Water Quality along a Mekong Tributary in Northern Lao PDR

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Abstract

Access to sufficient amounts of clean water is both a fundamental human need and right. Yet, more than 1 billion people worldwide can not access clean water and 2.6 billion people live without adequate water sanitation (UNDP 2006). Improving the access of poor people to water has the potential to make a major contribution towards poverty eradication. In Lao PDR where 78% of the population is rural, many inhabitants are likely to be exposed to water quality-related hazards due to lack of access to potable water and/or water sanitation. In this context, this study focuses on stream water quality along a Mekong tributary that flows within a mountainous, composite land-use catchment of northern Lao PDR. Water quality was found to vary greatly depending on **(i)** the location along the stream **(ii)** the prevailing rainfall conditions and **(iii)** stream flow conditions. Overall, water quality reflected the balance between the stream self-cleaning potential and human pressure on the riparian zone. Besides these human induced pollutions we also noted spontaneous enrichments in metals in swampy areas fed by dysoxic groundwater. Based on our survey, we propose recommendations to improve or maintain stream water quality and for environmentally friendly management of surface water resources in the uplands of northern Lao PDR.

Keywords: Riparian area management; Payment for Environmental Services; Upland communities; Laos.

Introduction

More than 60% of developing countries' rural populations (i.e. more than 2 billion people as per 2004) lack access to sufficient amounts of clean water (WHO-UNICEF 2006) and are at risk of exposure to water quality-related hazards such as infectious diseases and intoxication by chemicals and/or radio-elements. In Lao PDR, 78% of the population is rural, living standards are very low overall and numerous communities still lack adequate water supply and sanitation infrastructures. A decade ago, the United Nations (UN 1998) concluded optimistically on stream water quality in Lao PDR. This conclusion was partly based on a limited dataset (34 measurements made in the country's main rivers), and on the fact that the country's population density is low. While the population density remains low today (24 people per km^2; NSC 2005), we undertook this survey to test whether water quality assessment based on main rivers only properly reflects water quality as experienced at the community level. The Mekong basin includes hundreds of waterways upon which many rural communities rely to fulfil their daily needs. Most such waterways get very turbid during periods of storm flow (Maniphousay and Souvanthong 2004), which greatly increases the occurrence of infectious diseases and intoxication, *via* particle-bound transport (Lamaningao and Sugiura 2004). Our survey was conducted in a typical composite land-use catchment of northern Lao PDR, near the city of Luang Phrabang, along a perennial third order stream passing through villages close to the Mekong corridor but having no direct access to the main waterway. While, we did not intend to identify and analyse all factors and processes contributing to surface water quality, we tried to identify the main causes contributing to the spatial variability of some water quality indicators in the context of northern Lao PDR. Among the underlying factors studied, we paid attention to (i) land use along the riparian area; (ii) wastewater discharge along the stream and (iii) suspended sediment loads during floods.

Materials and methods

The Houay Xon catchment

The study was conducted along the Houay Xon stream, part of the Mekong basin in northern Laos (Luang Prabang Province). This stream drains a catchment of about 22.4 km^2 and flows into the Nam Dong River before its confluence with the Mekong (Figure 1). The 10.6 km long perennial stream flows down along a mountainous environment representative of the sloping lands of the Mekong valley. Within the catchment, altitudes range from 280 to 1336 m, with a mean slope gradient of about 31%. Composite land uses typical of northern Lao PDR occur within the catchment. The Houay Xon flows through five villages, successively. The overall land use units (Figure 1) roughly match the catchment's main morpho-hydrological units: (1) the south-eastern Phu Phung massif predominantly covered by old secondary forest; (2) the upland areas of the north-eastern and south-western parts, under shifting cultivation with short fallow; (3) the residential areas surrounded by teak plantations found along the main stream; and (4) the irrigated gardens in the peri-urban area of Luang Prabang, located on an alluvial terrace of the Mekong. The mean annual rainfall recorded at Luang Prabang from 1960 to 2006 is 1263 mm, about 77% of which falls from mid-May to mid-October, with high inter-annual variability (SD 345 mm, coefficient of variation 27%, min. 444 mm, max. 2100 mm). In 2007, the year this study was completed, the annual rainfall was 1139 mm.

Field survey

To relate water quality data to the catchment's spatial features (land use, human activities, etc...), we made spatially distributed measurements. Temperature (T), pH, electrical conductivity at 25ºC (EC), redox potential (Eh), and dissolved oxygen content (DO) were measured using a YSI MPS (Multi Probe System/Data Logger) meter. All sensors were checked daily before starting measurements. DO data were transformed to oxygen saturation (DO-sat) in %, using the formula of Hua (1990). To analyse the effects of land use on water quality at baseflow, 109 point-observations were made along the Houay Xon (83, 100-m apart stations) and its main tributaries (26 stations), at the end of the dry season (31 May 2007) until the confluence with the Nam Dong River. To examine the impact of floods, regardless of domestic wastewater discharge, 11 observation stations were established 20 metres apart, within the Houay Pano catchment (upstream Houay Xon). These stations were sampled once during a low flow period prior to the rainy season (28 May 2007) and then again during the first storm flow of the rainy season (4 Jun 2007) (Table 1). The sampling point locations were approximated using a portable GPS (GARMIN XL12) and an altimeter (SUUNTO Instrument). Stream discharge at the different sampling points was estimated by chemical tracing (Silvera et al 2007).

Water sample collection and laboratory analysis

Seventy water samples were collected to determine the suspended solid load (SL) and total colony count at 37ºC (CC37). Samples were collected on the day or the day after each of the physico-chemical surveys described above. Samples were collected by immersing bottles, neck pointing upstream, so that there was no contamination by bed sediments. SL, expressed in mg l^{-1}, was estimated as the weight of solid retained on a pre-weighed 0.45µm membrane after filtering a known volume of sample (about 1 litre). Sampling was always carried out at the same time of the day, i.e. mid morning to early afternoon. Water samples for total flora determinations were stored in a cool, dark ice box and delivered to the Nam Papa Lao laboratory in Vientiane within 12 hrs. CC37 was estimated following the standard pour plate method. The results are expressed as colony forming units (CFU) per ml.

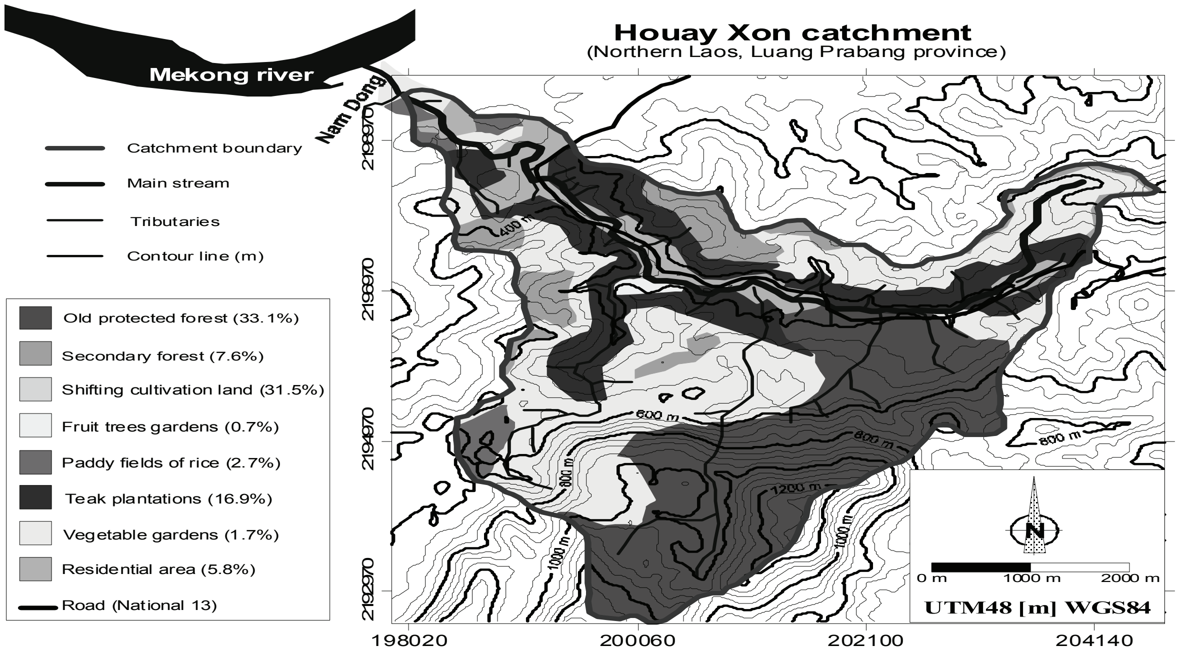

Figure 1. Main land uses (percentage of the total catchment area), contour lines and permanent stream paths within the Houay Xon catchment in 2007.

Results and discussion

Potential hazards due to naturally contaminated groundwater

In the upper part of the catchment (Houay Pano stream, land under shifting cultivation), orange-coloured iron oxide flocculated at several points within the stream channel. These metal-rich colloidal features occurred at a location where reducing conditions prevail: DO-sat of 12 % (triangle 1, Figure 2), pH=6.9 and Eh=88 mV. The Eh-pH measured at this station is compatible with the presence of soluble ferrous iron hydroxides ($FeOH^{+}$) in stream water, corresponding to local ex-filtration of subsurface water (Ribolzi et al 2005). Soluble iron compounds are common in soil solutions with high levels of organic matter (1-6 % in Houay Pano soils). When dissolved organic matter enters groundwater, the water may become anaerobic and iron becomes soluble. During the ex-filtration process, aeration of the Fe^{2+} charged groundwater leads to the precipitation of amorphous oxides, due to the rapid oxidation of Fe^{2+} at near neutral pH (Stumm and Morgan 1981). This in turn alters the pH in the vicinity of groundwater inflow sites. Oxidizing bacteria may accelerate this flocculation process. The presence of dissolved iron or colloidal features in streamwater should not be considered hazardous in itself; yet, it indicates local physico-chemical conditions under which toxic metals can be mobilized (e.g. Cu, Cd, Zn, As). Farmers commonly use such groundwater sources for various purposes: fish ponds; drinking water; small irrigation; watercress beds. Such practices may not be innocuous as streambed sediments, stream water and aquatic vegetation exposed to subsurface inflows can accumulate metals. To avoid this risk, such seepage waters should only be used after aeration and deposition of their metallic ions (e.g. into streambed sediment).

Table 1. Descriptive statistics of some hydrological characteristics of the Houay Pano stream during baseflow and stormflow periods for 11 selected observation points: median; arithmetic mean; standard deviation (sd); minimum (min) and maximum (max) values of stream discharge; temperature (T); electrical conductivity at 25°C (EC); pH; redox potential (Eh); dissolved oxygen content transformed to oxygen saturation (DO-sat); suspended load (SL); total colony count at 37□C (CC37). Differences between base flow and storm flow (threshold of significance: □/2 = 0.025) are significant for all the parameters (Wilcoxon test, paired samples) except DO-sat. Mean pH is calculated from H^+ concentrations. $CFU.ml^{-1}$, colony-forming units per ml.

Flow regime		**Discharge**	**T**	**EC**	**pH**	**Eh**	**DO-sat**	**SL**	**CC37**
(date)		l/s	°C	$\mu S.cm^{-1}$		mV	%	$g.l^{-1}$	$CFU.ml^{-1}$
BASE	median	0.4	25.6	388	8.3	163	70.6	0.23	808
(28 May 2007)	mean	0.4	25.7	374	7.8	158	67.1	0.38	1152
	sd	0.1	0.8	31	–	25	21.3	0.50	861
	min	0.3	24.4	309	6.9	88	12.0	0.06	186
	max	0.6	26.9	417	8.5	181	91.8	1.85	2760
STORM	median	5.0	23.9	195	7.6	227	81.2	8.66	19000
(4 Jun 2007)	mean	4.4	23.9	196	7.6	226	73.1	8.80	42469
	sd	1.4	0.2	16	–	8	23.8	3.98	55984
	min	2.4	23.7	170	7.5	216	23.9	2.42	3840
	max	5.3	24.5	232	7.9	238	93.4	18.72	183000

Impact of land use and human activities along the riparian area on water contamination

Livestock roaming

In the upper catchment under shifting cultivation, livestock was seen roaming close to and in the stream causing sediment particles to be mobilised and SL values to reach up to 2 $g.l^{-1}$ (Figure 2, triangle 2). This increased turbidity was associated with local microbiological pollution (CC37>2000 CFU ml^{-1}). This is consistent with previously reported correlation between faecal bacteria (*Escherichia coli*) load and turbidity at near-base-flow in a mixed-use watershed (Randall et al 2006). Stream water contamination by faecal coliform through soil leaching also seems higher in areas partly or fully covered with pastures than in forested and cultivated areas (George et al 2004). In the Houay Xon, bacterial contamination was very local, most probably due to dung piles rolling down from a livestock shelter into the stream. It is noteworthy that, due to the filtering effect of aquatic plants, acceptable levels of suspended solid content and sessile (attached) bacteria were recovered a short distance (~100 m) downstream from the contamination point.

Use of fertilizers

In addition to increased sediment load in the river (Valentin et al., 2008), water quality in the Houay Xon is affected by a variety of pollution sources. Upstream Herbicide use amongst upstream farmers has recently become more common. The chemicals used are principally Paraquat Dichloride and glyphosate-isopropylamonium. Paraquat is classed as toxic for humans and presents a serious risk to aquatic environments.Glyphosate-isopropylamonium is less toxic for humans and the environment but there is still the potential for the water table to become contaminated (PAN, 2007). While fertilizers are not used in the Houay Pano catchment, their use is widespread the market gardens where at least two types of fertilizers are used. Downstream, rice growers frequently use chemical and organic fertilizers. The most common chemical inputs are urea (N46 P0 K0 and N16 P20 K0). Manure is extensively used because it is 5 times cheaper than chemical fertilizers. Fertilizers often end up in the stream, either during application in plots adjacent to the stream or through runoff, soil erosion and the occurrence of landslides.

Fish breeding activities

Fishponds found in Ban Lak Sip and Ban Donkang are filled by diverting the stream or by placing a pond directly in the course of the stream, which means that wastewater flows directly into the Houay Xon. None of the fish farmers own equipment or have set up a system for collecting or treating the wastewater. The waste consists primarily of fish food and excrements. Whilst the food is mostly organic, fish excrement, affects the microbiological quality of the stream by encouraging the growth of coliform bacteria. Thus this economic activity poses a serious risk to the health of the surrounding villagers. Measurements of the E. coli concentration, an indicator of health risk, show that after Ban Lak Sip the stream is unsuitable for swimming/washing, with a level of 230 MPN/100mL, more than double the safe standard. It is difficult to calculate the volume of wastewater released by the ponds, especially since 80% of the informants leave the ponds open to the stream permanently. Given that the system for managing the water level in the ponds is approximately the same in the studied area, we can calculate an average outflow of > 80 m3 per week per fish farm. The pollution caused by the fish farms is thus of a relatively small scale in terms of toxicity but the amount of waste is large.

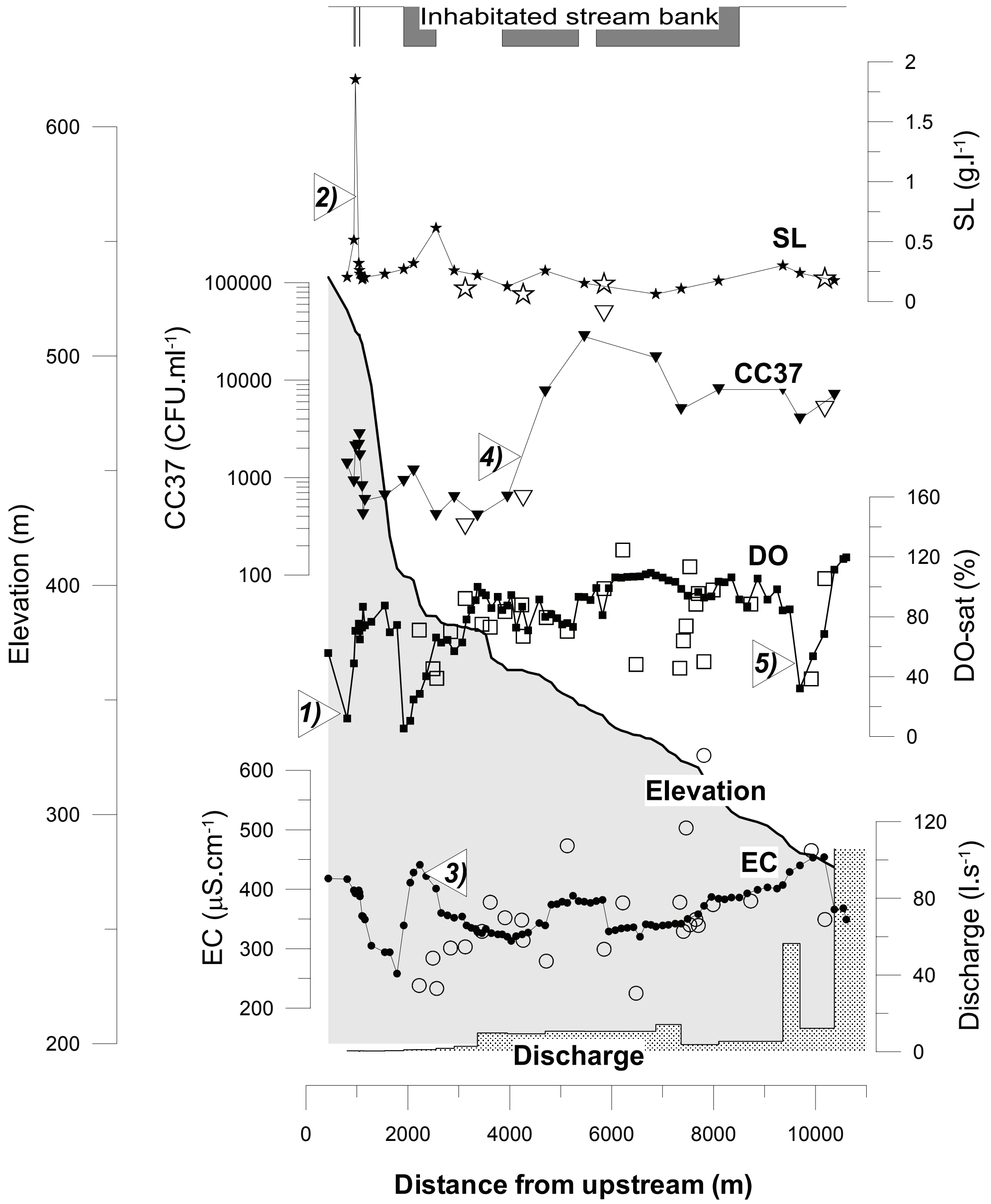

Figure 2. Morpho-hydrological characteristics of the Houay Xong river (solid black symbols) and its tributaries (hollow symbols) at the end of the 2007 dry season (i.e. low flow regime): elevation; main river discharge; electrical conductivity at 25°C (EC); dissolved oxygen content transformed to oxygen saturation (DO-sat); total colony count at 37°C (CC37); suspended sediment load (SL); location of the inhabited areas along the stream bank. Triangular labels indicate striking positions along the stream: 1) Reach with subsurface seepage; 2) Livestock straying within the riparian zone; 3) Domestic wastewater discharge; 4) Urbanized area along stream banks; 5) Agro-industrial discharge.

Domestic wastewater and household refuse

The physico-chemical characteristics of the stream water changed dramatically when it passed through the first upland village (Ban Lak Sip): DO-sat decreased from 88 to 5%, CC37 doubled, EC increased from 298 to more than 400 µS.cm^{-1} (Figure 2, triangle 3), temperature increased from 26.0 to 30.2 µC, pH decreased from 8.2 to 7.2 and Eh decreased from 220 to less than 120 mV. These changes were clearly related to (I) domestic wastewater discharge, (ii) human and animal excrements and (iii) household refuse accumulation in the stream bed. These factors, in association with low stream discharge conditions, led to organic matter enrichment of the stream and a decrease in the stream velocity, which in turn induced anoxic conditions (Figure 2). After a distance of about 1km downstream from Ban Lak Sip, natural filtration and other processes led to the recovery of stream quality back to its initial characteristics (Figure 2). Then, in and up to 900 m downstream from ban DonKang, DO-sat remained high (i.e. between approximately 80 and 110%) in spite of numerous waste water discharge points and domestic activities. This rather steady oxygenation rate is due to the stream being fed by oxygenated tributaries (dilution effect) and, above all, a turbulent flow regime that maintains aerobic conditions. Further downstream, the DO-sat suddenly decreased down to 32% because of organic-rich waste water discharge from an alcohol distillery (Figure 2, triangle 5). Once again, it took approximately 1 km for the DO-sat to return to its original level. Contrary to DO-sat, CC37 increased considerably from Ban Donkan onwards (Figure 2, triangle 4), and remained high until the confluence with the Nam Dong. Tributary inflows did not lower the CC37.

Impact of floods on water contamination

The stormflow measurements described below were conducted within the Houay Pano catchment during the first main runoff event of the 2007 rainy season. This event occurred a short time after the farmers of Ban Lak Sip had slashed and burned approximately 42% of the catchment area for annual cropping. Almost all the riparian zone and large hillslope areas were therefore bare; the soil surface and stream banks were unprotected, hence exposed to erosion. This flood was the result of a sudden intense downpour of 54 mm (maximal rainfall intensity of 110 mm.h^{-1} calculated over 6 min time steps) that produced considerable amounts of suspended sediments at the main outlet of the Houay Pano catchment (1.7 Mg ha^{-1}, i.e. ~23 % of the annual suspended yield). Table 1 presents a comparison between base and storm flow observations. No significant differences between base and storm flow were found for DO-sat (P value > 0.025). In contrast, stream flow dilution by rainwater lowered T, EC and pH during storm flow, while Eh increased significantly. Unsurprisingly, SL was much higher under storm flow conditions, corresponding to i) soil erosion in inter-rill areas (Chaplot et al 2007), rills and gullies (Chaplot et al 2005) and ii) the washing-out of free aggregates and some of the fragmented organic matter accumulated at the soil surface throughout the dry season. All the samples collected during the flood and one collected at base flow had SL >1 g/l, values which may greatly affect water usage and aquatic life, from phytoplankton to fish, by limiting light penetration. SL, especially when particles are small (less than 63µm), carry many substances that are harmful or toxic. In rivers, these fine particles are a food source for filter feeders which are at the base of the food chain, leading to biomagnification of chemical pollutants in fish and, ultimately, in humans. High SL also limits reservoir life through sedimentation of suspended matter. Microbiological studies of waterways are usually not carried out during rainfall-runoff events. Even though, during and after such events, there are often significant increases in turbidity and suspended solid loads, which are frequently interpreted as an indication of bacteriological contamination. Table 1 also shows that CC37 soared under storm flow conditions. These observations are consistent with those of George et al (2004) who reported that, in small streams, fecal coliform bacteria were linked to particles and that their abundance was proportional to the suspended sediment content.

Conclusions and recommendations

The expansion of Luang Prabang and its population growth pose a major challenge to city planners. In the near future, it will lead to an increased demand for sanitation infrastructures and freshwater resources, notably for irrigated peri-urban market gardens. The current expansion follows a centrifugal dynamic that radiates from the historic peninsular city and proceeds uphill along the course of waterways. The following recommendations are suggested in order to reduce or mitigate potential negative impacts of this urbanisation process on water quality:

- Riparian zones along streams and rivers should be managed in an environmentally friendly and sustainable manner.
- Extraction of stream water for industrial and irrigation purposes should be managed according to estimates that take into account rainfall variability and upstream land use. Over-extraction of stream water will place freshwater resources under stress.
- Authorities should encourage the development of community-based water sanitation systems as unprocessed domestic wastewater discharge is currently rising.

To support the above mentioned recommendations, we suggest that an agreement between the city of Luang Prabang and the surrounding villages be implemented. This agreement may follow the Payment for Environmental Services (PES) concept: rural dwellers could loosen the pressure on riparian areas in return for which the urban citizens could finance sanitation infrastructures upstream *via*, for example, the taxation of profits made on certain tourist activities in Luang Prabang. Finally, our study raises the issue of the spatial scale relevance of field observations regarding the question that needs to be answered, i.e. do upland people of northern Lao PDR have access to good quality surface water? Strategies that consist in monitoring large rivers generally provide a smooth integrated fingerprint of entire watersheds (e.g. UN 1998). This is unquestionably useful for global water resource management at the regional scale. However this approach may mask system internal variability and hence part of the local community level reality. Conclusions from such large scale studies should therefore be considered with the greatest care.

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