inon pop_tot
Culex brevipalpis	2329	24	12	pluvio.cum
Aedes aegypti	1571	24	12	Stream (small river)
Anopheles peditaeniatus	1257	24	11	treatment temp.moy MNDWI.54
Anopheles vagus	1164	24	8	NDVI.46 treatment:mois.an
Culex gelidus	1089	24	12	nb_enf
Culex bitaeniorhynchus	695	24	12	NDVI.2 MNDWI.34
Culex fuscocephala	660	24	10	temp.moy
Aedes albopictus	551	24	12	nb_enf
Armigeres subalbatus	527	23	12	NDWIGAO.58
Anopheles sinensis	265	22	11	NDVI.29
Aedeomyia catasticta	256	20	12	MNDWI.90
Culex nigropunctatus	139	20	11	NDVI.33
Coquillettidia crassipes	109	20	11	pluvio.cum
Anopheles barbumbrosus	88	14	5	temp.moy
Mansonia annulifera	79	14	9	perim.eau.tot pop_tot
Anopheles nitidus	62	14	7	MNDWI.72
Uranotaenia rampae	54	16	9	perim.eau.tot

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

Results

Understudied species

Species name	N	N schools	N missions	Factors
Anopheles indefinitus	7894	24	11	treatment NDVI.90
Culex quinquefasciatus	5693	24	12	perim.zone.inon pop_tot
Culex brevipalpis	2329	24	12	pluvio.cum
Aedes aegypti	1571	24	12	Stream (small river)
Anopheles peditaeniatus	1257	24	11	treatment temp.moy MNDWI.54
Anopheles vagus	1164	24	8	NDVI.46 treatment:mois.an
Culex gelidus	1089	24	12	nb_enf
Culex bitaeniorhynchus	695	24	12	NDVI.2 MNDWI.34
Culex fuscocephala	660	24	10	temp.moy
Aedes albopictus	551	24	12	nb_enf
Armigeres subalbatus	527	23	12	NDWIGAO.58
Anopheles sinensis	265	22	11	NDVI.29
Aedeomyia catasticta	256	20	12	MNDWI.90
Culex nigropunctatus	139	20	11	NDVI.33
Coquillettidia crassipes	109	20	11	pluvio.cum
Anopheles barbumbrosus	88	14	5	temp.moy
Mansonia annulifera	79	14	9	perim.eau.tot pop_tot
Anopheles nitidus	62	14	7	MNDWI.72
Uranotaenia rampae	54	16	9	perim.eau.tot

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

Results

Understudied species

Species name	N	N schools	N missions	Factors
Anopheles indefinitus	7894	24	11	treatment NDVI.90
Culex quinquefasciatus	5693	24	12	perim.zone.inon pop_tot
Culex brevipalpis	2329	24	12	pluvio.cum
Aedes aegypti	1571	24	12	Stream (small river)
Anopheles peditaeniatus	1257	24	11	treatment temp.moy MNDWI.54
Anopheles vagus	1164	24	8	NDVI.46 treatment:mois.an
Culex gelidus	1089	24	12	nb_enf
Culex bitaeniorhynchus	695	24	12	NDVI.2 MNDWI.34
Culex fuscocephala	660	24	10	temp.moy
Aedes albopictus	551	24	12	nb_enf
Armigeres subalbatus	527	23	12	NDWIGAO.58
Anopheles sinensis	265	22	11	NDVI.29
Aedeomyia catasticta	256	20	12	MNDWI.90
Culex nigropunctatus	139	20	11	NDVI.33
Coquillettidia crassipes	109	20	11	pluvio.cum
Anopheles barbumbrosus	88	14	5	temp.moy
Mansonia annulifera	79	14	9	perim.eau.tot pop_tot
Anopheles nitidus	62	14	7	MNDWI.72
Uranotaenia rampae	54	16	9	perim.eau.tot

Limit of relative abundance. Interest of presence/absence

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

Results

	Factors	Species name	N	N schools	N missions
Environmental data	NDVI.2	*Culex bitaeniorhynchus*	695	24	12
	NDVI.29	*Anopheles sinensis*	265	22	11
	NDVI.33	*Culex nigropunctatus*	139	20	11
	NDVI.46	*Anopheles vagus*	1164	24	8
	NDVI.90	*Anopheles indefinitus*	7894	24	11
	MNDWI.34	*Culex bitaeniorhynchus*	695	24	12
	MNDWI.54	*Anopheles peditaeniatus*	1257	24	11
	MNDWI.72	*Anopheles nitidus*	62	14	7
	MNDWI.90	*Aedeomyia catasticta*	256	20	12
	NDWIGAO.58	*Armigeres subalbatus*	527	23	12
Meteorological data	temp.moy	*Anopheles barbumbrosus*	88	14	5
		Anopheles peditaeniatus	1257	24	11
		Culex fuscocephala	660	24	10
	pluvio.cum	*Coquillettidia crassipes*	109	20	11
		Culex brevipalpis	2329	24	12
Spatial data	perim.eau.tot	*Mansonia annulifera*	79	14	9
		Uranotaenia rampae	54	16	9
	perim.flood.area	*Culex quinquefasciatus*	5693	24	12
	Stream (small river)	*Aedes aegypti*	1571	24	12
Demographic data	Nb children	*Aedes albopictus*	551	24	12
		Culex gelidus	1089	24	12
	Total population	*Culex quinquefasciatus*	5693	24	12
		Mansonia annulifera	79	14	9
Area	treatment	*Anopheles indefinitus*	7894	24	11
		Anopheles peditaeniatus	1257	24	11

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

Results

Importance of environmental and spatial data

	Factors	Species name	N	N schools	N missions
Environmental data	NDVI.2	*Culex bitaeniorhynchus*	695	24	12
	NDVI.29	*Anopheles sinensis*	265	22	11
	NDVI.33	*Culex nigropunctatus*	139	20	11
	NDVI.46	*Anopheles vagus*	1164	24	8
	NDVI.90	*Anopheles indefinitus*	7894	24	11
	MNDWI.34	*Culex bitaeniorhynchus*	695	24	12
	MNDWI.54	*Anopheles peditaeniatus*	1257	24	11
	MNDWI.72	*Anopheles nitidus*	62	14	7
	MNDWI.90	*Aedeomyia catasticta*	256	20	12
	NDWIGAO.58	*Armigeres subalbatus*	527	23	12
Meteorological data	temp.moy	*Anopheles barbumbrosus*	88	14	5
		Anopheles peditaeniatus	1257	24	11
		Culex fuscocephala	660	24	10
	pluvio.cum	*Coquillettidia crassipes*	109	20	11
		Culex brevipalpis	2329	24	12
Spatial data	perim.eau.tot	*Mansonia annulifera*	79	14	9
		Uranotaenia rampae	54	16	9
	perim.flood.area	*Culex quinquefasciatus*	5693	24	12
	Stream (small river)	*Aedes aegypti*	1571	24	12
Demographic data	Nb children	*Aedes albopictus*	551	24	12
		Culex gelidus	1089	24	12
	Total population	*Culex quinquefasciatus*	5693	24	12
		Mansonia annulifera	79	14	9
Area	treatment	*Anopheles indefinitus*	7894	24	11
		Anopheles peditaeniatus	1257	24	11

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**)

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**)

New modeling approach : allows modeling of all captured species
Advantage to obtain **environmental data on** **understudied species**

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**)

New modeling approach : allows modeling of all captured species
Advantage to obtain **environmental data on** **understudied species**

Importance of **local** field data and importance of **scale**
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

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**)

New modeling approach : allows modeling of all captured species
Advantage to obtain **environmental data on** **understudied species**

Importance of **local** field data and importance of **scale**
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

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 ?

AFD
AGENCE FRANÇAISE
DE DÉVELOPPEMENT

ECOMORE II

Institut de Recherche
pour le Développement
FRANCE

international network
Institut Pasteur

Institut Pasteur
du Cambodge