METEOROLOGICAL FACTORS INFLUENCING THE INTENSITY OF MALARIA OUTBREAK IN ZIMBABWE*

KAZUHIKO MOJI[1], REIKO TSUYUOKA[2], B. MAKUNIKE[3] and HIROSHI TANAKA[4]

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Abstract: Correlation between meteorological data observed at Gokwe and intensity of malaria outbreak or the number of clinical malaria cases occurring at malaria season in whole Zimbabwe was studied. Meteorological year (Met Year) in this country starts in July at the coldest month and ends in the next June, and malaria peak season lasts from January to May. The correlation of the number of clinical malaria cases at peak season in thousand (Mp) and meteorological factors was calculated from the data in 8 years from Met Year 1990/1991 to 1997/1998.

Among single factors, correlation was highest with a total rainfall (mm) in a year (Rt) followed by that in January (R1), in February (R2) and average temperature in August (Av8), showing the coefficients of 0.873, 0.870, 0.862 and 0.739, respectively. The adjusted R^2 of the above factors were 0.722, 0.717, 0.700 and 0.470, respectively, where Av8 was non significant statistically. In two meteorological factors, the correlations higher than a single factor were a combination of R1+R2 with an adjusted R^2 of 0.792. Malaria at peak season will be increased by more rainfall in January, February and total in a year, and may be high average temperature in August. Formulae of regression lines are as follow, and by these, intensity of malaria outbreak at malaria season will be indicated.

1. $Mp = 361.30 \times Av8 - 6{,}182.96$ (approximation)
2. $Mp = 3.12 \times R1 + 43.37$ (good fit)
3. $Mp = 1.82 \times R1 + 2.47 \times R2 - 15.02$ (best fit)
4. $Mp = 1.463 \times Rt - 323.21$ (good fit for retrograde study)

Key words: Malaria, Intensity of outbreak, Meteorological factors, rainfall, Zimbabwe

INTRODUCTION

Malaria is an important disease in Zimbabwe, even if its intensity of outbreaks (the number of malaria cases in a year) was reported to be hypo- or meso-endemic in nature (Taylor and Mutambu, 1986). A retrograde study on malaria outbreaks in Zimbabwe (Freeman, 1995) suggested that among meteorological factors, only temperature in September influenced the intensity of malaria outbreaks in a year, and this analysis was reported later (Freeman and Bradley, 1996). The study was interesting and important, but no one has followed these findings later. In the above reports, a parameter used for the intensity of malaria was the number of malaria cases among inpatients and outpatients at Central Hospital at Harare, the capital city of Zimbabwe where no malaria occurs at altitude of 1,450 m. The meteorological data were referred to the weather station at the same city. There is a question whether the number of patients in a hospital coming from malarious areas outside of the City, and meteorological survey data at its neighbour actually represented the intensity of malaria outbreaks in this country and climate of malarious areas, respectively. The present authors attempted to make clear the relationship between climate and the intensity of malaria outbreak using more direct parameters.

MATERIALS AND METHODS

For the intensity of outbreaks, monthly incidence of clinical malaria cases reported by rural health centres was used. The meteorological data in the malarious area were collected, and a set of nearly complete data was found at

1 School of Allied Medical Sciences, Nagasaki University, Sakamoto 1-7-1, Nagasaki 852-8520, Japan
2 Department of Medicine and Clinical Science, Kyoto University Graduate School of Medicine, Kyoto 606-8507, Japan
3 Director, Department of Epidemiology and Disease Control, Ministry of Health and Child Welfare, Kaguvi Bld. P.O. Box CY1122, Causeway, Harare, Zimbabwe
4 Professor Emeritus, Institute of Medical Science, the University of Tokyo. (Home Address) 19-9 Izumi-honcho 2, Komae City, Tokyo 201-0003, Japan

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Gokwe Town and was taken into consideration in this study.

As the season of malaria transmission is a period from January to May in this country, the malaria peak occurs at the beginning of a calendar year. The study of influence of climate to the intensity of outbreak in a calendar year was considered to be inappropriate since meteorological factors after malaria season had no influence to the preceding malaria outbreak.

By chance, referring to the records of meteorological surveys in this country, the Meteorological Year (Met Year) has already been defined in starting in July, the coldest month, and ends in the next June. Since the malaria season comes at the last part of the Met Year, use of this calendar was found to fit our purpose.

The meteorological factors defined in this country and referred to the present study are rainfalls measured by mm, and average, maximum and minimum temperatures at degree Celsius in each month.

Monthly occurrence of all clinical malaria cases detected in the rural health centres in Zimbabwe was collected in 8 years from Met Year 1990/1991 to 1997/1998. Then correlation coefficients (r) were calculated between a total number of clinical malaria in a Met Year and corresponding meteorological factors such as average, maximum and minimum temperatures, and rainfalls in every months.

The coefficients were not so high with any factors of climate. Comparatively higher coefficients are shown in the maximum temperature in June, rainfalls in January and in December where the coefficients (r) were 0.774, 0.766 and -0.748, respectively, at risks between 5% and 1%. Although the coefficients were significant, they were not satisfactorily high, and rainfall in December showed negative correlation. The meaning of preliminary study was not readily understood.

Then, another modification was given to the number of malaria cases under an assumption that any meteorological factors before malaria season might influence the number of malaria cases at the high transmission period form January to May (peak season). The numbers of malaria cases at peak season were calculated by each Met Year, and correlation coefficients between meteorological factors and the intensity of outbreaks were calculated to find out what factors were more influential to malaria outbreaks.

The correlation coefficients of each meteorological factor to the intensity of malaria outbreak, and their significant levels are shown in Table 1. The meteorological factors showing the coefficient (r) higher than 0.7 were the average temperature in August, rainfalls in January and February, and a total rainfall in a Met Year with such high coefficients as 0.739, 0.870, 0.862 and 0.873, respectively, at risks of < 1% except the average temperature in August (Table 1). Rainfalls were generally more influential to the malaria outbreak than the temperature.

The important figures of meteorological data and malaria occurrence at peak season in 8 years are listed up in Table 2, and the regression line analysis was made based on this table.

Table 1 Pearson correlation calculated by multi- regression analysis and their significant levels

Pearson Correlation	Mp	Av8	R1	R2	Rt
Mp	1.000	0.739	0.870	0.862	0.873
Av8		1.000	0.778	0.541	0.758
R1			1.000	0.762	0.884
R2				1.000	0.892
Rt					1.000
Significant Level					
Mp	/	0.180	0.002	0.003	0.002
Av8		/	0.011	0.083	0.015
R1			/	0.014	0.002
R2				/	0.001
Rt					/

Table 2 Observed data of important meteorological factors in 8 years and the number of clinical malaria cases at transmission season used for regression line analyses.

Met Year	Mp Y	Av8 X1	R1 X2	R2 X3	Rt X4
1990/1991	308.16	18.2	165.8	74.2	489.0
1991/1992	172.54	19.3	106.0	14.3	526.7
1992/1993	657.74	18.2	81.3	156.1	639.9
1993/1994	421.78	18.2	187.4	146.4	637.0
1994/1995	363.17	18.3	70.4	40.4	329.6
1995/1996	1,186.58	20.4	333.2	251.7	1,005.0
1996/1997	1,138.05	19.6	354.0	207.6	1,069.0
1997/1998	1,169.84	19.7	328.4	149.7	775.1

Met Year; Meteorological year
Mp; Malaria cases at peak season in thousand
Av8; Average temperature in August
R1; Rainfall in January
R2 Rainfall in February
Rt Total rainfall in a Met Year

RESULTS

Single meteorological factors: The formulae of regression lines obtained by each of single factors are as follows;

1. $Mp = 361.30 \times Av8 - 6182.96$

where Mp is no. of clinical malaria in thousand at peak season, and Av 8 is the average temperature at degree Celsius in August.

2. $Mp = 3.12 \times R1 + 43.37$

where R1 is rainfall in January in mm.

3. $Mp = 4.49 \times R2+92.75$

where R2 is rainfall in February.

4. $Mp = 1.463 \times Rt - 323.21$

where Rt is the total rainfall in a Met Year.

Using the above 4 formulae, estimation of the intensity of malaria outbreaks at peak season in the same Met Year is described with r^2 and adjusted R^2 in Table 3. The figure r^2 tends to fit optimistically how well the estimate fits the observed figure. Adjusted R^2 attempts to correct r^2 to more closely reflect the goodness of fit. The correlation coefficient (r) of each model was considered here as the coefficient in the multiple regression analysis (R) when only one dependent variable is used. The fit of calculated figures to the observed ones of malaria cases is better in the order of a total rainfall in a year, monthly rainfalls in January and February, and average temperature in August, according to adjusted R^2 (Table 3).

Multiple meteorological factors: Multiple regression analyses and ANOVA were performed using the Statistical Package for the Social Sciences (SPSS; SPSS Inc., Chicago, IL, USA) to calculate formulae of regression lines using the above mentioned 4 meteorological factors. All the 4 factors were entered first to the model, and factors were removed one by one from the model according to the backward method. All the formulae are presented with multiple regression coefficient (R), adjusted R^2, F-value of the result of ANOVA, and its probability.

The formulae using all 4 meteorological factors are as follows:

a. $Mp = -0.45 \times Rt+3.39 \times R2+1.39 \times R1+141.59 \times Av8 - 2425.55$

($R=0.936$, Adjusted $R^2=0.712$, $F=5.33$, $p=0.10$)

Then the total rain was removed first from the model:

b. $Mp = 2.62 \times R2+1.13 \times R1+108.67 \times Av8 - 1955.79$

($R=0.933$, Adjusted $R^2=0.774$, $F=8.98$, $p=0.03$)

Average temperature of August was removed next from the model.

c. $Mp = 2.47 \times R2+1.82 \times R1 - 15.02$

($R=0.923$, Adjusted $R^2=0.792$, $F=14.34$, $p=0.008$)

Finally, R2 was removed and R1remained in the formula

d. $Mp = 3.12 \times R1+43.37$

($R=0.870$, Adjusted $R^2=0.717$, $F=18.71$, $p=0.005$)

Estimation by formulae using more factors is usually considered to be closer to the observed figures, but the adjusted R^2 is largest in formula c, using 2 meteorological factors, R 1 and R2. This was presumably caused by only 8 sets of the corresponding meteorological data and observed malaria cases in 8 Met Years.

Two meteorological factors: The formulae constructed by two meteorological factors, other than formula c, are shown below in the order of larger adjusted R^2.

e. $Mp = 3.41 \times R2+188.39 \times Av8 - 3343.9$

($R=0.921$, Adjusted $R^2=0.786$, $F=13.94$, $p=0.009$)

f. $Mp = 1.62 \times R1+0.80 \times Rt - 194.77$

($R=0.898$, Adjusted $R^2=0.729$, $F=10.41$, $p=0.017$)

g. $Mp = 2.13 \times R2+0.85 \times Rt - 182.78$

($R=0.892$, Adjusted $R^2=0.714$, $F=9.74$, $p=0.019$)

h. $Mp = 1.23 \times Rt + 88.84 \times Av8 - 1852.2$

($R=0.881$, Adjusted $R^2=0.686$, $F=8.66$, $p=0.024$)

i. $Mp = 2.68 \times R1+76.30 \times Av8 - 1316.86$

($R=0.876$, Adjusted $R^2=0.673$, $F=8.22$, $p=0.026$)

There was no combination of 2 factors to elevate R^2 figure than the above formula c involving R1and R2.

Table 3 Calculated estimation of malaria cases by single factorial formulae and observed figures at each peak season

Formula no.	1 Av8	2 R1	3 R2	4 Rt	Mp observed
1990/1991	392.70	5560.67	425.91	390.73	308.16
1991/1992	790.13	374.09	156.96	445.77	172.54
1992/1993	392.70	297.03	793.64	611.04	657.74
1993/1994	392.70	628.06	750.09	606.81	421.78
1994/1995	428.83	263.02	274.15	158.01	363.17
1995/1996	1,187.56	1,082.95	1,222.88	1,144.09	1,186.58
1996/1997	898.52	1,147.85	1,024.87	1,237.53	1,138.05
1997/1998	934.65	1,067.98	764.90	808.44	1,169.84
r^2	0.546	0.757	0.743	0.847	
adjusted R^2	0.470	0.717	0.700	0.722	

Table 4 Calculated estimation of malaria cases by single- and bi-factorial formulae

Time of estimation	Sep.	Feb.	Feb.	Mar.	Mar.	Mp
Formula no.	1	2 or	i	c or	e	Observed
1990/1991	392.70	560.67	516.14	470.01	337.82	308.16
1991/1992	790.13	374.09	439.81	213.22	340.79	172.54
1992/1993	392.70	297.03	289.68	518.51	617.10	657.74
1993/1994	392.70	628.06	574.03	687.66	584.02	421.78
1994/1995	428.83	263.02	268.10	212.90	241.40	363.17
1995/1996	1,187.56	1,082.95	1,132.64	1,213.10	1,357.55	1,186.58
1996/1997	898.52	1,147.85	1,127.34	1,142.03	1,056.46	1,138.05
1997/1998	934.65	1,067.98	1,066.36	952.43	877.86	1,169.84
adjusted R^2	0.470	0.717	0.673	0.792	0.786	

Formula 1; involves Av8
2; R1
i; Av8, R1
c; R1, R2
e; Av8, R2

Estimation of intensity of malaria at peak: The above mentioned formulae can be utilised for obtaining approximate estimation of intensity of malaria outbreak in a Met Year (Table4). Useful formulae among all are the formula 1, 2, c and e with statistical significance. In early September, using Av8, the first approximation is available (Formula1, adjusted R^2= 0.470 without statistical significance). Then in early February, an estimation is made by using R1 (Formula 2, adjusted R^2= 0.717). Then in early March, better estimation is available using R1 and R2 (Formula c, adjusted R^2= 0.792). The total rainfall in a Met Year also showed a high correlation (adjusted R^2= 0.722) which can be used for a retrograde study. When the malaria data and meteorological data are accumulated more in the future, the reliability of the above proposed formulae will be examined for their goodness of fit, and also the formulae using more parameters may predict the intensity of malaria outbreak precisely.

DISCUSSION

The reliability of meteorological factors which influenced quantitatively the intensity of malaria outbreaks with highly statistical significance, can be extended to their relationships in the future. It means that the above formulae with highly statistical significance are useful for estimating the intensity of outbreaks in the future. Another issue in this study is a value of clinical malaria cases since proven malaria cases are not available in field health stations. However, at malaria peak season, high ratio of proven malaria is involved in clinical malaria, whereas in the other seasons, proven ones are involved only at around 5%.

In the present study, the rainfall was more influential to the intensity of malaria outbreak, and this finding was different from the results by Freeman and Bradley (1996) who gave an importance only to the temperature in September, although some meaning was given also to the temperature in August with a low significance in this study. Important results in this study are to point out the value of rainfall in January, February and a total of the Met Year by highly statistical significance, and their values will be consistent in the future.

The estimation of malaria occurrence, however, was changed much by the month of calculation in the same year. For example in Met Year 1991/1992 (Table 4), the estimated figure of malaria was comparatively high, but it was corrected to a lower level by less rain in January (Table 2) and further by drought in February (Table 2).

The results obtained herein gave an acceptable understanding of the physical influence of climate to the vector *Anopheles.* A higher temperature in August, possibly in September too, at the early spring in this country may enhance the start of hatching of the vector mosquitoes, and develop larvae to make larger population at the starting point of vector proliferation and increase the outbreak. The rainfalls in January and February also stimulate the growth of vector population. On the contrary, even if the estimate in September is large, the transmission will be suppressed by less rain in January and February. We are grateful, if this short note stimulates the interest of workers who will make better and precise correlations between meteorological factors and intensity of malaria outbreaks, leading to a better forecast.

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