

UNDERSTANDING THE RELATIONSHIP BETWEEN LAND USE/LAND COVER  
AND MALARIA IN NEPAL

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## ABSTRACT

Malaria is one of the leading causes of mortality and morbidity globally. Land use/land cover (LULC) change have been found to affect the transmission and distribution of malaria in other regions, but no study has attempted to examine such relationships in Nepal. Therefore, this study was conducted in Nepal to assess LULC change between 2000 and 2010, to study the spatial and temporal trend of malaria incidence rate (MIR) between 1999 and 2015, and to understand the relationship between LULC and malaria. The land cover types used for this study are forest, water bodies, agriculture, grassland, shrubland, barren areas, built-up areas and paddy areas. Change detection techniques were used to study LULC change. The temporal trend of MIR in 58 districts, and the relationship between MIR and LULC were evaluated using Poisson and negative binomial regression. Forest, water bodies, snow cover, and built-up area increased in Nepal by 28.5%, 2.96%, 55.12% and 21.19% respectively while the rest of the LULC variables decreased. MIR decreased significantly in 21 districts; however, four districts namely Pyuthan, Kaski, Rupandehi and Siraha had a significantly increasing trend of MIR. During 2001, 2002, and 2003, MIR was positively related to water bodies and paddy areas. Similarly, MIR of 2010 was negatively related to grassland. However, there was no relationship between LULC and MIR in 2000, 2011, 2012 and 2013. It may be because MIR is decreasing significantly in the country and thus the influence of LULC change is also decreasing.

# UNDERSTANDING THE RELATIONSHIP BETWEEN LAND USE/ LAND COVER AND MALARIA IN NEPAL

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## GENERAL AUDIENCE ABSTRACT

Malaria is one of the major public health concern worldwide. Among many other factors, Land use/land cover (LULC) change have impact in the transmission and distribution of malaria which have been studied in other regions, however, no study has attempted to examine such relationships in Nepal. Therefore, this study was conducted in Nepal to understand the relationship between LULC and malaria. The land cover types used for this study are forest, water bodies, agriculture, grassland, shrubland, barren areas, built-up areas and paddy areas. The relationship between malaria incidence rate (MIR) and LULC were evaluated using Poisson and negative binomial regression. Water bodies and paddy cultivation had positive relationship with MIR during 2001, 2002, and 2003. Similarly, MIR of 2010 was negatively related to grassland. However, there was no relationship between LULC and MIR in 2000, 2011, 2012 and 2013. It may be because MIR is decreasing significantly in the country and thus the influence of LULC change is also decreasing.

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Kabita Ghimire, PhD is a committee member. She has helped by suggesting additional variables to be added in the analysis. She has also provided her editorial comments.

Yang Shao, PhD is a committee member. He proposed to add additional variables to the analysis. He has also suggested possible methods of analysis.

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# CHAPTER 1: INTRODUCTION

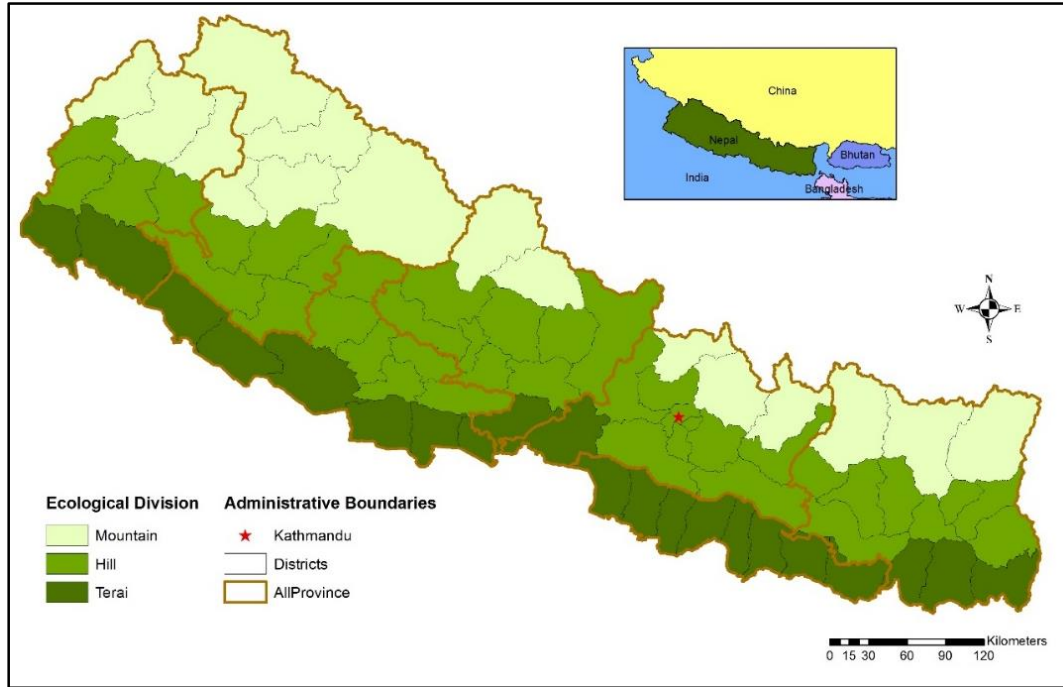
## 1.1 Background

Malaria is one of the most significant public health problems worldwide (CDC, 2017). In fact, “malaria is by far the most serious vectored disease in the world and one of the three diseases targeted by the World Health Organization (WHO) with the Global Fund” (Meade and Emch, 2010, p. 117). In 2016, 216 million cases of malaria occurred globally, resulting in 445,000 deaths, which were mostly children in Africa (CDC, 2017). Malaria was endemic in 106 countries in 2016 and 3.2 billion people live in areas at risk of malaria transmission (CDC, 2017).

Malaria is a vector-borne disease that occurs in warm and humid environments. The vector is a female mosquito from the *Anopheles* genus, which transmits the parasite *Plasmodium* from one person to another. When a mosquito bites an infected person, the blood containing *Plasmodium* enters its body, matures, and reproduces. When the infected mosquito then bites a healthy person, the *Plasmodium* enters the body of that healthy person and continues its life cycle. This person is now infected with malaria and may display symptoms, which include fever, vomiting, chills, and headache (CDC, 2017); however, the disease can be fatal if untreated or if treatment is delayed. Malaria in humans is caused mainly by four different species of *Plasmodium*: *P. falciparum*, *P. ovale*, *P. malariae*, and *P. vivax* (WHO, 2018a; Quammen, 2012). Among the four species, *P. falciparum* pose the greatest risk because *P. falciparum* malaria can be fatal if untreated within 24 hours of the onset of symptoms; the other forms of malaria cause significant morbidity but are rarely life-threatening (WHO, 2018b). Additionally, a new strain of *Plasmodium* has been recently found to cause human malaria called *Plasmodium knowlesi*, which is primarily a macaque malaria but several human cases have been found recently in some part of Malaysia (Quammen, 2012). It is different from the other four in the sense that it is zoonotic in nature, meaning that a mosquito biting an infected macaque transmits *P. knowlesi* to humans rather than following the typical human to human transmission (Quammen, 2012).

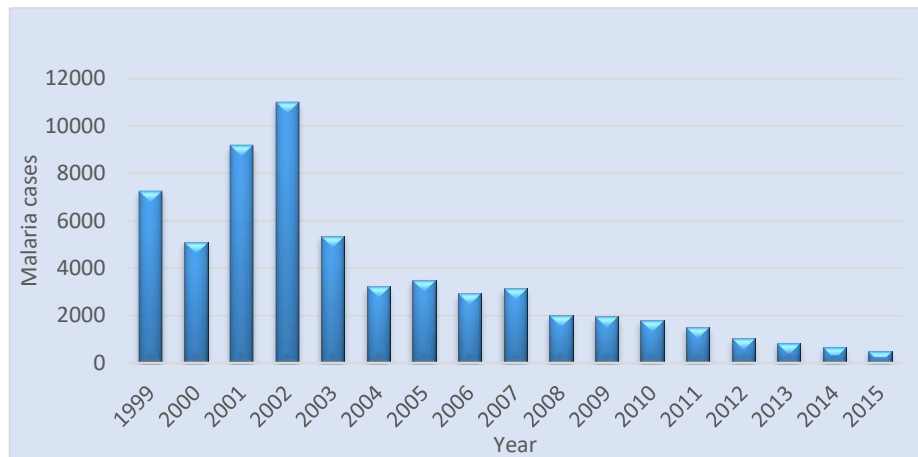
Malaria is an old disease; its symptoms were described in ancient Chinese medical writings (CDC, 2017). While human populations have lived with malaria for a long time, its impact has been uneven through various regions. The disease has been eliminated from some areas while the others are still struggling to control it. For example, the United States and Europe rarely have autochthonous malaria transmission despite a past history of the disease. The governments of many countries have conducted control and elimination campaigns and invested millions of dollars to control malaria. However, there has been only limited success. Few countries, for example United Arab Emirates (2007), Morocco (2010), Turkmenistan (2010), Armenia (2011), Maldives (2015), Sri Lanka (2016) and Kyrgyzstan (2016), have been able to eliminate malaria recently, and a significant number of cases occur every year elsewhere (WHO, 2018b).

Nepal is also endemic for malaria. In fact, “malaria was a significant cause of morbidity and mortality in Nepal throughout much of the 20th century” (UCSF, 2015). The surveys done in the low-lying terai region (Figure 1.1) in the 1920s found that nearly half of the population suffered from malaria, and the mortality rate was 10–15 percent (UCSF, 2015). The terai is valued for cultivation potential, and with the presence of malaria into the 20<sup>th</sup> century in the region, a large part of cultivable land in Nepal was uninhabitable (Sakya, 1981). After the start of anti-malarial operations in the 1950s, several areas in the terai were freed from this disease by the end of 1960s (Sakya, 1981). As a result, people began to migrate to the terai and settle in areas previously considered unsafe due to malaria (Sakya, 1981). Now, about 50% of the population of Nepal lives in the terai because the land is flat and fertile (CBS, 2014).



**Figure 1.1: Major ecological and administrative division of Nepal**

Following the reduction of malaria in the terai, Nepal continued control efforts and is working toward potentially eliminating the disease. Annual malaria cases have been steadily declining in Nepal by roughly 85% after the outbreak of 2002 and the annual parasite incidence (API), has remained below 1 since 1993, except for an outbreak in 2002 (UCSF, 2015). API is calculated as the ratio of confirmed cases per 1000 population during a year. In addition, no deaths have been recorded since 2012 (DoHS, 2016). Nepal also surpassed the 2015 targets of Millennium Development Goals (50 malaria cases per 100,000 populations and 0.03 deaths per 100,000 population) (DoHS, 2016; UCSF, 2015; WHO, 2011). The country also successfully achieved one of the goals of the Roll Back Malaria program by reducing malaria cases and deaths by 75 percent between 2000 and 2015, ahead of schedule (UCSF, 2015). Currently, Nepal is in the pre-elimination phase according to World Health Organization (UCSF, 2015; WHO, 2011) and aiming to be malaria free by 2026 (DoHS, 2016). However, many factors may create obstacles to meeting this aim, including land use/land cover (LULC) change.



**Figure 1.2: Annual malaria cases in Nepal from 1999 to 2015 (Data Source: DoHS (1999-2015))**

## 1.2 Problem Statement

Many studies have found an association between LULC change and malaria in different parts of the world (Krefis, et al., 2011; Stryker & Bomblies, 2012; Vanwambeke, et al., 2007; Lindblade, et al., 2000). In fact, many have shown that LULC change has been responsible for increasing malaria transmission (Ijumba & Lindsay, 2001; Koudou et al., 2005; Yasuoka & Levins, 2007). However, the relationship between LULC and malaria is poorly understood in Nepal. Over the past few decades, LULC change has occurred in Nepal due to natural as well as anthropogenic factors (Paudel, et al., 2016). Studies have reported a decrease in forest and snow/glacier cover and an increase of agricultural land and urban built up areas (Paudel, et al., 2016).

Despite the declining trends of malaria in the country due to human interventions, malaria has expanded into new areas which were previously considered non-endemic (Badu, 2012; Dhimal, et al., 2014a; Dhimal, et al., 2014b; Dhimal, et al., 2014c, Ghimire, 2016). In addition, there have been considerable changes in LULC in Nepal, which can affect the distribution of malaria. However, no study has attempted to study the association between malaria and LULC in Nepal, and the current research intends to fill this research gap. Thus, the aim of this study is to explore whether the spatio-temporal distribution of malaria in Nepal can be related to LULC change. The understanding of the links between LULC and incidence of malaria is of critical importance to initiate effective policies for disease control. The results of this study will inform

government and public health officials about the association of these environmental variables with malaria and will aid in the planning of control efforts. Such information is vital for Nepal as it is aiming to be malaria free by 2026.

### **1.3 Research Questions**

This thesis addresses basic and applied research questions. The basic questions involve exploring the relationship between LULC and malaria incidence rate, while the applied questions identify additional areas in which public health officials should apply control efforts for eliminating malaria. The basic and applied research questions are as follows:

#### **Basic questions:**

1. How has LULC changed between 2000 and 2010?
2. What was the spatial and temporal trend of malaria incidence rate between 1999 and 2015?
3. Which components of LULC are related to malaria incidence rate?

#### **Applied questions:**

1. Which LULC components should health officials be more concerned about?
2. Which areas need more control efforts?

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## CHAPTER 2: LITERATURE REVIEW

### 2.1 Theoretical Framework

This research broadly contributes to the sub-discipline of medical geography, which involves the study of spatial patterns of health and disease. According to Gesler (2003), medical geography employs geographical concepts and techniques to study issues related to disease and health. It is described as the study of disease patterns as influenced by regional or global climate, microbiology, pollution, or other environmental factors; and the relationship between the health of populations and the places in which they live. It aims to improve the understanding of why certain diseases occur in some places and not others. The sub-discipline's value lies in its ability to help us understand the spatial patterns of diseases, which in turn helps governments and health officials conduct health programs in specific areas that experience certain diseases.

Within medical geography, this research is based on two theoretical frameworks: landscape epidemiology and disease ecology. Landscape epidemiology (Figure 2.1) deals with the idea that landscape characteristics typically constrain diseases to certain areas by constraining the environment in which vectors, reservoirs, and pathogen can survive (Reisen, 2010). For example, many vector-borne diseases are present in sub-Saharan Africa because much of the continent is in the tropics and has high biodiversity with frequent interaction between humans and wild species. More specifically, malaria occurs in warm and humid places but not at high elevations because the disease is transmitted by mosquitoes, which thrive in warm and humid places and cannot survive extreme cold. This information on landscape characteristics can be used to intervene and interrupt the disease transmission cycle.

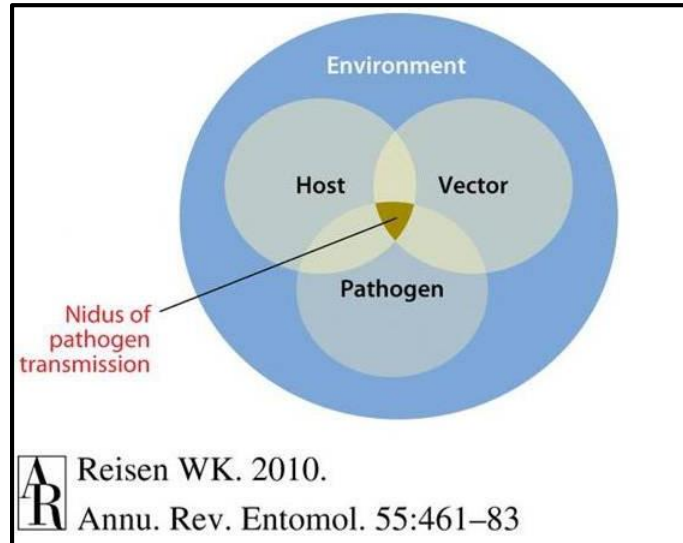


Figure 2.1: Landscape epidemiology (Reisen, 2010)

Similarly, disease ecology helps explain how human populations, physical and built environments, and human behavior interact either to prevent or produce disease (Gesler, 2003). It follows the model of the Triangle of Human Ecology (Figure 2.2). While habitat conditions create certain opportunities and challenges to human health, these habitat conditions are often created by the people's behavior themselves (Meade & Emch, 2010). For example, people might create artificial ponds to collect water for dry periods. The pond can create favorable habitat for mosquitoes to breed. If the temperature is also suitable, the population of mosquitoes might increase and even one imported malaria case can cause a local malaria epidemic. Additionally, individual health outcomes depend on the genetics, nutrition, and immunology of the particular population living within certain vector habitats (Meade & Emch, 2010). If the place had no malaria before, people will be more vulnerable to the disease as compared to those living in an endemic location. In this way, concepts within landscape epidemiology and disease ecology can be combined to understand how land cover disturbances can affect the cycle of many diseases, including mosquito-borne diseases like malaria.

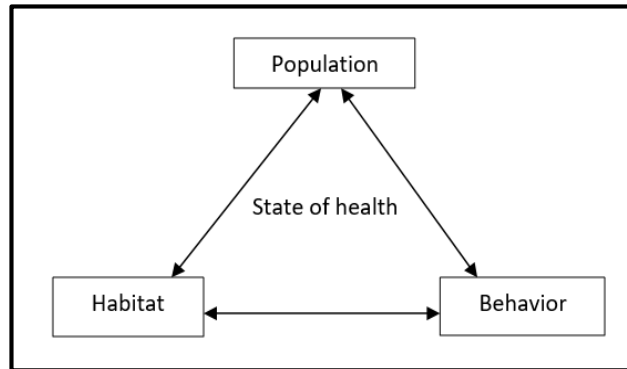


Figure 2.2: Triangle of human ecology (Meade & Emch, 2010)

## 2.2 Malaria in Nepal

There is a conflicting information on when was the first entomological transmission of malaria was recorded in Nepal. According to Shrestha et al., (1991); Jung, (2001) as mentioned in Ghimire (2016), the first entomological transmission of malaria was recorded in Nepal in 1925 in the Chitwan and Makwanpur districts of the terai region in Central Nepal by Major Phillips of the Indian Military Service during an epidemiological survey. However, Pradhan et al., (1970) asserts that the first case of entomological transmission of malaria was recorded in 1955 from Chitwan valley, and the vector was *An. fluviatilis* (Peters et al., (1955) as mentioned in Pradhan, et al., 1970).

Malaria transmission occurs in Nepal throughout the year, however transmission increases during the monsoon, between May and July, because of the creation of standing water suitable for mosquito breeding (UCSF, 2015; WHO, 2011). All ages are affected by this disease, however the majority of the cases are reported among adult males (WHO, 2011). Imported malaria from bordering India is another important concern in Nepal (WHO, 2011). Due to control programs, indigenous cases are declining, however there is no change in the number of imported cases, thus the percentage of imported cases contributing to total malaria cases is increasing (WHO, 2011). Thus it could be challenging for Nepal to achieve complete eradication if the malaria is continually imported. *Plasmodium vivax* and *Plasmodium falciparum* are the only species of parasites detected in Nepal (WHO, 2011). Most of the cases are caused by *P. vivax*, but during the outbreaks, *P. falciparum* are usually responsible (UCSF, 2015; Dhimal, et al., 2014c). Malaria cases have been reported from 65 of the 75 districts of Nepal (WHO, 2011;

Dhimal, et al., 2015; UCSF, 2015). Among the 65 districts, 13 are considered high risk districts (WHO, 2011; UCSF, 2015), based on an API of more than 1 per 1000 (WHO, 2011).

### **2.3 Malaria vectors in Nepal**

In 1960s, *An. minimus* was the primary malaria vector with *An. fluviatilis* as the secondary vector in the forest belt of terai and while *An. fluviatilis* was the only vector in the hilly region (Brydon et al., (1961) as mentioned in Pradhan, et al., 1970). Shrestha (1966) also confirmed that *An. minimus* was confined only in the terai region while *An. fluviatilis* was distributed from the terai to the mountains up to an elevation of 1981 m above msl (Pradhan, et al., 1970). A study done by Pradhan et al (1969) found that *An. fluviatilis*, *An. maculatus maculatus*, and *An. maculatus willmori* were found in Khater and Gum valleys of Mugu, above the elevation of 1067 m above msl (Pradhan, et al., 1970) and at that time, *An. fluviatilis* and *A. maculatus willmori* were found to have sporozoites of malaria parasites. Moreover, *An. maculatus willmori* was found up to elevation of 3170 m above mean sea level (Pradhan, et al., 1970).

The primary malaria vector in the terai, *An. Minimus*, was eliminated in the 1960s through indoor residual spraying (UCSF, 2015; Dhimal et al., 2014d). From then onwards, *An. fluviatilis* has been the primary malaria vector in the terai and hilly zones while *An. annularis* is a secondary vector (UCSF, 2015). *An. maculatus willmori* is found in the mountain zone, however, malaria transmission is negligible in this region, mostly occurring at lower elevations (UCSF, 2015; Dhimal et al., 2014d).

### **2.4 History of the Malaria Control Program in Nepal**

A malaria control program started in Nepal with the establishment of the Insect-borne Disease Control (IBDC) unit in 1954 with support from the United States Agency for International Development), then named USOM (United States Overseas Mission) with the objective of controlling malaria in the terai belt of eastern and central Nepal (DoHS, 2016; WHO, 2011). However, the first attempt at controlling malaria was made a few years before in

1950 with the establishment of a malaria control unit for the Gandaki hydropower project (WHO, 2011). Then in 1958, the first nationwide public health program, the Malaria Eradication Program, was launched under the Nepal Malaria Eradication Organization with assistance from USOM and World Health Organization (WHO) (DoHS, 2016; WHO, 2011). The program's objective was to eradicate malaria from the whole country within a limited time period (DoHS, 2016; WHO, 2011). For this purpose, Nepal was divided into three malaria zones: Eastern, Central and Western Zone (WHO, 2011).

According to Sakya (1981), an estimated 2 million cases of malaria occurred in Nepal annually before the start of the anti-malarial activities in the 1950s, with a fatality rate of about ten percent. After the start of the anti-malarial operations, the number of cases dropped to 2500 in 1970 (Sakya, 1981) which was the lowest recorded case total until 2012. After that, malaria cases began to rise slowly in early 1970's (Sakya, 1981). A massive outbreak occurred in Kapilvastu, Rupandehi and Nawalparasi districts, and the country's case total increased to 9375 in 1973 and 14647 in 1974, a six-fold increase from the 2500 cases reported in 1970 and 2787 cases reported in 1971 (EDCD, 2010). In addition, the Nepal Malaria Eradication Organization also faced many technical and financial problems (Sakya, 1981). By then, the aim of eradicating the disease by 1973 had already failed and achieving this aim in the near future also seemed impossible (Sakya, 1981). Thus, the eradication program was changed to a control program in 1978 (DoHS, 2016; WHO, 2011) as per the recommendations from the review team from the WHO and USAID (WHO, 2011). Then in 1998, the Roll Back Malaria (RBM) initiative was launched following the call of the WHO to revamp malaria control programs (DoHS, 2016). Its aim was to control malaria transmission in forests, foothills, terai and within hill river valleys, which accounted more than 70% of the total malaria cases in the country (DoHS, 2016).

Nepal regularly performs revisions of the malaria control strategy to incorporate changes in the contributing ecological, epidemiological and socioeconomic factors. The first revision was made in 1992 in accordance with the Global Malaria Control Strategy of the WHO, followed by a second revision in 2007 (WHO 2011). "The current strategic plan maps out a two-tiered approach to elimination, beginning with a 2011–2016 short-term focus on scaling up coverage of interventions and eliminating transmission foci, and a 2017–2026 long-term vision of national elimination through intensified surveillance, border screening, and mopping up of residual transmission" (UCSF, 2015).

## **2.5 Land Use/Land Cover (LULC) change and Malaria**

Land cover refers to the physical land type observed at the earth surface (e.g., forest and water bodies) while land use denotes the human use of land (e.g., agriculture and built-up areas) (Stefani et al., 2013). According to Magori (2015), LULC change is a major factor affecting the transmission of vector-borne diseases in the tropics (Sheela, et al., 2017). Land use change affects the distribution and abundance of vectors through habitat modification, and can even influence interactions between human and mosquitoes, including the biting rate (Vanwambeke, et al., 2007). For example, changes in vegetation may affect the local climate by altering evaporation, which in turn may affect the development rates of the parasite and vector as well as mosquito biting rates (Lindblade, et al., 2000). Krefis AC, et al., (2011), in a study done in Ashanti Region, Ghana, found that banana/plantain cultivation, swamps, and impervious surfaces in built-up areas increased malaria risk while forest, orange, cacao, and palm tree plantation was found to have the opposite effect. In addition, determinants like water, deforested areas, and road coverage had no significant influence on malaria incidence in Ashanti. Land use changes affected local hydrological processes like pool persistence and depth in the highland region of Ethiopia, which thereby affected the local mosquito population (Stryker & Bomblies, 2012). In particular, mosquito abundance was sensitive to flow resistance associated with varying land cover types. This study showed that the conversion of agricultural land to forest caused a decrease in the mosquito population. In addition to the vegetation type, the distance between land use and breeding habitats was also a determining factor for mosquito abundance in this location. For example, land use changes near breeding habitats had a greater influence on mosquito abundance than those that were farther away (Stryker & Bomblies 2012). Vittor et al. (2009) found a negative relationship between dense forest and malaria risk whereas a positive relationship between bare surfaces and malaria transmission risk in the Peruvian amazon. Similarly, Savannah and steppe LULC types were positively related to malaria as they were found to be promoting the abundance of adults and/or larvae of malaria vectors (Stefani et al., 2013).

### ***2.5.1 Malaria and water bodies***

Water bodies are the predominant risk factor for malaria transmission because they provide breeding sites for mosquitoes. Irrigation development in the Mahaweli Project in Sri

Lanka which included reservoir, canal margins, and seepages provided increased breeding sites for many mosquito species (Amerasinghe & Ariyasena, 1991) and brought huge malaria epidemics (Amerasinghe & Ariyasena, 1991; Yasuoka & Levins, 2007).

Construction of dams have also resulted in increased malaria transmission due to the formation of large water bodies behind the dam. For example, a study in the Ethiopian highlands compared malaria in villages situated near dams with those situated further away, and found that there was a sevenfold increase in malaria in villages nearer to the dams (Ghebreyesus et al., 1999; Ijumba & Lindsay, 2001). Similarly, the increased prevalence of malaria in Cameroon was associated with the construction of small and medium-sized dams and over 100 small artificial lakes for aquaculture (Ripert & Raccurt, 1987; Ijumba & Lindsay, 2001). The increased malaria transmission in the Uasin Gishu Highlands in Kenya was also found to be associated with the building of dams (Khaemba et al., 1994; Ijumba & Lindsay, 2001).

### ***2.5.2 Malaria and agriculture***

Agriculture is one of the important LULC variables, that have significant impact in malaria transmission because it involves watering which provides breeding sites for mosquitoes. In the highland area of Uganda, all malarial indices were higher in villages near cultivated swamps as compared to those near natural swamps, although the differences were not statistically significant (Lindblade, et al, 2000). Malaria transmission risk seems to have increased in villages near cultivated swamps due to the increase in temperature because of the replacement of natural papyrus swamps by cultivation (Lindblade et al, 2000). Several studies have found that *Anopheles* spp do not breed in papyrus swamps but could be found in the ditches formed during cultivation, leading to several malaria outbreaks (Lindblade et al., 2000).

The increased number of mosquito breeding sites formed by the cotton and vegetable irrigation scheme in the Lower Tana River Basin in Kenya resulted in 54% higher malaria transmission than in the surrounding non-irrigated areas (Ijumba & Lindsay, 2001). Similarly, sugarcane cultivation in Swaziland was reported to be associated with the resurgence of malaria, where a lack of proper maintenance of the irrigation canals led to waterlogging and created breeding sites for malaria vectors (Packard, 1986; Ijumba & Lindsay, 2001). This study concluded that malaria would have been prevented if the irrigation system was properly maintained to avoid the waterlogging. Additionally, the study also found that immigrants from

neighboring countries brought new strains of the *Plasmodium* parasite, compounding the malaria problem.

### ***2.5.3 Malaria and rice cultivation***

The rice paddy that support human populations by growing rice (food) are also the producer of malaria mosquitoes that kills millions of people annually. Irrigated rice fields provide ideal breeding sites for mosquitoes and may also extend their breeding season, leading to higher densities of mosquitoes and thus longer duration of malaria transmission (Ijumba & Lindsay, 2001; Jarju et al., 2009; Koudou et al., 2005). The rice fields support mosquito breeding cycles through the creation of stagnant water in fallow fields, irrigation channels, field channels and seepage water collection (Sharma et al., 1994). The maximum number of malaria mosquitoes are found in the beginning of rice cultivation, when paddies are first flooded and rice is short (Jarju et al., 2009) and decrease as the rice plants reach a height of 76 cm and above (Sharma et al., 1994).

The density of the principal malarial vector in rural parts of central Côte d'Ivoire was several-fold higher in irrigated rice fields than in traditional crop cultivation, including vegetable growing (Koudou et al., 2005). The findings of this study suggest that the distance of human settlements to irrigated rice fields and the practice of rice cultivation twice a year influenced the transmission dynamics of malaria.

The biting rates of mosquitoes were also found higher among villagers involved in irrigated rice cultivation than those performing in a different agro-ecosystems, during non-rainy seasons (Koudou et al., 2005). For instance, the biting rate in a village near a rice field, in Senegal, was found to be 17-fold higher than in a village that was 5km away from a rice field (Koudou et al., 2005). Similarly, in an irrigated sub-arid ecosystem of Madagascar, biting rates were significantly higher resulting into increased malaria transmission (Marrama et al., 2004; Koudou et al., 2005). Another example that shows that rice irrigation is highly related with increased malaria incidence comes from Zatta in Côte d'Ivoire. There was a significant reduction in malaria prevalence rates, and malaria transmission was restricted to the second half of the main rainy season when rice irrigation was interrupted in Zatta in 2003 (Koudou et al., 2005).

However, there is an apparent paradox in some recent studies in Africa about the relationship between rice irrigation and malaria (Ijumba & Lindsay, 2001). Ijumba and Lindsay



(2001) found that malaria transmission increases with rice irrigation in non-endemic areas, where people have little or no immunity to malaria parasites; however, the endemic areas show little or no impact on malaria when rice irrigation is introduced (Ijumba & Lindsay, 2001; Koudou et al., 2005). In fact, in some sites, malaria transmission is less in irrigated communities than surrounding areas even though there were more mosquitoes (Ijumba & Lindsay, 2001). It might be due to the increased use of anti-malarial drugs; carefully planned malaria control activities in the endemic regions; and the economic growth brought about by the production and sale of rice that improved the living standard of the people who could afford bed nets to protect themselves from mosquitoes (Ijumba & Lindsay, 2001). In addition, some studies also suggested that very high mosquito densities can reduce transmission by reducing the longevity of mosquitoes (Koudou et al., 2005).

#### ***2.5.4 Malaria and change from forest cover to agriculture***

Malaria transmission is influenced by changes in mosquito ecology and human behavior patterns in deforested regions (Yasuoka & Levins, 2007). In Kenya, deforestation resulted in the increase of local temperatures and humidity, which in turn affected the densities and development of local vector populations (Afrane et al., (2008); Minakawa et al., (2005); Yasuoko and Levins (2007) as mentioned in Stryker & Bomblies, 2012). In a study done in the Peruvian Amazon to understand the impact of deforestation on the human-biting rate of *Anopheles darlingi*, Vittor et al., (2006), found that biting rate of *A. darlingi* was more than 278 times higher in deforested sites than in the predominantly forested areas.

The relationship between deforestation and malaria incidence is not the same everywhere. Deforestation sometimes increase some *Anopheles* population and can decrease others (Yasuoka & Levins, 2007). Large-scale deforestation in Kanchanaburi, Thailand from 1986 to 1995 was associated with decreased malaria incidence as it eliminated breeding sites of *An. dirus*; however in northeast India, deforestation increased *An. fluviatilis*, where *An. minimus* was historically the primary malaria vector, thereby increasing malaria transmission period (Yasuoka & Levins, 2007).

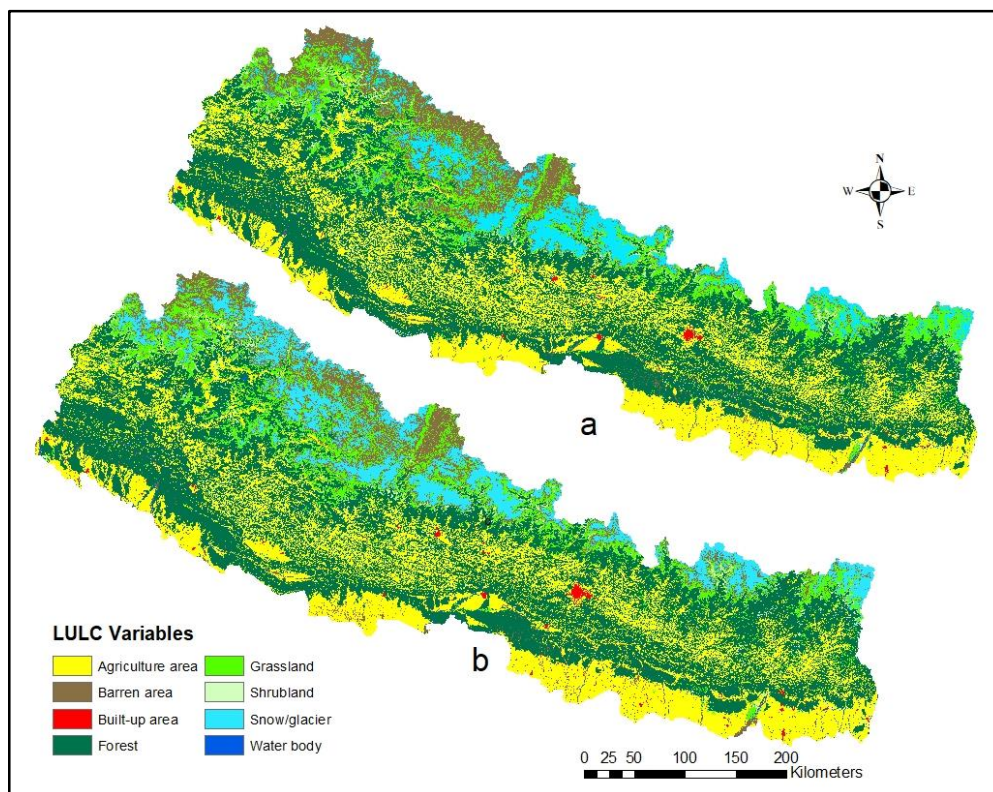
Most of the time, the relationship between deforestation and malaria incidence or transmission depends on the subsequent land use followed by deforestation. However, this relationship is also not the same everywhere. The deforestation that was followed by cacao

plantations in Trinidad during the 1940s provided breeding sites for *An. bellator*, the local principal malaria vector, resulting in a huge malaria epidemic, which was controlled only after the cacao trees were reduced and plantation techniques were modified (Downs & Pittendrigh, 1946; Yasuoka & Levins, 2007). Similarly, deforestation that was done for sugarcane cultivation in Kanchanaburi, Thailand eliminated shady breeding habitats for *An. dirus*, however created sunny breeding grounds for *An. minimus*, causing high malaria transmission among resettled cultivators in that place (Yasuoka & Levins, 2007). Olson et al., (2010) found that deforestation between 1997 and 2000 in Mancio, Lima County, Brazil resulted in a 48% increase in malaria incidence. In particular, there was higher abundance of *An. darlingi* larvae in shrubland cover (which developed five years after deforestation) than in forested areas. Similarly, tea plantations that replaced natural forest in 1875 in Sri Lanka, favored *An. culicifacies* breeding which resulted into severe epidemic malaria among non-immune populations in drought years. (Yasuoka & Levins, 2007). In southeast Thailand, deforestation, followed by development of coffee and rubber plantations, favored the breeding of *An. minimus* and converted a malaria-free region into a malaria-hyper-endemic area (Yasuoka & Levins, 2007). Conversely, in Karnataka, India, coffee plantations following large-scale deforestation, was associated with reduced malaria transmission as coffee plantations reduced seepages, which were the principal breeding sites for the vector *An. fluviatilis* (Yasuoka & Levins, 2007). Similarly, the massive deforestation for cassava plantations in Cholburin, Thailand, by 1985 reduced the density of *An. dirus* drastically and resulted in a marked reduction in malaria prevalence (Prothero, 1999; Yasuoka & Levins, 2007).

## **2.6 Land Use/Land Cover (LULC) change in Nepal**

The major types of LULC in Nepal are forest, shrubland, grassland, agricultural land, barren areas, snow/glacier cover, water bodies and built-up areas Uddin, et al., 2014). The dominant form of land cover in Nepal is forest, covering about 39.1% of the total area followed by agricultural land covering 29.83%. (Uddin, et al., 2014). There has been an unprecedented rate of urbanization in Nepal over the past 30 years, and the rate of decrease of forest cover and increase of cropland has been very high since 1970s (Paudel, et al., 2016). However, only very few studies have been done to examine LULC change of Nepal (Uddin, et al., 2014).

Despite a successful community forestry program, some areas in Nepal show a high rate of deforestation; in a remote watershed of Jumla district, approximately 90 trees per month were lost over a study period of 5 years, or 4% of the forested area per year (Uddin et al., 2015). In this watershed, there was increase of grassland by 6.83% and a slight decrease of agriculture land. Due to the growing impact of human activities since the 1950s, forested areas in the mountainous region of eastern Nepal have undergone continuous change (Kellenberger, et al., 2006). While earlier studies reported the decrease of forest cover inside Kanchenjunga Conservation Area (KCA) during the 1970s and 1980s, a recent study found that forest cover in the KCA increased about 1% between the years 1989 and 2000 (Kellenberger, et al., 2006). This study also found that frozen ground and barren land were converted into alpine grasses. A study done in the Koshi Tappu Wildlife Reserve (KTWR) in the terai region to detect spatial and temporal land use and cover change between 1976 and 2010 showed that forests and the wetland areas such as marshes/swamps and rivers/streams were reduced by 94% and 30% respectively while the grassland increased by 79% of their original state (Chettri, et al., 2013).



**Figure 2.3: LULC in Nepal (a:2000) and (b: 2010) (Data from ICIMOD; Uddin et al., 2014)**

## **2.7 Conclusion**

Given this body of literature, it is important to understand the relationship between LULC and malaria in Nepal, which has been understudied. In addition, Nepal is preparing for malaria eradication by 2026. According to Nepal Malaria Programme Review by WHO (2011), “Malaria control in the declining phase requires greater vigilance and perfection” (p. 37) and it has recommended to further entomological research “to provide information on mosquito fauna of the country, vector distribution map, trends of vector densities over time, vector surveillance and incrimination, vector biting and resting behavior, mosquito breeding sites, susceptibility status to insecticides, monitoring the impact of interventions etc.” (p. 37). However, it has failed to recommend to explore the influence of LULC change on malaria. While the literature identifies a relationship between LULC change and malaria in different countries and regions of the world, this study intends to study this relationship in Nepal. Thus, this study aims to fill this research gap and contribute to public health efforts in Nepal in identifying high risk areas and to concentrate the limited resources in those areas to control and eliminate malaria.

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## **CHAPTER 3: UNDERSTANDING THE RELATIONSHIP BETWEEN LAND USE/LAND COVER AND MALARIA IN NEPAL**

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## **Abstract**

Malaria is one of the leading causes of mortality and morbidity globally. Land use/land cover (LULC) change have been found to affect the transmission and distribution of malaria in other regions, but no study has attempted to examine such relationships in Nepal. Therefore, this study was conducted in Nepal to assess LULC change between 2000 and 2010, to study the spatial and temporal trend of malaria incidence rate (MIR) between 1999 and 2015, and to understand the relationship between LULC and malaria. The land cover types used for this study are forest, water bodies, agriculture, grassland, shrubland, barren areas, built-up areas and paddy areas. Change detection techniques were used to study LULC change. The temporal trend of MIR in 58 districts, and the relationship between MIR and LULC were evaluated using Poisson and negative binomial regression. Forest, water bodies, snow cover, and built-up area increased in Nepal by 28.5%, 2.96%, 55.12% and 21.19% respectively while the rest of the LULC variables decreased. MIR decreased significantly in 21 districts; however, four districts namely Pyuthan, Kaski, Rupandehi and Siraha had a significantly increasing trend of MIR. During 2001, 2002, and 2003, MIR was positively related to water bodies and paddy areas. Similarly, MIR of 2010 was negatively related to grassland. However, there was no relationship between LULC and MIR in 2000, 2011, 2012 and 2013. It may be because MIR is decreasing significantly in the country and thus the influence of LULC change is also decreasing.

**Keywords:** Malaria, Land Use/Land Cover Change, Poisson Regression, Negative Binomial Regression

### 3.1 Introduction

Malaria is one of the leading causes of mortality and morbidity globally. About half of the world population was at risk of malaria in 2016 (WHO, 2018b). Sub-Saharan Africa carries the highest share of the malaria burden with 90% of the cases. The remaining cases occur in other regions including South-East Asia, the Eastern Mediterranean, the Western Pacific and the Americas (WHO, 2018b). The disease is caused by the parasite *Plasmodium*, transmitted by the infected female mosquito of the *Anopheles* species. The reservoir, or underlying source of infection for mosquitoes, are humans. The initial symptoms of the disease, which include chills, fever and headache, may not be easily identified as malaria. It is a preventable and curable disease, however, it can be life threatening if not treated in time.

Malaria transmission depends on environmental factors related to the parasite, the vector, and the human host (WHO, 2018b). LULC is one of the important environmental factors known to influence malaria incidence and transmission (Lindblade et al, 2000; Ijumba & Lindsay, 2001; Yasuoka & Levins, 2007 etc). LULC variables such as forests, water bodies, and agricultural practices especially paddy cultivation has been associated with malaria.

Forests and forests fringes are the most malarious regions in south east Asia and thus the term ‘forest malaria’ is commonly used in this region. (Prothero, 1999; Bharati and Ganguly, 2013; Dash, et al., 2008). When houses are located close, forests and secondary vegetation can provide resting sites for malaria mosquitoes that return to the forest after feeding (Stefanie et al 2013). In addition, deforestation is also found to influence malaria transmission and distribution which is different in different regions. In northeast India, deforestation resulted in an increase of *An. fluviatilis* and eventually increased malaria transmission, while in Kanchanaburi, Thailand, large-scale deforestation from 1986 to 1995, decreased malaria incidence as it eliminated breeding sites of *An. dirus* (Yasuoka & Levins, 2007). Few studies showed that subsequent land use following deforestation had more influence on malaria transmission than deforestation itself and the impact was again different in different regions. For example, cacao plantations followed by forest clearing in Trinidad during the 1940s, provided breeding sites for *An. bellator*, and caused a large malaria epidemic, which was controlled only after the number of cacao trees was reduced and plantation techniques were modified (Downs & Pittendrigh, 1946; Yasuoka & Levins, 2007). Irrigated rice cultivation, after deforestation in Java-Bali, Indonesia, increased malaria incidence as they provided favorable breeding places and also prolonged the breeding

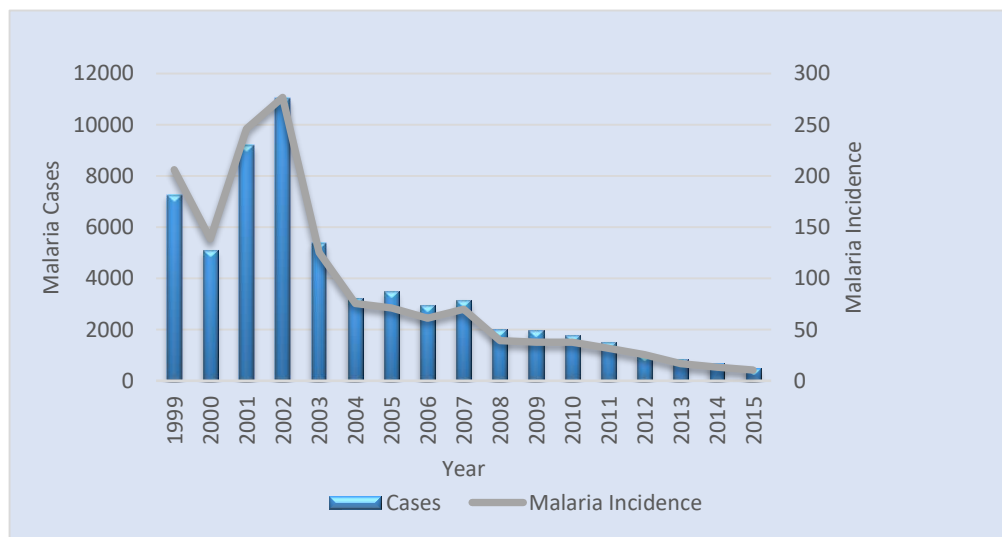
season for *An. aconitus*. On the other hand, in Cholburin, Thailand, large-scale deforestation for cassava plantations by 1985 reduced malaria prevalence markedly as it drastically reduced the density of *An. dirus* (Prothero, 1999; Yasuoka & Levins, 2007). Similarly, coffee plantations in Karnataka, India, followed by massive deforestation, reduced malaria transmission by reducing seepages which were the principal breeding sites of *An. fluviatilis* (Yasuoka & Levins, 2007).

Water bodies are found to have positive relationship with malaria transmission as they provide breeding habitats for mosquitoes resulting into high mosquito density, which is the most important factor for malaria transmission. Construction of dams in the Ethiopian highlands, Cameroon, the Uasin Gishu Highlands in Kenya, and in other areas have resulted in increased malaria transmission due to the formation of large reservoirs behind the dam with near-standing water bodies (Ghebreyesus et al., 1999; Ripert & Raccurt, 1987; Khaemba et al., 1994; Ijumba & Lindsay, 2001).

Agriculture is also found to have influenced malaria transmission in different countries. For example, malaria transmission risk increased in villages near cultivated swamps in the highland area of Uganda, as compared to others near natural papyrus swamps because of the formation of ditches and the increase in temperature due to cultivation that provided better breeding conditions for *Anopheles spp*, which do not breed in papyrus swamps (Lindblade et al, 2000). Additionally, the irrigation scheme developed for cotton and vegetable farming in the Lower Tana River Basin in Kenya resulted in 54% higher malaria transmission than in the surrounding non-irrigated areas (Ijumba & Lindsay, 2001). Moreover, paddy cultivation is even more related to malaria incidence and transmission as paddy fields are flooded with water for a long time and thus provide suitable breeding sites for mosquitoes that transmits malaria. Irrigation development for paddy fields has been a perennial subject of debate as it increases malaria transmission in the surrounding areas by providing good breeding habitats for malaria mosquitoes (Ijumba & Lindsay, 2001) The density of the principal malarial vector in rural parts of central Côte d'Ivoire was several-fold higher in irrigated paddy fields than in areas with traditional crop cultivation, including vegetable cultivation (Koudou et al., 2005). In the same study, the biting rates of mosquitoes during the non-rainy season were also found to be higher among villagers involved in irrigated paddy cultivation than those working in a different agro-ecosystem (Koudou et al., 2005).

The malaria incidence rate decreased steadily between 1999 and 2015, with some fluctuations (Figure 3.1). This decrease is a great achievement and is mainly due to the control efforts of public health officials beginning in the 1950s. Mostly adult working age males are the victims of malaria in Nepal (WHO, 2011) and household income is generally dependent on them, so there continues to be a considerable economic burden of malaria in Nepal despite the recent decrease in incidence.

Nepal is now aiming to be malaria free by 2026 (DOHs, 2014), however, changes on LULC, which is under researched in Nepal, might create challenges in meeting this aim. Some research has been done to understand the impact of climate change on malaria incidence in Nepal, and those studies have found that climate change is increasing malaria cases and shifting the range of the disease (Badu, 2012; Dhimal, et al, 2014a; Dhimal, et al, 2014b; Dhimal, et al, 2015; Bhandari, et al., 2013; Ghimire, 2016). However, no study has elucidated the relationship between malaria and LULC, which has been shown to significantly influence malaria transmission in other parts of the world. Thus, this study aims to understand the relationship between land use/land cover variables and malaria incidence in Nepal. The results will be helpful to public health officials as they plan control efforts to effectively eliminate malaria from Nepal.



**Figure 3.1: Annual malaria cases and malaria incidence rate in Nepal from 1999 to 2015 (Data Source: DoHS (1999-2015))**

### 3.2 Study Area

Nepal is a small mountainous country in the central Himalayas with an area of 147,181 km<sup>2</sup> and a population of 26,494,504 according to the 2011 census (CBS, 2014). It is a landlocked country bordering China in the north and India on the other sides (Figure 3.2). It extends up to 800 km in length while breadth varies from 90-200 km. Within this relatively short distance, the elevation varies greatly from about 60 meters above sea level in the south to 8848 m (at the summit of Mt. Everest) in the north. Based on the elevation variation, Nepal is broadly divided into three ecological regions: terai, hills and mountains.

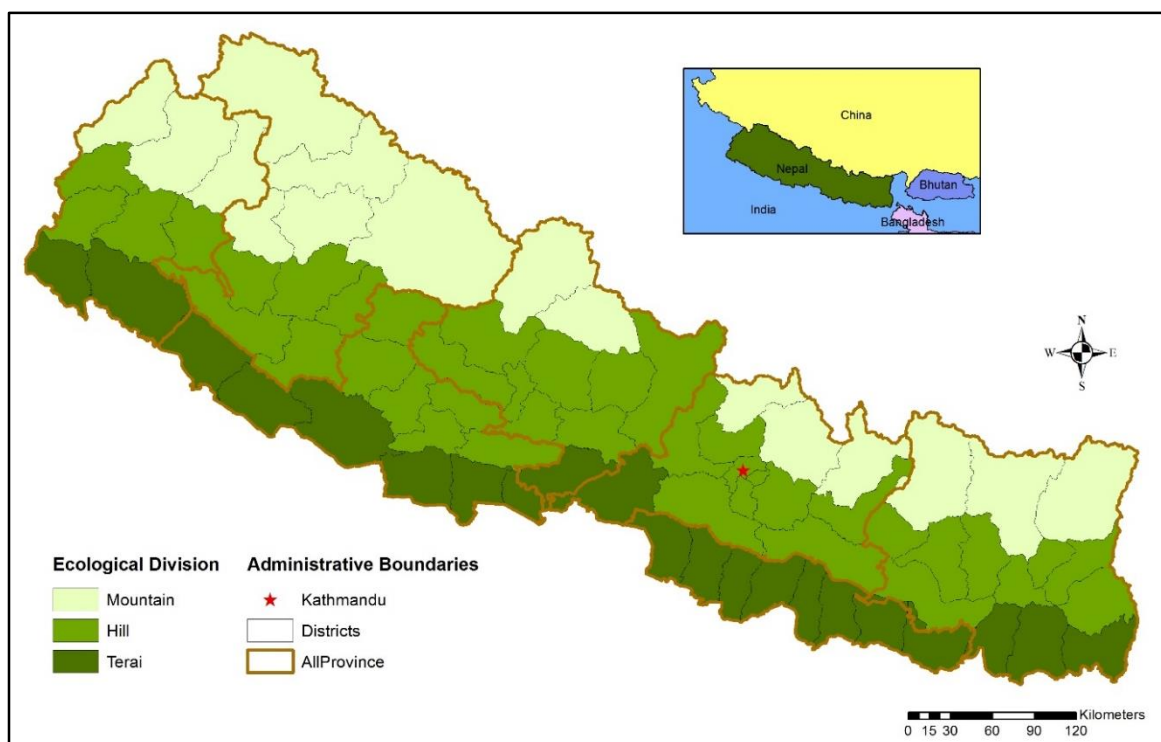


Figure 3.2: Major ecological and administrative division of Nepal

Terai, or flat lands, lie in the southernmost part of the country bordering India. The region consists of 17% of the country's total area but it includes 50% of the population, according to the 2011 census (CBS, 2014). It is the most densely populated region because the flat and fertile land is suitable for agriculture and transportation is easy in the region. There are 20 districts in this region. The elevation of this region ranges between 70 meters to 1000 meters (Gurung, 2008 as mentioned in Ghimire, 2016). The average summer temperature is between 27°C to 32°C and mean annual precipitation is approximately 1600 mm (Gurung, 2008 as mentioned in Ghimire, 2016).

The land use types of the region mostly consist of cultivated land, forests, swamps and urban areas (Ghimire, 2016). The climate of terai region is subtropical or tropical, making malaria endemic because of the suitable climate for mosquito survival and reproduction.

The hill region comprises 65% of the total land area of Nepal and 43% of the population. There are 39 districts in this region. The elevation ranges between 500 meters to 3000 meters (Gurung, 2008 as mentioned in Ghimire, 2016). The region receives mean annual precipitation of approximately 1800 mm and the average summer temperature is between 15°C to 27°C (Gurung, 2008 as mentioned in Ghimire, 2016). The major land use types of the region are forest, cultivated area, shrub lands, slides and slips and urban areas (Ghimire, 2016). Hilly region has a temperate climate which supports mosquito survival and reproduction year round (Ghimire, 2016). Kathmandu, the capital of the country is located within the hill region. The population of the Kathmandu Valley was 2,510,788 in 2011 (CBS, 2014), which is nearly 10% of the total population of the country.

Finally, the mountain region lies in the northern most part of the country where the Himalayas border China. The region covers about 16% of the total land area and includes about 7% of the population. There are 16 districts in the Mountain region. It is the least densely populated region in Nepal because of its rugged topography and steep slopes. The elevation ranges between 3000 meters to 8848 meters. The region receives mean annual precipitation of approximately 600 mm and the average summer temperature is below 0°C to 10°C (Gurung, 2008 as mentioned in Ghimire, 2016). The land cover types of the area are grazing lands, rocks, rocky outcrop, forest and permanent snow and ice (Ghimire, 2016). This region comprises eight of the 10 highest mountains of the world including Mount Everest. Mountain region, having alpine to sub-alpine climate is generally less hospitable for mosquito survival.

For administrative purpose, Nepal was divided into five development regions, 14 zones, 75 districts, 53 municipalities, and 3,918 village development committees (VDCs). However, with the commencement of a new constitution in 2015, Nepal is now divided into seven provinces, and 744 various local bodies (including four metropolitan cities, 13 sub-metropolitan cities, 246 municipalities, and 481 rural municipalities) (Aksha, et. al., 2018).

### 3.3 Materials and Methods

#### 3.3.1 Data

Multiple datasets were used for the study: malaria cases by districts, district-level population data, and land use land cover (LULC) data. The available record of district wise annual indigenous malaria cases from 1999 to 2015 was obtained from the annual reports of the Department of Health Services of the Government of Nepal. The data included cases caused by both *Plasmodium vivax* and *Plasmodium falciparum*. Out of 75 districts, only 58 districts were included for the study purpose because 11 districts, mostly located in the mountain region, did not have any indigenous malaria cases and six districts had five or fewer years with malaria cases during the study period of 1999 to 2015. The districts with no indigenous malaria cases are Solukhumbu, Myagdi, Manang, Mustang, Humla, Rasuwa, Nuwakot, Kathmandu, Bhaktapur, Dolakha and Jajarkot. The six districts with malaria cases less than five are Rolpa, Baglung, Khotang, Dolpa, Mugu and Darchula.

Population data for census years 2001 and 2011 were obtained for each district from the Central Bureau of Statistics (CBS), Nepal (CBS, 2014). The population for non-census years between 2001 and 2011 was extrapolated on the basis of the population growth rate between the census years. Similarly, population for years 1999 and 2000 was extrapolated on the basis of population growth rate of 1991 and population for years from 2012 to 2015 were extrapolate on the basis of population growth rate of 2011.

LULC data for Nepal for 2000 and 2010, at a spatial resolution of 30m and prepared using public domain Landsat TM, were downloaded from the International Centre for Integrated Mountain Development (ICIMOD) geoportal (<http://geoapps.icimod.org/landcover/nepallandcover/>). Land use/land cover in this dataset has been classified into eight classes: forests, shrubland, grassland, agriculture, barren, water, snow/glacier, and built up area. Classification categories were the same for both years. Additionally, area of rice paddy for all districts was obtained from the publications of the Ministry of Agricultural Development, Government of Nepal for 2000 and 2010 (MoAD, 2013). In addition to agriculture, we also examined the potential role of rice paddies specifically to understand its relationship with malaria in Nepal because rice paddies are flooded with water for a long duration, which provides suitable breeding habitats for mosquitoes, and many studies have



shown that rice cultivation is associated with increased malaria transmission ((Ijumba & Lindsay, 2001; Jarju et al., 2009; Koudou et al., 2005; Sharma et al., 1994)

### **3.3.2 Methods**

#### *3.3.2.1 Data Preparation*

##### *1. Malaria incidence rate (MIR)*

For data analysis, MIR was used instead of malaria case data because MIR is adjusted by the total population of the district and also allows consideration of district wise differences in population across time and space. MIR was calculated by dividing the malaria case data by population for each district in each year. The formula used for calculating MIR is

$$\text{malaria incidence rate} = \frac{\text{malaria case of a district}}{\text{Population of that district}} * 10,000$$

##### *2. LULC data*

The percentage of each of the eight classes of LULC from ICIMOD data was calculated for all districts for the years 2000 and 2010 using ‘zonal statistics as table’ in ArcGIS 10.4.1 (ESRI, Redland, CA). Area of rice paddies for all districts obtained from MoAD reports were converted into percentages. Among the nine LULC variables, only eight of them were used. Snow was removed from the analysis because we did not find an association between snow and malaria incidence in any other studies and malaria does not occur in very cold places, such as those with continual snow cover.

#### *3.3.2.2 Change Detection Techniques*

Using change detection techniques, the change in percentage of each LULC variable between 2000 and 2010 was calculated within all districts. The change in LULC between 2000 and 2010 for all of Nepal was then calculated by taking a sum of all the changes in each LULC variables.

### 3.3.2.3 *Poisson regression and Negative Binomial regression*

The temporal trend of MIR from 1999 to 2015 was quantified using either Poisson regression or negative binomial regression because they work best for count data (Piza, 2012; Patience & Osagie, 2014). Count data are those which are obtained by counting the number of occurrences of a particular event, such as disease incidence (Everitt, 2002; Patience & Osagie, 2014).

Poisson regression and negative binomial regression models are two different sub-types of Generalized Linear Models (GLM), which are an extension of the linear modeling process that allow models to be fitted to data that follow probability distributions other than the normal distribution (Patience & Osagie, 2014; Gore & Jumi, 2017; Kakchapati & Ardkaew, 2011). A Poisson regression model is a special case of a generalized linear model (GLM) with a log link, and thus the Poisson regression is also called Log-Linear Model (Patience & Osagie, 2014; Gore & Jumi, 2017). The response variable follows a Poisson distribution (Gore & Jumi, 2017), which is often used to model rare events (Larget, 2007; Patience & Osagie, 2014). It is commonly used for modeling the number of cases of disease in a specific population within a certain time (Gore & Jumi, 2017; Kakchapati & Ardkaew, 2011). A characteristic of the Poisson distribution is that its mean is equal to its variance (Kakchapati & Ardkaew, 2011). If the observed variance is greater than the mean, the data are over-dispersed and the Poisson model is not appropriate for that data (Kakchapati & Ardkaew, 2011). Poisson models for disease counts are often over-dispersed, due to clustering (Gore & Jumi, 2017; Kakchapati & Ardkaew, 2011). In this case, negative binomial regression is more appropriate as it allows for the over-dispersion that commonly occurs for disease counts because the negative binomial model contains an extra parameter that allows the variance of a measure to exceed its mean (Gore & Jumi, 2017; Kakchapati & Ardkaew, 2011). Therefore, when incidence data within a district were not over-dispersed, we used a Poisson model to examine the temporal trend in malaria data and a negative binomial model when over-dispersion was present.

In the temporal trend analysis using either Poisson or negative binomial regression, the malaria incidence rate was the response variable and the explanatory variable was time in years coded from 0 to 16 years. In the temporal trend analysis, among the 25 districts that has statistically significant trends, Poisson regression was used in 20 districts and negative binomial regression was required for five districts due to over-dispersion of the data.

Additionally, the relationship between malaria incidence rate and LULC variables was also analyzed using Poisson regression and negative binomial regression. In this analysis, the response variable was the malaria incidence rate and the different LULC variables were the explanatory variables. The analysis was completed in two time periods. As we had LULC data for 2000 and 2010, we studied the relationship between LULC variables from 2000 and malaria incidence rates of 2000, 2001, 2002 and 2003 individually; and between LULC variables from 2010 and malaria incidence rates of 2010, 2011, 2012 and 2013 individually. We considered multiple years because we assumed that the change in LULC can have impacts on mosquito reproduction and survival into the future. For 2000, 2001, 2002 and 2003, negative binomial regression was used due to over-dispersion and for 2010, Poisson regression was most appropriate. For the rest of the years, results were not statistically significant.

### 3.4. Results and Discussion

#### 3.4.1 Changes in Land Use and Land Cover

Land use and land cover change occurred in Nepal between 2000 and 2010 (Table 3.1). Among the LULC variables, the greatest change occurred with agricultural land (57.85% decrease) followed by snow (55.12% increase). Built-up areas increased by 21.19% over 10 years which indicates that rapid urbanization is occurring in Nepal. Other LULC variables, like forest, increased by 28.5% while grassland decreased by 40.88%. Paddy fields decreased by 1.51%.

<b>LULC category</b>	<b>Percentage change</b>
Forest	28.50
Shrubland	-0.38
Grassland	-40.88
Agriculture	-57.85
Barren Area	-8.66
Water bodies	2.96
Snow/glacier	55.12
Built-up Area	21.19
Rice Paddy	-1.51

### 3.4.2 Trend of malaria incidence rate (MIR)

The trend analysis showed that more districts in Nepal are experiencing a decrease in malaria than an increase. Twenty-one districts experienced a statistically significant decreasing trend of MIR between 1999 and 2015 (Figure 3.3; Table 3.2). However, four districts, namely Kaski, Pyuthan, Rupandehi, and Siraha, experienced a statistically significant increasing trend of MIR. Kaski and Pyuthan are located within the hill region while Rupandehi and Siraha are in the terai.

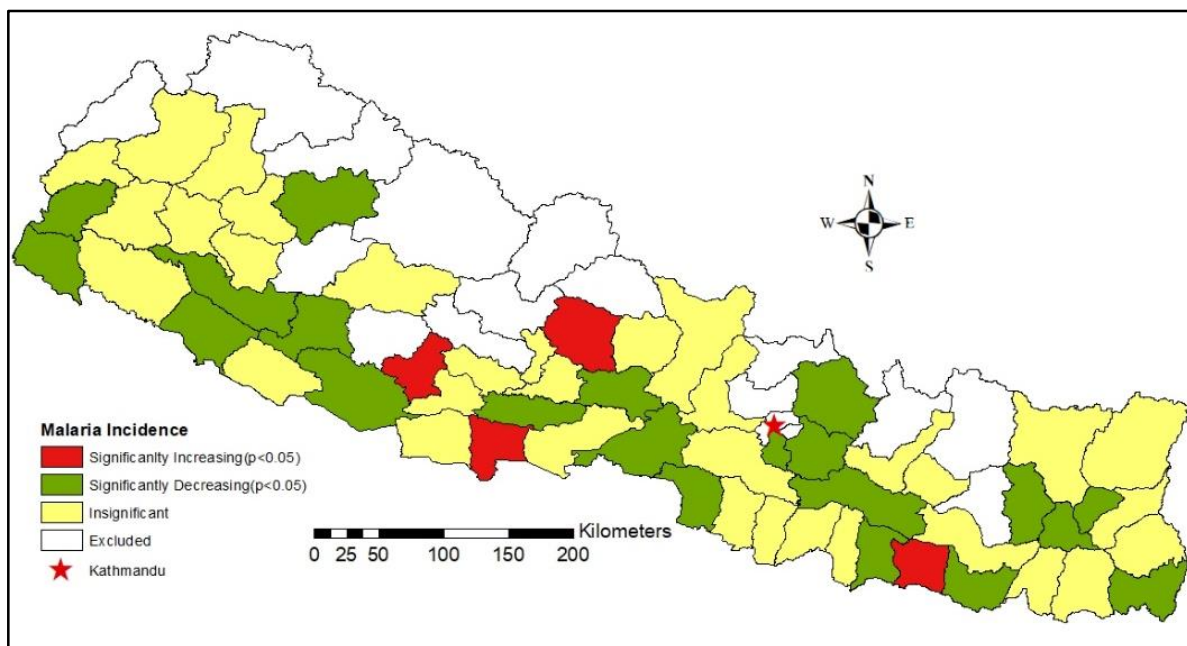


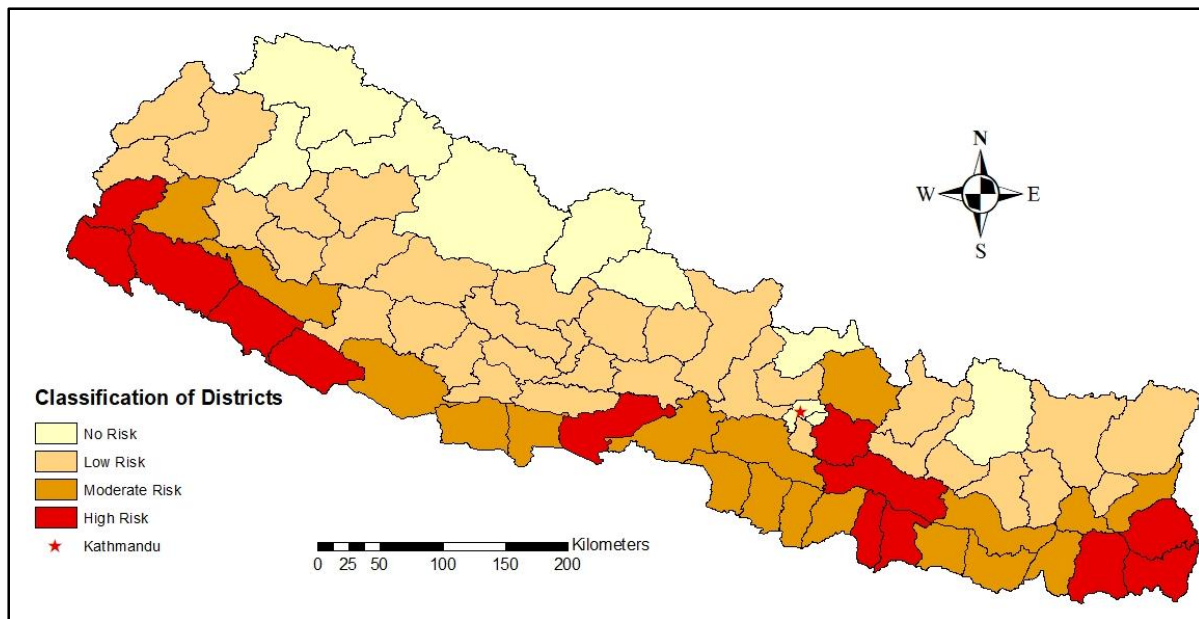
Figure 3.3: Districts with significantly increasing and decreasing trends of MIR

**Table 3.2: Districts with statistically significant temporal trends of MIR with Poisson and negative binomial regression**

District	Increasing/Decreasing	Model Type	P-value
Bardiya	Decreasing	Poisson	<.0001
Bhojpur	Decreasing	Poisson	<.0001
Chitwan	Decreasing	Poisson	<.0001
Dang	Decreasing	Poisson	<.0001
Dhanusa	Decreasing	Negative Binomial	<.0001
Jhapa	Decreasing	Negative Binomial	<.0001
Jumla	Decreasing	Poisson	<.0001
Kanchanpur	Decreasing	Negative Binomial	<.0001
Parsa	Decreasing	Poisson	<.0001
Saptari	Decreasing	Poisson	0.0011
Terhathum	Decreasing	Poisson	<.0001
Dhankuta	Decreasing	Negative Binomial	<.0001
Sindhupalchok	Decreasing	Poisson	0.0005
Dadeldhura	Decreasing	Negative Binomial	0.0003
Surkhet	Decreasing	Poisson	0.0063
Salyan	Decreasing	Poisson	<.0001
Palpa	Decreasing	Poisson	<.0001
Tanahu	Decreasing	Poisson	0.0096
Kavre	Decreasing	Poisson	<.0001
Lalitpur	Decreasing	Poisson	<.0001
Sindhuli	Decreasing	Poisson	<.0001
Kaski	Increasing	Poisson	0.0165
Pyuthan	Increasing	Poisson	0.0027
Rupandehi	Increasing	Poisson	0.0099
Siraha	Increasing	Poisson	0.0103

MIR is significantly decreasing in general across Nepal mostly due to the control efforts operating since 1950s. The Department of Health Services (DoHS) developed a risk map (Figure 3.4) identifying the districts at greatest risk and those with little risk based on annual parasite incidence per 1000 people (DoHS, 2013). We compared the results of this study with the DoHS map, and we found that none of the districts identified as ‘high risk’ was found to have a significantly increasing trend of malaria incidence rate. Among the 18 ‘moderate risk’ districts, seven experienced a significantly decreasing trend, and two of those districts experienced a significantly increasing trend. Finally, among the 34 ‘low risk’ districts, seven did in fact experience a significantly decreasing trend; however, two experienced a significantly increasing trend. Thus, this comparison shows that all the districts identified as ‘high risk’ actually have experienced a significant decreasing trend of malaria incidence rate between 1999 and 2015; however, there are districts in which malaria incidence rate is increasing in both low and

moderate risk districts. This discrepancy may have resulted because of the concentration of malaria control efforts mainly in ‘high risk’, followed by ‘moderate risk’ districts, with the remaining ‘low risk’ districts receiving less attention (DoHS, 2013; DoHS, 2017). Thus, additional factors are playing a role in increasing MIR in those districts. Therefore, it is necessary to conduct studies at finer scale to understand if LULC is responsible for these statistically significant increasing trends of MIR specifically in these four districts.



**Figure 3.4: Classification of districts with different risk of malaria by DoHS (DoHS, 2013)**

### ***3.4.3 Relationship between Land use/Land Cover and Malaria***

When comparing land use/land cover and malaria, malaria incidence rate (MIR) of 2001, 2002 and 2003 had a significant positive relationship with water bodies and paddy cultivation, and MIR of 2010 had a significant negative relationship with grassland. However, malaria incidence rate of 2000, 2011, 2012 and 2013 had no significant relationship with any LULC variables. Water bodies and paddy cultivation provide favorable breeding sites for mosquitoes, which may be the reason behind the positive relationship of malaria incidence rate with water bodies and paddy cultivation during 2001, 2002 and 2003. These findings seem to agree with other researches that found positive relationship of malaria with water bodies and paddy

cultivation (Ghebreyesus et al., 1999; Ripert & Raccurt, 1987; Khaemba et al., 1994; Ijumba & Lindsay, 2001; Koudou et al., 2005).

**Table 3.3: Relationship between LULC variables and MIR**

<i>LULC 2000</i>		
Malaria Incidence Rate	Relationship	Significant LULC variable
2000	-	-
2001	Positive	Water, Paddy
2002	Positive	Water, Paddy
2003	Positive	Water, Paddy
<i>LULC 2010</i>		
2010	Negative	Grassland
2011	-	-
2012	-	-
2013	-	-

These results suggest that LULC variables were significant factors in the malaria incidence rate during the early 2000s, but recently they are not significant in influencing malaria. It may be because the malaria incidence rate is decreasing mainly due to control efforts, and thus the influence of LULC variables is decreasing. This finding is similar to what researchers have found in countries like Tanzania and Gambia in Africa. Those studies found that in endemic areas, the introduction of crop irrigation had little or no impact on malaria transmission (Ijumba & Lindsay, 2001; Koudou et al., 2005). In fact, in some sites, malaria transmission was less in irrigated communities than in surrounding areas even though there were more mosquitoes (Ijumba & Lindsay, 2001). This discrepancy was due to the increased use of anti-malarial drugs across the region; carefully planned malaria control activities in the endemic regions; and the economic growth brought about by the production and sale of rice that improved the living standard of the people who could then afford bed nets to protect themselves from mosquitoes (Ijumba & Lindsay, 2001). This explanation can potentially apply in Nepal too. As malaria control efforts have been scaled up in recent decades, malaria incidence rate is decreasing drastically and thus the LULC variables now have less influence. Additionally, the changes in socio-economic condition of the people might have affected the trend, which needs to be studied further.

The negative relationship of MIR with grassland may be because the grassland is not suitable for breeding. The relationship between grassland and malaria has not been mentioned in other studies. Unexpected findings from the study include the lack of a relationship between MIR with forests. The high incidence or presence of malaria near the forest belts in Nepal have been mentioned in several studies (WHO, 2011; DoHS, 2014; Sherchand et al., 1996 as mentioned in Ghimire, 2016). However, this study did not find any significant relationship between forests and MIR.

#### ***3.4.4 Comparison of average LULC percentage in districts with increasing and decreasing MIR***

When comparing average percentage of each LULC variables between group of districts with a statistically significantly increasing or decreasing MIR trend, and within statistically non-significant districts (Table 3.4), we found that rice paddies are greater in percentage in MIR increasing districts as compared to decreasing districts, which supports the positive relationship found between rice paddies and MIR. The area devoted to grasslands is approximately double the percentage in decreasing districts than in increasing districts, which again supports the negative relationship between grassland and MIR. However, area of water bodies was slightly higher in percentage in decreasing districts than in the increasing ones, which contradicts the positive relationship between water bodies and MIR.

In addition, the difference between forests and agricultural land were also distinct between increasing and decreasing districts. Agricultural lands were greater in percentage in increasing districts than in decreasing districts. This finding is logical because agricultural activities often involve watering crops through irrigation, which provide breeding sites for mosquitoes and have been found to increase malaria transmission in different parts of the world (Lindblade, et al, 2000; Ijumba & Lindsay, 2001; Packard, 1986). On the other hand, forests were greater in percentage in decreasing districts than in increasing ones. While we see a difference in forested and agricultural cover when comparing districts with either increasing or decreasing MIR, we didn't find a statistically significant relationship between MIR with forests and agricultural lands in our study.



**Table 3.4: Comparing average percentage of LULC variable between districts with statistically increasing MIR, statistically decreasing MIR, and statistically non-significant districts**

LULC variables	Average value for statistically increasing districts		Average value for statistically significantly decreasing districts		Average value for statistically not significant districts	
	2000	2010	2000	2010	2000	2010
Agriculture	52.91	51.87	38.81	38.60	38.36	37.40
Barren	2.73	3.19	2.86	2.58	2.95	3.35
Built-up	0.54	0.61	0.59	0.77	0.26	0.36
Forest	33.74	34.43	50.94	51.27	46.97	47.34
Grassland	2.41	2.65	4.38	4.03	6.78	6.36
Shrubland	1.61	1.74	1.19	1.17	1.85	1.85
Water bodies	0.58	0.46	0.73	0.83	0.54	0.56
Rice Paddy	31.07	26.70	16.99	16.24	14.67	14.67

### 3.4.5 Limitations

Several limitations were present in this study. Analyses were conducted using the available annual district malaria incidence rate. Finer scale malaria data from smaller administrative units like municipalities and Village Development Committees report weekly and monthly data that could have given an improved understanding of the spatial and temporal malaria trend as well as its relationship between LULC variables for future studies. In addition, the malaria reporting systems in Nepal have not been able to capture malaria data adequately from private health facilities (Ghimire, 2016). Incorporating malaria data from private health facilities might provide a better understanding of the relationship with LULC variables. An additional limitation of this research is that it has only included LULC variables. The additional factors that can affect malaria are impacts of control efforts, changes in socio-economic conditions of the people, distance to health facilities, climate change, migration, and other variables.

### 3.5 Conclusion

This study has important findings that elucidate the relationship between LULC and malaria in Nepal. The main objective of this study was to examine the relationship between LULC and malaria incidence rate in Nepal. The findings show that there was a significant positive relationship between malaria incidence rate with water bodies and paddy cultivation in 2001, 2002 and 2003; a significant negative relationship with grassland in 2010; and no relationship with any LULC variable in 2000, 2011, 2012, and 2013. The study also found a significant change in LULC in Nepal between 2000 and 2010, with the greatest change in the categories of agriculture and snow/glacier followed by grassland and forests. Moreover, the study found that, in opposition of the general trend of decreasing MIR in the country, four districts, namely Pyuthan, Kaski, Rupandehi and Siraha, had an increasing MIR trend between 1999 and 2015. Comparing the average percentage of LULC variables between the four districts with an increasing MIR and the 21 districts with a decreasing MIR, we found that rice paddies cover a higher percentage of area in increasing districts than decreasing districts but grassland and water bodies cover a higher percentage of land in decreasing districts than increasing districts. However, this comparison is based on average values, and the relationship may be different at finer scales in each district. Thus, it is necessary to study the relationship between LULC and malaria at a finer scale, using municipality data, particularly within those districts identified as having a significantly increasing trend in MIR to see if LULC is contributing to the increasing trend locally.

This study identified some LULC features, i.e. water bodies and rice paddies, that had a positive relationship with MIR as they may provide breeding habitats for *Anopheles* mosquitoes. This information, along with details on the four districts with a statistically significant MIR trend, will be helpful for public health officials to increase control efforts in those four districts and in areas near water bodies and paddy fields, which may aid in their effort to eliminate malaria from Nepal. LULC change does have an influence on mosquito populations and disease transmission risk, but transmission can be prevented through control efforts and increased awareness among the people. Vanwambeke, et al. (2007) also suggested that policy intervention, education campaigns, and adoption of preventive measures can counteract (or enhance) effects caused by LULC change. In addition, malaria prevalence and distribution is not only affected by LULC variables but a combination of several other factors such as socio-economic conditions,

available health facilities, public awareness and prevention measures, and other environmental changes such as climate change. Thus, further research needs to be done incorporating these factors too because understanding the factors that are associated with the distribution of malaria is crucial for decision making and designing a policy to control and eventually eradicate malaria from Nepal.

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