GE3216 Applications of GIS & Remote Sensing

GIS and Public Health- Case of Dengue in Singapore

Submitted by:

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INTRODUCTION

Dengue is a common disease found in Singapore. In the 1960s it was a major cause of childhood death and as of 2013, the dengue incidence rate in Singapore stands at 404.9 per 100000 Singaporeans (Satku, 2015). In the South-East Asia Region dengue has a high case-fatality rate that ranges from 1% to 5%, depending on the country (World Health Organisation, 2009). Dengue cases have been on the rise in 2016, with the highest weekly figure in over a year being reported in the week of January 10 to January 16 (Lee, 2016). Thus, dengue is a very immediate and pressing problem in Singapore.

Previous research has explored the various factors that contribute to the number of dengue cases in a country. In Hawaii, the high densities of *Aedes spp.*, the vector mosquitoes of dengue, is significant correlated with high rainfall and dense tropical vegetation (Halstead, 2008). In Cambodia, dengue cases are predominantly during the rainy season (Pink, 2016). A study in Puerto Rico has shown a positive correlation between rainfall and an abundance of vector mosquitoes (Halstead, 2008).

High temperatures have been shown to have both a positive and negative relationship with the number of dengue cases. High ambient temperatures are favorable for dengue transmission in Indonesia (Hanley & Weaver, 2010) but maximum survival rates are 20–30 °C (Tun-Lim *et al.*, 2000) and studies in Bangkok and New Orleans have shown that extremely high temperatures negatively impact the survival of the adult vector mosquito (Focks *et al.*, 1993).

Other studies have also indicated that socio-economic factors such as population density may accelerate the transmission of dengue in countries such as Brazil (Filho *et al.*, 2016).

The proximity to construction sites has also been shown to have a relationship to the number of dengue cases in an area, as evinced in a study focusing on Saudi Arabia (Acton, 2012). The relationship between construction sites and dengue will be explored in this project because the National Environmental Agency (NEA) has deemed it noteworthy enough to identify it as a potential breeding site for mosquitoes (Fig 1).

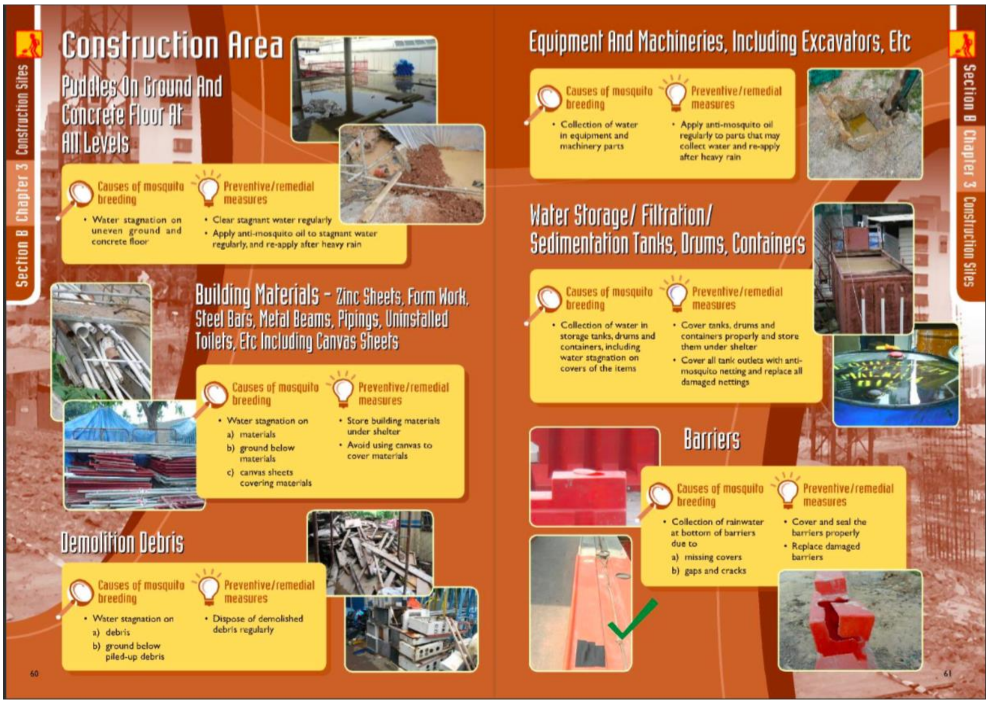


Figure 1: NEA's guidebook on prevention of mosquitoes for construction sites.

Another interesting area of research would be the common misconception that mosquitoes breed in natural waterbodies (Gaines, 2016). *Aedes spp.* in urban landscapes travel a maximum of 25m a day (Morlan & Hayes, 1958) and with this misconception, a consequential assumption would be that there would be a higher number of dengue cases nearer to waterbodies as opposed to further. This project will aim to elucidate the relationship between the proximity to waterbodies and dengue cases.

Despite the large amount of research that has been afforded to this issue globally, less research has been done in the context of Singapore. Few of them being Wang *et al.* (2012) and Pinto *et al.* (2011). This report will thus aim to investigate the relationship between the occurrence of dengue cases and 1) distance to vegetation, 2) distance to waterbodies, 3) rainfall, 4) temperature, 5) population density, and 6) distance to construction sites in the context of Singapore. Based on previous research in other tropical countries, the authors hypothesized significant relationships between these factors and the occurrences of dengue cases in a given area.

METHODOLOGY

Choice of timeframe

The research timeframe was set in 2015 due to availability of data. Taking into consideration Singapore's monsoonal climatic conditions (Meteorological Service Singapore, 2016), one month each from the South West and North East monsoons (July and January) as well as the inter-monsoon season (April and October) was selected as the four main research timeframe. The intervals of three months between each selected period ensured systematic sampling.

Choice of unit scale and method of spatial analysis

The raster model, which divides spatial data into discrete units (Shekhar & Hui, 2007), is often used to model geographic space (Fotheringham & Rogerson, 2008). When the boundaries of the discrete units are created artificially and can be changed, analyses of data according to the different boundaries are inconsistent due to the different spatial configurations (Openshaw & Taylor, 1979), referred to as the modifiable areal unit problem (MAUP) (Fotheringham & Hui, 2008).

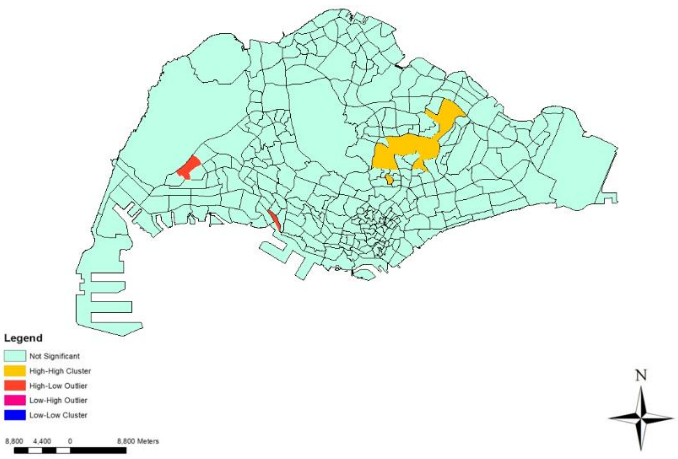
Fishnet cells were created as a sampling unit using the spatial extent of Singapore's mainland. The spatial pattern of dengue cases in Singapore was then analysed with three types of division units of different characteristics: (a) units demarcated according to the Urban Development Authority of Singapore, (b) a grid of squares of 500×500m, and (c) a grid of squares of 1000×1000m.

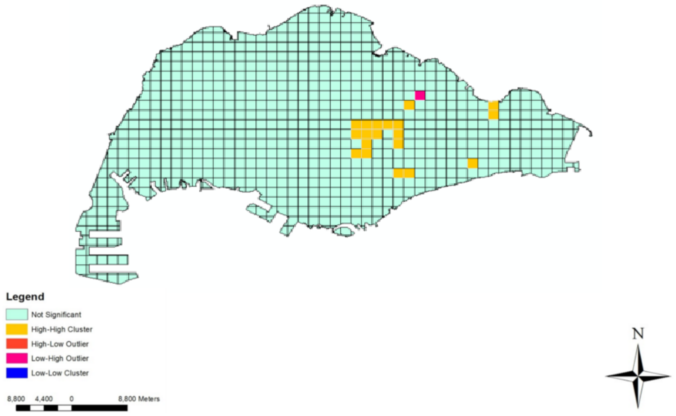
The dengue data used in this project is considered areal data because it involves an aggregated quantity for each discrete unit of Singapore (Smith, 2016). Moran's I was used to measure the relationship among the values of dengue cases according to the spatial arrangement of the polygons (Chang, 2012) (Fig 2).

The final analysis was conducted on dengue data divided according to the polygons in 500m cells because it had the smallest scale and was of a uniform size throughout. Cells that 1) fell completely within the boundary of Singapore's mainland, 2) have a population density greater than zero, 3) not located on vegetation patches, and 4) not located on reservoirs, were used for the following regression analysis.

Dengue Data

Data from the middle and last date of each selected month was used. The addresses for dengue cases were obtained from the website SGCharts: Outbreak (http://outbreak.sgcharts.com) which collates past dengue data released by the NEA (Fig 3 & 4). Subsequently, the addresses are checked individually using a Housing Development Board (HDB) search engine "HDB Map Services" (http://services2.hdb.gov.sg/web/fi10/emap.html#), to confirm their exact position, address and building number (Fig 5). The postal codes for residential buildings with dengue clusters were checked against SingPost's postal code search engine. The postal codes are also matched to Singapore Land Authority's (SLA) address data for further accuracy. Matching the data to SLA's address data provides the latitude and longitude of the postal codes with respect to SVY21 of these residential building with dengue clusters are searched in SingPost's Postal Code search engine (http://beta.singpost.com/find-postal-code). Eventually, the addressed not found in SLA dataset were further analysed in an online batch geocoding software (www.findlatitudeandlongitude.com/batch-geocode/#.Vv9Zjvl97IV).

(A) 



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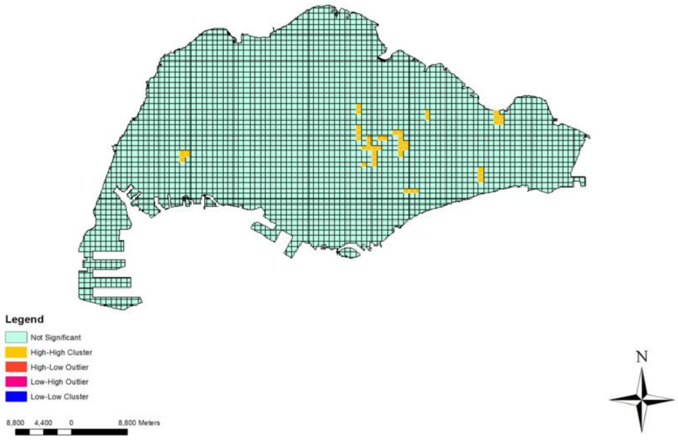


(C)

Figure 2: Example of MAUP in January. Local Moran's I calculated based on (A) subzones(B) fishnet with 1000×1000 m cells, and (C) fishnet with 500×500 m cells.

Figure 3: Clusters in the eastern region of Singapore (Outbreak.SGcharts).

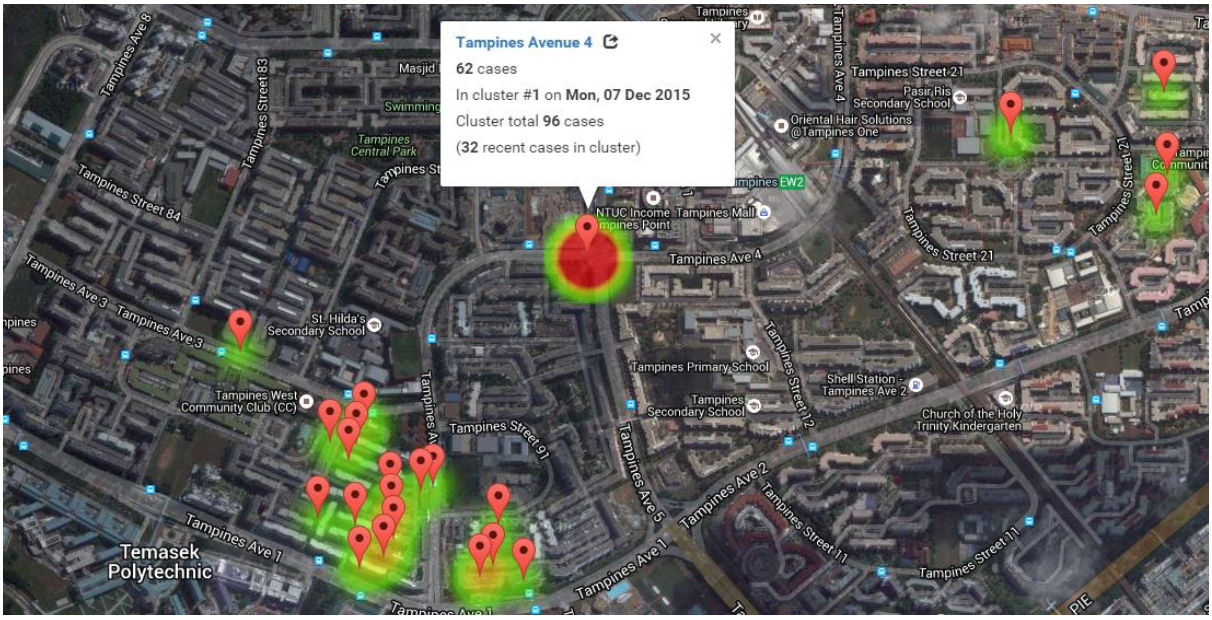


Figure 4: Information of a individual cluster (Outbreak.SGcharts).

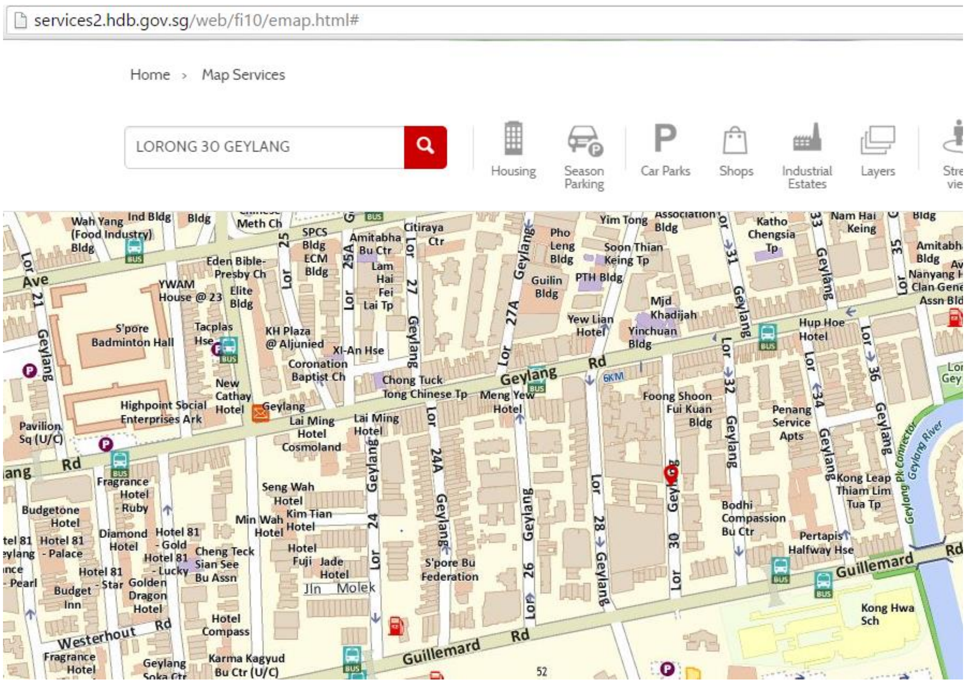


Figure 5: A search engine from HDB.

For each of the four month, number of dengue cases in each cell was calculated by joining the point feature class of dengue cases and the fishnet cells. The sum of number of cases in each cell was generated along with the spatial join. The distribution of number of dengue cases in each cell was highly skewed, such that most of the cells have no dengue cases, but some cells have as high as 134 cases. Such skewness resulted in serious overdispersion. Therefore, the count data was converted to binary data, with one denoting the presence of dengue cases in a particular cell, and zero denoting the absence.

<u>Proximity to Vegetation and Waterbodies</u>

A satellite image exported from CartoDB (http://www.cartodb.com) was used to classify the land cover on Singapore's mainland (Fig 6A). The satellite image was georeferenced and then clipped using the boundary of Singapore's mainland for clipping geometry (Fig 6B). Interactive supervised classification on the satellite image using the Image Classification tool. Training samples were selected for three land cover types, namely non-vegetated area, vegetation, and waterbody. The raster layer generated from supervised classification was then converted to a vector layer without simplifying the polygons (Fig 7). Two separate polygon feature classes were obtained for vegetation and waterbodies, respectively.

(A)

(B)

Figure 6: Satellite image of (A) Singapore and its surrounding area, and (B) Singapore's mainland.

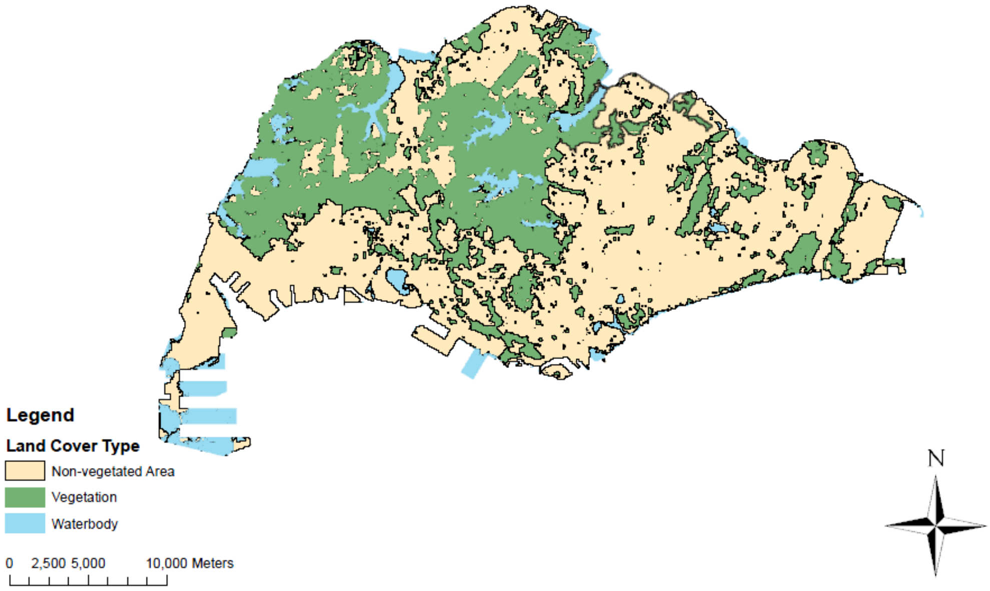


Figure 7: Land cover type on Singapore’s mainland, classified into non-vegetated area, vegetation, and waterbody.

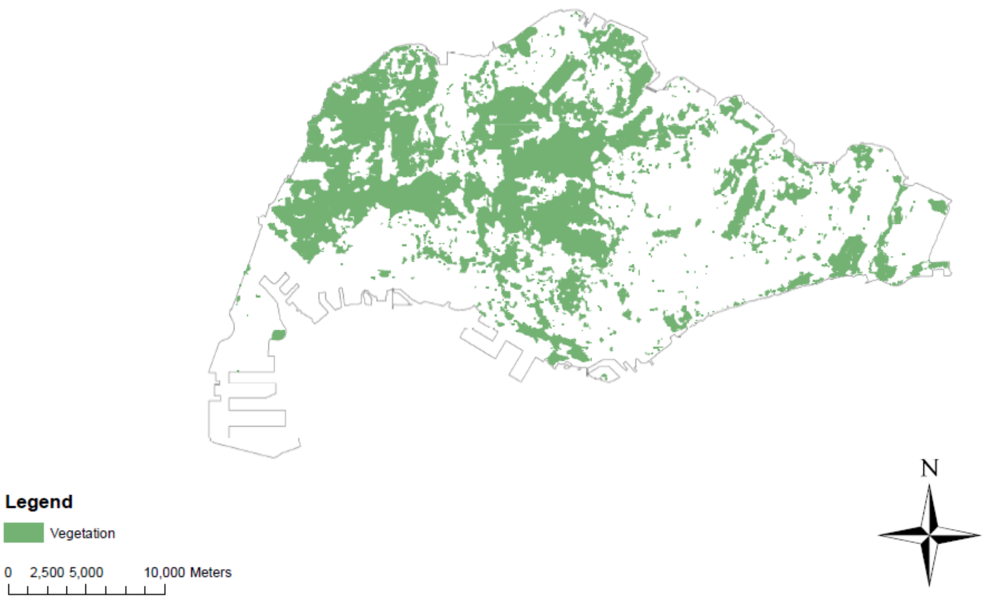
They were used to filter out fishnet cells that locate in natural reserves and reservoirs. The inclusion of these cells leads to negative correlation between proximity to vegetation and risk of dengue, as there is no residential building in large vegetation patch or on reservoir. Such relationship would not be meaningful and would mask the effects of other factors. Using the identity tool, cells with centroids on vegetation or water bodies were excluded for linear regression analysis.

They were also used to calculate the proximity of the centroids of all cells to vegetation or waterbodies, in order to test the possible effects of living near forests/parks and reservoirs on the risk of dengue. Using the Near tool, the distances of all cell centroids to the nearest vegetation polygon were calculated as a proxy of the distance of all cells to the nearest vegetation, as proximity analysis from polygons to polygons appeared to be too computationally intensive (Fig 8). Proximity analysis was carried out for waterbodies similarly. Search radius was not specified, as a negative value denoting the absence of vegetation in a searching area would be meaningless in linear regression. Rather, the actual distances were used.

Temperature and rainfall

Maps for average daily temperature (°C) and monthly total rainfall (mm) in selected months were retrieved from website of Meteorological Service Singapore (http://www.weather.gov.sg/climate-detailed-view/). The maps were manually digitized into feature classes. For each month, the average temperature and monthly total rainfall of each cell centroid was identified using the Identity tool (Fig 9).

(A)



(B)

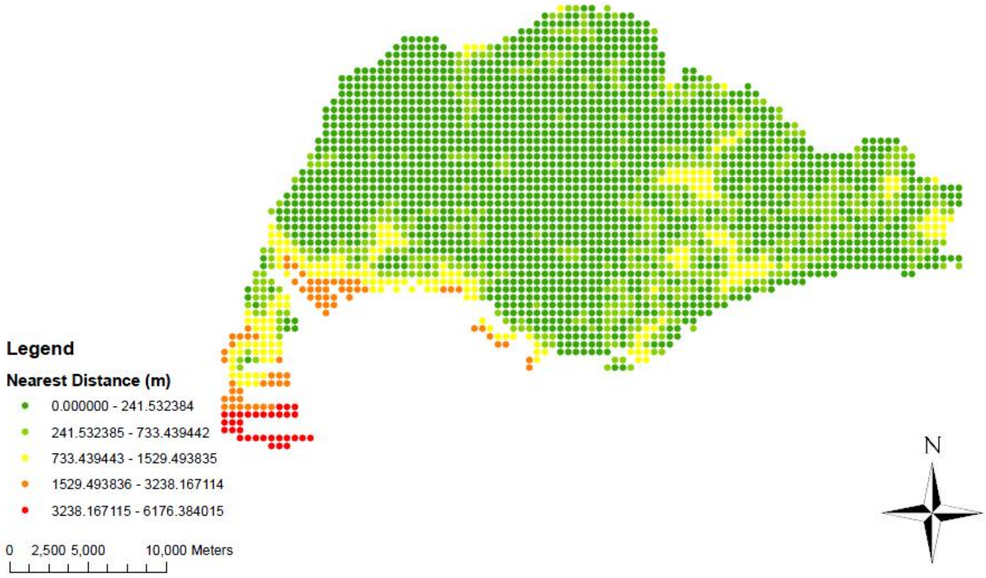
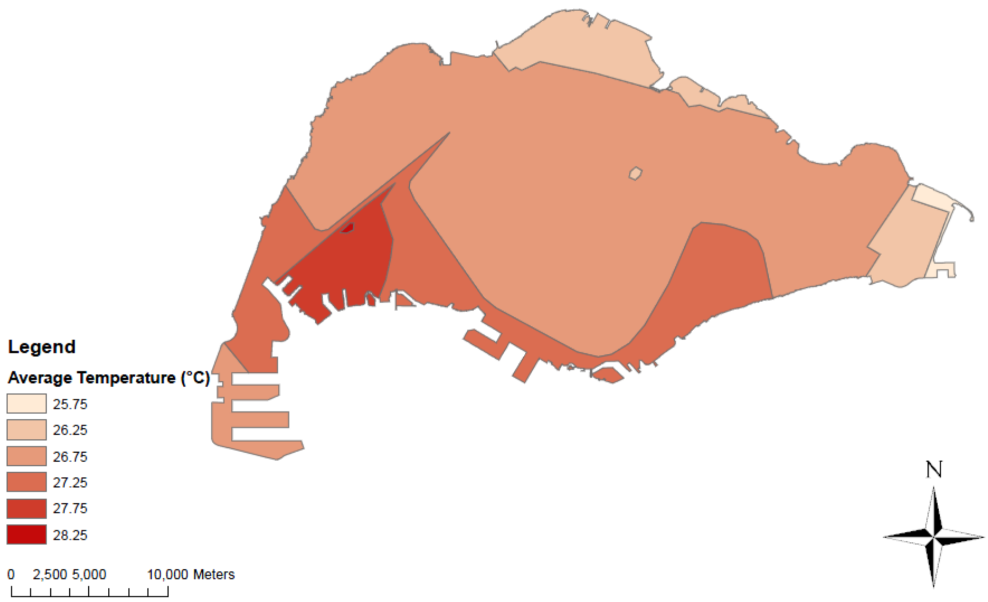


Figure 8: (A) Vegetation on Singapore's mainland, and (B) Distance of each cell to the nearest vegetation patch was calculated using centroids.

(A)



(B)

Figure 9: (A) Average temperature (°C) in Jan 2015, and (B) Average temperature of each cell was identified using centroids.

Linear Regression

Data including month, presence of dengue cases, population density, temperature, rainfall, distance to construction site, distance to vegetation, and distance to waterbodies was compiled into one datasheet (Fig 10). The data was then processed in R software for linear regression. As the presence/absence of dengue cases in each cell takes the form of zero or one, the data was fit with a generalized linear model (GLM) using binomial distribution using the following code.

```
model<- glm (Case ~ Population.Density + Temperature + Rainfall
+Distance.to.Construction.Sites + Distance.to.Vegetation
+ Distance.to.Waterbodies,
data=dengue, family=binomial(link=”logit”))
```

summary (model)

Only first order effects were included in order to avoid overfitting. Regression analyses were performed for all four selected months, with varying temperature and rainfall. Full models were then selected by Akaike Information Criterion (AIC) in a stepwise algorithm.

selected.model<- stepAIC (model, trace=0, direction=”both”)

summary (selected.model)

The dengue cases were then mapped together with the fitted values in order to evaluate the power of the models. Log odds of dengue occurrence were converted to probabilities for better visualization.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	MAUP	Month	ID	Name	Area	Pop	ConsDist	Temp	Rain	Case	Density	VegDist	WaterDist	Bino	Pre01	Pre04	Pre07	Pre10
2	500	1	1	NA	0	0	17451.72	0	0	0	0	5551.796	689.2891	0	6.137961	-50.7139	-9.04322	-34.7069
3	500	1	2	NA	0	0	17172.98	0	0	0	0	5429.189	551.6275	0	5.981932	-50.874	-8.94268	-34.6934
4	500	1	3	NA	0	0	16904.44	0	0	0	0	5350.677	430.512	0	5.882018	-50.9922	-8.84582	-34.6804
5	500	1	4	NA	0	0	16646.59	0	0	0	0	5318.214	309.4089	0	5.840706	-51.0747	-8.75281	-34.6679
6	500	1	5	NA	23145.56	0	16399.93	0	0	0	0	5329.876	188.3405	0	5.855546	-51.1232	-8.66384	-34.6559
7	500	1	6	NA	85089.46	0	16164.98	0	0	0	0	5387.293	67.48964	0	5.928616	-51.1363	-8.57909	-34.6445
8	500	1	7	NA	147644.3	0	15942.25	26.75	62.5	0	0	5489.835	0	0	4.639604	-3.89223	-8.09961	-4.80743
9	500	1	8	NA	210199.1	0	15732.26	26.75	62.5	0	0	5635.037	0	0	4.824388	-3.78006	-8.02387	-4.79724
10	500	1	9	NA	225178.9	0	15488.95	26.75	62.5	0	0	5819.707	0	0	5.0594	-3.6374	-7.9361	-4.78543
11	500	1	10	NA	102736.6	0	15209.03	0	0	0	0	6040.227	108.3289	0	6.75954	-50.6125	-8.23428	-34.5981
12	500	1	11	NA	15042.5	0	14940.61	0	0	0	0	6292.829	541.4293	0	7.081001	-50.2117	-8.13746	-34.5851
13	500	1	12	NA	0	0	14684.32	0	0	0	0	6573.816	747.7858	0	7.438585	-49.8966	-8.04502	-34.5726
14	500	1	13	NA	0	0	14440.79	0	0	0	0	6879.71	1017.944	0	7.827866	-49.532	-7.95718	-34.5608
15	500	1	14	NA	0	0	14210.69	0	0	0	0	7207.341	1418.885	0	8.244809	-49.0885	-7.87418	-34.5496
16	500	1	15	NA	0	0	13994.68	0	0	0	0	7553.881	1863.775	0	8.685816	-48.6095	-7.79627	-34.5392
17	500	1	16	NA	0	0	13793.42	0	0	0	0	7916.848	2326.451	0	9.147727	-48.1094	-7.72367	-34.5294
18	500	1	17	NA	0	0	13607.56	0	0	0	0	8190.634	2801.981	0	9.496148	-47.6721	-7.65663	-34.5204
19	500	1	18	NA	0	0	13427.25	0	0	0	0	8420.552	3284.785	0	9.78874	-47.2652	-7.59159	-34.5116
20	500	1	19	NA	0	0	13214.25	0	0	0	0	8673.228	3772.073	0	10.1103	-46.8386	-7.51477	-34.5013
21	500	1	20	NA	0	0	13016.99	0	0	0	0	8946.736	4262.306	0	10.45836	-46.3945	-7.44361	-34.4917
22	500	1	21	NA	0	0	12836.18	0	0	0	0	9239.226	4754.574	0	10.83059	-45.9348	-7.37839	-34.4829
23	500	1	22	NA	0	0	12672.53	0	0	0	0	9548.952	5248.304	0	11.22474	-45.461	-7.31936	-34.475
24	500	1	23	NA	0	0	12526.71	0	0	0	0	9874.295	5743.118	0	11.63877	-44.9747	-7.26677	-34.4679
25	500	1	24	NA	0	0	12399.35	0	0	0	0	10213.76	6238.76	0	12.07078	-44.4771	-7.22083	-34.4617
26	500	1	25	NA	0	0	12259.84	0	0	0	0	10344.95	6735.046	0	12.23773	-44.1401	-7.17051	-34.455
27	500	1	26	NA	0	0	11848.26	0	0	0	0	10048.49	7231.844	0	11.86046	-44.1331	-7.02205	-34.435
28	500	1	27	NA	0	0	11443.73	0	0	0	0	9768.646	7729.055	0	11.50433	-44.1132	-6.87614	-34.4154
29	500	1	28	NA	0	0	11047.02	0	0	0	0	9506.874	7507.64	0	11.17119	-44.4206	-6.73305	-34.3961
30	500	1	29	NA	0	0	10659	0	0	0	0	9264.709	7150.114	0	10.86302	-44.7774	-6.59309	-34.3773
31	500	1	30	NA	0	0	10280.66	0	0	0	0	9041.742	6805.353	0	10.57927	-45.1134	-6.45662	-34.3589
32	500	1	31	NA	0	0	9913.106	0	0	0	0	8785.927	6480.824	0	10.25372	-45.4651	-6.32404	-34.3411

Combined500

Figure 10: Compiled datasheet for linear regression.

Predicting future risks

Risks of dengue were predicted in the context of global warming. Corlett (2012) expected an increase of 2.7–4.2 °C in average temperature in Singapore by 2100. Therefore, probabilities of dengue occurrences were predicted using the selected generalized linear models, with a 3.45 °C increase in temperature.

Results

Linear Regression

In January, the occurrence of dengue in a cell was positively correlated to population density, and distance to vegetation, but negatively correlated to rainfall (Table 1, Fig 11).

Table 1: Generalized linear model with a binomial distribution for the occurrence of dengue cases in January.

	Estimate	Standard Error	z value	Pr(>|z|)	Significance
(Intercept)	-0.92725	0.564444	-1.643	0.10043	
Population Density	8.703946	3.240455	2.686	0.007231	**
Rainfall	-0.02271	0.006772	-3.354	0.000797	***
Distance to Vegetation	0.001273	0.000359	3.547	0.00039	***

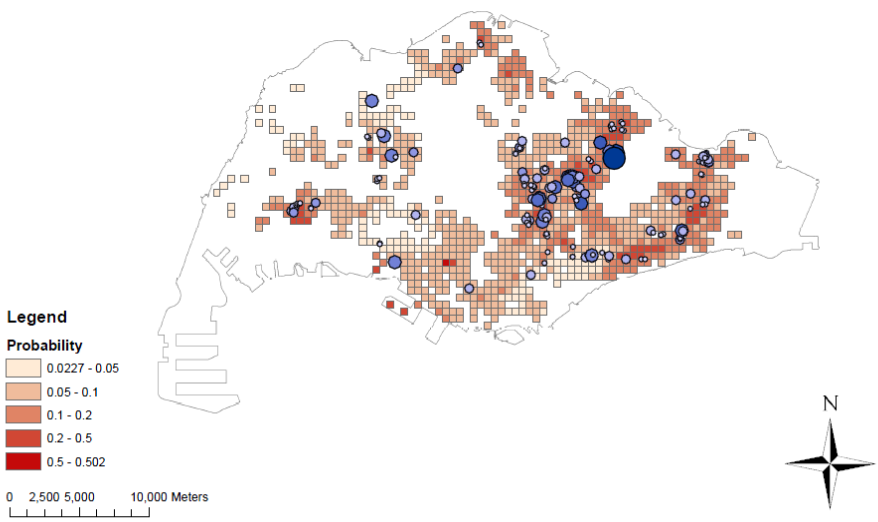


Figure 11: Fitted probabilities of dengue occurrence in January.

In April, the occurrence of dengue in a cell was positively correlated to temperature and distance to waterbodies (Table 2, Fig 12).

Table 2: Generalized linear model with a binomial distribution for the occurrence of dengue cases in April.

	Estimate	Standard Error	z value	Pr(>|z|)	Significance
(Intercept)	-5.53E+01	1.95E+01	-2.842	0.00448	**
Temperature	1.78E+00	6.69E-01	2.659	0.00785	**
Rainfall	5.41E-03	3.51E-03	1.539	0.12369	
Distance to Vegetation	7.73E-04	5.07E-04	1.525	0.12721	
Distance to Waterbodies	4.75E-04	1.69E-04	2.814	0.00489	**

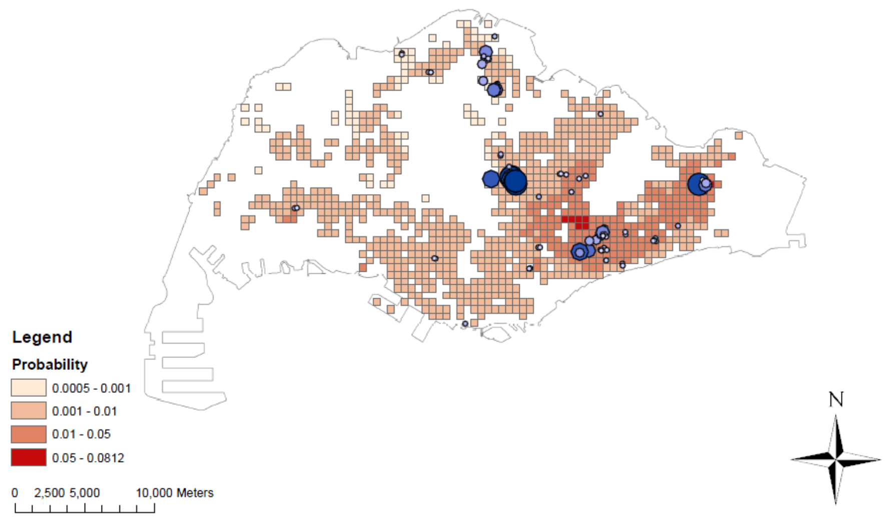


Figure 12: Fitted probabilities of dengue occurrence in April.

In July, the occurrence of dengue in a cell was positively correlated to population density, but negatively correlated to distance to construction sites (Table 3, Fig 13).

Table 3: Generalized linear model with a binomial distribution for the occurrence of dengue cases in July.

	Estimate	Standard Error	z value	Pr(>|z|)	Significance
(Intercept)	-2.74838	0.44141	-6.226	4.77E-10	***
Population Density	8.893837	3.289184	2.704	0.00685	**
Rainfall	0.006386	0.003573	1.787	0.07389	.
Distance to Construction Sites	-0.00036	0.000162	-2.226	0.02604	*

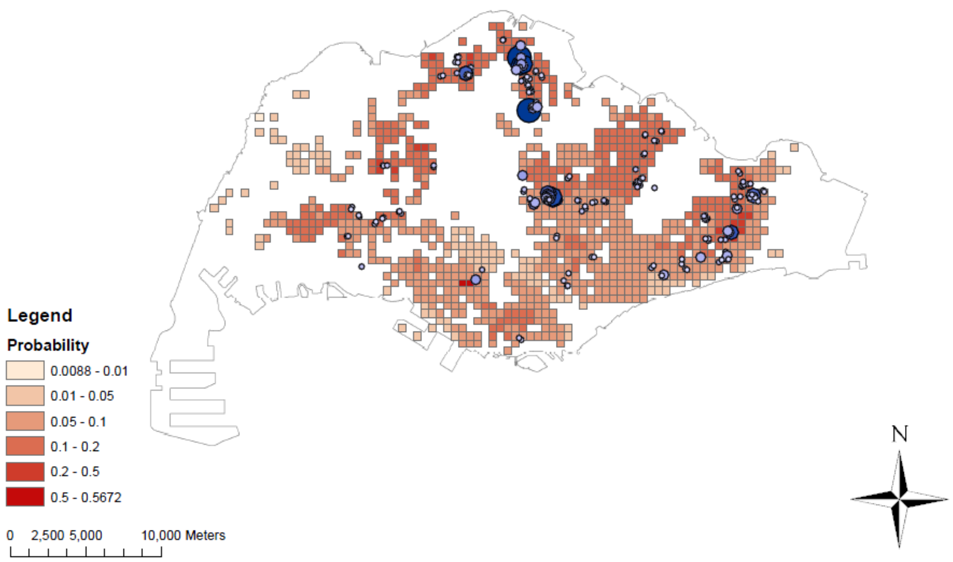


Figure 13: Fitted probabilities of dengue occurrence in July.

In October, the occurrence of dengue in a cell was positively correlated to population density and temperature (Table 4, Fig 14). Longer distance to construction sites was also associated with increased probabilities of dengue occurrence, although the association was only marginally significant.

Table 4: Generalized linear model with a binomial distribution for the occurrence of dengue cases in Oct.

	Estimate	Standard Error	z value	Pr(>|z|)	Significance
(Intercept)	-3.39E+01	9.52E+00	-3.556	0.000376	***
Population Density	7.65E+00	3.20E+00	2.393	0.016731	*
Temperature	1.12E+00	3.32E-01	3.359	0.000783	***
Distance to Construction Sites	-4.85E-05	2.64E-05	-1.842	0.065542	.

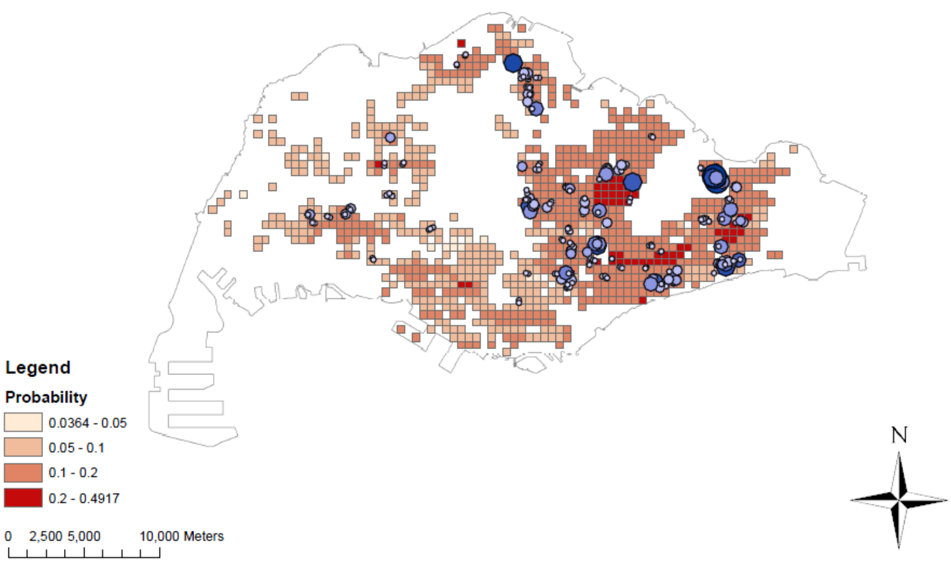


Figure 14: Fitted probabilities of dengue occurrence in Oct.

In summary, the occurrence of dengue cases appeared to be associated with different factors in different month (Table 5).

Table 5: Factors associated with the occurrence of dengue cases in selected months. (+: Positive correlation; -: Negative correlation.)

	Jan	Apr	Jul	Oct
Distance to Construction Sites			-	
Distance to Vegetation	+			
Distance to Waterbodies		+		
Population Density	+		+	+
Rainfall	-			
Temperature		+		+

Prediction

As temperature was significantly associated with dengue occurrences in Apr and Oct, future risk maps were produced for these two month, using the corresponding linear regression models. It was observed that with a 3.45 °C increase in temperature, the probability of dengue occurrences in residential areas in Apr increased from 0.0005–0.0812 (by 2015) to 0.1857–0.976 (by 2100) (Fig 15). Similarly for Oct, the probability of dengue occurrences in residential areas increased from 0.0364–0.4917 (by 2015) to 0.6392–0.9784 (by 2100) (Fig 16).

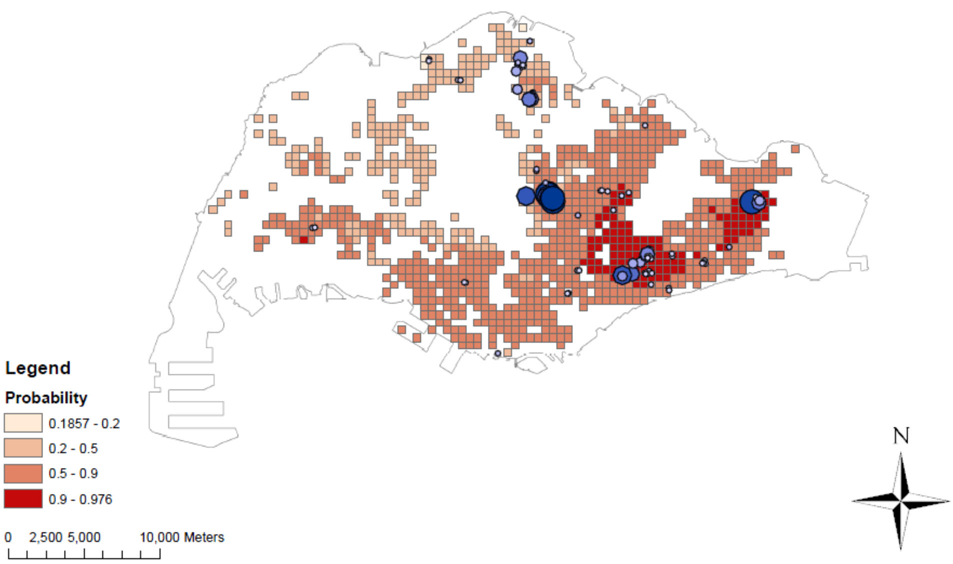


Figure 15: Predicted risk map for Apr 2100, with a 3.45 °C increase in temperature. (Dengue cases in Apr 2015 are plotted for reference.)

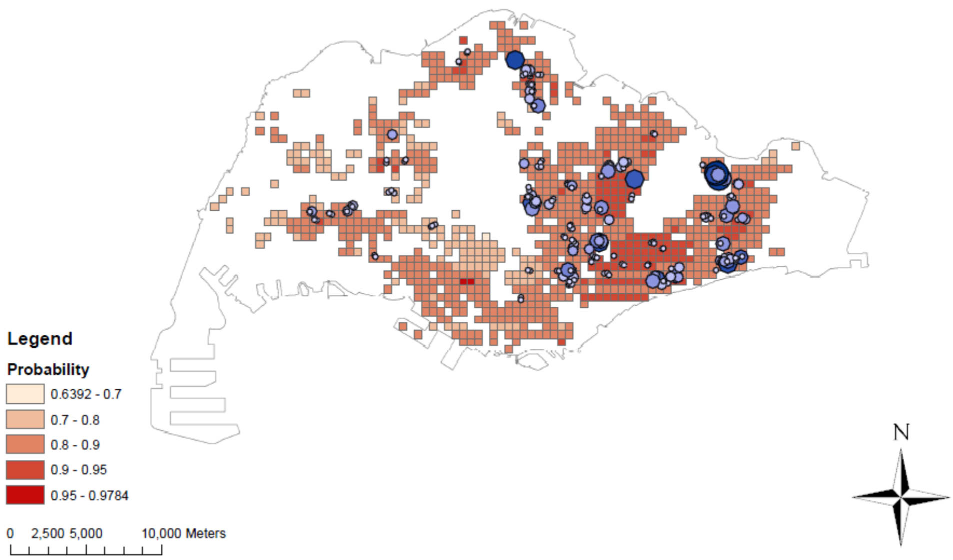


Figure 16: Predicted risk map for Oct by 2100, with a 3.45 °C increase in temperature. (Dengue cases in Oct 2015 are plotted for reference.)

DISCUSSION

Forests/Parks and reservoirs do not increase risk of dengue

Results from linear regression show that distance to vegetation and distance to waterbodies was positively correlated with the probability of dengue occurrence in Jan and Apr respectively.

The large patches of vegetation in Singapore, namely forests and parks, are not likely to increase the risk of dengue (Fig 17). This is supported by research that shows that the vector of dengue fever, *Aedesaegypti,* is restricted to human-modified environments, and disperse less into forest areas (Lounibos, 2002; Maciel-de-Freita *et al.*, 2006).

Results also show that Singapore's large waterbodies, mainly the reservoirs, do not elevate risk of dengue in the surrounding areas (Fig 18). This could be because 1) fish and other predators in reservoirs reduce the number of mosquito larvae, 2) wind and water transfer between reservoirs increase mixing, 3) Public Utilities Board actively managing the reservoirs by BTi application and aeration, which could deter mosquito breeding (Low, 2010).

Instead of being potential mosquito breeding sites, distance to vegetation or waterbodies may be used to indicate increased urbanization. It was tested using linear regression that the distance to vegetation was positively correlated with population density, and temperature. Similar relationships were found among distance to waterbodies, population density, and temperature. In particular, the loss of green cover and the increase of impervious surface area important indicators for urbanization (Yuan *et al.*, 2007; Petralli *et al.*, 2014). The effects of vegetation and waterbodies on risk dengue should be discussed in relation to urbanization.

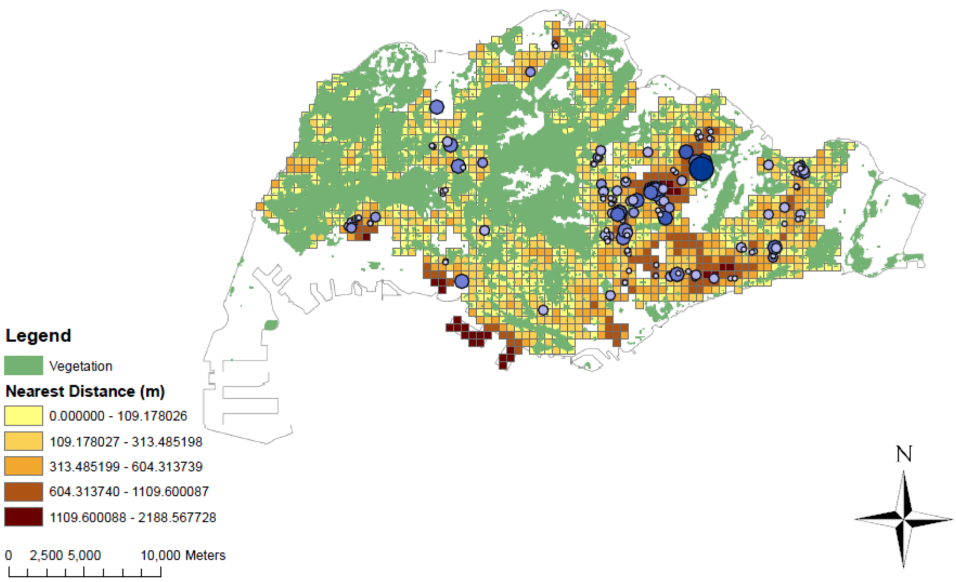


Figure 17: Nearest distance to vegetation (m) and dengue cases in January.

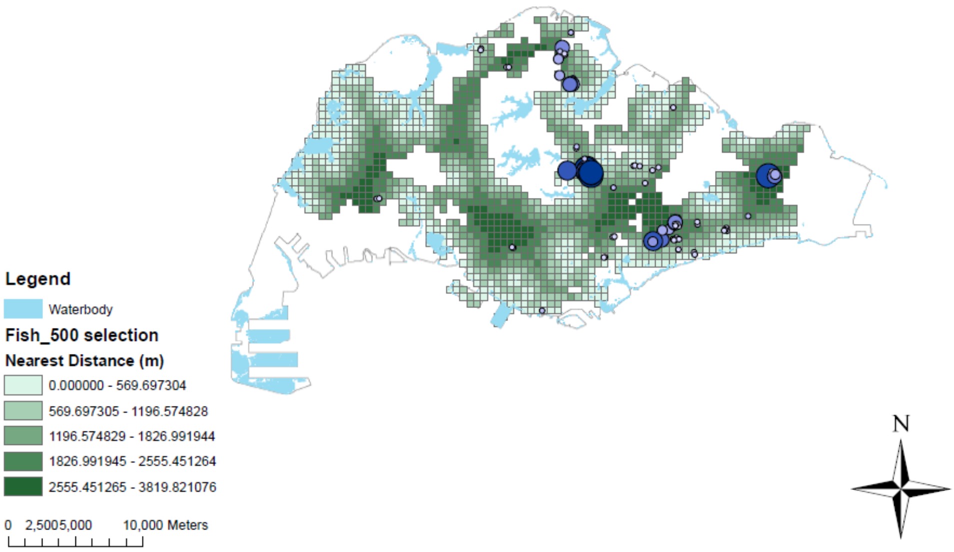


Figure 18: Nearest distance to waterbodies (m) and dengue cases in April.

Effects of temperature and implications

Results showed a positive correlation between temperature and number of dengue cases in the months of April and October (Fig 19 & 20). This is consistent with previous research showing that temperature is a significant climatic variable contributing to dengue in Singapore (Pinto *et al.*, 2011).

The gradual increase in global temperature is anticipated to raise the occurrences of vector borne diseases such as dengue (Husain and Chaudhary, 2008). Thus with the effect of global warming, Singapore will continue to be a favorable breeding ground for Aedes mosquitoes with predicted temperature increases of 2.7 to 4.2 °C by 2100 (Corlett, 2012). A 3.45 °C increase in temperature, areas with the probability of dengue occurrences higher than 0.1 will expand, and the highest probability of dengue occurrences in Singapore will also increase, implying that a larger area and a larger population will be at risk (Fig 16 & 17).

In addition, the frequent occurrences in areas with high population density could also be explained by Urban Heat Island effect across Singapore. Urban areas have a higher temperature than non-urban areas and the feeding and breeding patterns of mosquitoes are accelerated in urban areas (Araujo *et.al*., 2014). Hence, the prevalence of dengue in urbanised areas are linked to the temperature, which in turn directly relates to that of the population density.

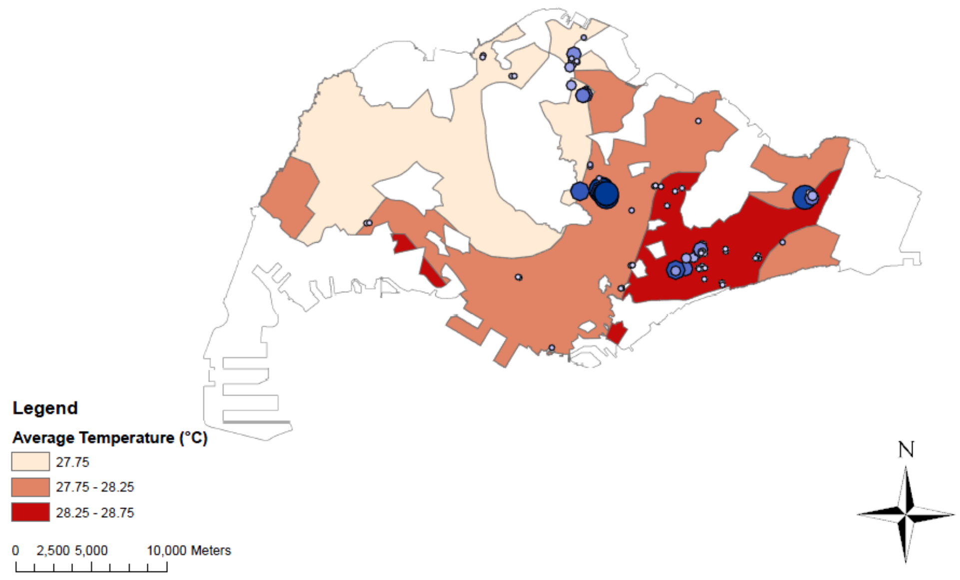


Figure 19: Average temperature (°C) and dengue cases in April.

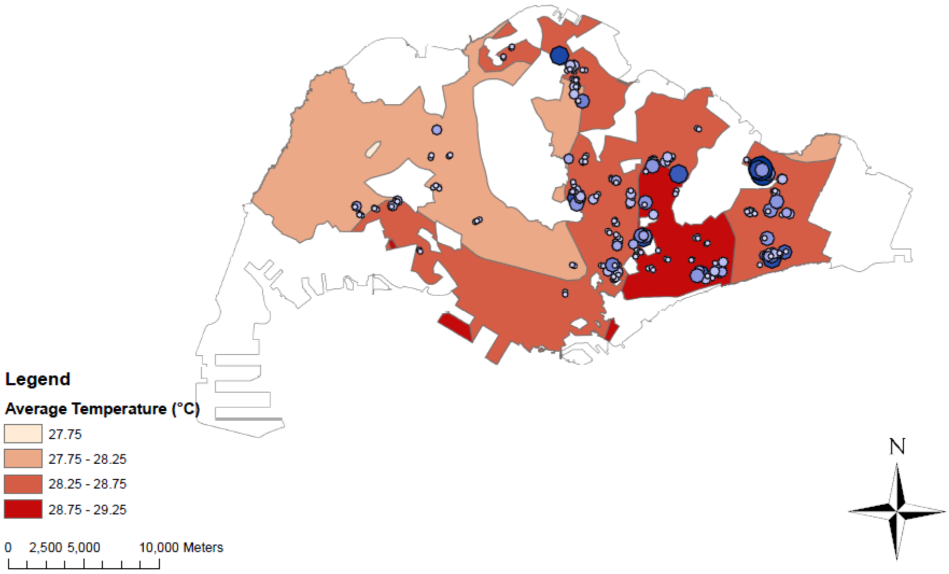


Figure 20: Average temperature (°C) and dengue cases in October.

Population Density

A positive correlation between population density and frequency of dengue occurrences can be observed in three out of the four months (Fig 21, 22 & 23). There could be a direct relationship between population density and dengue occurrences. Given the same area, cells with greater population densities are expected to have larger populations that are susceptible to dengue transmission. Naturally, there would be higher probabilities that dengue cases occur in these cells and thus a higher actual occurrence of dengue cases in these cells.

The high frequency of dengue occurrences in densely populated areas is consistent with the short dispersal distance of *Aedes spp.*, which is usually 25 to 50m from their breeding sites (Morlan & Hayes, 1958). With limited dispersal ability, *Aedes spp.* dominate in and are restricted to urbanized areas with higher population density, where humans are in close proximity to each other.

Such relationship could also reflect the effect of urbanization, which is seen in areas with sizeable population, and is observed in Taiwan as well (Wu *et al.*, 2003). Urbanization is accompanied with the increase of concrete structures, such as water storage containers and concrete drains. These structures could accumulate temporary bodies of artificial water, potentially utilized as breed sites of mosquitoes (Hales *et al.*, 1999; Kumar *et al.*, 2001; Chadee *et al.*, 2005).

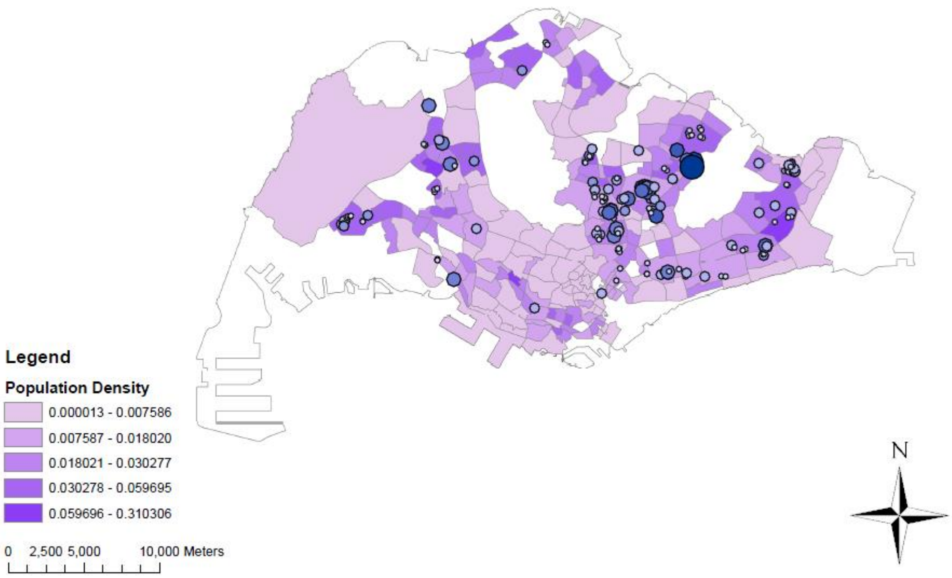


Figure 21: Population density (individual/m^2) and dengue cases in January.

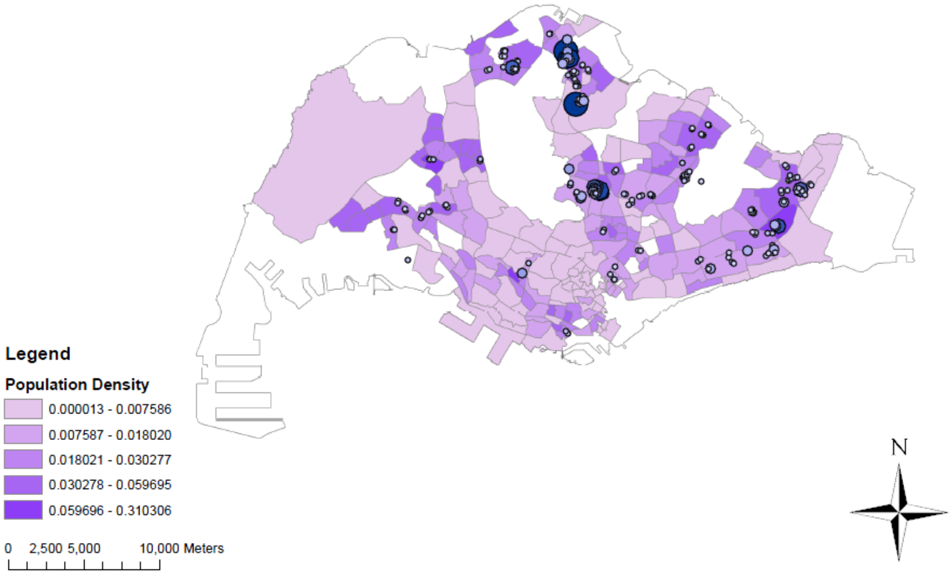


Figure 22: Population density (individual/m^2) and dengue cases in July.

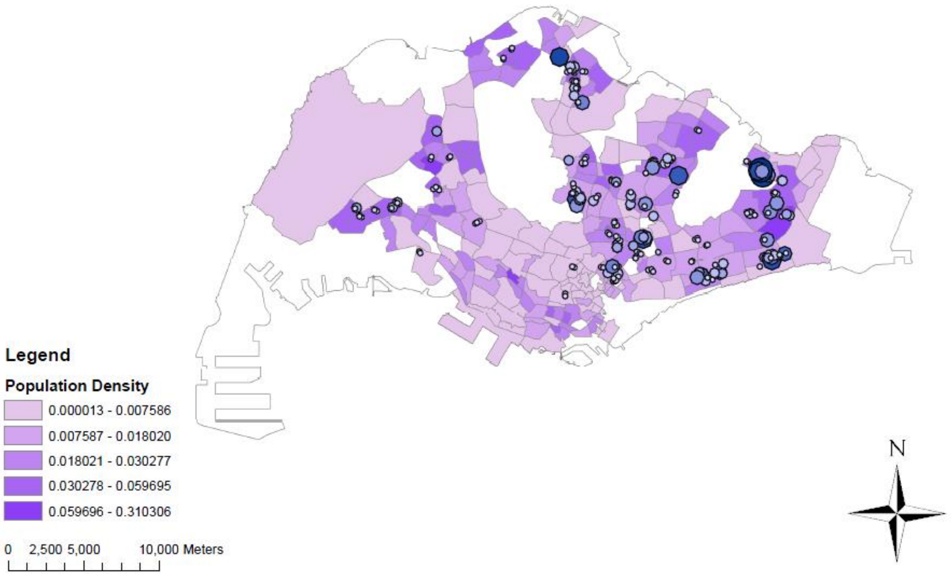


Figure 23: Population density (individual/m^2) and dengue cases in October.

<u>Effects of construction sites and rainfall was variable</u>

There was a significant negative correlation between proximity to construction sites and number of dengue cases in the month of July (Fig 23). The presence of stagnant water in construction sites could have resulted in a potential breeding site for Aedes mosquitoes (Kholedi *et. al*., 2012). However, the effects of construction sites in other months was unclear.

Although rainfall was shown to be a significant factor in January, the effect couldnot be visualized, and the underlying mechanism was unclear (Fig 24). This could be an artefact due to the small sample size, and more research is needed to test this hypothesis.

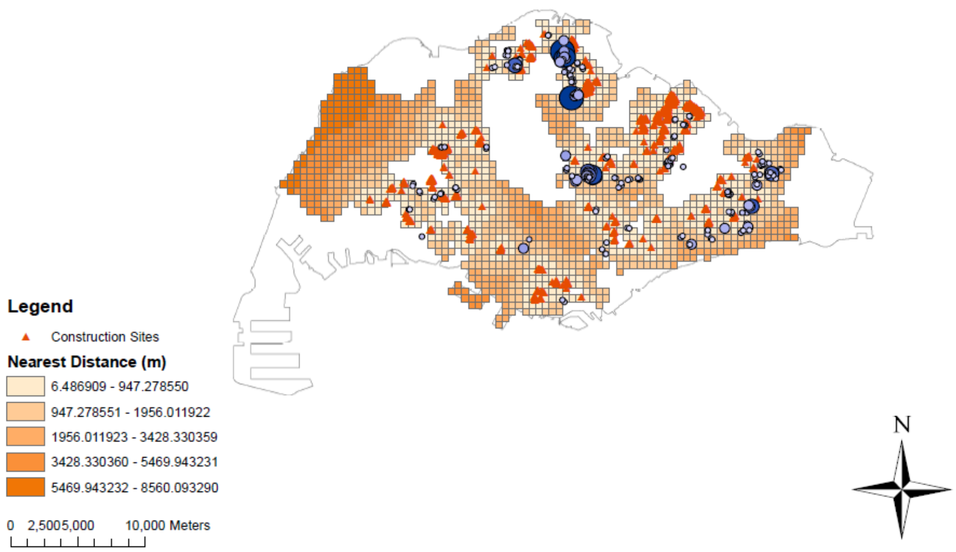


Figure 24: Nearest distance to construction sites (m) and dengue cases in July.

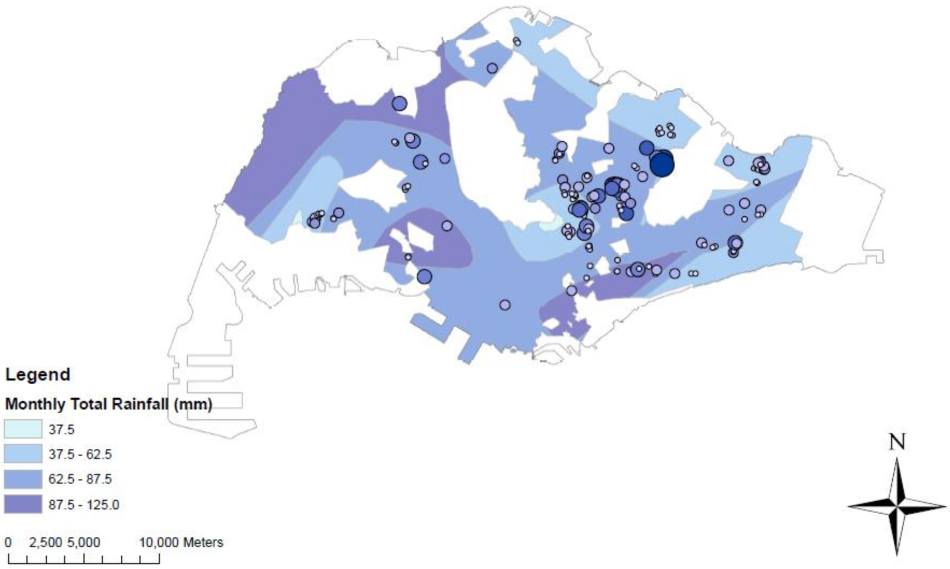


Figure 25: Monthly total rainfall (mm) and dengue cases in January.

Limitations and caveats

The analyses in this paper were based on four months in one year of dengue data due to time and labor constraints. However, the authors recognise that the conclusions drawn and predictions made would be more reliable if dengue records from a longer time period were analysed.

Another limitation might be the discrete units used to divide Singapore. This project used a 500 m cells to analyse the pattern of dengue cases affecting people in Singapore. The number of residential buildings within each cell could have confounded the analysis. More information about the mechanisms underlying the spatial distribution of dengue cases might be obtained, if buildings were used as the unit of analysis. However, this could not be done because of the lack of data source on residential buildings and the time and labor constraints.

Future Directions

Aside from the factors tested in this study, many other factors could have a relationship with the spatial distribution of dengue in Singapore, including housing types, domestic ornamental plants, and drainage systems in households. Also, analysing the interactions between different factors, whether they compound or negate the effects of each other, would be an interesting research route. Furthermore, a more holistic prediction map could be generated when the other factors' predicted change in year 2100 are taken into consideration as well.

Conclusion

Our project shows that occurrence of dengue cases is positively correlated with 1) proximity to vegetation, 2) proximity to waterbodies, 3) population density, and 4) temperature. The occurrence is negatively correlated to distance to construction sites. The effect of rainfall on occurrence of dengue cases is unclear due to limited evidence.

All in all, dengue is a pertinent problem in Singapore and with the lack of research specific to Singapore, projects investigating dengue in Singapore such as this are likely to value-add to academia regardless of the direction pursued.

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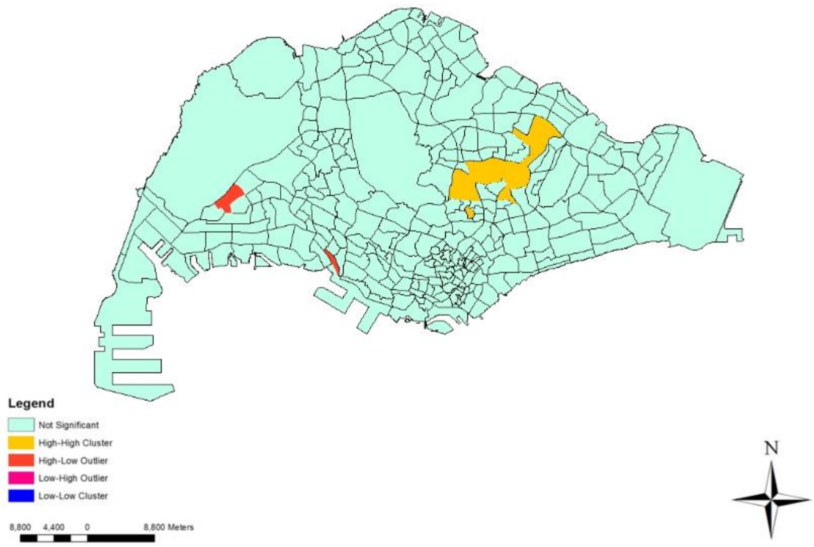
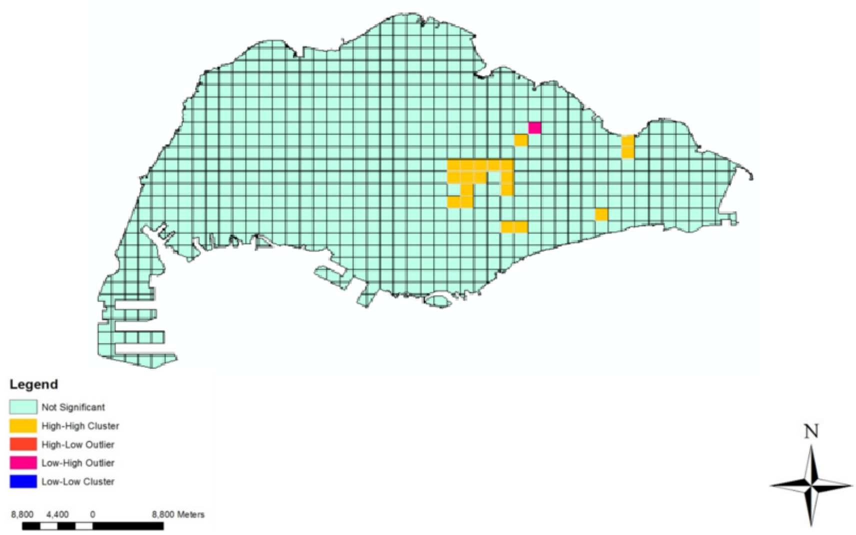
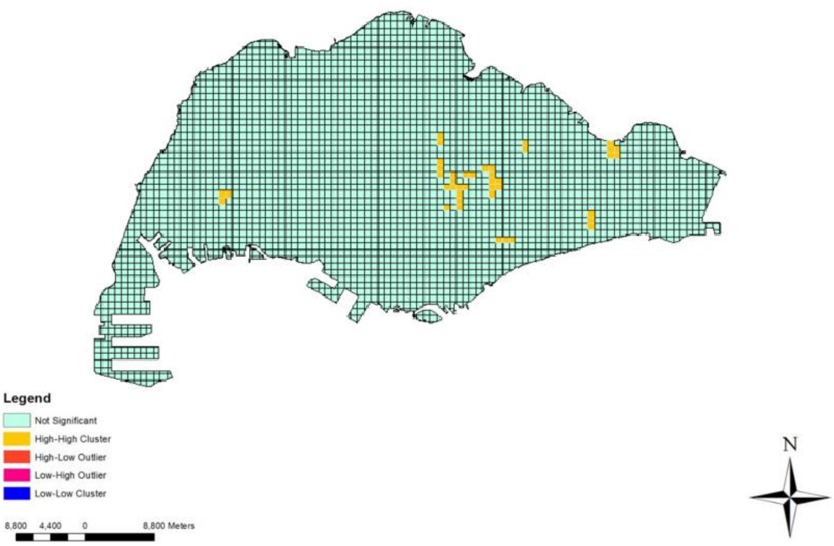
Appendix

Local Moran's I analysis for subzone, fishnet (1000m cell), fishnet (500m cell) (in order) for the MAUP problem

For Month of January

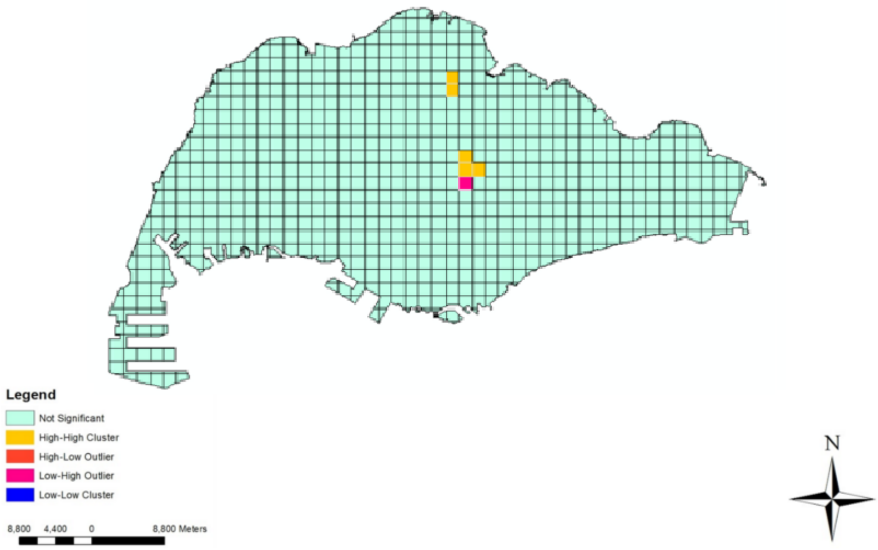


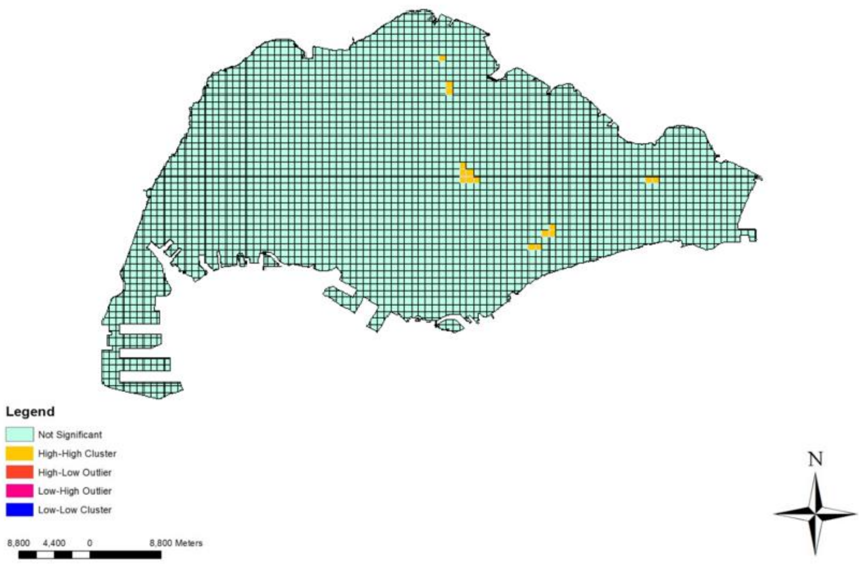




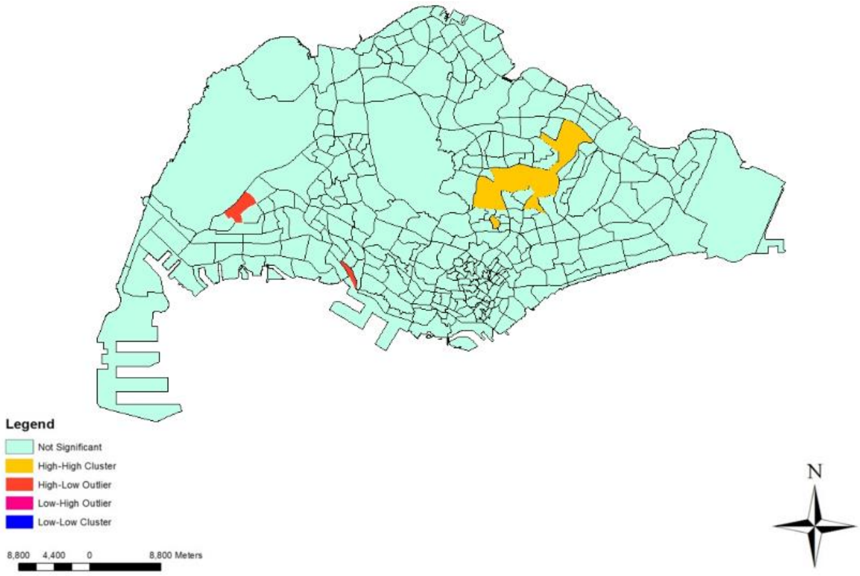
For month of April

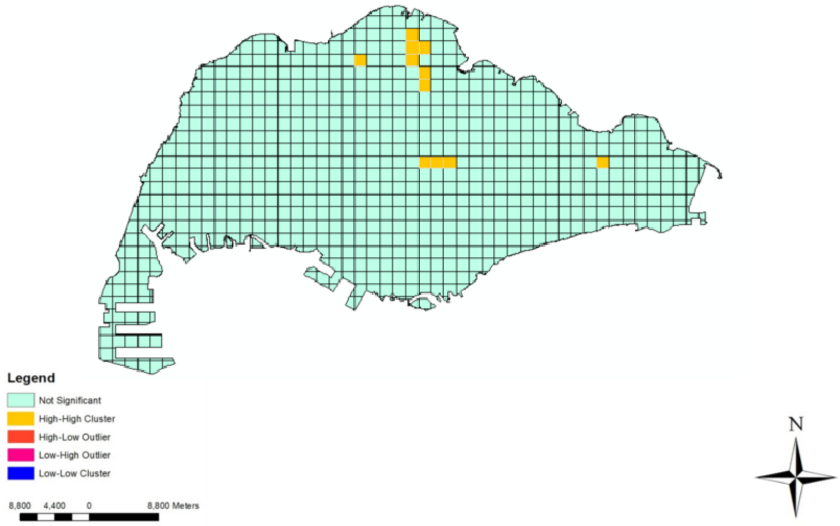
No significant result for Subzone Global Moran I, hence local Moran I analysis not possible

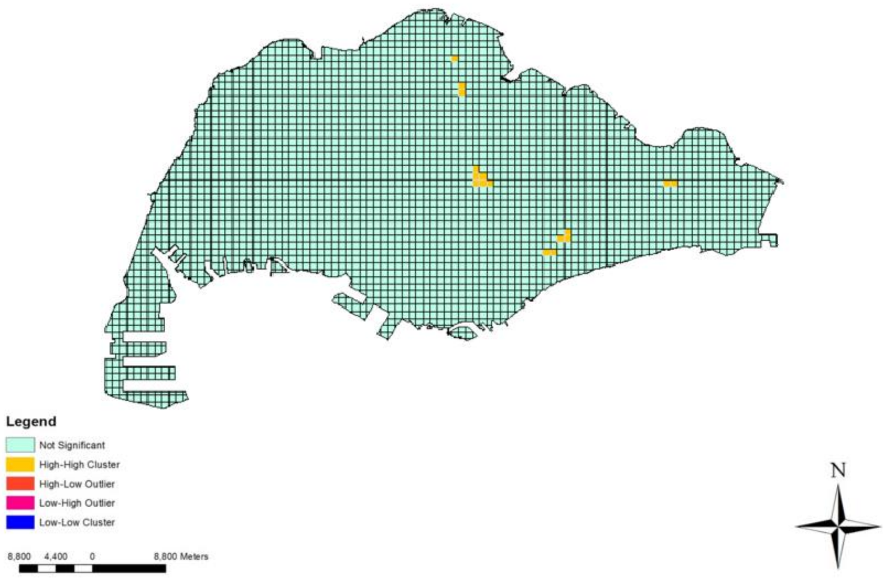




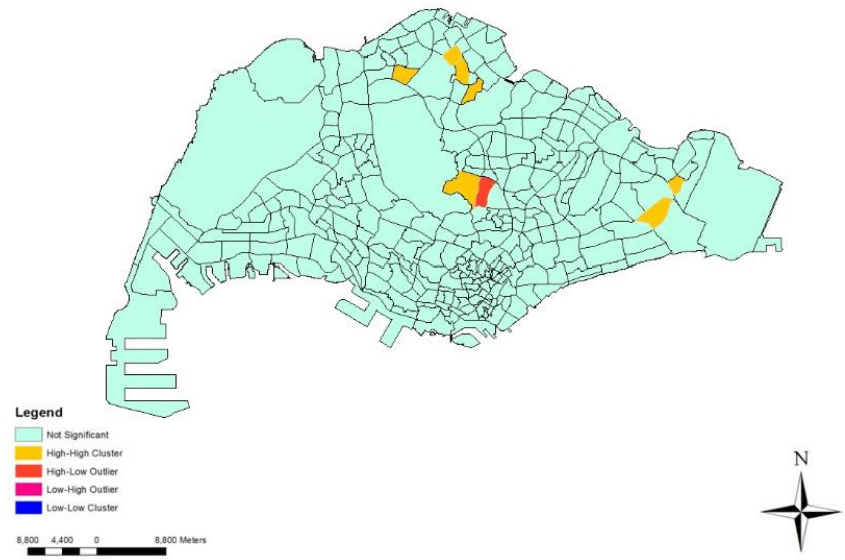
For month of July







For month of October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High-Low Outlier
Low-High Outlier
Low-Low Cluster
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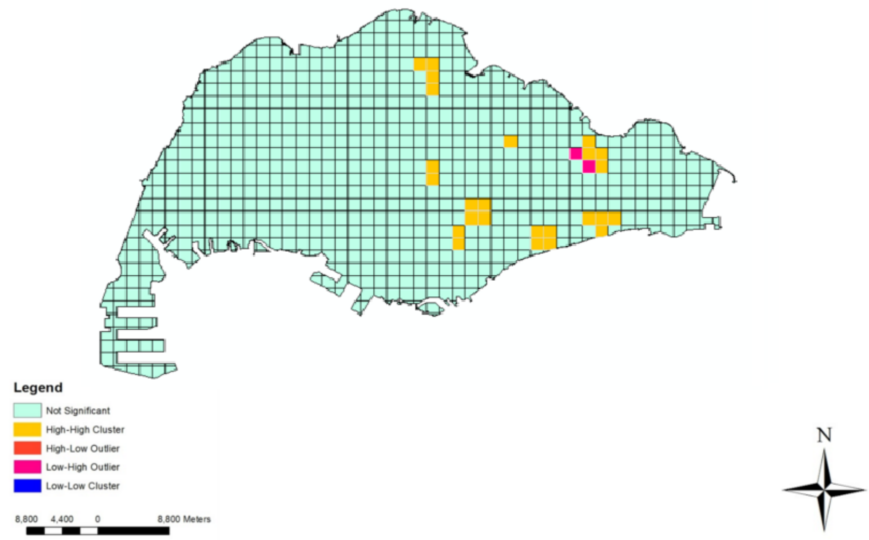
N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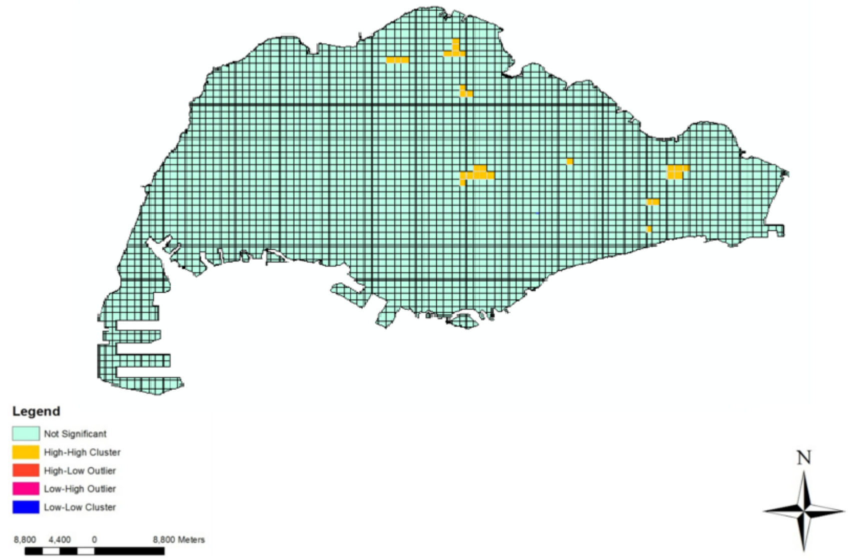
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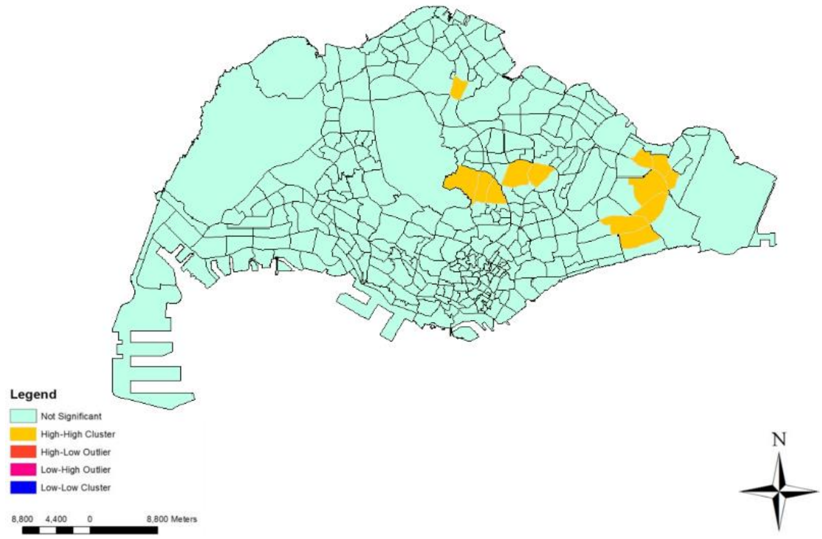
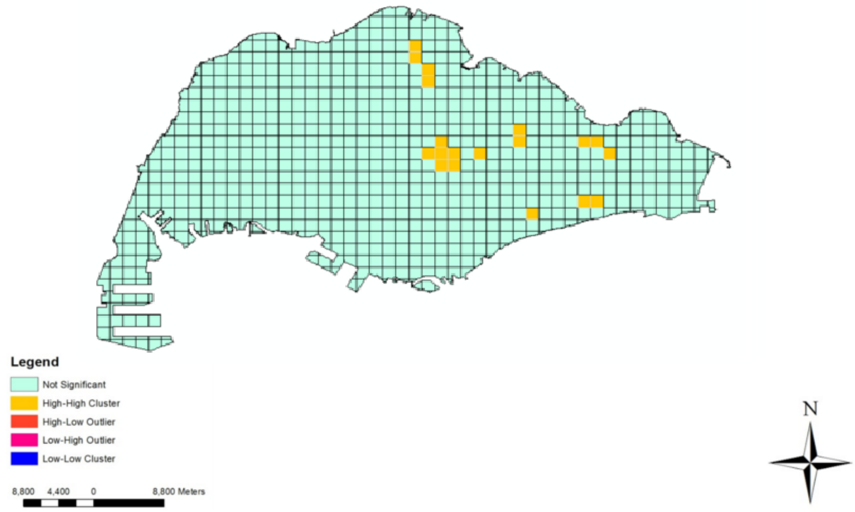
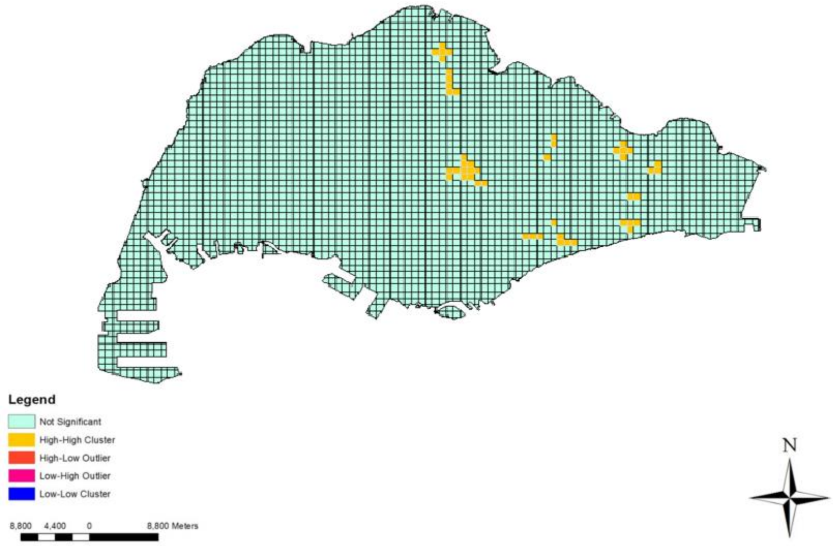
For the entire year of 2015






Legend
Not Significant
High-High Cluster
High-Low Outlier
Low-High Outlier
Low-Low Cluster
8,800 4,400 0 8,800 Meters
N