ການປະເມີນຄຸນນະພາບນ້ຳ ຕາມສາຂາແມ່ນ້ຳຂອງ ໃນເຂດພູດອຍ ທີ່ມີການນຳໃຊ້ທີ່ດິນແບບປະສົມ

ໂອລິວີເອ ຣິໂບນຊີ, ຢຸລຽດ ກູນີ, ພອນໄຊ ແສງສຸລິຈັນ, ອາແລງ ປີແອເຣ,
ໂອລິດ ແສງຕາເຮືອງຣຸ່ງ

ບົດຄັດຫຍໍ້

ປະຊາຊົນລາວສ່ວນໃຫຍ່ ປະມານ 78% ແມ່ນອາໃສຢູ່ເຂດຊົນນະບົດ, ການເຂົ້າເຖິງນ້ຳສະອາດ ແລະ ສາທາລະນະປະໂຫຍດ ຍັງບໍ່ທັນທົ່ວເຖິງໃນບາງເຂດຫ່າງໄກສອກຫຼີກ ສະນັ້ນ ຄວາມສ່ຽງຈາກບັນຫາຄຸນນະພາບນ້ຳຕໍ່ສຸຂະພາບ ອາດຈະເກີດຂຶ້ນໄດ້. ຈຸດປະສົງຂອງການສຶກສາຄັ້ງນີ້ ແມ່ນເພື່ອປະເມີນຄຸນນະພາບນ້ຳໃນລະດັບເຂດຊຸມຊົນ ໂດຍນຳໃຊຂໍ້ມູນຕົວຊີ້ບົ່ງຈາກສະໜາມ ເຊັ່ນ: ອົກຊີບັນຈຸ, ເຊື້ອບັກເຕຣີ ແລະ ຕະກອນແຂວນລອຍໃນນ້ຳ. ຜົນການສຶກສາເຫັນວ່າ ຄຸນນະພາບນ້ຳແມ່ນຜັນແປ ຂຶ້ນກັບສະຖານທີ່, ການກະຈາຍຂອງປະລິມານນ້ຳຝົນ ແລະ ສະພາບຂອງສາຍນ້ຳ. ການແປປ່ວນຂອງຄຸນນະພາບນ້ຳ ແມ່ນເນື່ອງມາຈາກຄວາມສົມດຸນ ລະຫວ່າງ ຂະບວນການບຳບັດໂດຍທຳມະຊາດ ແລະ ພຶດຕິກຳຂອງຄົນ ເຊັ່ນ: ການຕັ້ງພູມລຳເນົາ, ການຖາກຖາງພື້ນທີ່ແຄມນ້ຳ ແລະ ການປົດປ່ອຍຂອງເສດລົງນ້ຳ. ການກຳເນີດຂອງນ້ຳເສຍ ແລະ ສິ່ງທີ່ເປັນຜົນກະທົບຕໍ່ຄຸນນະພາບນ້ຳມີດັ່ງນີ້: 1) ມີເຊື້ອບັກເຕຣີ ແລະ ມີຄວາມຂຸ່ນສູງ ເນື່ອງມາຈາກການເຮັດຄອກສັດໃສ່ແຄມນ້ຳ; 2) ອົກຊີແຊນບັນຈຸໃນນ້ຳຕ່ຳ ແລະ ການປົນເປື້ອນຂອງເຊື້ອບັກເຕຣີສູງ ຍ້ອນປະລິມານນ້ຳໄຫຼໜ້ອຍ ແລະ ສຸຂະອະນາໄມບໍ່ພຽງພໍ; 3) ເຊື້ອບັກເຕຣີສູງ ເນື່ອງມາຈາກການຂະຫຍາຍພູມລຳເນົາຕາມແຄມນ້ຳ; 4) ອົກຊີບັນຈຸໃນນ້ຳຕ່ຳ ເນື່ອງຈາກອິນຊີວັດຖຸຈາກສິ່ງເສດເຫຼືອຂອງໂຮງງານ; 5) ຕະກອນດິນ ແລະ ບັກເຕຣີສູງ ຍ້ອນການເຊາະເຈື່ອນຂອງດິນໃນເຂດສູງຊັນ. ນອກຈາກມົນລະພິດຈາກມະນຸດແລ້ວ ກໍ່ຍັງມີມົນລະພິດທາງທຳມະຊາດ ເຊັ່ນ: ການເກີດສະໜິມໂລຫະຈາກນ້ຳໃຕ້ດິນ. ພວກເຮົາໄດ້ສະເໜີຄຳແນະນຳດັ່ງກ່າວ ເພື່ອປັບປຸງ ແລະ ຮັກສາຄຸນນະພາບນ້ຳ ໃຫ້ຄົງຕົວກັບສິ່ງແວດລ້ອມ ຕະຫຼອດໄປ.

Assessment of water quality along a tributary of the Mekong River in a mountainous, mixed land-use environment of the Lao P.D.R.

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Abstract

In the Lao PDR 78% of the population are classified as rural and efforts to improve access to potable water and sanitation infrastructures are reaching limited areas, these inhabitants may be particularly affected by water quality-related hazards. The objective of this study was to complete a preliminary assessment of stream water quality, at the community-level, using a set of field indicators (i.e. oxygen content, total bacteriological flora and suspended load). Our findings concluded that the water quality is extremely variable depending on the location along the stream and the prevailing rainfall and water flow conditions. Changes in water quality were affected by an uncertain balance between potential self-cleaning processes in the stream environment and human pressure in the riparian zone (i.e. urbanization, riparian vegetation removal, wastewater discharges, stream flow extractions). Several interesting observations were noted that influence water quality: **(i)** high bacteria and turbidity levels were related to free ranging livestock roaming near the stream in isolated areas; **(ii)** very low oxygen content and high bacteriological contamination downstream of small remote villages due to low stream discharge and poor sanitation conditions; **(iii)** high bacteria levels along continuously urbanized reaches; **(iv)** low oxygen content following organic-rich wastewater inflows from a small agro-factory; **(v)** very high suspended load and bacteria levels during flood events due to soil erosion of steep cultivated hillslopes. Besides pollution related to these human activities we also noted "naturally" metal-rich stream water when crossing swampy areas fed by dysoxic groundwater. We propose a set of pro-poor recommendations to improve or maintain good stream water quality in the uplands and for environmentally friendly management of surface water resources.

Key words: *Water quality-related hazards; riparian zone; land uses; wastewater discharges; Mekong river; Lao P.D.R*

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Introduction

Freshwater quality is an issue of concern for human health and the sustainability of environments globally. The risks arise from infectious agents, toxic chemicals and radiological hazards. According to the World Health Organization, the most affected populations live in rural areas of developing regions (WHO-UNICEF, 2006). In 2004, more than three out of every five rural inhabitants, that is over 2 billion people, did not have access to a basic sanitation facility.

In the Lao PDR, 78% of the population lives in a rural setting, and attempts to improve drinking water and sanitation infrastructures are impacting very limited areas, suggesting that communities in these areas may be predisposed to water quality-related hazards. Ten years ago, the United Nations (UN, 1998) reported that human activities have little effect on river water quality in the Lao PDR: "As the country has a low population density, the small amount of wastewater discharged from the towns and industries usually flows through the natural canal systems undergoing self-purification over a long distance before entering the rivers". The UN experts based their conclusions on the country's low population density and a limited number of measurements made (34 for the entire country) in large rivers. Is this diagnostic still valid today in view of the current, still low, population density (24 people per km2; NSC, 2005)? Does an overall assessment based on main rivers which drain large areas reflect community level reality? Besides the major tributaries of the Mekong River, there are hundreds of small order perennial rivers and streams (i.e. "the natural canal systems" cited above). What about the rural people living in villages along these water paths? Rural communities in Laos are often reliant on stream water resources because access is easy and exploitation is less expensive compare to groundwater resources. However, studies have shown that stream water resources encounter problems related to increased turbidity during periods of storm flow (Maniphousay and Souvanthong, 2004), and water and excreta-related diseases are among the most frequently occurring diseases in Laos (Lamaningao and Sugiura, 2004).

The overall goal of this study was to undertake a preliminary assessment of stream water quality at the community level, in a typical mixed land-use area of northern Lao PDR (in the vicinity of

Luang Phrabang city). Measurements were made along a perennial third order stream passing through villages close to the Mekong corridor but having no direct access to the main river. This study does not intend to identify and analyze all factors and processes contributing to surface water quality in the uplands of the Lao PDR. Our objective was to identify the main causes contributing to the spatial variability of water quality indicators (i.e. oxygen content, total bacteriological flora, suspended load) in a watershed that includes some karstic features. Among the underlying factors studied, we paid specific attention to **(i)** land use along the riparian area; **(ii)** wastewater discharges and **(iii)** suspended sediment yield during floods.

Materials and methods

Description of the Houay Xon catchment

The study was conducted along the Houay Xon stream (UTM zone 48, WGS84 coordinates: 197860-204760 E, 2192570-2199820 N), part of the Mekong basin of 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). Table 1 shows the main morpho-hydrological characteristics of the catchment. The source of the Houay Xon is in the upper Houay Pano (Valentin et al., this issue). The stream is 10.6 km long, perennial and has irregular topography since it flows within a mountainous environment which is representative of the sloping lands of the Mekong valley (Figure 2). In the catchment, the altitude ranges from 280 to 1336 m, with a mean slope gradient of approximately 31%. The highest altitudes are found in the south, within the Phu Phung mountain range (Figure 1). The geological substrate is composed of Permian to Upper Carboniferous argillite series (shales, mudstones, and fine-grained sandstones) overlaid by karstified limestone cliffs. The karstic cliffs were observed at the extreme north-east of the catchment (i.e. boundary of the Houay Pano headwater catchment) and in the south (i.e. upper Phu Phung). The landscape and relief features are strongly influenced by a complex network of fault lines which controls the direction of the main stream path. The Houay Xon hydrographic system is highly dissymmetric; most of its tributaries are located on the left bank (southern area) and drain more than 80% of the total catchment area. This area includes the karstic system of the upper Phu Phung massif with its underlying geological formations, and constitutes the main groundwater reservoir of the catchment. Part of this water resource is exploited by a drinking water factory (Nam Papa State Company).

The catchment is a typical mixed-use area of northern Lao PDR. The Houay Xon flows through five villages, successively: Lak Sip, Donkang, Kouathineug, Ma and Phoumok. The overall land use units (Figure 1) are roughly influenced by the morpho-hydrological sets: (1) the south-eastern Phu Phung massif (i.e. highest unit with the steepest slopes) is mainly covered by an old protected forest; (2) the upland areas of the north-eastern dog-ear and the south-western part are under shifting cultivation with short fallow; (3) residential areas surrounded by teak plantations are found along the main stream (Figure 2); and (4) irrigated gardens in the peri-urban area of Luang Prabang City are located downstream in a lowland unit (i.e. gently sloping alluvial terrace of the Mekong).

The mean annual rainfall recorded at Luang Prabang from 1960 to 2006 was 1263 mm, about 77% of which falls during the monsoon season from mid-May to mid-October, with high inter-year variability (SD 345 mm, coefficient of variation 27%) leading to a minimum of 444 mm and a maximum of 2100 mm. In 2007, the year of this study, the cumulative rainfall was 1139 mm.

Hydro-chemical measurements in the field

Temperature (T), pH, electrical conductivity at 25°C (EC), redox potential (Eh), and dissolved oxygen content (DO) were measured using a YSI MPS (Multi Probe System/Data Logger) meter. All of the meter's sensors were checked daily before each sampling survey: the pH probe was calibrated using standard pH 4.00 and 7.00 buffer solutions; the Eh probe was verified in a 220mV (at 25°C) electrolytic solution; and the cell constant of the EC probe was set with 1413 μS/cm standard buffer. The DO sensor was calibrated following the air calibration method. Because of the inherent covariance of water temperature and DO, all DO data were transformed to oxygen saturation (DO-sat) in %, using the formula of Hua (1990) and correcting for atmospheric pressure. Two field surveys were conducted in 2007:

- First, in order to analyse the effects of land use on water quality at baseflow (Figure 3a-3e), 109 observations points were surveyed along the Houay Xon (83 stations distributed at 100-m intervals) and its main tributaries (26 stations), at the end of the dry season (31 May 2007) until the confluence with the Nam Dong River.

- Secondly, to examine the impact of floods (Figure 3f) regardless of domestic wastewater inputs, 11 stations were established in close proximity (about 20-meter distance between each) and located within the Houay Pano catchment (upstream Houay Xon), were sampled on two dates (Table 2): (1) during a period of low flow just before the rainy season (28 May 2007) and (2) during the first storm flow of the rainy season (4 Jun 2007).

Water sample collection and laboratory analysis

Seventy water samples were collected to determine the suspended solid load (SL) and total colony count at 37°C (CC37). Samples were collected on the same day or the day following each of the physico-chemical surveys described above. The positions of the sampling stations were chosen based on the reach characteristics (i.e. riparian land uses, hydro-morphology and physico-chemistry). The samples were collected by submerging the sample bottles upstream; taking care to avoid collecting disturbed bed sediments with the sample (i.e. neck of the bottle pointing upstream). SL, expressed in mg l^{-1}, was estimated as the weight of material retained on a pre-weighed 0.45 μm membrane after filtering a known volume of sample (about 1 litre). In general, sampling was carried out at approximately the same period of the day, i.e. mid morning to early afternoon. Water samples for total flora determinations were stored in the dark, placed on ice in a cool 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.

Morpho-hydrological determina-tions

The sampling point locations were approximated using a portable GPS (GARMIN XL12) and an altimeter (SUUNTO Instrument). For the detailed surveys along the Houay Pano stream, a combination of a compass (SUUNTO Instrument), a clinometer (SUUNTO Instrument) and a decametre was used to survey elevation changes and distance between sampling points. We systematically duplicated these measurements (vertical and horizontal angles) by taking a forward and a backward sight at each waypoint. Stream discharge measurements at the different sampling points were estimated by chemical tracing following the method recommended by Silvera et al. (2007).

Results and discussion

Most conventional hydrological studies are based on flow monitoring and measurement of water quality parameters at the outlet of a catchment. In a mixed land-use areas, it is difficult, if not impossible, to relate this type of time-series observations to the spatial features of the catchment. In order to overcome this obstacle, we surveyed spatial-series observations along the main channels so that the various spatial features could be directly related to the stream water quality changes. In the Houay Xon catchment, the footprint of human activity increases going downstream (Figure 1). Results are presented by first describing the situation upstream and then our findings as we follow the main water course downstream (Figure 2).

Potential hazards due to naturally contaminated groundwater

In the upper part of the catchment (Houay Pano stream, land under shifting cultivation), we observed orange-coloured iron oxide flocculation at several points within the stream channel. Figure 3a shows these metal-rich colloidal features at station 2, where we measured reducing conditions: low DO-sat (12 %, see triangular label 1 in figure 4) and the lowest pH (6.9) and Eh (88 mV). The Eh-pH pair measured at this station (Figure 4) was within the range for soluble ferrous iron hydroxides ($FeOH^+$), near the theoretical equilibrium between soluble $FeOH^+$ and ferrous iron (Fe^{2+}). At this point in the catchment, these physico-chemical conditions could not be attributed to local waste water inputs or any human activities. Instead, these corresponded to local ex-filtration of subsurface water with a low pH, Eh and DO-sat (Ribolzi et al., 2005). Soluble iron compounds are common in soil solutions with high levels of organic matter (1-6% in the soil of Houay Pano). When dissolved organic matter enters groundwater, the water may become anaerobic and iron becomes soluble. During the ex-filtration process, groundwater containing Fe^{2+} becomes aerated. Since the oxidation of Fe^{2+} at near neutral pH is very rapid, the ionic form may precipitate as amorphous oxides (e.g. Stumm and Morgan, 1981) which then contribute to lowering the pH in the vicinity of groundwater inflow sites. Oxidizing bacteria may accelerate this flocculation process.

The presence of dissolve iron or colloidal features in streamwater should not be considered dangerous in itself, but rather as a useful indicator of local physico-chemical conditions that can potentially favour the mobility of toxic metals such as the so-called atmophile elements (e.g. Cu, Cd, Zn, As). Farmers often take advantage of these groundwater inflows for various purposes: fish ponds; drinking water collection; small irrigation, watercress beds (Figure 2a). However, such practices may entail health risks as streambed sediments, stream water and aquatic vegetation in the vicinity of subsurface inflows can accumulate metals (Huon et al., this issue). In order to limit the risk, seepage waters from soil containing high levels of organic matter should be used only after aeration and the deposition/sequestration of metal ions (e.g. into the streambed sediment during stream transport).

Impact of land use and human activity along the riparian area

Livestock roaming

In the upper land of the catchment under shifting cultivation, livestock was observed roaming close to and in the stream causing sediment particles to be mobilised (Figures 2b) with SL values which can increase up to 2 g.l^{-1} (Figure 4, triangular label 2). This turbidity increase was associated with a local increase in microbiological pollution (CC37>2000 CFU ml^{-1}). This is consistent with the findings by Randall et al. (2006), who observed a strong correlation between faecal bacteria (Escherichia coli) load rate and turbidity at near base flow in a mixed-use watershed. George et al. (2004) studied stream faecal coliform inputs through soil leaching in a temperate climate. They observed that rural streams, located upstream from any waste water outfall, flowing through areas partly or fully covered with pastures were more contaminated than those flowing through forest and cultivated areas. In our case, the main source of bacteria was from the soil surface and very local, most probably due to a dung piles rolling into the stream from a livestock shelter situated on the stream bank.

It is interesting to note that, due to the filtering effect of aquatic plants in the streambed, only a short distance of downstream flow (~100 m) was necessary to recover acceptable levels of suspended solid content and eliminate most of the sessile (attached) bacteria (Galvez, 2007).

Domestic wastewater and household refuse

The physico-chemical characteristics of the stream water changed dramatically when it passed through the first upland village (i.e. Lak Sip): DO-sat decreased from 88 to 5%, CC37 doubled, EC increased from 298 to more than 400 µS.cm^{-1} (Figure 4, triangular label 3), temperature increased from 26.0 to 30.2 °C, 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 excrement and (iii) household refuse accumulation in the stream bed (Figure 2c). These factors which were associated with low stream discharge conditions, (Figure 4) led to organic matter enrichment of the stream and a decrease in the stream velocity, which in turn contributed to the anoxic conditions (Figure 4) and a noticeable smell in the vicinity of the stream path.

Between Lak Sip and the following village (DonKang), the Houay Xon flows through the lower Phu Phung protected zone (Figure 1), and is therefore not contaminated by any waste water. Figure 4 shows that after a distance of about 1 km downstream, natural filtration and other processes led to the recovery of stream quality back to the initial characteristics. Than, in and up to 900 m downstream from DonKang, DO-sat remained high (i.e. between approximately 80 and 110%) in spite of the numerous waste water discharge points and domestic activities (Figure 3d). This rather steady oxygenation rate is due to the stream being fed by oxygenated tributaries (dilution effect) and, above all, a turbulent flow regime favourable to maintaining aerobic conditions. After 900m, the DO-sat suddenly decreased down to 32% because of organic-rich waste water discharge from an alcohol distillery (Figure 4, triangular label 5). Once again, it took approximately 1 km for the initial level of DO-sat to return to its original state. Contrary to DO-sat, CC37 increased considerably from Donkang village onwards (Figure 4, triangular label 4), and remained high until the confluence with the Nam Dong. Tributary inflows did not lower the CC37.

Flood Impacts

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 the Lak Sip village 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 2 presents a comparison between base flow and storm flow observations (i.e. 11 observation points at two dates). No significant differences between base flow and storm flow were found for DO-sat (P value > 0.025). Contrasting this, T, EC and pH values were lower during storm flow while Eh was significantly higher. Dilution of stream flow by rainwater (lower T, EC and pH; higher Eh) explains the differences observed. Unsurprisingly, SL was much higher during the storm flow. These higher values result from various soil erosion processes affecting inter-rill areas (Chaplot et al., 2007), rills and gullies (Chaplot et al., 2005) and the washing-out of free aggregates and part 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. Such high values may greatly affect water usages 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 part of the food chain, leading to biomagnification of chemical pollutants in fish and, ultimately, in man. It can also limit reservoir life through sedimentation of suspended matter.

Microbiological studies of watercourses 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 2 also shows that CC37 were considerably higher during the storm flow sampling survey. These observations are consistent with those of George et al. (2004) who reported that fecal coliform bacteria were linked to particles in small streams and that the fraction increased with suspended sediment content.

Conclusion, research perspectives and recommendations

The observations presented above were conducted along a perennial third order stream passing villages close to the Mekong corridor but having no direct access to this main river. The objective was to undertake a preliminary assessment of stream water quality at the community-level and based on in situ measurements of several operational parameters (i.e. oxygen content, pH, electrical conductivity, suspended sediment load, total bacteriological flora).

This study confirmed that, due to poor sanitation conditions, a high degree of bacteriological contamination occurs in stream water passing villages and peri-urban areas. The most common source of pollution was from urban household wastewater, which may potentially contain pathogens (but also nutrients). Pollution of water sources from industrial effluent was not as common.

The downstream section of the catchment mostly includes irrigated peri-urban gardens (via natural streams or small diversion channels) which supply Luang Prabang city with vegetables. These market gardens rely largely on surface waters that could be increasingly polluted by the rapidly growing population. Thus the question of water quality and the potential associated health risks are an important area of study.

The expansion of Luang Prabang city and its population growth pose a major challenge for 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 is characterised by a dynamic from the ancient peninsula city, following the stream water paths and spreading progressively up hill slopes. The following recommendations are suggested in order to reduce or mitigate potential negative impacts on water quality:

- Riparian zones along streams and rivers should be managed in an environmentally friendly and sustainable manner. A strip of natural vegetation on the bank should be preserved and protected in order to maintain the sediment-filtering function of this zone. Encroachment of stream banks by residences, non strengthened fish ponds or informal hydraulic infrastructures should be strictly limited and controlled in order to prevent material or even human losses generated by landslides or flood hazards.

- Environmental discharge thresholds should be estimated and then base on these estimates, water which is extracted from the river system for manufacture activities and irrigation should be regulated following a seasonal schedule taking into account rainfall variability and upstream land use. Over-extraction of stream water will place freshwater resources under stress.

- Authorities should organise and encourage the development of community level decentralised sanitation systems. If not, direct domestic wastewater discharges will rise and stream water passing villages and Luang Prabang will turn into sewage. Local inhabitants and tourists would not only be inconvenienced by bad smells but also health concerns if the polluted water is still used to irrigate food crops.

Extending basic drinking water and sanitation services to peri-urban areas and neighbouring villages in order to reach the poorest people is of the utmost importance to prevent outbreaks of cholera and other water-related diseases. To support the above mentioned recommendations, we suggest that an agreement between the Luang Prabang city 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 be considered with the greatest care.

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Table 1 – *Selected hydro-morphological characteristics of the Houay Xon catchment: surface (A) and planar (Ap) areas; perimeter (P); minimum (Zmin), maximum (Zmax) and mean altitude (Zmean); length of the main stream (L); Gravelus index of compactness (Gc) which is the ratio of the perimeter to the perimeter of a circle which have the same surface area; drainage density (Dc); mean slope gradient (S).*

A	Ap	P	Zmin	Zmax	Zmean	L	Gc	Dc	S
km^2		m					km^{-1}	$km.km^{-2}$	%
22.4	20.7	26529	280	1336	592	10605	1.6	1.4	31

Table 2 – *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).*

Flow regime (date)		**Discharge** l/s	**T** °C	**EC** μS.cm^{-1}	**pH**	**Eh** mV	**DO-sat** %	**SL** g.l^{-1}	**CC37** 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

Differences between base flow and storm flow (threshold of significance: $\alpha/2 = 0.025$) 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.

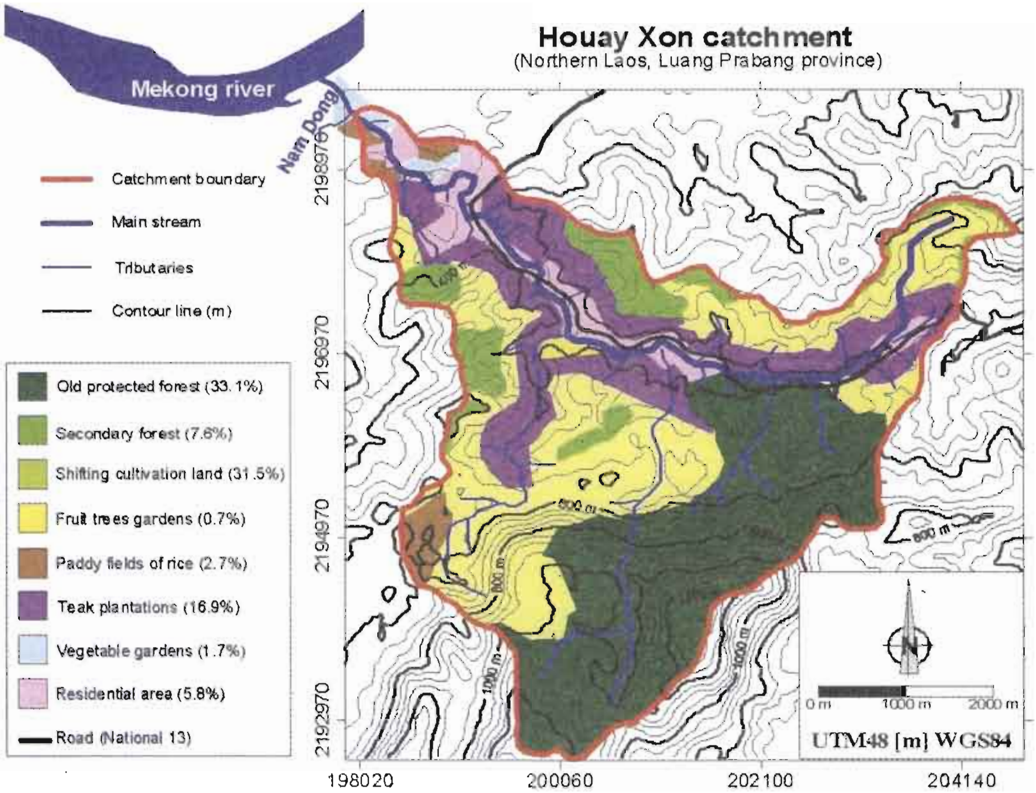

Figure 1 – *Main land uses (percentage of the total catchment area), contour lines and permanent stream paths within the Houay Xon catchment in 2007.*

Figure 2 – *(**a**) Orange-coloured iron oxides flocculation and biofilms in a watercress bed of the upstream Houay Pano catchment; (**b**) Turbid stream water due to livestock straying; (**c**) The Houay Pano stream invaded by household refuse in the Ban Lak Sip village; (**d**) A young lady doing the dishes in the Houay Xon river; (**e**) Corridor of residential blocks recently built on the stream bank of the Houay Xon river; (**f**) Houay Pano during a small flood.*

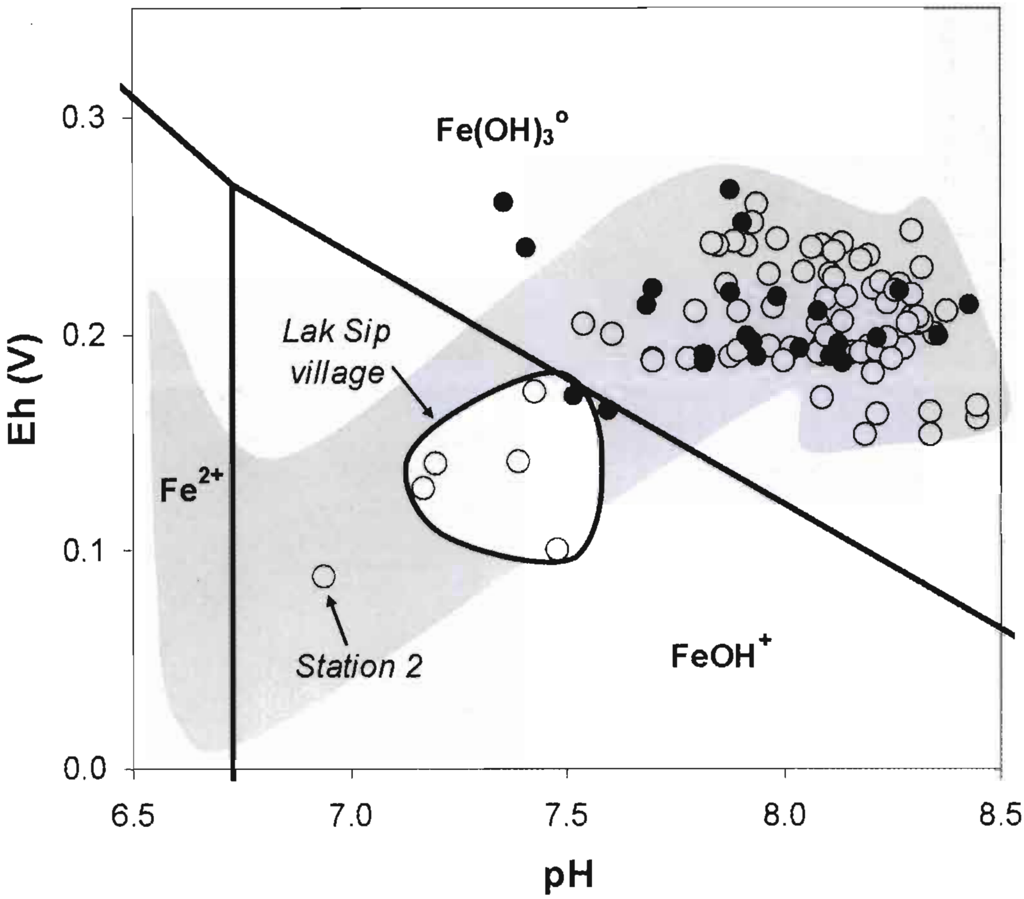

Figure 3 *– Eh-pH diagram of dissolved iron species at 25°C; Stream water of the Houay Xon (o) and its tributaries (•). Continuous black lines indicate the theoretical boundaries of predominance domains between species. the Grey area shows the overall trajectory of pH-Eh conditions from soil water within organic-rich horizons (i.e. lowest pH and Eh values) to downstream water including bicarbonated water originated from calcareous zones (i.e. higher pH values).*

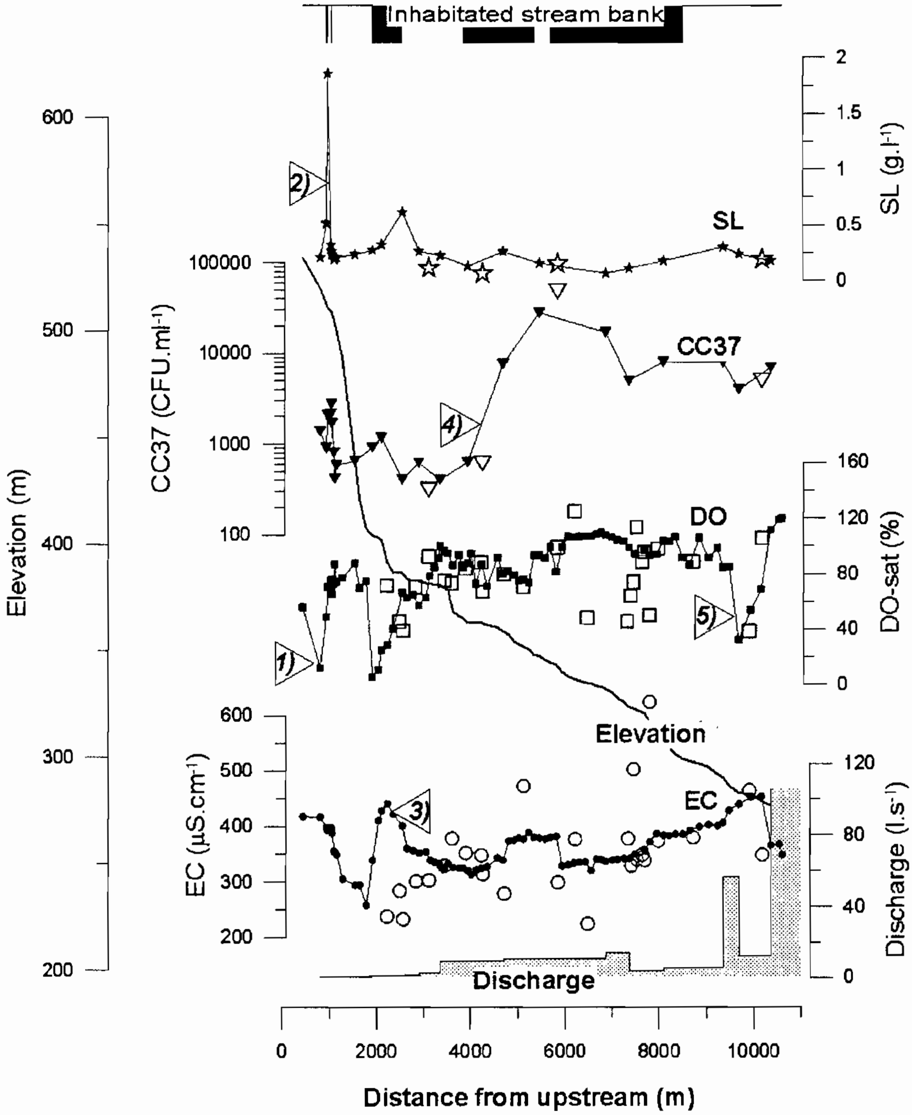

Figure 4 – *Morpho-hydrological characteristics of the Houay Xong river (solid black symbols) and its tributaries (hollow symbols) at the end of the 2007 dry season (i.e. low flow regime): elevation; main river discharge; electrical conductivity at 25°C (EC); dissolved oxygen content transformed to oxygen 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.*

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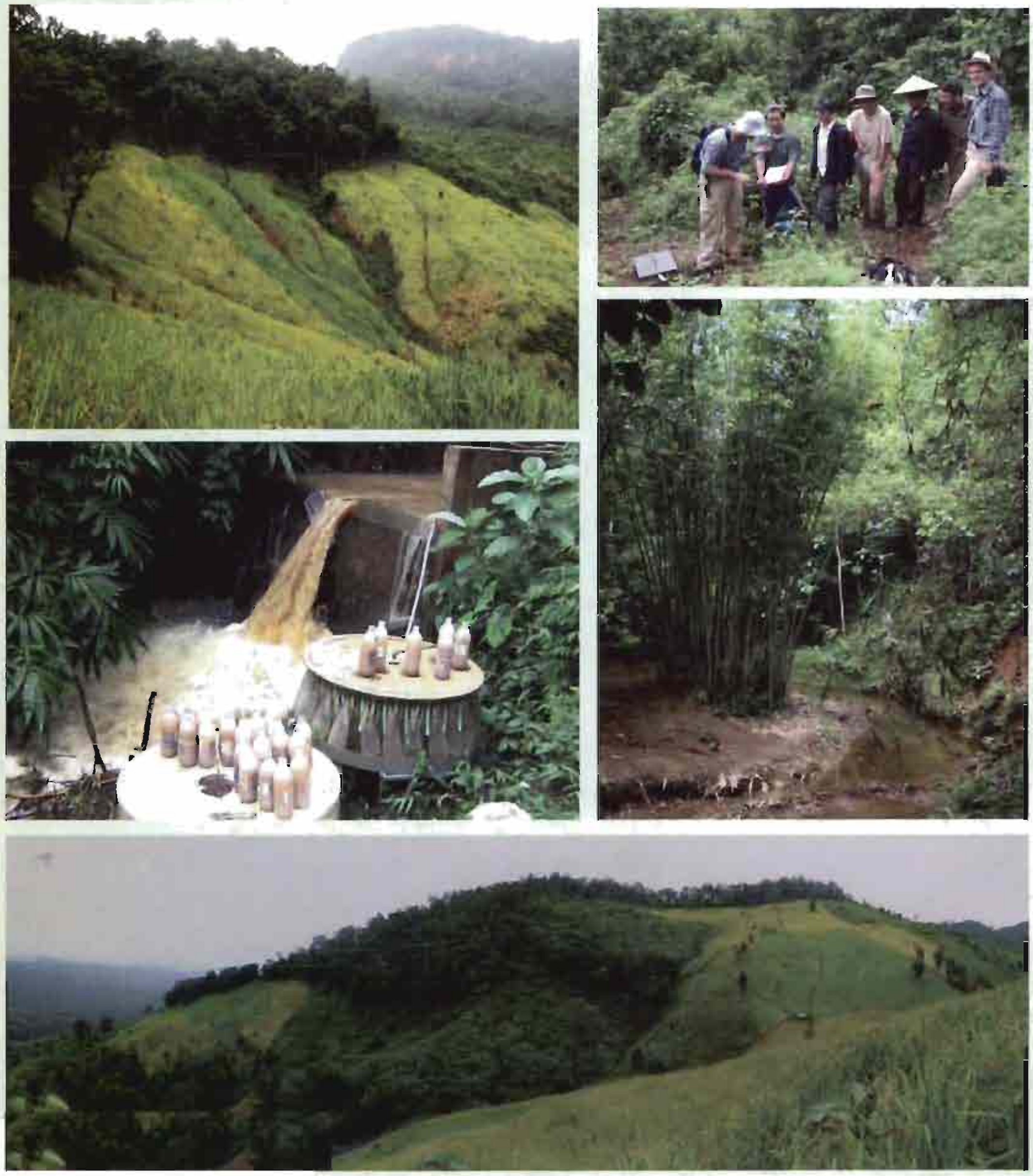

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