Evaluation of Land Use Changes on Schistosomiasis Disease Prevalence in Sichuan Province, China

Abstract This study examines the impact that 5 land use/land cover types have had on schistosomiasis human infection rate data for the time period 1978-2003. Schistosomiasis is a water-borne disease that is caused by any of five parasitic *Schistosoma* flatworm species and is prevalent throughout much of the developing world and many region specific areas in China, including the Sichuan Province. Studies have shown that in the Sichuan Province, the disease has started to reemerge over the past decade despite national control efforts to eradicate the disease. Despite these recent trends, there have been very few studies which have assessed long term land use impacts on schistosomaisis transmission. Using satellite imagery from the United States Geological Survey (USGS) and human infection rate data from China's Center for Disease Control (CDC), regression tests were performed to assess the strength of correlation between land use changes and general land cover types and prevalence data. Correlation results from this study suggest positive relationships between water availability and infection rate. Similarly, urbanization and road development also experienced strong positive correlation with infection rate data while vegetation was inversely related to the prevalence data.

Introduction

Numerous epidemiological studies have linked rising infectious disease risks in developing countries to human-derived changes in the environment (Mouchet and Carnevale, 1997; Gratz, 1999; Molyneux 2003). Changing land uses have the potential to create environments that promote the survival of intermediate hosts or vectors that transmit diseases (Norris 2004). Mosquito-based diseases like malaria, for example, are linked to urban and rural water supplies; by extension, land modifications that generate additional standing water environments create suitable breeding habitats for malaria's disease vectors. Specific modifications include dam construction, deforestation, agricultural development, urbanization, and road construction. Collectively, these landscape alterations may raise overall health risks depending on transmission cycles and vector habitat requirements.

One of the most prevalent diseases that may be influenced by environmental land use change is schistosomiasis, a serious public health problem in developing nations that is linked with lack of sanitation and poor water quality. Schistosomiasis is a water-borne disease that is caused by any of five parasitic *Schistosoma* flatworm species. The intermediate host of the parasite is a freshwater snail that releases cercariae, the larval stage of the parasite which is capable of infecting mammalian hosts via skin contact. For this reason, hydrologic (waterways) and social (human and domestic animal movement) factors have been designated as the most common modes of snail and cercarial larvae transport (Yang *et al*. 2008).

According to the World Health Organization, 600 million people worldwide are at risk of being infected with schistosomiasis while 200 million are infected (World Health Organization). Schistosomiasis has generated the most risk in Africa while also creating serious public health problems in China, mainly in the rural, mountainous regions of the Sichuan Province and valley basins along the Yangtze River. Previous studies have linked the major schistosomiasis outbreaks in Africa to dam construction projects including the Aswan Dam in Egypt and the Diami in Senegal (Malek 1975; Southgate

1997). Concerns of future outbreaks caused by the construction of the Three Gorges Dam have also been raised in rural China (Allen *et al.* 2002).

China has historically been a schistosomiasis hotspot due to the lack of sanitation and water contamination in many rural areas. In China, disease is caused primarily by *Schistosoma japonica* whose intermediate host is *Oncomelania hupensis,* a freshwater snail that inhabits irrigation ditches that run adjacent to agricultural fields. *S. japonica* is endemic to the following landscapes: marshland and lake, plain and water networks, hilly and mountainous (Zhou *et al.* 2007). In the hilly and mountainous regions (i.e. Sichuan province), *O. hupensis* is distributed along valley floors, grassy hill slopes, or on the vertical sides of terraced fields or irrigation canals (Yang *et al*. 2008). These habitats are often isolated from each other, creating patches of dense snail concentrations (high transmission risk area) and other areas with much lower snail concentrations (low transmission risk area) (Zhou *et al*., 2005; Liang *et al*., 2006).

Though China experienced significant disease control success over the past several decades as a result of its national anti-schistosomiais program, Liang (2006) found that the disease is reemerging in Sichuan province, China. At the end of 2004, eight counties within the Sichuan province were confirmed to have local disease transmission. Liang and coworkers found that disease reemergence has been tied to recent funding cuts, resulting in less anti-schistosomiasis health employees, as well as to reduced control and surveillance efforts. Additionally, they concluded that reemergence has been influenced by a variety of environmental and socioeconomic factors. Specifically, the recent increase in irrigation canal construction throughout Sichuan's Jingyang County has increased the potential for parasite diffusion. Road development has also connected neighboring villages which has allowed the disease to be passed on to areas where it had never existed before. Unfortunately, the extent to which development and land-cover changes have influenced disease transmission, however, is still unclear. Establishing a working knowledge of how land use changes have impacted schistosomiasis infection rates should, thus, provide further insight into why reemergence at the local level is taking place.

Previously, remote sensing (RS) and geographic information systems (GIS) have enabled researchers to quantify the effects of landscape changes on transmission rates for a variety of diseases. Such approaches are ideal for detecting change since both satellite imagery and aerial photographs provide high spatial and temporal resolution (Shuman and Ambrose, 2003). Additionally, RS is used to detect, delineate, and/or classify landscape structures (Bobbe *et al*. 2001). For example, researchers have used RS and GIS tools to provide a spatial understanding of disease transmission and distribution for the following diseases: malaria, Lyme disease, and rift valley fever (Wood *et al*. 1992; Kitron and Kazmierczak 1997; Linthicum *et al*. 1990). A typical geospatial approach involves first classifying RS imagery into known disease vector habitats; the classification data is often then imported into a GIS for spatial analysis (Graham *et al.* 2004). Risk map production, which uses classified data, is often the goal of many GIS-based studies.

Because geospatial approaches offer a powerful diagnostic tool for characterizing disease transmission and risk, I utilize RS and GIS methods in the present study. My research objective is to identify the relationship between historical landscape changes (i.e. road construction, and residential development) and schistosomiasis disease prevalence in Deyang, Sichuan Province, China. Infection rate data, collected from China's Center for Disease Control (CDC) for the years 1978, 2001, 2002, and 2003 and from Liang (2006) for 2004, and Landsat Multispectral Sensor (MSS) and Enhanced Thematic Mapper (ETM+) satellite imagery were used to identify the specific land-cover types that best correlate with disease prevalence. All infection rate data report the total number of surveyed participants as well the number of participants testing positive for schistosomiasis. I analyze infection and satellite data for the years 1978, 1982, 2001, 2002, and 2003 in order to account for the effects of temporal variation on my correlations. I hypothesized that (a) historical land use changes would correlate strongly with infection rate data and (b) road construction and changes in water availability would correlate more strongly with rising infection rate data than any other landscape change.

Alternative hypothesis should reveal that land cover changes, in general, and road and water coverage, in particular, are not related to the recent rise in infection rates.

Methods

Study Design The Sichuan province is located in south-western China (latitude 26.52° N to 34.32° N, longitude 97.35° E to 108.52° E). Sichuan is the fifth largest (485,000 km^2) and fourth most populated (84 million, 2000 census) province in China. Ninety percent of the province is mountainous or hilly, with plains and plateaus covering the rest of the area. Sichuan is one of the most important agricultural regions in China (Liang 2006). Landsat imagery was collected specifically for Sichuan's Deyang County since in 2004 it experienced the highest human infection rate out of any other county within Sichuan (Liang 2006).

To understand which land cover types best correlate with infection rate data, satellite images were classified into five land cover types using ENVI's (Environment for Visualizing Imagary) maximum likelihood supervised classification procedure. The maximum likelihood algorithm uses the distribution of data within each class and calculates probability functions for each class. Each pixel is then assigned to a specific class for which the highest probability is calculated. Each pixel was assigned to one of the following land cover types: water, vegetation, forests, non-irrigated agriculture, urban, and road. The land cover types I chose were based on similar cover types used by Yang *et al.* (2008) to assess landscape effects on schistosomiasis prevalence in other counties in Sichuan.

Separate regions of interest (ROIs) were chosen for each class based on selecting groups of pure (i.e. pixels that were not mixed with multiple land covers) individual pixels to represent the different cover types and were used as input training data for the supervised classifications. Google Earth was used to help validate my training data and separate all non-irrigated agriculture from other types of vegetation including forests and irrigated agriculture. Overall accuracy for each classification was measured using the Kappa coefficient and commission and omission error report for each class type.

Class statistics showing the area (in km^2) represented by each cover type were produced using ENVI's post-classification tool. Each individual class statistic was plotted for each year. For 1978, class data was compared to infection data taken from 1982. For years 2001-2003, classification data was compared to infection data that was taken from the same year. Infection data taken from Liang (2006) was also used to show the date (a) when Deyang achieved transmission control (i.e. 1995), (b) when the first reported case of schistosomiasis took place following disease control (i.e. 2000), and (c) when the rate of infection rate rose sharply and reemergence became clear (i.e. 2004). In addition to human infection data, snail infection data was also taken from Liang (2006) for the years 2000-2004. All data that was used in this study is summarized in Table 1.

Data Sources

Year	Landsat Satellite Sensor	Human Infection Data	Snail Infection Data
1978	MSS	NA	NA
1982	NA	China CDC	NA
1995	NA	China CDC	NA
2000	NA	Liang (2006)	China CDC
2001	ETM+	China CDC	China CDC
2002	ETM+	China CDC	China CDC
2003	ETM+	China CDC	China CDC
2004	NA	Liang (2006)	China CDC

Table 1. A list of all data sources used in this study. Note: Landsat MSS is 4 bands (Red, Green, Blue, Near Infrared), spatial resolution 79m. Landsat ETM+ is 7 bands, spatial resolution 30m

Data Analysis Since no samples were taken during this study, there was no need to apply inferential statistics. Only qualitative comparisons were made between land cover change and infection rate to identify possible trends and environmental drivers of reemergence.

Results

Changes in land-use within Deyang, Sichuan were correlated with schistosomiasis infection rate information for the years 1978, 2001, 2002, and 2003. The rate of infection peaked in 1982 and plunged in 2002.

	Year	Historical accumulated # people infected	# People checked for infection	Identified Infected Patients	Infection Rate
Human Infection Data	1982	51905	NA	13215	1.94
	1995	55074	250998	4868	1.94
	2000				
	2001	55315	60175	21	0.03
	2002	55317	67082	13	0.02
	2003	55320	63992	16	0.03
	2004	55320	72641		

Table 1. Percent infection rate from 1978 to 2003 for Deyang, Sichuan

Areas (km^2) represented by each land cover type were derived from supervised classifications using the ENVI software. Vegetation represented the largest land cover type for each year, but its total land area decreased roughly 36% from 1978 to 2003. On the other hand, pixels classified as urban experienced the greatest percent increase in total cover area for both years (38.7%). Road development also experienced a percent increase (11.6%). Additionally, water availability increased by over 40% for the same time period (Table 2).

Land Type	1978 Total Area = 1904.8	2001 Total Area = 1905.4	2002 Total Area = 1907.4	2003 Total Are = 1905.4	Percent Change (1978-2003)

Dry Agriculture	105.2	175.57	311.09	290.30	
Road	25.06	59.52	35.54	81.16	
Urban	7.63	54.95	58.67	51.79	
Vegetation (includes irrigated Ag)	626.38	455.62	630.07	510.18	
Forest	NA	122.70	NA	83.38	NA
Water	30.15	73.84	50.92	72.64	
Unclassified	1110.34	963.20	821.11	815.96	NA

Table 2. Total area (km^2) of each land cover class for Deyang as determined by ENVI classification of satellite maps.

The 1978 classification map for Deyang, Sichuan had an overall accuracy of 94.0% (kappa = 0.91) while in 2003, overall accuracy was 96.4% (kappa = 0.95). In 1978, the road class had the highest commission error (77.2 %) and lowest user accuracy (22.8%) for any land cover. In 2003, roads again had the highest commission error (40.4%) and lowest user accuracy (59.%) (Table 3).

Overall Accuracy (%) **(Deyang 1978)** = 94.0 **(Deyang 2003)** = 96.4				
Kappa Coefficient **(Deyang 1978)** = 0.91 **(Deyang 2003)** = 0.95				
Class	**Commission Error (%)**	**Omission Error (%)**	**Producer Accuracy (%)**	**User Accuracy %)**
Shadow	* (2.9, 0.0)	* (1.0, 0.5)	* (99.0, 99.5)	* (97.1, 100.0)
Grassland	* (1.5, 5.0)	* (0.8, 5.0)	* (99.2, 95.0)	* (98.5, 95.0)

Road	* (77.2, 40.4)	* (0.0, 3.5)	* (100.0, 96.5)	* (22.8, 59.6)
Urban	* (11.9, 2.4)	* (1.3, 2.4)	* (98.7, 97.6)	* (88.1, 97.6)
Vegetation	* (0.9, 1.7)	* (1.7, 0.0)	* (98.3, 100.0)	* (99.1, 98.3)
Water	* (0.2, 1.1)	* (10.2, 8.8)	* (89.8, 91.2)	* (99.8, 98.9)

Table 3. Accuracy Assessment (w/ Kappa Coefficient) for 1978 and 2003.
* (Deyang 1978, 2003)

Of all the land cover types assessed, water availability had the strongest correlation with infection for the given time period (R^2 = 0.7788). Similarly, urbanization and road development were also strongly positively correlated with infection (R^2 = 0.7023 and 0.5394, respectively). Vegetation cover was the only land cover type that yielded a negative correlation with infection rate (R^2 = 0.4712) (Figure 1).

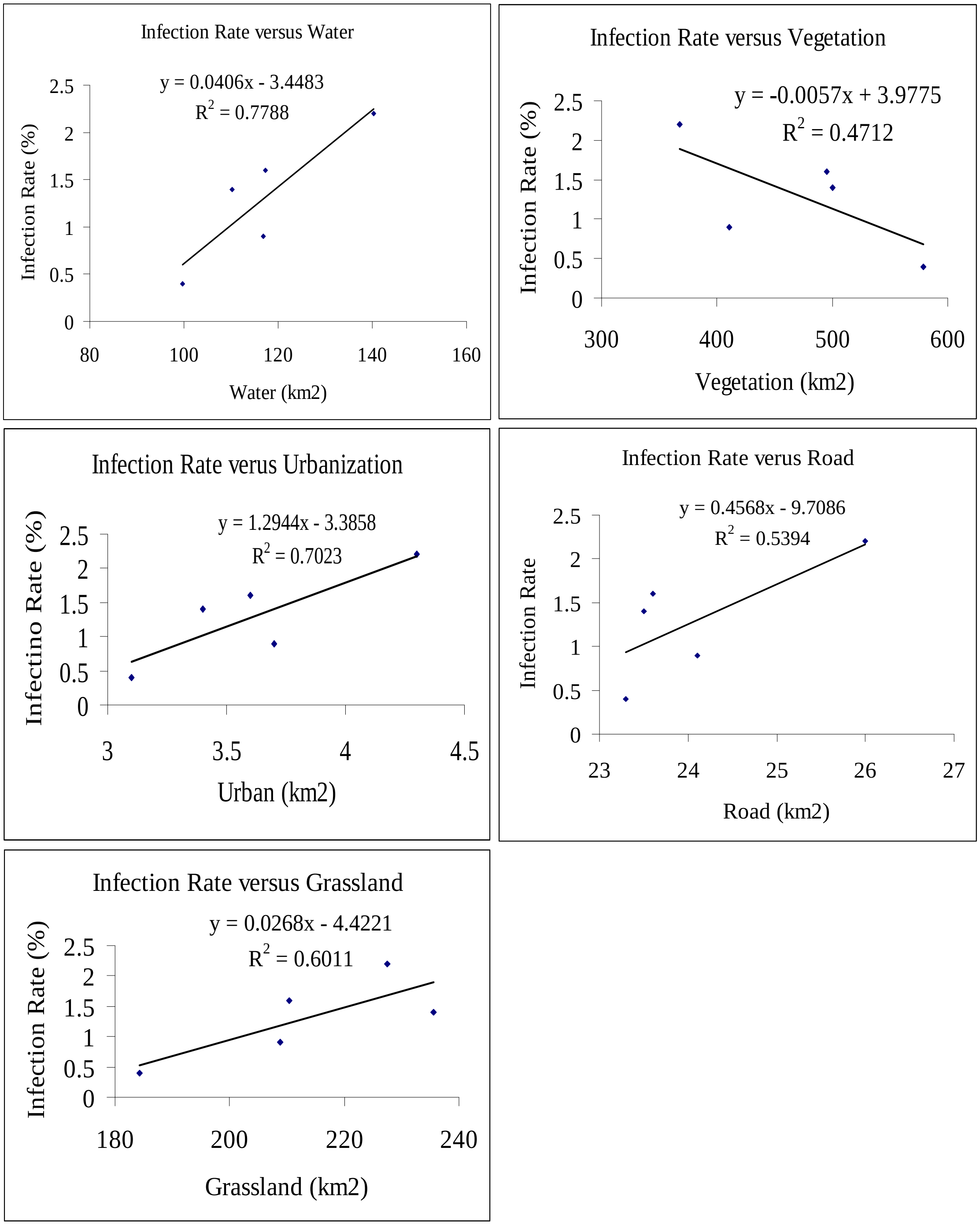

Fig 1. Correlation coefficient analysis showing the positive relationship between percent infection rate and total area of "Grassland" pixels in Deyang County for the time period 1978 – 2003.

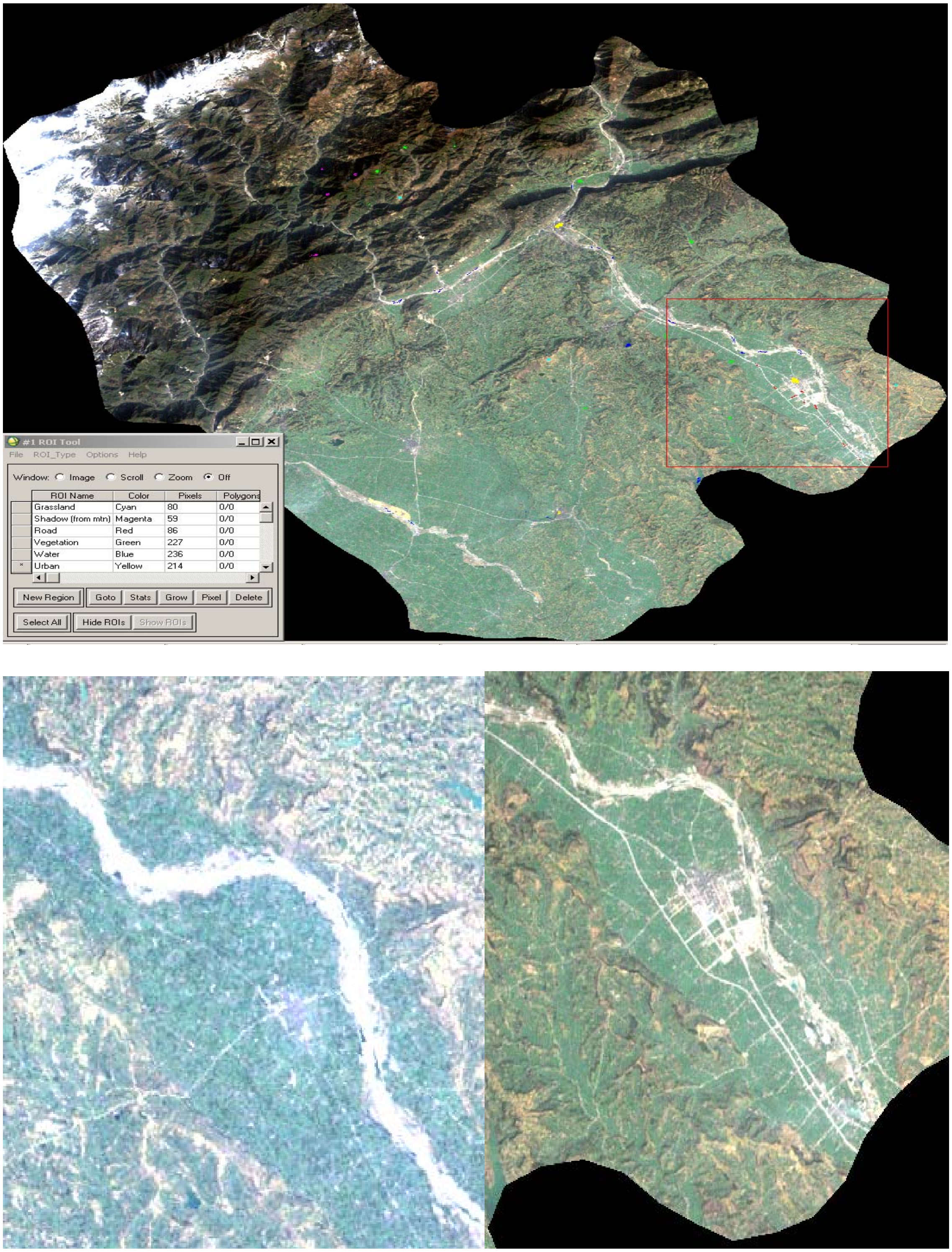

Fig 2. Deyang, China (Top) Landsat ETM+ image (January 27, 2003) Deyang, China. (Bottom Left) Landsat MSS image zoomed in on river and urban center (August 3, 1978). (Bottom Right) Zoomed in on ETM+ image.

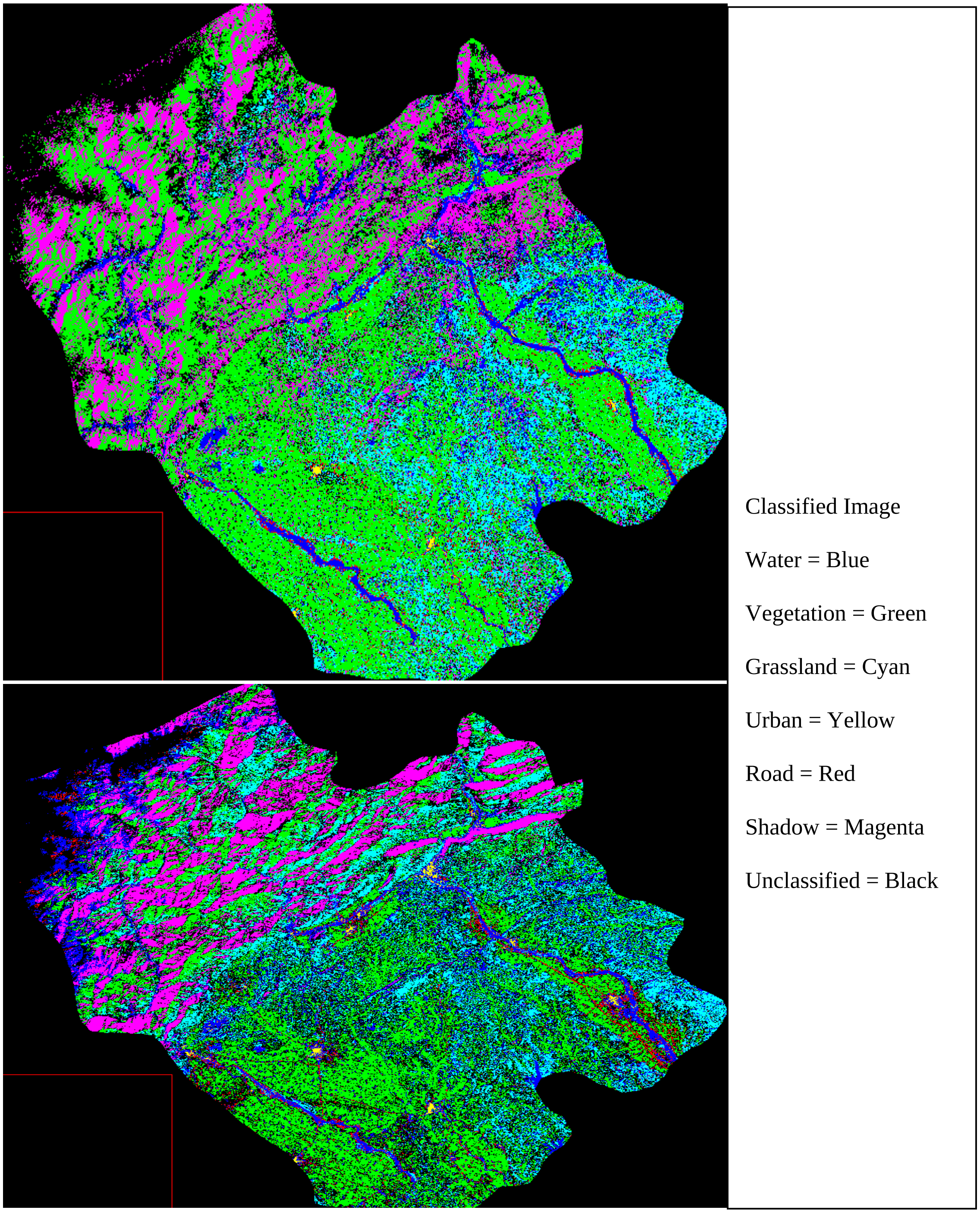

Fig 3. (Top) Supervised classification of Deyang August 3, 1978 (Bottom) Supervised classification of Deyang January 27, 2003.

Discussion

This study investigated the potential impacts of county-level land use changes on the reemergence of schistosomiasis in two counties of the Sichuan Province, China. This project also addressed the temporal limitations of the Yang *et al.* (2008) study by analyzing schistosomiasis disease prevalence trends over a 25 year period (1978 - 2003). Additionally, the supervised classification maps above represent only actual changes in land use for 1978 and 2003. Dummy classification data was used to generate my classification results for 1981, 1982, and 1984, since I am still in the process of classifying the MSS imagery for those years. Dummy infection rate data was also used for every year except 2003 to generate my correlations for Deyang county, since I have yet to receive prevalence data for those years.

Based on the "dummy" results from above, schistosomiasis is reemerging in Deyang. This is evident from the fact that infection rates in the county have increased every year from 1978 to 2003 except for 1984 (Table 1). Changes in land use within Deyang were correlated with disease prevalence for the period 1978 – 2003. Both road and urban development increased significantly during this time and were strongly correlated with infection rates. Of the land cover types assessed, however, water had the strongest positive correlation with infection data (R^2 = 0.7788) (Figure 1) and the total area of pixels classified as water increased roughly 40% from 1978 to 2003. This suggests that increasing water abundance has enabled the disease to spread more easily. This was expected considering the fact that the disease is spread through contact with water containing the *Schistosoma* parasite. Hydrological dynamics has created additional habitat for the intermediate host, *Oncomelania hupensis,* a freshwater snail that is known to inhabit irrigation ditches that run adjacent to agricultural fields. Additionally, vegetation cover was negatively correlated with disease prevalence. This finding suggests that deforestation to make room for agriculture (notably rice paddies) may be helping drive the trend of disease reemergence and elevated infection rates relative to the late 1970s and early 1980s.

Similarly, the aforementioned results indicate a positive association between urban and road development and increases in disease prevalence. This result was also expected since road networks link neighboring villages that may be located in areas without water sources contaminated with the *Schistosoma* parasite. Social connectivity, as defined by roads and trails, and travel between neighboring locations has already been linked to increasing disease risk and prevalence for HIV and various diarrheal diseases at the local level (Eisenberg *et al.* 2006 and Tanser *et al.* 2000). Ferguson (2008), however, found no statistically significant relationship between the prevalence in a village of schistosomiasis and social connectivity. However, Ferguson suggests that social connections between villages may still be an important factor for initial introduction of schistosomiasis to a village, but that disease prevalence may be influenced by other inter-village movements, notably agricultural work or contact with irrigation ditch water, which promote disease transmission.

I am still in the process of creating slope maps in ArcGIS. A visual analysis of Landsat imagery at least indicates, however, that Deyang County is located in a mountainous area with upstream rivers that feed into more urban areas which are located on the valley floors. Slope maps will help to aid understanding for the trends in disease prevalence within the Sichuan province since *O. hupensis* tends to distribute along valley floors and grassy hill slopes (Yang 2008) and also because slope influences water distribution.

Future research efforts to address land use change impacts on schistosomiasis disease prevalence should incorporate higher resolution satellite data. The data used in the current study was 30 m for the ETM+ (2003 image) image and 79 m for all MSS data (1978 image). Higher resolution imagery will not only help to validate classification results but will enable the researcher to classify smaller land cover objects such as irrigation ditch canals which may only be a few meters wide. Future efforts should also consider drug treatment to avoid potential confounding and making inaccurate conclusions regarding the land use/infection rate correlation results.

This project has helped to elucidate the degree to which human impacts have engendered schistosomiasis disease reemergence at the local level. Specifically, by identifying the relationship between reduced vegetation cover, road networks, and urbanization on schistosomiasis prevalence, this project has helped to bridge the gap in knowledge of how anthropogenic related land use changes can potentially influence disease transmission.

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