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VISUALIZING WATER QUALITY TRENDS IN CHIANG MAI RICE PADDIES: POSSIBLE LINKS BETWEEN ENVIRONMENT AND HEALTH RISKS

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ABSTRACT: *Liver fluke (Opisthorchis viverrini) infection is a health concern throughout Thailand. Liver flukes use the Bithynia spp. snails, which inhabit rice paddy fields, as first intermediate hosts in their life cycle. Water quality and environmental factors could have an effect on snail distribution and their incidence of parasitic infection. Another area of health concern is the presence of Escherichia coli in the paddy water and the risk for human contact. Four rice paddy fields were studied around the Chiang Mai area. Sites 1 through 3 included an irrigation canal and rice paddy and Site 4 was only a rice paddy. Water quality data were automatically recorded every 15 minutes at sites 1 through 3 (canals) over a 48-hour period using a Hydrolab Datasonde 4a, which measures temperature, pH, turbidity, conductivity, and dissolved oxygen. Water grab samples were tested for the presence of E. coli. Snails were collected, identified, and their parasitic infection was determined. Bacteria levels typically were higher in the irrigation canals than in the rice paddies and levels progressively were lower at paddy sub-sites, moving away from the irrigation canal source water. Bacteria levels and base turbidity levels at the Site 1 canal always were higher, while dissolved oxygen levels were lower than the other canal sites. Rain events impacted Hydrolab parameters and bacteria levels; for example turbidity and bacteria levels increased during these events. The physical environment (soil type, land use, drainage) was characterized in ArcView using various available digital layers, satellite images and airphotos. The GIS maps helped to identify links between the physical conditions and water quality trends and to identify areas of high health risk in paddy fields. In particular, site 1 was most impacted by urban land use, had the poorest water quality, and the highest incidence of snails infected by O. viverrini.*

INTRODUCTION

Infection by the liver fluke, *Opisthorchis viverrini* is a human health concern in Northern Thailand. It has been estimated that in North and Northeastern Thailand, seven million people are infected (Upatham and Viyanant, 2003) resulting in an economic cost in the order of $84.6 million (1991 USD) a year (Loaharanu and Sormani, 1991). *Bithynia* spp. snails are first intermediate hosts in the fluke's life cycle and, in particular for this region, the liver flukes use *Bithynia (Digoniostoma) siamensis funiculata* for their host (Figure 1). The fluke eggs hatch in the digestive tract of the snails and then become cercaria, which is the free-swimming larval stage (Upatham and Viyanant, 2003). After leaving the snail, the cercaria penetrates the scales of a cyprinid fish, becoming a metacercaria, which is the infectious stage (Upatham and Viyanant, 2003). Humans become infected by consuming raw or undercooked fish. Infection can cause hepatobiliary (i.e. liver and bile duct, kidney) diseases and even cancer of the bile duct (Sithithaworn and Haswell-Elkins, 2003). These snails are known to inhabit rice paddy fields in the Chiang Mai region. There also has been a resurgence of farming fish in rice paddies.

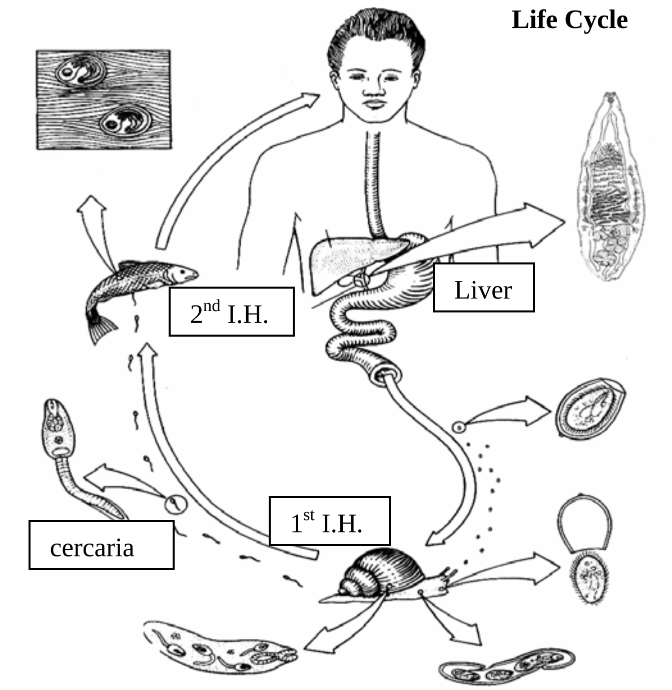

Figure 1. The life cycle of the liver fluke, *Opisthorchis viverrini*. The snail serves as the first intermediate host (IH), followed by the cyprinid fish as the secondary intermediate host. The adult liver fluke is found in the bile tract of a human.

In the Mae Ngud reservoir in Chiang Mai, five species of cyprinid fish (a common food fish) were found to be infected by metacercariae, with the incidence of infection ranging from 5.93% to 43.39% for the different species of fish (Sukontason et al., 2001). A potential health risk occurs if cyprinid fish were to be farmed for food in paddies known to contain *Bithynia* snails and *O. viverrini*.

Bacteria, specifically *Escherichia coli*, also are a risk to human health, especially for farmers in Thailand, as they have frequent contact with rice paddy water. *E. coli* is an indicator of fecal contamination and is known to cause gastroenteritis (Madigen et al., 2003). *E. coli* is found naturally in the bile tract of humans and warm-blooded animals and is the predominant fecal coliform found in their waste (i.e., 99.9% in cows, 97% in sheep and humans) (Drapcho et. al., 2001).

It is estimated that 41.5% (21.28 million hectares) of the land in Thailand is used for farming and of that, 51% is used for rice paddies (Chainuvati and Athipanan, 2001). Rice commonly is grown first in a corner of the paddy, called a "nursery." After germination the plants are left to grow for up to 50 days and then they are transplanted by hand into rows, a process which may take several days. Levees are built in between rows of rice to allow for flooding during the growing season and the paddies are dry throughout the rest of the year. Most farmers use commercial fertilizers for rice paddies, but a few do use animal waste. Water or swamp buffalo often are used to plow the fields and there are many instances where poultry are abundant, both contributing to animal waste in the paddies. Even if buffalo are not used for plowing, the farmer still guides a motorized tilling machine through the paddy and comes in contact with the water. The Ping River, the principal waterway of the area, is known to be highly contaminated by chemicals from agricultural run-off, but also from hotel and factory wastewater (Sumaduddhi and Techawongtham, 2003).

Thailand surface water quality standards for fecal coliform are 1,000 MPN/100 ml (National Environment Board, 1992). The United States Environmental Protection Agency (1998) summarized bacteria standards used by each state. In

New York State, the standard for recreational primary contact is 200 fecal coliform/100 ml. Many states are replacing fecal coliform with *E. coli* as the water quality standard in the belief that *E. coli* is a better indicator of the potential for human health impact. The water quality standard for *E. coli* varies from state to state, but frequently a level of 126 per 100 ml is used.

Water quality (temperature, dissolved oxygen, turbidity, conductivity, and pH) could have an effect on the distribution of the *Bithynia spp.* snails in the paddy fields. These water quality trends could be influenced by the physical environment (types of soils, land use, topography, source water), as well as meteorological conditions (i.e., storm events versus dry weather). GIS has been used as a decision support tool to help visualize and analyze spatial patterns in the management of snail-borne disease in various areas of the world, for example, Japan and Egypt (Abdel-Rahman et al., 2001; Kristensen et al., 2001; Nihei et al., 2004). The goals of our study were twofold: i) combine snail distribution/infection, bacteria levels, water quality data, and available GIS digital layers of the physical environment in a GIS database; and ii) examine spatial and temporal trends in water quality as they might relate to health risks (e.g. gastroenteritis, liver fluke infection).

MATERIALS AND METHODS

Four rice paddy fields were studied in the Chiang Mai area in the Ping River watershed (Figure 2) during the beginning of the rainy season (July, 2004). Within these sites, subsites were selected for sampling. Site 1 included an irrigation canal, as well as two rice paddies, Sites 2 and 3 included an irrigation canal and a rice paddy, and Site 4 included only a rice paddy (Figures 3 through 5).

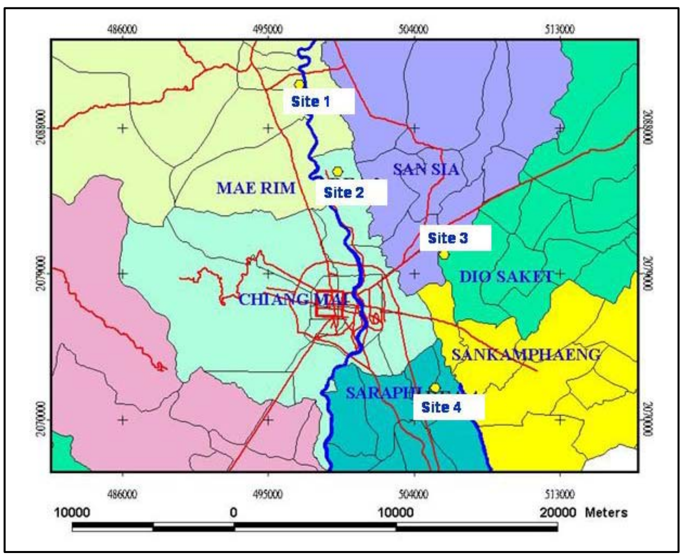

Figure 2. Map of the study area and all sites.

Figure 3. Site 1, paddy 1.

Figure 4. Bacteria sampling at Site 2, irrigation canal.

Figure 5. Snail sampling at Site 3, rice paddy.

These sites were studied for a two week period. At each site, snails were sampled using hand collection in 4-m^2 plots for 10-minute intervals. Subsequently, the snails were taken to the lab, identified, and their parasitic infection was determined using crushing and shedding methods. On snail sampling days, a Hydrolab Datasonde 4a was used to collect water quality data for that particular day and time. These data included the temperature, dissolved oxygen (concentration and percent saturation), conductivity, turbidity, and pH of the water. During the second week, the Hydrolab was left in the irrigation canal at each site (1-3) for a 48-hour period to automatically log water quality data at 15-minute intervals. Water grab samples were tested for the presence of *E. coli* at each site/subsite, using Coliscan® Easygel® kits. At each subsite, 1-ml of water was collected, plated, and allowed to incubate at room temperature for 48-hours before bacteria colonies were counted. The physical environment (soil type, land use, topography, source water) was characterized in ArcView using various available digital layers, satellite images, and air photos.

RESULTS

During the period of our water quality study, *Bithynia (Digoniostoma) siamensis funiculata* snails were found only in the rice paddies of Site 1 and only in Paddy 1 were the snails infected with *O. viverrini* cercaria. The snail study is ongoing through Chiang Mai University's Faculty of Medicine, Department of Parasitology and results are reported by Ngern-klun et al. (2004).

To illustrate generally observed trends, results of the continuous Hydrolab monitoring for the Site 1 irrigation canal are shown in Figure 6. Results of the Hydrolab spot readings at each site are shown in Table 1. Results of the *E. coli* sampling are summarized in Figures 7 through 10.

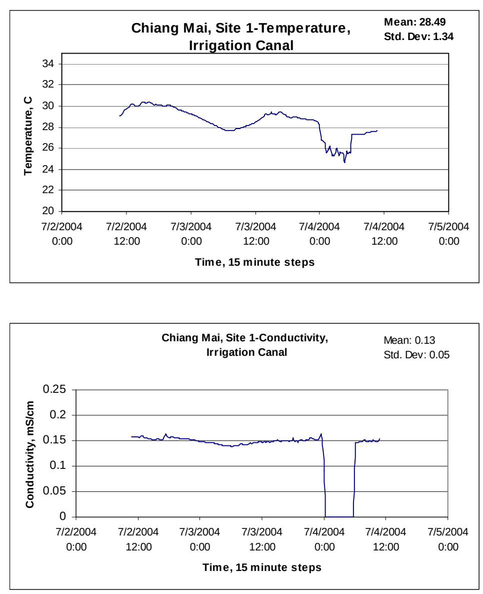

Figure 6. Hydrolab data (7/2/04 to 7/4/04) from the irrigation canal at Site 1.

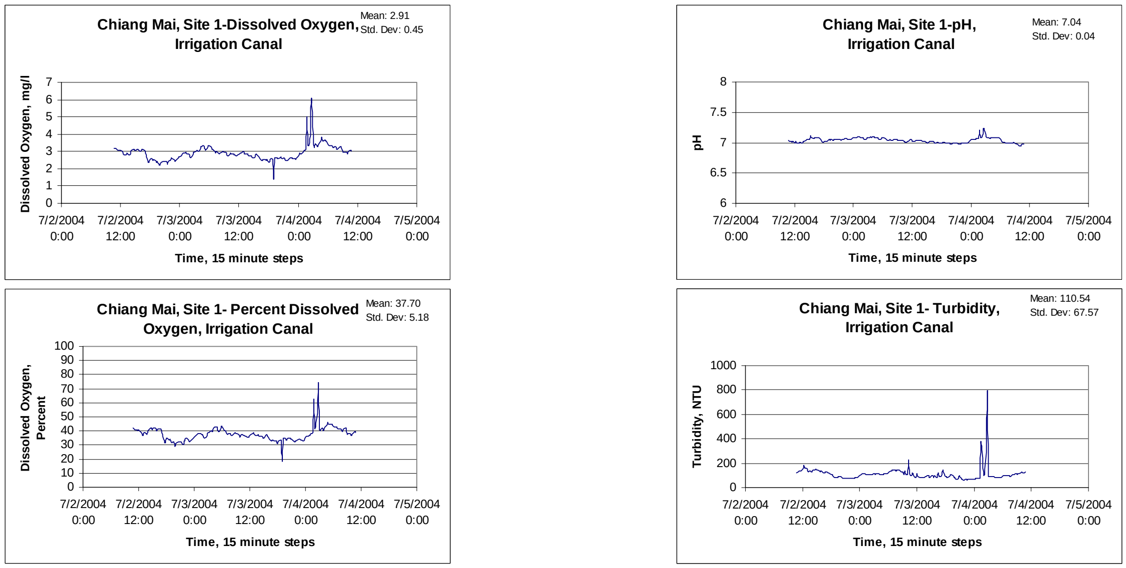

Figure 6 (Continued). Hydrolab data (7/2/04 to 7/4/04) from the irrigation canal at Site 1.

Table 1. Water quality readings for spot tests

Date	Time	Site	SubSite	Dissolved Oxygen (mg/L)	Dissolved Oxygen (Percent)	pH	Conductivity mS/cm	Temperature ^{O}C	Turbidity NTU
6/30/04	10:00	3	D*	2.7	34.4	6.99	0.2074	27.30	53
6/30/04	10:15	3	P	7.56	95	7.66	0.1729	27.30	13
6/30/04	11:15	4	P	3.44	51.5	6.72	0.2239	36.66	403
7/2/04	10:00	1	D	2.97	38.7	7.10	0.1588	28.73	109
7/2/04	10:15	1	P1	3.66	48.1	7.18	0.1572	29.29	64
7/2/04	10:30	1	P2	4.35	57.5	6.75	0.1759	29.73	46
7/5/04	10:00	2	P	4.39	53.9	7.37	0.3657	26.06	18
7/5/04	10:15	2	D	5.58	78.7	7.68	0.2098	30.42	29
7/7/04	10:00	3	D	4.44	57.1	7.07	0.1368	27.20	19
7/7/04	10:15	3	P	6.93	93.5	7.07	0.1855	30.52	42
7/9/04	10:00	4	P	2.76	37.5	6.88	0.3466	30.20	35

*D= irrigation ditch/canal; P=paddy

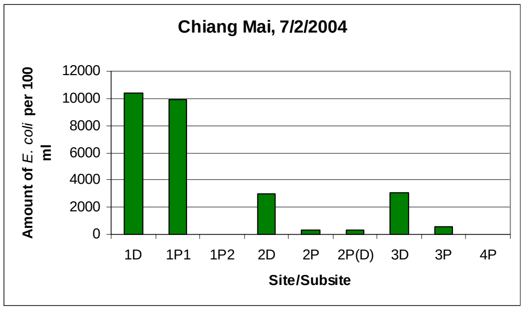

Figure 7. *E. coli* levels for all sites/subsites on 7/2/04, during a storm event.

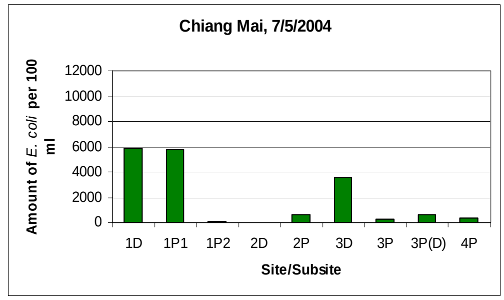

Figure 8. *E. coli* levels for all sites/subsites on 7/5/04, a dry weather day.

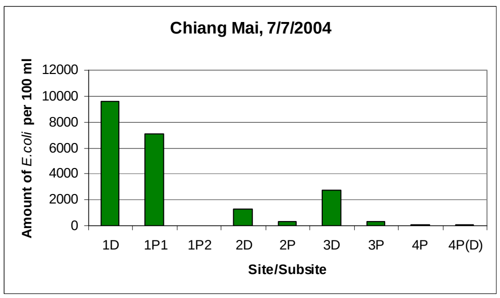

Figure 9. *E. coli* levels from all site/subsites on 7/7/04, a day with light rain.

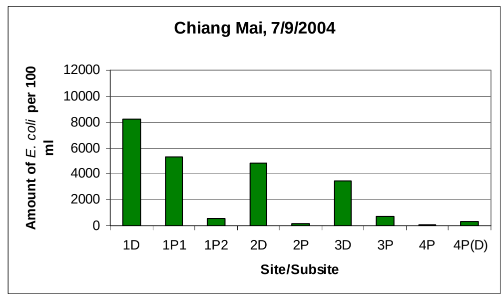

Figure 10: *E. coli* levels for all sites/subsites on 7/9/04, a day with light rain.

*P(D) = duplicate sample plate done on each day

DISCUSSION

Turbidity levels were greatest for storm events (e.g. 7/4/04, Figure 6) at all sites due to increased runoff and erosion. Higher bacteria levels also were associated with storm runoff. Conductivity decreased during the event of 7/4/04, representing a dilution of dissolved material. Similar dilution effects have been observed in rivers of North America and Hawaii (Irvine, 2003; Tomlinson and De Carlo, 2003; Irvine et al., in press). The storm runoff also increased oxygen levels (due to turbulent mixing and contact with the atmosphere) and decreased temperature in the canal.

Site 1 was the only site where *Bithynia (Digoniostoma) siamensis funiculate* were found and some (in paddy subsite 1, closest to irrigation canal) were parasitized by *O. viverrini*. Site 1 generally had the poorest water quality (highest bacteria levels, lowest dissolved oxygen, highest turbidity) of the four sites. Site 1 water comes from the Suthep Mountains, while water for the other sites comes from the Koontarn Mountains (Figure 11). Land use around Site 1 is the most urbanized (Figure 12) and this appears to negatively impact water quality. Site 4 had the lowest levels of *E. coli* and was the furthest from human impacted land (Figure 13). Sites 2 and 3 both had intermediate water quality and both sites had a mixed land use pattern, having both vegetation and residences. The soils surrounding Site 1 have a pH range of 6.0 – 7.5 (Figure 14) and the pH of the water was consistent with this, having an average of 7.04. The soils and vegetation of the rice paddies appear to effectively filter and clean the water, as *E. coli* levels generally were lower moving from the irrigation canal to the paddy sites progressively further from the canal (Figures 7 through 10).

In conclusion, Site 1 was found to be the poorest in overall water quality and represented the highest risk to human health. All sites had average bacteria levels higher than U.S. water quality standards and Sites 1 and 3 had levels higher than the Thailand surface water quality standards (Table 2). People (i.e., farmers) should be careful about direct contact with the water in paddy fields 1 through 3. People should not use Site 1, in particular, for aquaculture, as the bacteria levels are high and liver flukes are present that could infect the fish. Rice paddies further away from the irrigation canals have lower levels of *E. coli* and this should be taken into consideration when looking for fish farming areas. It has been shown that source water, soils, and land use all had an effect on the overall water quality in the rice paddies.

Table 2. Average bacteria level for all sites and relations to water quality standards in Thailand and the United States

Site	**Geometric Mean *E. coli*/100 mL**	**Above Thailand Water Quality Standard**	**Above United States Water Quality Standards**
1	3799	Yes	Yes
2	704	No	Yes
3	1102	Yes	Yes
4	164	No	Yes

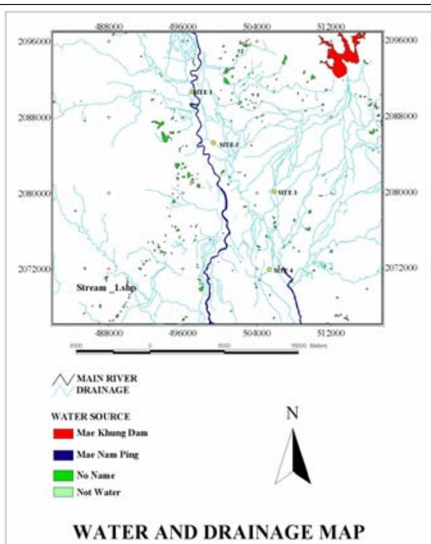

Figure 11. Source water for all sites.

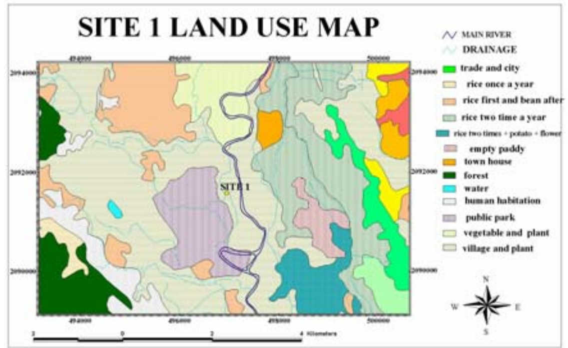

Figure 12. Land use for Site 1. This site was the most urban-impacted, with village and public park near the site area.

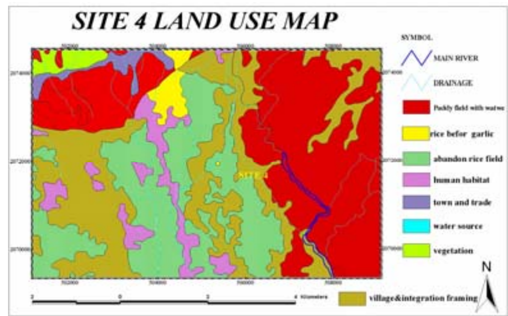

Figure 13. Land use for Site 4. This site was the least urban-impacted with vegetation and rice paddy fields being the dominant land use.

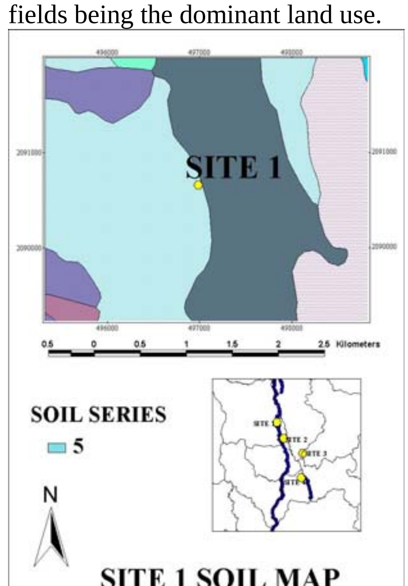

Figure 14. Soil type (Series 5) at Site 1. The soil texture on the top layer is clay and clay-loam or sandy clay loam; lower layer is loam or sandy loam. Soil pH is around 6.0-7.5.

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