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原　著

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ラオスの温暖化とマラリア：地球観測衛星データを用いた空間疫学研究

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〔Abstract〕

Background: Climate change is expected to impact the distribution of malaria, as its change affects the distribution of *Anopheles* mosquitoes, the intermediate host of malaria. In order to provide evidence contributing to malaria control in Lao PDR, the present study aimed to analyze the impact of global warming on the distribution of malaria using earth observation satellite data. Methods: Malaria distribution and earth observation satellite data (e.g. ground surface temperature and precipitation) of Lao PDR between 2002 and 2015 was obtained. Structural equation modeling (SEM) was conducted to identify the factors associated with malaria incidence. Results: SEM identified two factors independently associated with malaria incidence: ground surface temperature and forested land. A rise in average ground surface temperature of Lao PDR was observed. Specifically, the ground surface temperature appeared to be rising faster in the capital city (1.94 ℃) and in Lao PDR as a whole (1.61℃), than in the southern region where most malaria patients were observed (0.93℃) during 2002 to 2015. The ground surface temperature in the capital city was higher than in the southern regions, but malaria was not endemic. In addition, Sekong province located in the southern region with few malaria cases showed lower ground surface temperatures than adjacent malaria endemic provinces. Conclusion: To our knowledge, the present study is the first in Lao PDR, based on actual data analysis, to report that forested land is an important factor in addition to ground surface temperature when considering malaria distribution. Global warming appears to be steadily progressing in Lao PDR, and it is important to grasp, prevent, and intervene in the areas adjacent to malaria endemic areas where malaria patients may have been suppressed due to the low temperature.

〔Key words〕 Lao PDR, Climate Change, Vector Mosquito, Malaria, Earth Observation Satellite Data

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〔Japanese Abstract〕

背景：気候変動は媒介蚊の分布に影響を与えるため，マラリア分布にも影響を与えると予想されている。そこで，本研究はラオスの温暖化によるマラリア分布への影響を解析した。方法：2002年から2015年までのマラリア分布データおよび地球観測衛星データ（地表面温度・降水量等）を入手し，温暖化によるマラリア分布への影響を解析した。結果：共分散構造分析の結果，地表面温度上昇および森林面積増加がマラリア罹患数を有意に増加させていた。ラオスの平均地表面温度は上昇し，2002年に比べ2015年には1.61℃増加していた。首都の地表面温度およびその増加率は南部よりも高いがマラリアは流行していない。一方，マラリア流行地に隣接していながらマラリア患者が少ないセコン県は，マラリア流行地域に比べ低温であった。結論：本研究は，マラリア分布を考える際，地表面温度に加えて植生も重要な要素であることを実際のデータに基づきラオスで初めて報告した。温暖化は確実に進行しており，低温故にマラリア患者が抑制されてきた地域を把握し，重点的な介入の実施が求められた。

〔Japanese Keywords〕ラオス，気候変動，媒介蚊，マラリア，地球観測衛星データ

Ⅰ. Introduction

Malaria is an acute febrile disease caused by *Plasmodium* parasites, which are transmitted to humans through the bites of infected female *Anopheles* mosquitoes[1]. Four specific parasite species that causes human malaria are *P. falciparum*, *P. vivax*, *P. malariae*, and *P. oval*. According to the latest report, in 2020, nearly half of the world's population was at risk of malaria and there were an estimated 241 million cases and 627,000 deaths[2].

As climate affects the distribution of *Anopheles* mosquitoes, climate change is expected to impact the distribution of malaria. In fact, studies about the impact of climate change on malaria have increased in recent years. For example, climate change has been cited as a potential cause for the persisting malaria incidence and its notable increases in some areas[3)-5)].

Earth observation satellite data, with their advantages in spectral, spatial and temporal resolutions, have demonstrated great value in providing information. Earth observation satellite has been collecting environmental data (e.g. ground surface temperature, precipitation, etc.) for decades that are crucial to the understating of public health issues including early warning systems for infectious disease[6].

The present study aimed to analyze the impact of global warming on the distribution of malaria in Lao PDR using earth observation satellite data. The results provide important evidence contributing to malaria control and elimination in Lao PDR.

Ⅱ. Methods

1. Data sampling

To assess the impact of global warming on the distribution of malaria in Lao PDR, epidemiological data and earth observation satellite data were collected.

For epidemiological data, all the available data on the distribution of malaria (e.g. area, population, number of patients, malaria species, etc.) between 2002 and 2015 were collected from the Center of Malariology, Parasitology and Entomology (CMPE), National Institute of Public Health (NIOPH), and Institut Pasteur du Laos. Morbidity per 1,000 per year (API: Annual Parasite Incidence) and mortality per 100,000 per year were calculated and analyzed by province and district.

Earth observation satellite data, including land surface temperature, precipitation, and forested land between 2002 and 2015, were obtained from the Japan Aerospace Exploration Agency (JAXA), Public Health Monitor and Analysis Platform (JPMAP)[7]. The JPMAP utilizes MOD11/MYD11 products as land surface temperature data originally provided by the National Aeronautics and Space Administration (NASA) and United States Geological Survey (USGS), and Global Satellite Mapping of Precipitation (GSMaP) product as precipitation data provided by JAXA. Land cover product developed by the European Space Agency (ESA) Climate Change Initiative (CCI) provided the forested land data. All the satellite data were analyzed using Quantum Geographic Information System (QGIS) 2.18.22 (Development Team- Open Source Geospatial Foundation Project, 2018).

2. Statistical analyses

After all the correlations were examined, Structural Equation Modeling (SEM) analysis was conducted to identify the factors associated with the API. The fit of the model was examined in terms of degree of freedom (df), chi-square (CMIN), and comparative fix index (CFI)[8]. According to conventional criteria, a good fit was indicated by CMIN/df < 2, and CFI > 0.97, and an acceptable fit by CMIN/df < 3, and CFI > 0.95. All statistical analyses were conducted using SPSS version 24.0 and Amos 24.0 (SPSS Inc, Chicago, IL, USA).

Ⅲ. Results

1. Malaria distribution data

In Lao PDR, while the population increased every year between 2000 and 2014, the API showed a decline until 2011 and an increasing trend since 2012 (Figure 1). Meanwhile, malaria mortality showed a steady decline.

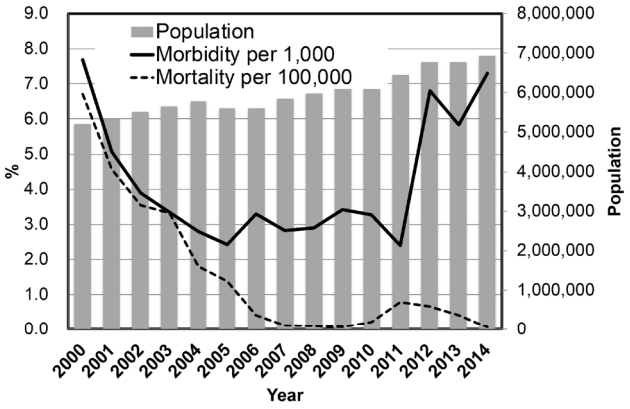

Figure 1. Malaria trend in Lao PDR

Analysis of the API per district showed that malaria is prevalent mainly in the southern provinces in Lao PDR (Figure 2). Comparing the data for 2008 to that of 2015, epidemics in the mid-west provinces were subdued, while the southern region continued to experience epidemics. In Champasack province located in the southern region, the API was 33.17 in 2014. In contrast, the API in Vientian (the capital city) was never above 1.0 since 2000, and malaria is not endemic.

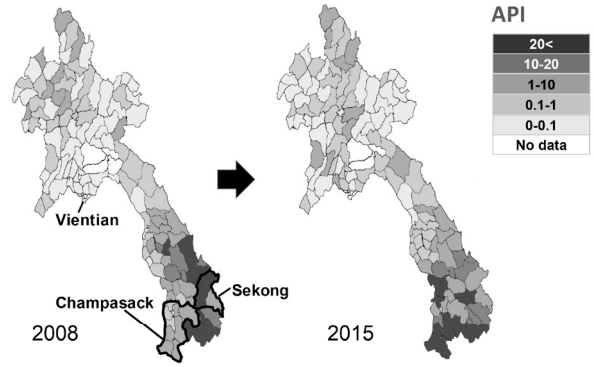

Figure 2. Annual Parasite Incidence (API) by district in Lao PDR

2. Earth observation satellite data

In Lao PDR, the average ground surface temperatures were highest in the capital city, followed by the southern provinces, mid-west provinces, Sekong, and northeast provinces (Figure 3). Sekong is a mountainous area located in the southern provinces, and the ground surface temperature was lower than the adjacent malaria endemic areas. The ground surface temperature in Sekong was about the same as in the northeast provinces of Lao PDR.

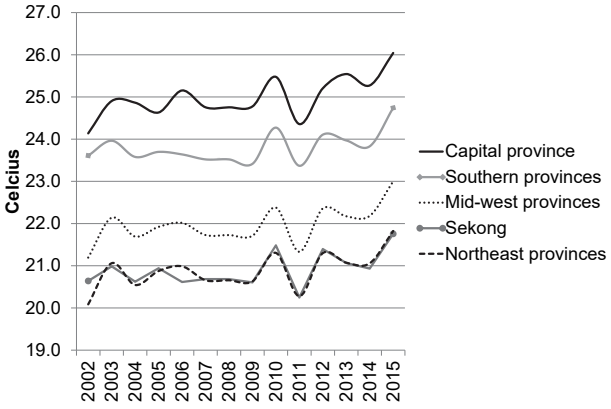

Figure 3. Average ground surface temperatures per year during 2002 to 2015 in Lao PDR

The average ground surface temperatures showed a rise between 2002 and 2015 (Figure 3). The rise appeared faster in the capital city (1.94℃) compared to that of Lao PDR as a whole (1.61℃). The rise in the southern region between 2002 and 2015 was lower where most malaria patients are found (0.93℃). The fluctuations of the temperature during 2002 to 2015 were similar in all provinces.

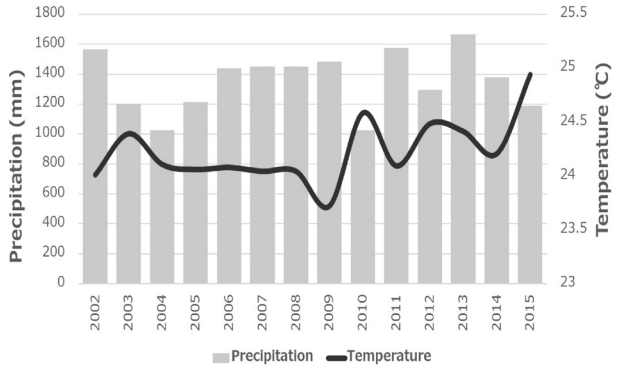

Figure 4. Average ground surface temperature and precipitation per year during 2002 to 2015 in Champasack province, Lao PDR

Compared to the ground surface temperature, the amount and yearly variation of precipitation was stable between 2002 and 2015 (Figure 4). Lao PDR has a tropical monsoon climate, and has a dry season (November to April) and wet season (May to October). During the dry season, the lowest monthly precipitation in 2002 was 18.0 mm in January, and in 2015 the lowest was 5.5 mm in February. Monthly precipitation in during the wet season was highest in August with 279.8 mm in 2002 and in August with 250.1 mm in 2015.

The forested land in Lao PDR showed decreases every year (data not shown). The deforestation rate was especially high in Champasack province, with 262.7 km^2 (1.9 % of the total area of the province) deforested between 2002 and 2015.

3. Structured Equation Modeling (SEM)

Based on the bivariate analysis, the SEM was built to examine the factors associated with the API (Figure 5). As a result, SEM using data for years 2002 to 2015 except for the capital city, identified two factors independently associated with malaria incidence: ground surface temperate and forested land. Furthermore, a decrease in forest area was associated with an increase in surface temperature ($p < 0.05$), and an increase in ground surface temperature was associated with an increase in precipitation ($p < 0.01$). The SEM adequately fit the data according to the conventional criteria (CMIN/df = 1.554, CFI = 0.996, and GFI = 0.997).

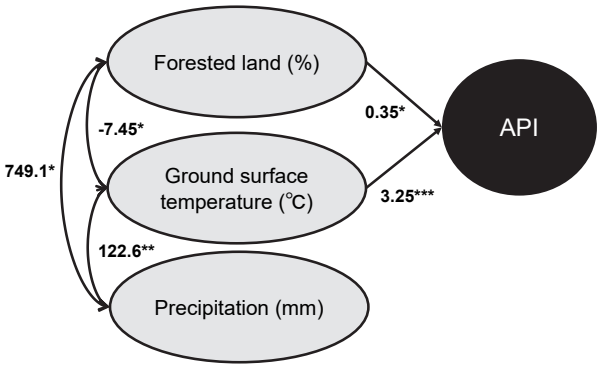

Figure 5. Structured equation modeling (SEM) using province data from 2002 to 2015, excluding data of the capital city

Ⅳ. Discussion

The present study aimed to analyze the impact of global warming on the distribution of malaria in Lao PDR using earth observation satellite data and malaria epidemiological data.

The malaria morbidity has been increasing since 2012 but mortality has declined since 2000 in Lao PDR. In 2012, funding from the Global Fund increased the number of tests, resulting in a sharp increase in the number of infected humans. On the other hand, it can be said that the mortality rate is decreasing due to the spread of appropriate treatment.

The final SEM, using the data for years 2002 to 2015 excluding the capital city, identified two factors independently associated with malaria incidence: ground surface temperate and forested land ($p < 0.05$). This suggests that the distribution of malaria vector mosquitoes has been affected not only by in-creasing ground surface temperature, but also by in-creasing forested land suitable for mosquito ecology. Malaria in Lao PDR are mainly forest malaria predom-inately transmitted by *Anopheles dirus*[9]. Forest ecosystems provide favorable conditions for the vector mosquitoes and human community living in for-ests are also the most challenging to diagnose and treat[10)-12)]. The findings confirm the need to consider the ecosystem including the distribution of vector and malaria[1), 13)].

Most studies on climate change and malaria distribution focus mainly on ground surface temperature and precipitation[14)-16)]. While the results of the pre-sent study supports this premise, in addition to temperature, forested land may also be an essential factor when considering the distribution of malaria. Although

no studies have been reported in Lao PDR, the canonical epidemiological understanding is that deforestation increases malaria risk in Africa and the Americas and decreases it in South-east Asia[17]. To our knowledge, the present study is the first in Lao PDR, based on actual data analysis, to report that forested land is an important factor in addition to ground surface temperature when considering malaria distribution.

In the Sekong province which is located in the southern region but has few malaria cases, the ground surface temperatures were lower than those in adjacent malaria endemic provinces, and were similar to those of northeast provinces where malaria was not endemic. Since Sekong province has a similar environment to adjacent malaria endemic areas, the increase in ground surface temperature might increase the risk of distribution of vector mosquitoes and patients in this province.

A limitation of the present study is that the analy-sis used district-based data. Improvements may be possible by obtaining more detailed and precise data. We are planning to carry out an analysis using the data obtained from other earth observation satellites such as radar satellites that can be observed in all-weather conditions including the presence of clouds.

Ⅴ. Conclusion

The ground surface temperature in Lao PDR was positively associated with malaria incidence, and the ground surface temperature has steadily increased every year in Lao PDR. The analysis also showed that the percentage of forested land was significantly associated with malaria incidence which may be due to vec-tor mosquito preference. In addition, it is important to grasp, prevent, and intervene in the areas adjacent to malaria endemic area, such as Sekong province, where malaria patients have been suppressed due to the low temperature in Lao PDR.

Ⅵ. Disclosure

There is no conflict of interest to disclose.

Acknowledgements

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