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Influences of Human Residence and Environmental Factors on Malaria Incidence in Korea

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우리나라 말라리아 발생에 미치는 주거와 환경 요인의 영향에 대한 연구

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Abstract : The number of malaria cases has been undulating for the past 10 years in Korea since the reemergence of malaria in early 1990's. Considering the spatial variations of malaria incidence across the northmost border areas near the demilitarized zone (DMZ), the occurrence of the disease seems to be influenced by the natural and human environment in the region. Malaria is an infectious disease that is transmitted to humans by the bites of vector-mosquitoes that carry malaria parasites, and its incidence rate depends on specific climatic and sociodemographic factors. This study found that the spatial characteristics of malaria incidence have varied depending on relative proportions of mosquito habitats, distance between mosquito habitats and human residence, the physical and sociodemographic environments of the city by urbanization, and local topography.
Key Words : malaria, DMZ, local topography, mosquito habitat, human residence

요약 : 우리나라의 말라리아는 1990년대 초에 재 출현한 이후로 그 발병사례가 지난 10년 동안 증감을 거듭해오고 있다. 말라리아의 주된 발병 지역이 비무장지대 인근의 남북한 경계를 따라 분포하고 있는 점을 고려할 때, 우리나라 말라리아 발생은 이 지역의 자연과 거주 환경에 의해 영향을 받고 있는 듯하다. 말라리아는 말라리아 원충을 옮기는 모기에 의해 감염되는 전염병이므로 이 질병의 발병율은 특정 기후 및 사회인구학적 인자들과 밀접한 연관성을 가지고 있다. 본 연구에서는 말라리아 발생의 공간적 특성이 모기 서식환경의 비율, 모기서식지와 주거지역 간의 거리, 도시화에 따른 자연환경 및 사회인구적 환경, 그리고 해당 지역의 국지적 지형과 관련이 있음을 논의하였다.
주요어 : 말라리아, 비무장지대, 국지적 지형, 모기서식지, 주거지역

1. Introduction

The World Health Organization (WHO) estimated that 300 to 500 million people were infected with malaria by 2000, resulting in 2.5million deaths per year. The number of malaria infections is concentrated mainly in Africa, but there are still large numbers of malaria infections in Asia. Due to the recent global warming, the habitat areas of the malaria vector, Anopheline mosquitoes, are expanding. Especially, malaria-prone areas are expected to increase from the current 42% of land surface to 60% under an assumption of 2℃ increase in temperature over the next 50 years (Hidore *et al.*, 2010). Malaria is transmitted by the bites of female Anopheline mosquitoes that carry malaria parasites, such as *Plasmodium vivax*, which is endemic on the Korean peninsula for centuries (Paik *et al.*, 1988). *Anopheles sinensis* is known as the primary malaria vector in Korea. This zoophilic mosquito species typically breeds in fresh, sunlit water including rice paddies (Ree *et al.*, 1967).

High-risk areas of malaria have been significantly reduced for the past decade. However, the recent resurgence of malaria spreads into highland areas, where climatic warming is taking place (Gallup and Sachs, 2001; Hay *et al.*, 2002). The spatial distribution and transmission

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of malaria are a highly climate-sensitive and difficult public health issue, and they are also associated with sociodemographic factors (Charlwood and Alecrim, 1998). Malaria infection is influenced not only by the distribution of surface water collections but also by the distance between the vector and humans. It is known that the vector's mobility is limited in highly-populated urban areas, but it is much longer in rural environment (Trape *et al*., 1992; Manga *et al*., 1993; Robert *et al*., 1993; Charlwood and Alecrim, 1998). Coexistence of anopheles vectors and malaria parasites mosquitoes is primarily influenced by rainfall and temperature conditions, and land use and land cover are also important factors for the dispersal of the vectors and malaria patterns (Machault *et al*., 2011; Park, 2012). The structure and arrangement of land uses play an important role, and human-induced landscape changes tend to increase mosquito populations (Wood *et al*., 1991; Overgaard *et al*., 2003; Norris, 2004). Since it has been known that the density of anopheles mosquitoes is positively correlated with water-related landscape components, spatial relationships between the vector's habitat preference and human residence need to be understood for effective controls of the disease (Zhou *et al*., 2012).

In 1984, eradication of endemic malaria was declared in Korea, but reemergence of malaria was reported in 1993. The annual number of malaria cases has been changing since it reached the peak(>4,000) in 2000 (Park *et al*., 2003; Yeom *et al*., 2005; Yeom *et al*., 2007; Jun *et al*., 2009; Park, 2010). Knowing that a significant number of malaria incidence remains as a continuing health threat to the public, the epidemiological management of the disease needs careful monitoring. Geographically, northmost counties in South Korea are the leading ones in terms of the number of malaria cases, but malaria incidence rates vary from county to county. High infection rates in these geographical areas led to a hypothesis that malaria dispersion in these border counties might be caused by north-origin malaria-bearing adult mosquitoes in the demilitarized zone (DMZ)(Park *et al*., 2009). The two Koreas, North and South Koreas, are divided by DMZ, and diverse natural wetlands are well maintained in DMZ. Study results based on epidemiological and demographic analyses suggested that *P. vivax* malaria reemerged from North Korea-origin infected mosquitoes, but it is still yet to be confirmed with malaria data from North Korea (Park *et al*., 2003). It is also notable that a number of malaria cases occurred in urban areas of the northmost counties farther than 30 km south of DMZ. This phenomenon indicates that civilian *P. vivax* malaria cases were geographically expanded to cities and counties located away from the borderline through local transmission of the disease (Yeom *et al*., 2005; Yeom *et al*., 2007).

The purpose of this study is to determine the influences of geospatial variables on malaria occurrence. The variables include local climatic conditions, relative proportions of mosquito habitats, distance from mosquito habitats to human residence, urbanization, and topography in the high-risk area. Correlations between these geospatial variables and malaria incidence are compared in order to identify the influence of each variable on malaria incidence in study area.

2. Materials and Methods

1) Study area

Ten study units near DMZ in Korea were selected as study area. The areas include one city and nine counties, which have been the hotspot of the disease for the past decade (Figure 1). While the reoccurrence of the disease

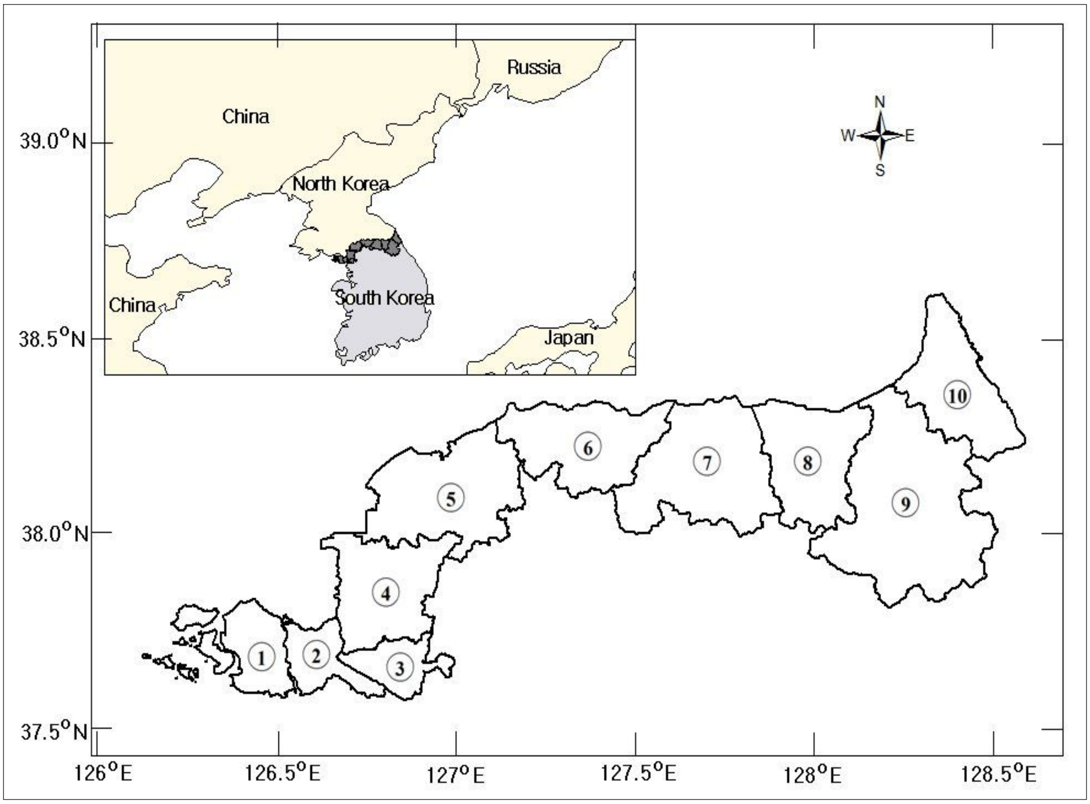

Figure 1. Study area. 1-Ganghwa County, 2-Kimpo County, 3-Goyang City, 4-Paju County, 5-Yeoncheon County, 6-Cheolwon County, 7-Hwacheon County, 8-Yanggu County, 9-Inje County, 10-Goseong County

has been concentrated near DMZ, malaria incidence rates varied from county to county. Considering the spatial variations of malaria incidence rates across the study area that has been classified as a high-rick area for the past 10 years, it is likely that the occurrence of the disease is influenced by the natural and human environments in the region. Malaria occurrence data were obtained from the Centers for Disease Control and Prevention (http://stat.cdc.go.kr/). Malaria incidence rates are defined as the number of malaria cases per 100,000 people.

2) Climatic data analyses

Daily temperature and precipitation data were collected from the Korean Meteorological Agency. Since malaria infection in Korea mainly occurs between June and September, mean temperature and precipitation were computed during the same months from 2001 to 2010. Ground weather stations within the study area are located in four difference counties, including Cheolwon County, Paju County, Ganghwa County, and Goseong County. Correlation analyses were conducted between climatic factors and malaria incidence in order to determine how these variables were correlated to each other.

3) Population distribution and urbanization

Land use and land cover data were used to determine physical environments favorable for mosquito breeding, including rice paddies, water bodies, and wetlands (Figure 2). Current land use maps were obtained from the Ministry of Environment (http://egis.me.go.kr). These maps are 30-meter resolution raster data and projected to the Transverse Mercator system for Korea. Water-related features, residential areas, and commercial areas were extracted from the land use maps and analyzed in detail using three primary approaches. Firstly, proportions of water-related environments were computed for each data enumeration unit and compared with malaria occurrence. Secondly, spatial buffers around rice paddies were created from 50 meters to 200 meters with 50-meter intervals. Human residence areas within each buffer were correlated with malaria incidence rates to show the impact of distance on malaria occurrence. Finally, the impact of urbanization on malaria cases was evaluated knowing that human activities at nighttime typically increase as residential and commercial areas rapidly expand.

4) Elevation effects

Digital Elevation Model (DEM) of Korea was constructed by the Ministry of Land, Infrastructure, and Transport and the Ministry of Environment. DEM data with 30-meter resolution were downloaded from a GIS database portal site (http://www.biz-gis.com/GISDB/). Descriptive DEM statistics of residential areas and rice paddies for each study unit were computed and their relationships with malaria incidence rates were calculated. For each study unit, the elevation statistics of residential areas and rice paddies were computed with vertical intervals of 50 meters. Since rice paddies are commonly distributed along floodplains near stream channels, elevation information about vector habitats and residential areas should be used to evaluate the effect of a topographic factor on malaria occurrence.

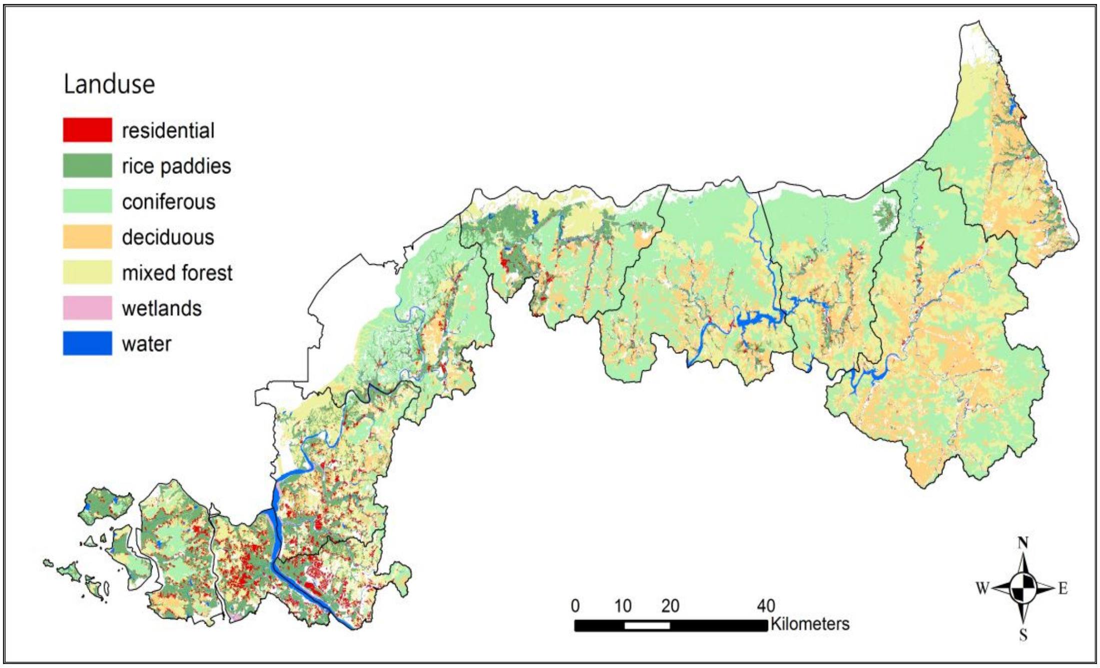

Figure 2. Land use and land cover map of the study area

3. Results and Discussion

1) Climatic factors

Climatic factors were not significantly correlated with malaria incidence rates. Study results indicated that precipitation and air temperature were not statistically correlated with malaria data. Coefficients of determination (R^2) ranged only from 0.005 to 0.414 for air temperature. This outcome deviates from general expectation that mosquitoes' biting activities increase with air temperature within limited temperature ranges (Epstein and Ferber, 2012). A previous malaria study in Korea reported that malaria infection began to occur from 16℃ and increased with rising temperature, and then infection rates decreased dramatically as temperature approached 30℃ (Shin, 2011). One possible reason for this disagreement in this study may come from the fact that the climatic variations are not large enough within the study region, and the relatively narrow latitudinal region may be a major reason for the weak correlations. While natural environments such as climatic conditions are obviously important factors in malaria infection in a broad scale, spatial processes between humans, vectors, and pathogens are also decisive causes of the distribution of malaria over the landscape (Reisen, 2010).

2) Land use and population distribution

Land use information has been included malaria studies because spatial relations between environmental factors and vectors' habitats are considered as important explanatory components (Diuk-Wasser et al. 2006). Landscape structure and arrangement of land uses may have impacts on the conditions, distribution, and total area of mosquito breeding sites. Spatial distribution of water-related features such as inland wetlands, coastal wetlands, rice paddies, and inland water bodies were analyzed to determine their relationships with malaria infection rates. Study results showed that only rice paddy patches had a statistically meaningful relationship with malaria incidence ($r=0.71$, $p<0.05$), while wetlands and coastal water bodies did not have any significant relationships with malaria occurrence. For example, high malaria incidence rates were observed in areas, where long and narrow patches of rice paddies were distributed near residential areas (Kim, 2013; Kim and Park, 2013). Norris (2004) also reported that rice paddies were the most important habitats for mosquito larvae because mosquito larvae had inhabited and survived well in shallow and steady water bodies.

Spatial relations between vector habitats and human population were represented by the distance from rice paddies to human residence areas. Distances from rice paddies to residential areas also had an inverse relationship with malaria occurrence. Correlation analyses showed that proportions of human residence area within 100 meters from rice paddies was strongly correlated with malaria incidence ($r=0.77$, $p<0.05$), but the strength of the relationship rapidly decreased as buffer distance became longer than 100 meters (Figure 3). Especially, Figure 3a showed that areas with higher percent residential land use within 100 meters from rice paddies had relatively higher malaria incidence rates. Zhou et al. (2012) conducted a malaria study in the Huang-Huai Plains, China and found that 74.2% and 16.4% of malaria cases were located within 60 meters and 60-120 meters from rice paddies, respectively. These results showed that water- related environments, especially the distributions of rice paddies, and their spatial relationships with human residence, played an important role in malaria infection.

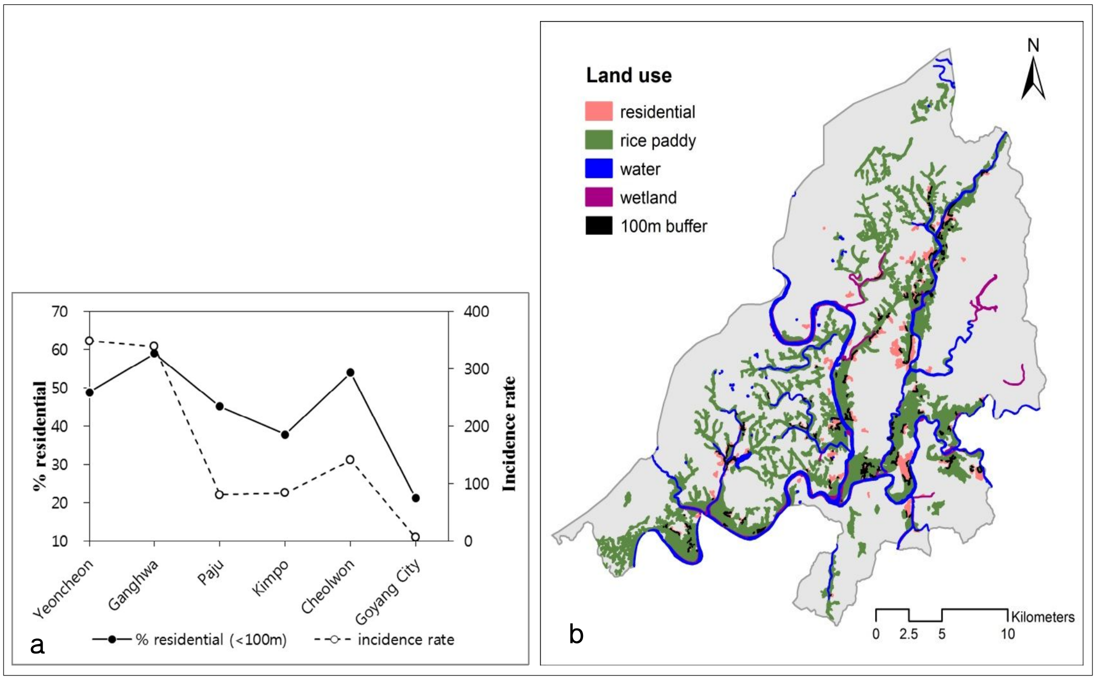

Figure 3. Relationships between malaria incidence and percent residential area of six counties selected in the study area (a). Distributions of rice paddies, residential area, wetland, and water bodies are represented as major land uses of Yeoncheon County, Gyeonggi Province as an example (b). Residential areas within 100 meters from rice paddies were buffered (shaded in black).

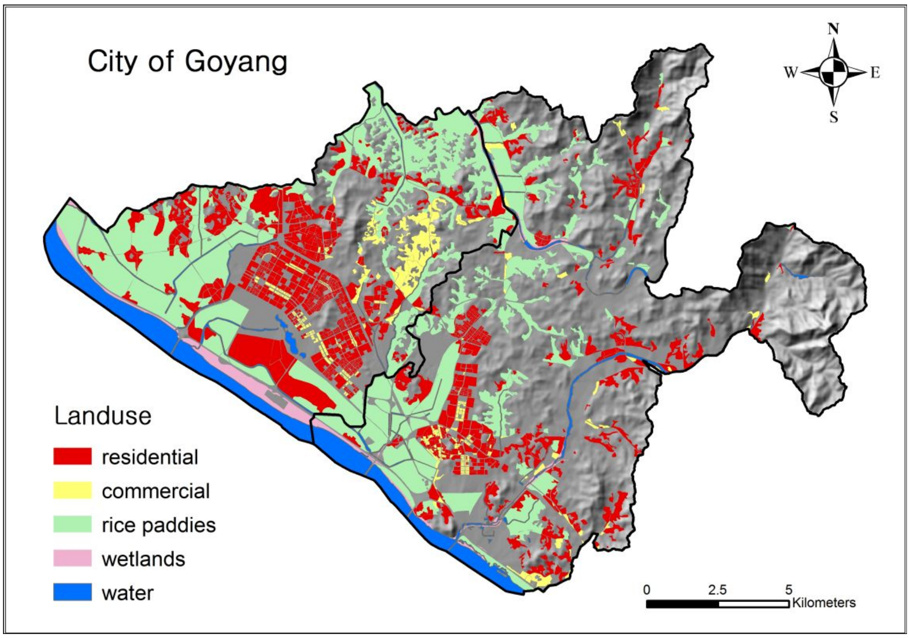

Figure 4. Major land use types are overlain over a hill-shaded image of topography of City of Goyang.

3) Urbanization

City of Goyang, the only city in this study, used to be a rural county, but rapid urbanization proceeded in the 1990's. As a result, Goyang County has become City of Goyang in 1992. For the past 20 years, the urbanization exacerbated land use changes in the area, and the proportion of commercial area of the city dramatically increased (Figure 4). For example, area of commercial sectors increased from 179.9 ha in 2002 to 870.2 ha in 2009 for the entire city, which is an increase of 383.7% during the period (Figure 5). Particularly, the western district (Ilsan District) experienced much more rapid transformation than the eastern part (Deokyang District). During the same period, there was 5,440 % increase of commercial area in Deokyang District compared to 92.4 % increases in Ilsan District. There is an obvious difference between the two districts in terms of malaria cases reported during the past 10 years (2001-2010). However, it is difficult to clarify what specific mechanisms have caused the result because diverse potential factors are involved in malaria infection and transmission. Despite the rapid urbanization, there are still substantial amounts of rice paddies near the residential and commercial areas, and increasing human activities at nighttime in the commercial and business districts might have influenced the malaria incidence in the city. In short, the physical and sociodemographic environments of the city may provide suitable conditions for malaria infection and transmission (Kim, 2013).

4) Topographic factor

Most rice paddies are located in lowlands such as floodplains. Using DEM data, this study further analyzed spatial relationships between malaria incidence rates and topographic variations. Study results showed that percent lowland residential area (elevation 〈 200 m) had a very weak correlation with malaria incidence rate, while higher area (elevation 〉 200m) had a significant inverse relationship ($r=-0.71^*$, $p<0.05$) (Figure 6). It is hard to determine if elevation would be a single important factor for malaria infection in this region because elevation is intimately associated with temperature and humidity, which are all important control factors of the abundance of malaria vectors (Minakawa *et al.*, 2002). Rather, this result indirectly indicates that malaria infection may decrease in residential areas in higher elevation compared to lowland

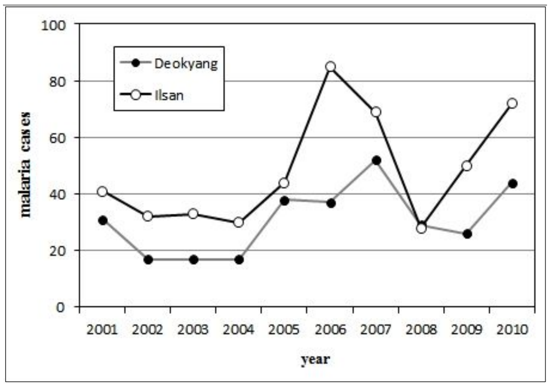

Figure 5. Malaria cases reported from 2001 to 2010 in Deokyang District and Ilsan District.

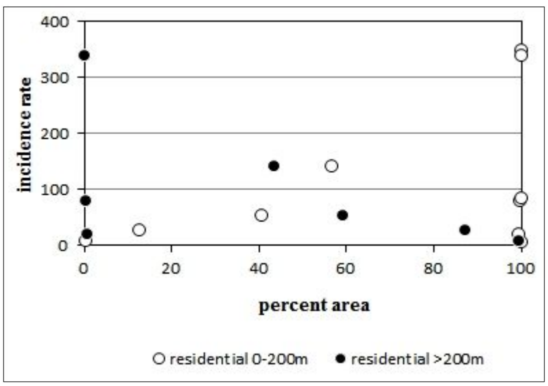

Figure 6. Malaria incident rates and percent residential area above and below 200 meters in each County.

residential areas, which are typically closer to rice paddies.

4. Conclusions

Occurrence of malaria, a major mosquito-borne disease, is an obvious climate-related issue. However, it should be realized that the disease is heavily associated with human activities and human-vector relationships across the landscape.

This study showed that spatial relationships between human residence and vector habitats such as rice paddies were an apparent factor for malaria infection. Distances from rice paddies to residential areas had a quite strong inverse relationship with malaria incidence rates, especially within 100 meters from the paddies. This relationship is also associated with topographic positions in the region, where elevation changes are somewhat significant along the narrow latitudinal zone. Correlation analyses showed that malaria incidence rates had a significant inverse relationship with elevated residential areas (elevation 〉 200m). However, elevation itself may not directly explain the changes of malaria incidence rates because temperature and humidity factors are also important and closely related with elevation changes. In terms of urbanization, both physical environments (e.g. ponds, wetlands, rice paddies, etc.) and sociodemographic environments (e.g. increasing nighttime activities) may have an influence on the malaria incidence rates of the city.

For further studies, advances in newer technologies such as remote sensing approaches can provide more accurate surface environments and landscape changes in conjunction with climatic data. Quicker and more accurate retrievals of land surface temperature can be made from current and future satellite sensors, and it may allow us to have deeper understanding of interactions between individual variables in the environments and human behaviors as well as vector ecology for malaria research.

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