THE ROLE OF ENVIRONMENTAL AND EPIDEMIOLOGICAL IN MAPPING SUSCEPTIBILITY MALARIA DISEASE IN RANAU DISTRICT USING REMOTE SENSING AND GIS

Shimatun Jumani Ibrahim (1), Norimaniah Mazelan (1), Zuraimi Suleiman (1), Jenarun Jelip (2), Mohd Hafizi Abdul Hamid (2), Hazil Sardi Soliano (1), Ong Chia Ching (2), Ahmad Shah Ibrahim (2)

[1]Malaysian Remote Sensing Agency, Ministry of Energy, Science, Technology, Environment and Climate Change, No. 13, Jalan Tun Ismail, 50480, Kuala Lumpur, Malaysia
[2]Disease Control Division, Ministry of Health Malaysia, Level 4, Block E10, Parcel E, 62590 Precinct 1, Putrajaya
Email: shimatun@remotesensing.gov.my; iman@remotesensing.gov.my

ABSTRACT

Malaria has been identified as a public health problem in Malaysia since the early 1960s. In 2011, The National Malaria Elimination Strategic Plan was introduced with the target of “zero” status for indigenous human malaria by 2020. Majority of cases in Malaysia are found in Sabah and Sarawak. Ranau district has the highest number of cases which 273 out of 1,660 total cases reported in Sabah in 2017. Most of the cases are contributed by zoonotic malaria compared to human malaria. Analysis using remote sensing and GIS techniques helps to identify the environment risk factors to malaria incidence. By using remote sensing and GIS data, this study produces the malaria susceptibility map in Ranau. Environmental and epidemiological related variables such as vegetation index (NDVI), land surface temperature (LST), soil moisture (SM), digital elevation model (DEM), land use/cover changes, distance to river, rainfall, population density and malaria cases have been used, integrated and analyzed by using multi criteria decision analysis (MCDA) method. Then, Analytical Hierarchy Process (AHP) Pairwise Comparison is applied to assign weightage to the variables that generated malaria susceptibility map. The map was categorized into five classes: very low, low, medium, high and very high. Almost 90% of Ranau district was identified as high susceptibility area to malaria transmission. The mean accuracy of the map was assessed by using epidemiological data of incidence case in year 2017, 2016 and 2015 shows about 99.42 $\pm$ 1.32 % with equivalent probability of 0.99 in high-level susceptibility of malaria for 2017 and can be used to predict the high susceptibiltity area of malaria in targeted year. The relation between malaria incidence distribution and susceptibility maps will help health policy makers to target control interventions at high susceptibility area and enhance the cost-efficiency of the program.

KEYWORDS: Remote Sensing, GIS, malaria, susceptibility

1.0 INTRODUCTION

Malaysia as a tropical country has battled to prevent and control the malaria over the last few decades since the introduction of the Malaria Eradication Programme in 1960. In 2011, the Malaria Control Programme was reoriented from control to elimination by Ministry of Health (MOH) and formulated The National Malaria Elimination Strategic Plan with the target of "zero" status for indigenous human malaria by 2020. The MOH acknowledges that the number of locally acquired human malaria has plummeted from 6,071 in 2008 to 85 cases in 2017, the number of knowlesi malaria (or monkey malaria in human) increased from 376 cases in 2008 to 3,614 cases in 2017 (MOH, 2018). Although efficient control activities have vastly reduced the transmission of the disease, it is still a problem in rural, less developed areas especially in Sabah and Sarawak (WHO, 2015). In 2010, the Sabah malaria control programme reported that nearly half of malaria cases in Sabah each year identified in foreigners from endemic countries are living and working in plantations, agriculture and logging areas, which carry a higher risk of contracting malaria (WHO, 2015, Yeop N., 2015). Ranau district is one of the greatest number of cases with 273 out of 1,660 total cases reported in Sabah from Januari to November 2017 and the end of 2017, overall cases increased to 328 cases. All these malaria notifications in Sabah are among from human infections with the zoonotic parasite *P. knowlesi* where both the major monkey reservoir (*Macaca fascicularis* and *Macaca nemestrina*) and mosquito vector (*Anopheles leucosphyrus* group) are present (Shearer 2016, William 2014). In Sabah, *Anopheles balabacensis* is the primary vector of *P. knowlesi* and is found in village, forest, and farming area (Wong, 2015) and deforestation and associated environmental changes are key drivers in *P. knowlesi* transmission (Kimberly, 2016).

In generally, malaria transmission depends upon the existence of the Plasmodium parasite, the presence of *Anopheles sp.* mosquitoes as a vector, a human and or in case of zoonotic malaria, and a natural host of monkey/simian population. The transmission of the disease influenced by many factors of receptivity and vulnerability (WHO, 2015). Receptivity refers to environmental factors which ecology, geography and climate suitable for malaria vector breeding habitat and in biting and resting behaviors. Vulnerability refers to the movement of infected humans particularly; migrant's workers from various country or infected *Anopheles* mosquitoes. Based on these factors, environmental and epidemiological related variables such as vegetation index (NDVI), land surface temperature (LST), soil moisture (SM), digital elevation model (DEM), land use/cover changes, distance to river, rainfall, population density and malaria cases data have been used in this study. All the variables are prepared, ranked and weightage assigned based on Analytical Hierarchy Process (AHP) result and overlay using ArcGIS 10.6.1 software to produce susceptible area map of malaria in Ranau, Sabah. Identify the susceptibility area and improved surveillance of migrant's workers can prevent malaria outbreak. Output from this study can help health authorities to understand more about spatial distribution of the disease related to the environment factors of the areas and use the information to make an appropriate plan for effective malaria control.

2.0 STUDY AREA

The study area is located approximately between upper left (latitude 5° 30' N and 116° 30' E) and lower right (longitude 6° 25' N and 117° 5' E) as shown in Figure 1 below. As of the 2010 Census, the population of the district was 95, 800. Total area is 3,608 km^2 and is at 1,176 m above sea level. The major economic activities are agriculture (50%), tourism (7%), and public sector (13%). The annual average temperature is 22 ºC, and the annual precipitation is 999.9 mm. The Ranau climate has a hot and humid throughout the year with rainy season falls in the months: January, April, May, June, July, August, September, October, November and December. On average, March is the driest month and October is the wettest month.

Figure 1. Study Area of Ranau District, Sabah

3.0 DATA DESCRIPTION AND METHODOLOGY

Different layers of thematic maps, which are related to the occurrence of malaria, were used and integrated through GIS environment to generate malaria susceptibility map area in Ranau as an output. The layer maps were used are epidemiological data (malaria cases), vegetation index (NDVI), land surface temperature (LST), soil moisture (SM), digital elevation model (DEM), land use/cover changes, distance to river, rainfall and population density

3.1 Epidemiological Data (Malaria Cases)

The epidemiological data on malaria cases obtained from Ministry of Health (MOH) for cases in year 2017, 2016 and 2015. This data has detailed information of the malaria victims included name, IC number, sex, occupation, address, registered case number, type of parasite, case classification, hospital, coordinate of the location of cause infection for indigenous cases and coordinate of residence for imported cases. There are 118 total cases in 2015, 75 cases in 2016 and increase up to 328 cases in 2017 was reported in Ranau district with relatively high *P.Knowlesi* transmission. All the cases were mapped as a point in GIS environment and used for analysis and result validation of susceptibility area of malaria in Ranau.

3.2 Vegetation Index (NDVI)

The study was used calibrated 30 m x 30 m Landsat 8 OLI accessed on 30 August 2017 to derive NDVI raster layers using near-infrared (NIR) and red (R) wavelength band as equation as follow:

$$NDVI = (NIR - R) / (NIR + R)$$

NDVI indicate the vegetation density of the area which higher amount of green vegetation in the ground indicate higher NDVI. Non-vegetation area shows the lowest NDVI. The map of NDVI was reclassified into five (5) classes by using Natural Breaks (Jenks) function in ArcGIS software. The more dense vegetation shows more suitable for mosquitoes to grow and breed and habitat for zoonotic host of simian. Each class was ranked based on percentage of average actual malaria cases occurred in 2015, 2016 and 2017. Classification and the rank of NDVI as Table 1 below:

Table 1: Classification of NDVI and Rank

NDVI	Average Case No. (2015, 2016, 2017)	%	Rank
Very Low	0	0.00	1
Low	6	3.26	2
Moderate	20	11.30	3
High	35	20.31	4
Very High	113	65.13	5

3.3 Land Surface Temperature (LST)

LST map was generated from Landsat 8 OLI data by using the input parameters of top of atmospheric (TOA) spectral radiance data converted to brightness temperature (BT), proportion of vegetation P_v and emissivity ε which the related algorithms as below (Franzpc, 2019):

$$BT = (K_2 / (\ln (K_1 / L) + 1)) - 273.15$$

Where K_1, K_2 is band-specific thermal conversion constant from the metadata and L is TOA.

$$P_v = \text{Square}((NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}))$$
$$\varepsilon = 0.004 * P_v + 0.986$$
$$LST = (BT / (1 + (0.00115 * BT / 1.4388) * \text{Ln}(\varepsilon)))$$

In this study, the map of LST was reclassified into five (5) classes which temperature below 22 ^{o}C were classified as low risk for malaria transmission. The temperature range from 22 to 26 as a very high risk for malaria disease which suitable to mosquito's incubation. Table 2 shows a classification and the rank of LST:

Table 2: Classification of LST and Rank

LST	Category °C	Average Case No. (2015, 2016, 2017)	%	Rank
Very Low	<19	0	0.19	1
Low	19-22	3	1.72	3
Moderate	22-26	165	95.02	5
High	26-29	5	2.87	4
Very High	>29	0	0.00	1

3.4 Soil Moisture (SM)

Soil moisture map was generated from Landsat 8 OLI data using the Tasseled Cap Transform (TCT) coefficient (M. Hasan et al., 2014) from ERDAS Imagine software. The imagery was classified by five wetness category of classes as very high, high, moderate, low and very low using Natural Breaks (Jenks) function in ArcGIS. The wetness relates to canopy of vegetation and soil moisture in targeted area. Classification and the rank of soil moisture as follow:

Table 3: Classification of Soil Moisture and Rank

Soil Moisture	Average Case No. (2015, 2016, 2017)	%	Rank
Very Low	6	3.45	3
Low	37	21.07	4
Moderate	131	75.29	5
High	0	0.00	1
Very High	0	0.00	1

3.5 Land use/cover

Images of SPOT 6/7 were used to extract land use/cover classification by visual interpretation for the whole study area by using ArcGIS 10 software. Nine (9) classes were delineated i.e. forest, mixed horticulture, oil palm, rubber, shrub and grassland, urban, wet paddy, others agriculture and cleared land. This classification is based on the order of vulnerability of *Anopheles sp.* mosquitoes breeding and resting sites, the simian host for zoonotic malaria (dense and fringing forest) and also the areas of risk population workers at logging sites, oil palm, rubber and urban areas, (Rose Nani, 2017, Rabi A., 2016). This vector land use/cover map was resampled to 30 m pixel size raster map. Classification and the rank of land use/cover in order of susceptibility malaria as Table 4 below:

Table 4: Classification of Land Use/Cover and Rank

Land Use/Cover	Average Case No. (2015, 2016, 2017)	%	Rank
Forest	105	60.34	5
Mixed Horticulture	13	7.28	3
Oil Palm	25	14.56	4
Rubber	10	5.94	3
Shrub/Grassland	12	7.09	3
Urban	5	2.87	2
Wet Paddy	3	1.72	2
Others Agriculture	0	0.00	1
Cleared Land	0	0.00	1

3.6 Digital Elevation Model (DEM)

The DEM map was generated by SRTM imagery for Ranau. The maximum height is 4,025 meter and lowest is 38 meter from sea level. DEM is related to the air temperature that affect to the malaria vector breeding which the vector lives not too high area, i.e below 500 meter of height (Joao L.F, 2018). The lowest surface represent the river network in the area. The map of DEM was reclassified into five (5) category of classification and the rank as shown in Table 5:

Table 5: Classification of DEM and Rank

DEM	Category (meter)	Average Case No. (2015, 2016, 2017)	%	Rank
Very Low	<100	4	2.11	2
Low	100-200	22	12.84	4
Moderate	200-500	114	65.52	5
High	500-1000	33	18.97	3
Very High	>1000	1	0.57	1

3.7 Distance to River (DTR)

Distance to river is one of the parameters that contribute to the increment of the malaria disease (Ahmad R., 2011). The closest area to the river causes the high susceptibility area especially to the small river has a slow running stream or stagnant flow which suitable for vector to breed (Hanifati et al, 2018) and fly range within 2 km (MOH, 2016). In this study, distance to river was divided into two parameter layer i.e Main River and Small River. For Main River, multiple buffer was done and classified into four (4) classes as 1000 m, 1500 m, 2500 m and above 2500 m to the river. For Small River, the multiple buffer zone also was generated into four (4) classes as 200 m, 400 m, 800 m and above 800 m to the river. These two vector maps of buffer zone to river was resampled to 30 m per pixel raster map. Classification and rank of distance to Main River and Small River as Table 6(a) and 6(b):

Table 6(a): Classification of DTR (Main River) and Rank

DTR (Main River) meter	Rank
1000	4
1500	3
2500	2
>2500	1

Table 6(b): Classification of DTR (Small River) and Rank

DTR (Small River) meter	Rank
200	4
400	3
800	2
>800	1

3.8 Rainfall

Monthly average rainfall data 2017 from 32 stations supplied by Department of Agricultural Sabah was used and analysed. The isohyet map was produced by using interpolation Inverse Distance Weighting (IDW) to connect points that having the same amount which maximum and minimum average is 291 mm and 202 mm. This map was classified into five (5) classes as very high, high, moderate, low and very low using Natural Breaks (Jenks) function in ArcGIS. The higher intensity of rainfall will increase the relative humidity, which support the survival of mosquitoes. However, in some cases, drought will cause epidemics due to local vector favours small and shallow water bodies (WHO, 2016). Classification and the rank of monthly average rainfall as follow:

Table 7: Classification of Rainfall and Rank

Rainfall	Average Case No. (2015, 2016, 2017)	%	Rank
Very Low	0	0.00	1
Low	1	0.19	2
Moderate	12	7.09	3
High	32	18.58	4
Very High	129	74.14	5

3.9 Population Density

Population by village in Ranau district data were identify by 2010 Population and Housing Census in Malaysia (STAT, 2010). The point distribution of population density was mapped and interpolate using Inverse Distance Weighting (IDW) to produce polygon of population density for the whole district. Almost 50% incidence case in 2017 occurred in low density of population which the area include fringing and dense forest, oil palm and other agriculture site. Population at high-risk to malaria transmission are people who living in locality with active malaria, migrants (foreign workers and mobile population), aborigine, workers in forest related sector (army, loggers, road/dam construction), (Rose Nani, 2017). Overall classes and rank of population was shown as Table 8 below:

Table 8: Classification of Population and Rank

Population	Average Case No. (2015, 2016, 2017)	%	Rank
Very Low	57	32.95	5
Low	35	20.31	3
Moderate	46	26.25	4
High	32	18.20	2
Very High	4	2.30	1

3.10 The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980) was applied to obtain the weightage for each individual layer map. This method based on pairwise comparison matrix is widely used as effective tool for decision maker to set the priorities and make the judgement based on their expert to the subject for problem solving. Integration of AHP in GIS has helped us to be more precise in defining risk areas of Malaria in decision-making and authorities can respond faster to situations before cases occur (Bindu Bhatt, 2014). The relative importance between two variable to produce susceptibility malaria map is measured according to a numerical scale from 1 to 9 as shown in Table 9 below:

Table 9: Numerical Scale of Pairwise Comparison Matrix by Saaty

Scale	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4, 6, 8		Intermediate values

Consistency Index (CI) was calculated by using Equation 2 as below. The consistency of the pairwise comparison scale evaluation was acceptable if Consistency Ratio (CR) is below 10%. If above 10%, the matrix considered to revise until meet an adequate level of acceptance.

$$CI = (\lambda - n) / (n - 1), \qquad CR = CI/RI$$

Where n is the dimension of comparison matrix, λ is deviation max from n is a measure of inconsistency and RI is Random Index (in this study, n= 9, RI = 1.45). Once the CR was accepted, the calculation of normalize geometric mean of the *n* row have been done to produce the weightage for each variable using this equation:

$$\text{Geometric mean} = \sqrt[n]{\prod_{i=1}^{n} \mathbf{X}_i}$$

4.0 RESULT AND DISCUSSION

Nine (9) variables from environment factor were prepared, ranked and assigned the weightage within the variables through AHP process to generate Malaria Susceptibility Map. The raster output of all the variables illustrated as in Figure 2. The 9 x 9 comparison matrix of AHP Pairwise method as presented in Table 10 are used to determine weightage for each variable. The result shows the land use/cover (20%) and NDVI (18%) presented the highest weightage, followed by DEM (15%), rainfall intensity (13%), LST (12%), soil moisture (9%), small river (8%), main river (3%) and population (3%). λ max value is 9.47; ratio index is 1.45; so consistency ratio (CR) is 0.04 i.e. <10% that is the comparison matrix is acceptable. Combination of these variables by computing their weights produced the malaria susceptibility map.

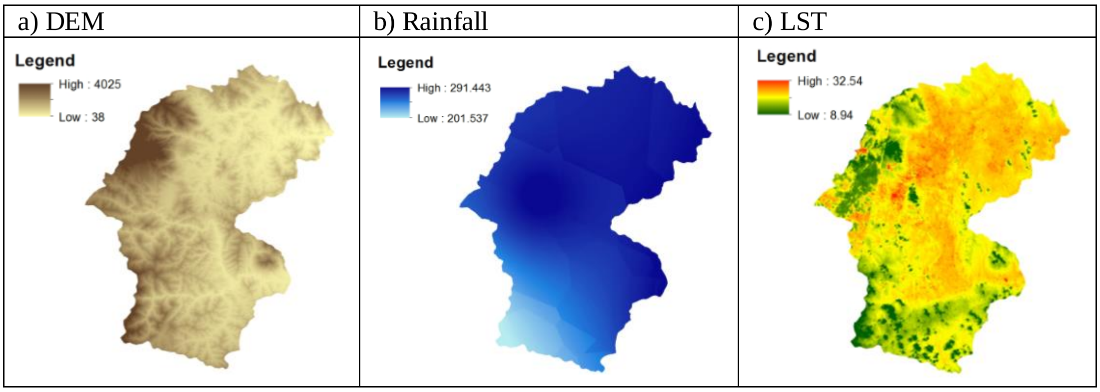
The weighted overlay function in ArcGIS was applied by using weightage percentage as a percentage influence for each variables. Figure 3 presents the malaria susceptibility map of Ranau district with four (4) classes' i.e. low, moderate, high and very high as a final output in this study. The percentage distribution by class result from malaria susceptibility map 2017 shown in Table 11. Ranau presented 0% area with very low, 1% low, 8% moderate, 50% high and 41% with very high level. This result indicate almost 90% of area is high susceptibility to malaria transmission disease especially in areas close to the forest and plantation (oil palm, rubber and others agriculture) edges bordering forest are mostly at the Northeast part of Ranau. The high vegetation density of part this area also have relatively higher humidity caused by large water evaporation, DEM below 500 meter and moderate temperature between 20-30^{0}C which suitable for Anopheles mosquitoes for breeding and resting. The low level of malaria susceptibility found from West to Southwest part of Ranau whereas the area is at above 700 m at sea level and low temperature which not suitable for mosquito's population.

Table 10: Pairwise Comparison Matrix for Malaria Susceptibility Variables

	NDVI	LULC	DEM	RF	LST	SR	SM	MR	Pop	GM	Weightage
NDVI	1.00	1.00	2.00	1.00	2.00	2.00	2.00	6.00	5.00	1.986	0.181
LULC	1.00	1.00	3.00	1.00	2.00	2.00	3.00	6.00	5.00	2.173	0.198
DEM	0.50	0.33	1.00	2.00	2.00	3.00	2.00	4.00	5.00	1.625	0.148
RF	1.00	1.00	0.50	1.00	1.00	2.00	1.00	5.00	4.00	1.395	0.127
LST	0.50	0.50	0.50	1.00	1.00	3.00	2.00	5.00	4.00	1.351	0.123
SR	0.50	0.50	0.33	0.50	0.33	1.00	1.00	6.00	4.00	0.883	0.081
SM	0.50	0.33	0.50	1.00	0.50	1.00	1.00	4.00	4.00	0.955	0.087
MR	0.17	0.17	0.25	0.20	0.20	0.17	0.25	1.00	1.00	0.284	0.026
Pop	0.20	0.20	0.20	0.25	0.25	0.25	0.25	1.00	1.00	0.316	0.029
Total	5.37	5.03	8.28	7.95	9.28	14.42	12.50	38.00	33.00	10.968	1.000

NDVI = normalized difference vegetation index, LULC = land use/cover, DEM = digital elevation model, RF = rainfall, LST = land surface temperature, SR = small river, SM = soil moisture, MR = main river, Pop = population, GM = geometric mean

Figure 2: The nine(9) variables of environment factors for malaria susceptibility map



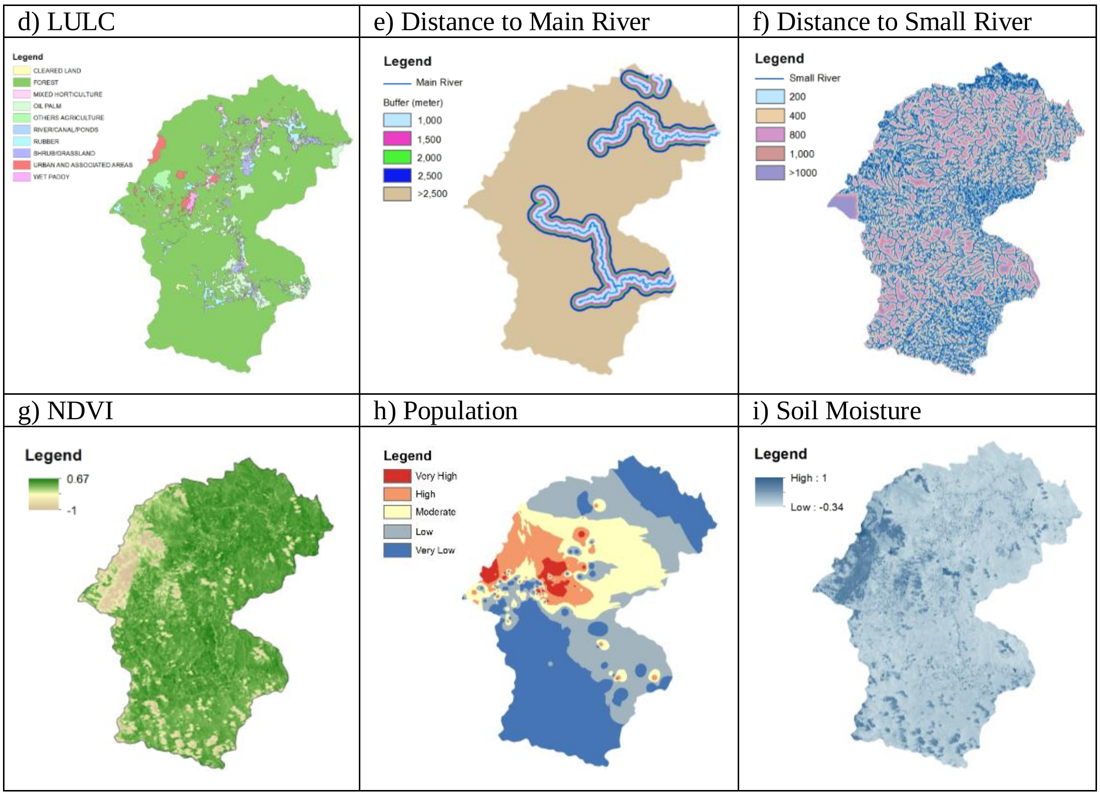


Figure 3: The Malaria Susceptibility Level Map of Ranau District

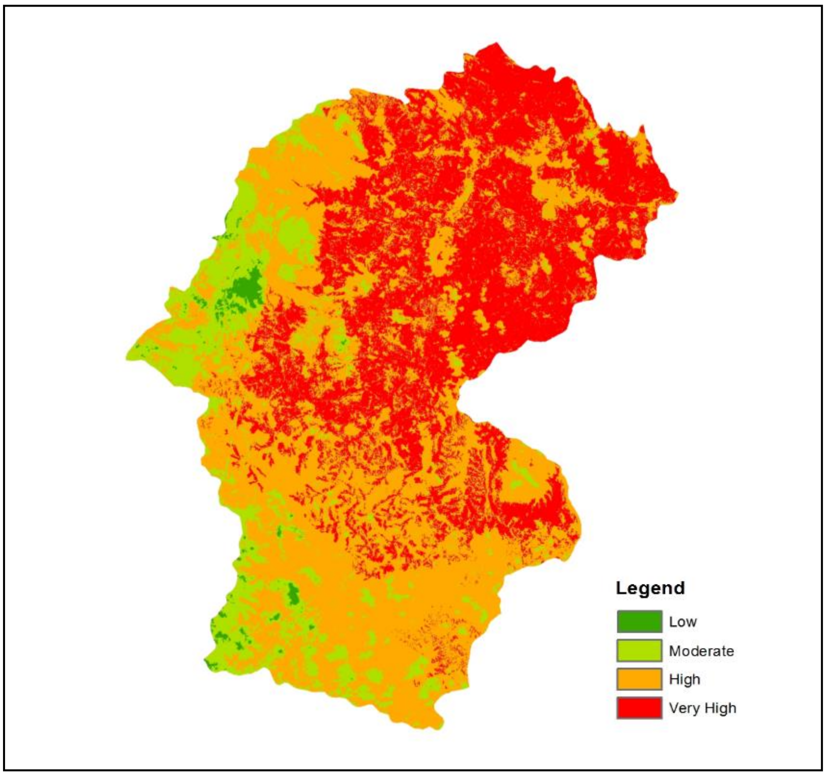


Table 11: The Percentage Area of Malaria Susceptibility Map in Ranau

No.	Class	Area (hectare)	Percentage (%)
1.	Low	3,426.30	1.04
2.	Moderate	26,112.69	7.91
3.	High	164,844.10	49.96
4.	Very High	135,568.60	41.09
		329,951.69	100.00

The validation of generated malaria susceptibility map, the incidence case of year 2017 were used and analysed by case distribution within 13 sub-district in Ranau based on low, moderate, high and very high classes (Table 12). Malaria incidence case 2017 was selected as the same acquisition year of Landsat 8 OLI image to study the relationship between physical environment factors in the field with malaria incidence case. Then, the classes was categorized by two (2) with combine the low and moderate as a "low"; and high and very high as "high" to calculate the mean accuracy of case distribution and produced variance and standard deviation for the malaria susceptibility map 2017 by using equation below:

Mean, $$\bar{x} = \frac{1}{n}\Sigma x_i$$

Variance, $$s^2 = \frac{1}{n-1}(\Sigma(x_i - \bar{x})^2)$$

Standard Deviation, $\sqrt{s^2}$

Table 12: The percentage of cases distribution by classes of malaria susceptibility in year 2017.

No.	Sub-District	Low	Medium		High		Very High		Total
			No.	%	No.	%	No.	%	
1	Bongkud		0	0	22	40.00	33	60.00	55
2	Kaingaran		0	0	2	13.33	13	86.67	15
3	Karanaan		0	0	5	45.45	6	54.55	11
4	Kundasang		0	0	1	25.00	3	75.00	4
5	Liposu		0	0	0	0.00	3	100.00	3
6	Ligawu		0	0	1	100.00	0	0.00	1
7	Lohan		0	0	6	50.00	6	50.00	12
8	Malinsau		0	0	4	57.14	3	42.86	7
9	Nalapak		0	0	10	15.15	56	84.85	66
10	Paginatan		1	1.59	22	34.92	40	63.49	63
11	Rondogung		1	4.55	4	18.18	17	77.27	22
12	Timbua		1	1.47	31	45.59	36	52.94	68
13	Togudon		0	0	1	100.00	0	0	1
									328

From the calculation, the mean accuracy is 99.42%, variance is 3.03 and standard deviation is 1.32. The mean accuracy of the incidence cases in high risk category in malaria susceptibility map 2017 is about 99.42 $\pm$ 1.32 % with equivalent probability of 0.99 and can be used to predict the high risk area of malaria in targeted year. By using this model, incidence case of year 2016 and 2015 was calculated with mean accuracy are 98.32 $\pm$ 2.15 % and 99.52 $\pm$ 2.64 % respectively.

5.0 CONCLUSION

The result of malaria susceptibility mapping in Ranau district of Sabah shows 90% of area is high-level susceptibility areas are found in Northeast part of Ranau. This study has given overview status of malaria susceptibility area of the district that useful for planning of control strategies of the disease. Remote sensing and GIS are important and effective tools to relate environment factors and epidemiological information to provide accurate of susceptibility level of malaria area. More studies should be carried out to map the malaria susceptibility area from the district level down to locality level for more precise estimation for quality control measures.

REFERENCES

1. Adhina Azdah Hanifati *et al 2018 IP Conf. Ser., Earth Environ.* Sci. 165 012012, Application of Remote Sensing and GIS for Malaria Disease Susceptibility Area Mapping in Padang Cermin Sub-District, District of Pesawaran, Lampung Province.
2. Ahmad R., Wan NWM Ali, Zurainee MN., Zamree I., Azahari A.H., Mohd N.I. and Lee H Lim, Mapping of Mosquito Breeding Sites in Malaria Endemic Areas in Pos Lenjang, Kuala Lipis,, Pahang, Malaysia, 2011.
3. Bindu Bhatt, Janak P Joshi, Analytical Hierarchy Process Modelling for Malaria Risk Zones in Vadodara District, Gujarat, 2014.
4. Franzpc, 2019. How to Calculate Land Surface Temperature with Landsat 8 Satellite Images. Available online: https://geogeek.xyz/how-to-calculate-land-surface-temperature-with-landsat-8-images.html (accessed on 11 July 2019).
5. Joao L. Ferrao, Sergio N., Jorge M. M., and Marco P., Mapping and Modelling Malaria Risk Areas Using Climate, Socio-Demographic and Clinical Variables in Chimio, Mozambique, 2018.
6. Kimberly M.F. 2016, Tommy R. A., Neal A., Paddy B., Matthew J.G., Amanda M., Timothy W., Jayaram M., Chris J.D. and Jonathan C., Association between Landscape Factors and Spatial Patterns of *Plasmodium Knowlesi* Infections in Sabah, Malaysia, Emerging Infectious Diseases,.pp 201-205.
7. Ministry of Health Malaysia (MOH), 2016. Garis Panduan Pencegahan Malaria Re-Introduction di Malaysia.
8. Ministry of Health Malaysia (MOH), 2018. Director General of Health Malaysia Press Statement: Zoonotic Malaria and the Prevention Program in Malaysia. Available online: http://www.moh.gov.my/index.php/database_stores/store_view_page/21/1087
9. Muhammad Hasan Ali Baig, Lifu Zhang, Tong Shuai & Qingxi Tong (2014) Derivation of a tasselled cap transformation based on Landsat 8 at-satellite reflectance, Remote Sensing Letters, 5:5, 423-431, DOI: 10.1080/2150704X.2014.915434
10. National Aeronautics and Space Administration (NASA). Landsat 8. Available online: http://landsat.gsfc.nasa.gov/landsat-data-continuity-mission (accessed on 11 July 2019).
11. Rabi A., 2016. Plasmodium Knowlesi Current Status and the Request for Review by an Evidence Review Group, Malaria Policy Advisory Committee, Geneva, Switzerland.
12. Rose Nani M., Strengthening Surveillance to reach at-Risk Populations and Support Health Security in Malaysia, 2017.
13. Saaty, T.L., Decision Making with the Analytical Hierarchical Process. *Int. J. Serv. Sci. 2008*.
14. Shearer FM, Huang Z, Weiss DJ, et al, 2016. Estimating geographical variation in the risk of zoonotic Plasmodium knowlesi infection in countries eliminating malaria. PLos Negl Trop Dis 2016; 10:e0004915.
15. William T, Jellip J, Menon J, et al. 2014. Changing epidemiology of malaria in Sabah, Malaysia: increasing incidence of Plasmodium knowlesi. Malar J; 13:390
16. Wong ML, Chua TH, Leong CS, 2015, et al. Seasonal and spatial dynamics of the primary vector of Plasmodium knowlesi within a major transmission focus in Sabah, Malaysia. PLoS Negl Trop Dis 2015; 9:e0004135.
17. World Health Organization (WHO), 2015. Eliminating Malaria Case study 8: Progress towards elimination in Malaysia, pp.1-24.
18. World Health Organization (WHO), 2016. Malaria Elimination: Guide for Participants pp.68-172.
19. World Weather & Climate Information. Available online: https://weather-and-climate.com/average-monthly-precipitation-Rainfall,ranau-sabah-my,Malaysia (accessed on 12 July 2019).
20. Yeop N., Hasim H., Yusoff U.N., Yusoff M., Mahpot N.R., 2015. Spatio-Temporal Distribution of Malaria in Perak, Malaysia.