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A policy dialogue on rice futures: rice-based farming systems research in the Mekong region

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A policy dialogue on rice futures: rice-based farming systems research in the Mekong region

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Policy actors convene with researchers to deliberate on rice futures in the Mekong region (Photo: Lisa Robins)

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The use of groundwater as an alternative water source for agricultural production in southern Lao PDR and the implications for policymakers

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Abstract

Groundwater is fast becoming an alternative source of fresh water for many rural communities in southern Laos in response to increasing rainfall variability and distribution, in conjunction with increasing competition for surface water resources, including for agriculture, hydropower and mining. However, characterisation of the region's aquifer system is based largely on information derived from hydrogeological studies in neighbouring parts of the Lower Mekong River Basin. The first objective of the research presented in this paper was to identify the nature and extent of the aquifer system, and seasonal groundwater behaviour, in the Soukhouma district, in southern Laos' Champassak province. The second objective was to explore the potential implications of overextraction of the groundwater resource. Our research findings highlight the need for well-informed guidelines and policy interventions for sustainable groundwater development in this region.

Introduction

Lao People's Democratic Republic (PDR) is classified as a 'least developed country' and a 'low-income food-deficit country'. In 2009, it was ranked 133 of 182 nations according to the United Nations Development Programme (UNDP) Human Development Index (World Food Programme 2011). Laos has a population of 6 million, 28% of whom are living below the poverty line (World Bank 2014a). The gross domestic product (GDP) per capita between 2009 and 2013 was reported to be US$1,417 (World Bank 2014b). The contribution of agriculture (including crop production, aquaculture and forestry) to GDP has decreased substantially over the past two to three decades. For instance, in 1992, agriculture accounted for 62% of GDP; in 2012, it accounted for 28% (World Bank 2014a). Despite this, agriculture remains a significant contributor to the national economy through employing ~76% of the population (MRC 2011). Historically, agriculture in Laos was largely driven by subsistence-oriented rice production (Manivong et al. 2014), but since the adoption of the New Economic Mechanism in 1986, there has been a drive toward commercialising agriculture, consistent with the philosophy of developing a market-oriented economy (Rasabud 2011). As such, there has been an expansion in the total area under cultivation in the past several decades. For example, results of the 2010/11 national census of agriculture showed that the area under agricultural production in 1998/99 was 0.98 million hectares (Mha); by 2010/11, this

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had increased to 1.6 Mha (Intharack 2014). Rice is the major agricultural commodity produced in Laos and, in 2010/11, accounted for ~0.99 Mha of total agricultural land use. Of this, 94% was dedicated to rainfed rice production, which is grown mainly in the lowlands; only 6% of land area was committed to irrigated, dry-season rice production (Inthrack 2014), primarily because rainfall is distinctly seasonal and access to adequate irrigation infrastructure in the dry season is extremely limited.

Cultivation of lowland, wet-season rice accounts for the majority of the total rice production by area in Laos (e.g. 72% in 2010/11; Intharack 2014) and plays an important role in the livelihoods of the rural population in these regions. Despite advances in technology (e.g. mechanisation of land preparation, improved varieties and the introduction of inorganic fertilisers) to overcome physical constraints (i.e. soil infertility, droughts and floods, pests and diseases) and to improve agricultural productivity, the incentive for farmers to produce beyond the individual household needs is limited. This is a result of increasing input costs, fluctuating output prices and uncertainties in trade policies (Newby et al. 2013, and is further exacerbated by weaknesses in the capacity of extension services, limited access to farm credit (Eliste et al. 2012) and the long-term migration of labour to neighbouring countries, where it is estimated that as many as 300,000 migrant workers (8% of the total workforce) are residing in Thailand alone (Manivong et al. 2014).

Water resources

In the Lower Mekong River Basin, the mean annual rainfall ranges from less than 1,000 mm/year in the central regions of Thailand to 2,500 mm/year in the mountainous areas of Laos (MRC 2010). Most of this rain occurs during the wet season (April–November), resulting in a distinct seasonal flow in the Mekong River. The average annual discharge is ~475 km^3 where a significant proportion (~40%) is derived from flow originating in the eastern tributaries between Vientiane (Laos) – Nakhon Phanom (Thailand), and Pakse (Laos) – Strung Treng (Cambodia) (MRC 2009; see Figure 1).

Fresh water availability in Laos is the highest in Asia, estimated at 53,000 m^3/capita (UNEP 2001). Despite the apparent abundance of fresh water, the high seasonality and non-uniform distribution of rainfall, together with the increasing demand for water from agricultural and non-agricultural uses such as mining and hydropower, are driving the search for other sources of water (Nhoybouakong et al. 2012). For instance, over the past few decades, the number of small surface water storages has progressively increased. These farm ponds provide a source of water that can be used to irrigate short-duration, high-value vegetable crops, or to support aquaculture (Vongsana et al. 2014). Additionally, the spread of electrification across the region in recent times has allowed the exploitation of groundwater for both domestic use and the small-scale irrigation of vegetables or other high-value dry-season crops. As the development of small, domestic-type groundwater bores across the region over the past decade has been so extensive, there is now an urgent need to gain a better understanding of the system so that future development does not compromise current use or system sustainability.

To date, few studies have been undertaken to assess the nature of groundwater in southern Laos. As a consequence, there is little knowledge upon which Lao policymakers can develop strategies to ensure the continuing, sustainable use of this resource. Literature searches have revealed a scarcity of information regarding the underlying hydrogeology of the Mekong alluvium in southern Laos, and of the accessibility, sustainability and quality of groundwater. Studies by the interim Mekong Committee (1986, cited in WEPA 2014) indicated that groundwater associated with the lower Mekong plain in southern Laos was likely to be associated with the Indosinian sediments geological formation. Aquifers associated with these formations, while exhibiting regional flow through rock of the Indosinian Moyennes and Superieures, were mainly freshwater sediments and yields of 12–24 litres per second (L/s) were possible (WEPA 2014). Two other studies undertaken in the past two decades (JICA 1995; Oriental Consultants Co. Ltd 2012) have provided a brief snapshot of shallow groundwater resources in the Champassak and Savannakhet provinces and indicated high seasonality of the depth to watertable and the close link between rainfall and recharge.

There is a growing need for further information regarding the nature of groundwater systems in southern Laos given the increasing dependence of rural communities on groundwater for domestic and cottage needs, combined with the increased rate of development of the resource and the temptation for high-production bores to enable dry-season irrigation.

Relevant, up-to-date knowledge will enable policymakers and planners at both regional and national levels to develop appropriate strategies and legislation to ensure sustainable and equitable economic development for Lower Mekong River Basin groundwater resources. In this paper, we describe the groundwater resource research that has been undertaken as part of Australian Centre for International Agricultural Research (ACIAR) Project CSE/2009/004 (*Developing improved farming and marketing systems in rainfed regions of southern Lao PDR*) in the Soukhouma district of Champassak province of southern Laos and consider the policy implications of our findings, especially for Lao policymakers.

Description of the study area

Soukhouma district was selected as the focus of this study as it is a major agricultural producing region in Champassak province (Figure 2) and poverty affects 70% of the population (Lao People's Democratic Republic 2004). It has also been identified as a priority area to improve livelihoods through research and development. Soukhouma district spans from the Mekong River in the east to Thailand in the west and covers 117,951 ha, of which about 10% is dedicated to rainfed rice production. Only 0.2% of the total area has access to irrigation infrastructure for dry-season production. Soukhouma experiences a tropical monsoon climate with distinct wet (Apr–Oct/Nov) and dry (Oct/Nov–Mar) seasons. Based on meteorological records obtained from the Department of Meteorology and Hydrology (2013), the average daily temperature is 27.8 °C, the average annual rainfall is 1,800 mm and the average annual reference evapotranspiration is estimated at 1,860 mm. The topography of the district is mainly represented by lowland plains, which extend approximately 20 km west of the Mekong River. Beyond the edge of the alluvial plain, elevation rises to gentle slopes

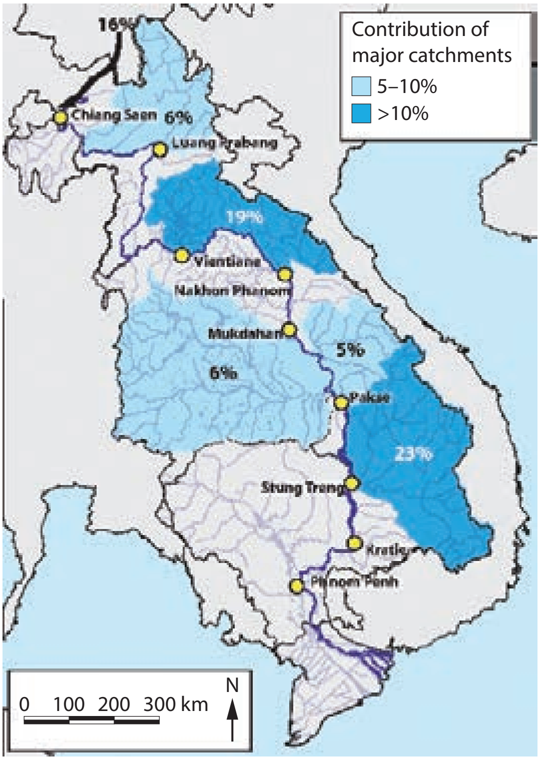

Figure 1. Contributions to flow of major catchments within the Lower Mekong River Basin.
Source: MRC (2009)

(~10–52 m above mean sea level, AMSL) while close to the mountainous border of Thailand, the elevation begins to rise from ~12 to 177 m AMSL along the border over a distance of less than 4 km. The network of streams within the district drains towards the Mekong River (Figure 3).

Figure 2. Map of Champassak province showing the location of Soukhouma district

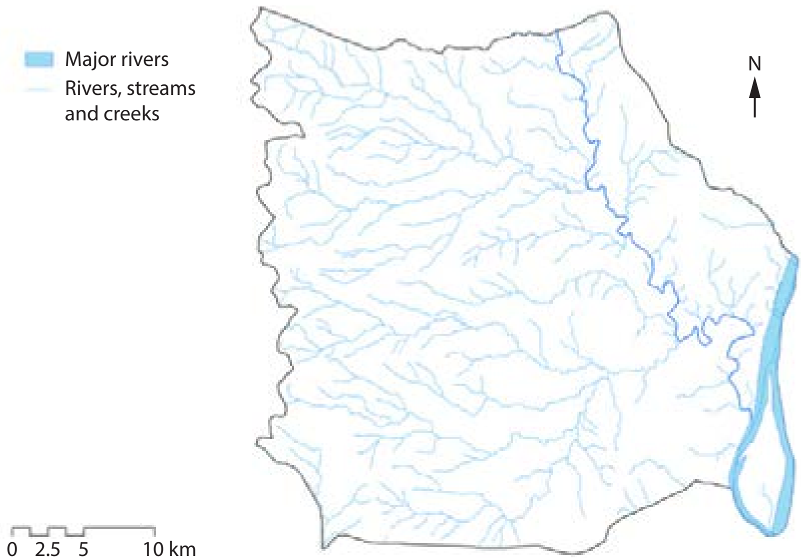

Figure 3. Stream network of Soukhouma district

Methodology

Groundwater and rainfall observation

Two approaches were used to understand the basic dynamics of the aquifer system within Soukhouma: the monitoring of 11 spatially separated existing domestic bores (Figure 4); and establishing a transect of five paired observation wells (Figure 5).

At each groundwater monitoring site, rain gauges were installed to enable rainfall to be measured daily. This information was used primarily to assess the

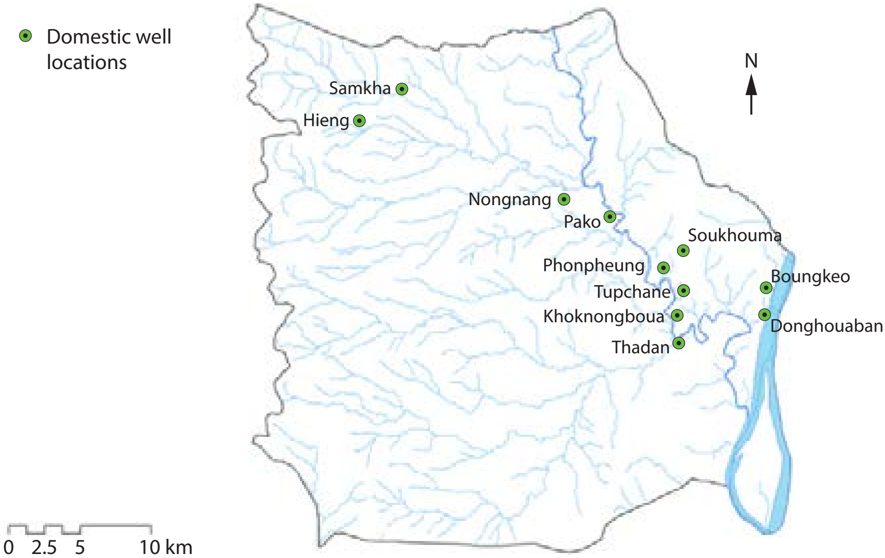

Figure 4. Location of domestic wells across Soukhouma district

Figure 5. Location of paired observation wells in Soukhouma district

response of the aquifer to rainfall; it also provided useful information regarding the distribution of rainfall across the district.

The shallow domestic wells—located along a transect from the Mekong River to the Thai border in a north-westerly direction—were monitored weekly for groundwater height and salinity (electrical conductivity, EC) using a water level meter (Solinst Canada Ltd, Ontario, Canada). Monitoring commenced on 2 October 2011 and ceased on 26 December 2013.

The paired observation wells were installed at five locations and were strategically placed to follow a north-westerly transect—from Boungkeo village near the Mekong River to the uplands about 2 km east of the Thai border (Figure 5). These sites were chosen as they appeared to follow a natural drainage line as determined from topographical (data not shown) and streamflow maps (Figure 3). The wells were developed between July 2012 (Boungkeo and Pako) and January 2013 (Soukhouma, Parkxang and Hieng). The shallow bores were approximately 25 m deep, while the deep bores varied in depth and ranged from 53 m at Parkxang to 120 m at Hieng. Further to the provision of additional groundwater-monitoring sites, the drilling logs and pumping tests conducted by the Department of Health and Sanitation (Pakse) provided useful information on lithology and discharge rates of each observation bore (C. Vote et al., unpublished report, 2013). Once established, these bores were monitored weekly for depth to water, salinity (EC) and temperature.

Characterisation of hydraulic properties and lithology of the aquifer

Based on well depth and lithological information provided by the drillers' logs, we concluded that most domestic and observation bores monitored during this project were drawing water from a deep confined sandstone aquifer located at depths of 25–70 m. Consequently, standard pumping test software (AquiferTest 2013.1) was used to characterise the hydraulic properties (i.e. hydraulic conductivity, transmissivity and storativity) of the aquifers using the Theis method (Theis 1935). The drilling logs also provided information to build a preliminary conceptual model of the aquifer system found within the Soukhouma district.

Determination of groundwater behaviour and regional groundwater flow

To determine areas of similar groundwater behaviour, geostatistical spatial interpolation methods (specifically, ordinary kriging) of the point-based groundwater data were employed to create a surface map of the area using standard tools within ArcGIS 10.1. Regional groundwater flow was analysed using the Darcy flow function. This model was used to generate raster data representative of groundwater flow vectors; the standard output being a groundwater volume balance residual raster, which is a measure of the difference between the flow of water into and out of individual cells (ESRI 2012). The inputs required to run the model include a set of raster data, which provide information regarding potentiometric surface, porosity (or specific yield) and saturated thickness of the aquifer and transmissivity.

Estimation of groundwater recharge

Groundwater recharge was estimated using the watertable fluctuation method. This is a simple, indirect method used to derive recharge in a shallow aquifer system, particularly in areas where there is a distinct wet and dry season (Andrade et al. 2005). It is based on the assumption that a rise in groundwater levels in an unconfined aquifer is attributed to recharge water arriving at the watertable (Healy and Cook 2002), where recharge (R) is calculated as in equation (1):

$$R = S_y \frac{\Delta h}{\Delta t} \tag{1}$$

where S_y = specific yield; $\Delta h/\Delta t$ = change in groundwater level (h) over a period of time (t).

Specific capacity of boreholes

The specific capacity of boreholes was determined by dividing discharge by drawdown (Fitts 2002) as given by equation (2):

$$SC = \frac{Q}{s} \tag{2}$$

where SC = specific capacity (L/s/m); Q = discharge (L/s); and s = drawdown in the pumped well (m). Since transmissivity is inversely proportional to drawdown, specific capacity is directly proportional to transmissivity.

Findings

Lithology, hydrogeology and hydraulic properties of observation bores

The drillers' logs indicated that the upper layer of the lithological profile within Soukhouma district comprised an unconsolidated material of silty sand and clay overlying a low conductive layer of mudstone and shale (4–40 m). At three locations, there was an additional layer of shale and sandstone (12–60 m). In all five instances, the underlying layer consisted of a sandstone aquifer that varied in depth and thickness. Artesian bore pressure observed during the installation of the wells implied that this particular aquifer may be confined.

The hydraulic properties of the aquifer system observed in this study are presented in Table 1. The storativity values ranged between 2.3×10^{-3} and 0.58, which suggested that the upper mudstone and shale layer may be only a weak confining layer. However, this information is inconclusive and more comprehensive studies are required to determine the precise nature of the aquifer system located within Soukhouma.

Temporal dynamics of groundwater levels

Fluctuations in watertable depth occur for numerous reasons, including recharge, changes in barometric pressure, evapotranspiration, lateral flow and pumping for industrial, domestic or agricultural use (Rasmussen and Crawford 1997; Crosbie et al. 2005). Figure 6 presents depth to the watertable and rainfall monitored at five selected domestic wells (Soukhouma, Pako, Khoknongboua, Tupchane and Phonpheung) from 1 October 2011 to 31 October 2012.

As illustrated in Figure 6, it appeared that groundwater levels responded to seasonal rainfall. Although the 2012 wet season began in April–May, groundwater levels in the bores did not begin to recover until June–July—by which time, 40% of total rainfall had been received. The 2–4 month lag is most likely attributable to the time taken to fill the soil profile following the dry season.

Maximum depth was recorded for all domestic wells, except Nongnang (data not shown), during the first few months of the wet season (late April–early July). Minimum depths were observed from early September to mid October, except for Tupchane where the minimum peak was reached on 7 August 2012. Domestic boreholes located further away from the river experienced less total annual fluctuation. The greatest differences in watertable heights were observed in those villages closest to the Mekong River (i.e. Boungkeo, Thadan, Donghouaban and Tupchane); this is indicative of the close linkage of surface–groundwater bodies between the Mekong River and the shallow aquifers in areas close to the river.

Initial observations of depth to groundwater indicated that the paired observation wells (both the shallow and deep bore) located at Boungkeo, Soukhouma, Pako and Parkxang appeared to penetrate the same aquifer system, as indicated by the similar depths to groundwater in both bores (data not shown). However, the paired bores located at Hieng appeared to be located in two different stratigraphic layers.

Estimates of groundwater recharge and groundwater flow

Groundwater recharge in this study, calculated using the watertable fluctuation method, appears to be overestimated, particularly for the bores situated at Soukhouma and Parkxang, which further implies that the sandstone aquifer may be confined rather than unconfined (see earlier section on 'Lithology, hydrogeology and hydraulic properties of observation bores'). Therefore, a predetermined value of 0.1 was

Table 1. Hydraulic properties of the aquifer estimated using the Theis approach

Site of observation well (village)	Transmissivity (m^2/day)	Storativity (dimensionless)	Hydraulic conductivity (m/day)
Boungkeo	173	0.01	3.76
Soukhouma	313	0.58	9.21
Pako	265	2.30×10^{-3}	8.83
Parkxang	174	0.58	7.57
Hieng	0.17	0.05	6.00×10^{-3}

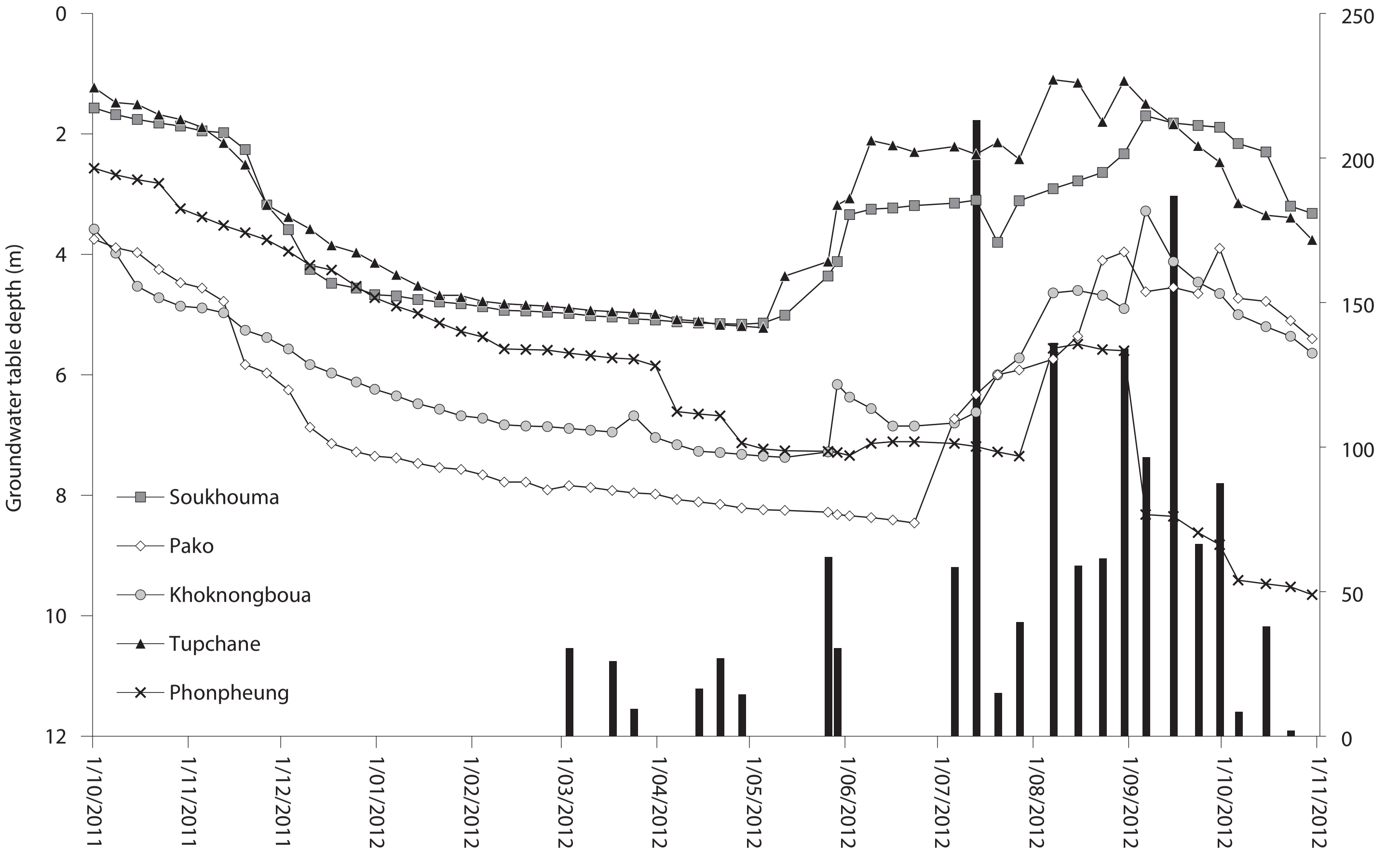

Figure 6. Rainfall and depth to the watertable at five domestic wells over the period 1 October 2011 to 31 October 2012 (vertical bars = rainfall)

substituted to estimate recharge. This value is based on known geological properties of similar sandstone formations (Fitts 2002). Estimated recharge values for the 28 April 2012 to 12 October 2012 period are presented in Table 2.

Table 2. Estimated groundwater recharge for the period 28 April – 12 October 2012

Site of domestic well (village)	Recharge	
	mm	%
Soukhouma	346	20
Samkha	371	22
Pako	456	27
Nongnang	158	9
Khoknongboua	409	24
Tupchane	412	24
Thadan	480	28
Boungkeo	464	27
Donghouaban	422	25
Phonpheung	352	21
Average	387	22

Note: percentage of annual recharge based on an average annual rainfall of 1,800 mm; Hieng was omitted from this analysis due to the difference in hydraulic properties.

As illustrated in Figure 7, the interpolated results indicated that recharge was greatest in the areas in the eastern part of the district. For example, the highest recharge estimate occurred at Tupchane (480 mm). There was also an area of high recharge at Pako (456 mm), which is situated on a tributary stream that drains into the Mekong River. Further to the west, recharge began to decrease and was least in Nongnang (158 mm). This is most likely attributable to a hydraulic gradient from the elevated areas in the north-west of the study area to the lowland plains in the east. The average recharge calculated across the region was 387 mm (Table 2) and represented ~22% of total rainfall received during this period.

Towards the end of the wet season (September 2012), the direction of groundwater flow calculated using the Darcy flow function showed that groundwater flowed predominately from west to east towards Soukhouma village (Figure 8). This model also indicated groundwater flow from the Mekong River back towards Soukhouma village (i.e. east to west); another indication of the strong surface-groundwater interactions near the river at this particular time.

Implications for policymakers

Numerous reports have indicated that substantial volumes of groundwater are believed to exist in the alluvial sediments associated with the Mekong River in South-East Asia. Although some aquifers probably contain salts, most are believed to contain mainly fresh water (WEPA 2014). These sources have great potential to supply the domestic water needs of rural communities. As electrification of the region proceeds, investment by many households and villages in shallow tube wells has ensured a supply of safe, reliable and comparatively cheap pressurised domestic water. As time progresses, rural communities will become increasingly dependent on shallow groundwater as their principal water source, of which signs are already evident. For instance, a household survey of three villages in Champassak province conducted in June 2013 indicated that water usage had increased beyond purely household needs, and that groundwater was more commonly being used to irrigate household gardens and small commercial vegetable plots. In the near future, this practice may become universal as householders identify groundwater irrigation of small plots as a means of improving food quality and deriving household income. Inevitably, this will lead to an increase in either the number of bores or expanding the size and depth of existing bores to access greater volumes of groundwater.

Global experience regarding the development of groundwater systems to ensure long-term sustainable use indicates that:

- it is easier and less stressful to plan and develop policy before a resource is developed
- system vision and knowledge, forward planning and policy development, together with supporting legislation, are necessary elements for enabling effective governance of a natural resource.

Groundwater use of the Mekong alluvial plain in southern Laos is in its infancy but pressures exist to increase usage of this resource. It would therefore seem timely, given the experience of others, for the Lao Government to develop policy and legislation to guide the sustainable development of this resource.

Interaction between surface and deeper groundwater systems

The research undertaken in ACIAR Project CSE/2009/004 (*Developing improved farming and*

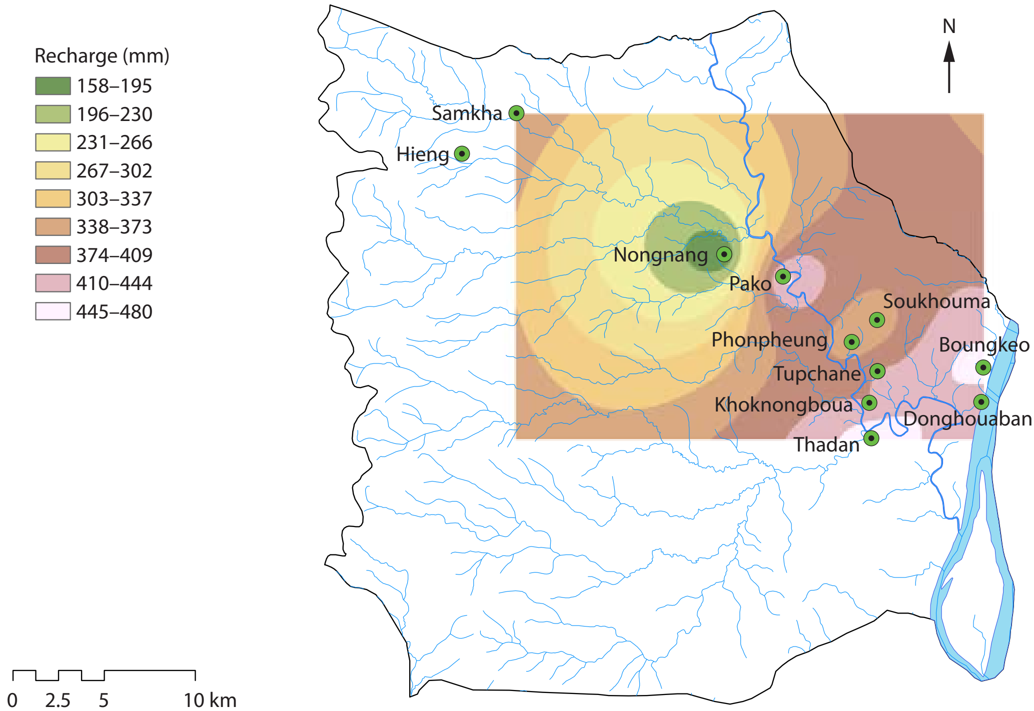

Figure 7. Spatial interpolation of regional groundwater recharge in the Soukhouma district for the period 28 April – 12 October 2012

marketing systems in rainfed regions of southern Lao PDR) focused on only the shallow aquifer of the Mekong alluvium. The intention in developing the deep observation wells was to drill beyond the surface system so as to understand the interaction between the deeper and shallow system. However, drillers' logs indicate that this intent may not have been realised; or that no tangible aquitard exists between the water-bearing layers. As indicated in Figure 6, watertable height across the alluvial plain is highly seasonal, clearly illustrating the relationship between rainfall and recharge after the onset of the wet season, and periods of discharge during the dry season.

Although it is probable that the aquifer system investigated in this study has capacity to allow for some irrigation using groundwater, extensive groundwater irrigation across the plain, particularly for crops with high water requirements (e.g. rice), is unlikely to be sustainable. This is particularly true for those areas where aquifers are replenished only by surface leakage and the lower average annual estimates of recharge do not meet crop water use requirements. This conclusion is based on several assumptions, including: the surface aquifer is fed only by surface recharge without appreciable lateral flow, and any subterranean system is separated by an impermeable aquitard from which upflow is negligible. As considerable knowledge gaps still exist, further detailed study of the groundwater systems within the region are required before adequately informed policy can be developed. At a regional scale, these studies should include:

- better estimates of recharge and lateral flow patterns
- the relationship between surface and underlying aquifers
- quality modelling to: (1) investigate various extraction scenarios on watertable levels, and recovery rates and impact on other users; (2) spatially distinguish areas and depths from where water can be extracted with minimal impact to other users; and (3) analyse impacts on groundwater behaviour and watertable levels based on regional climate-change predictions.

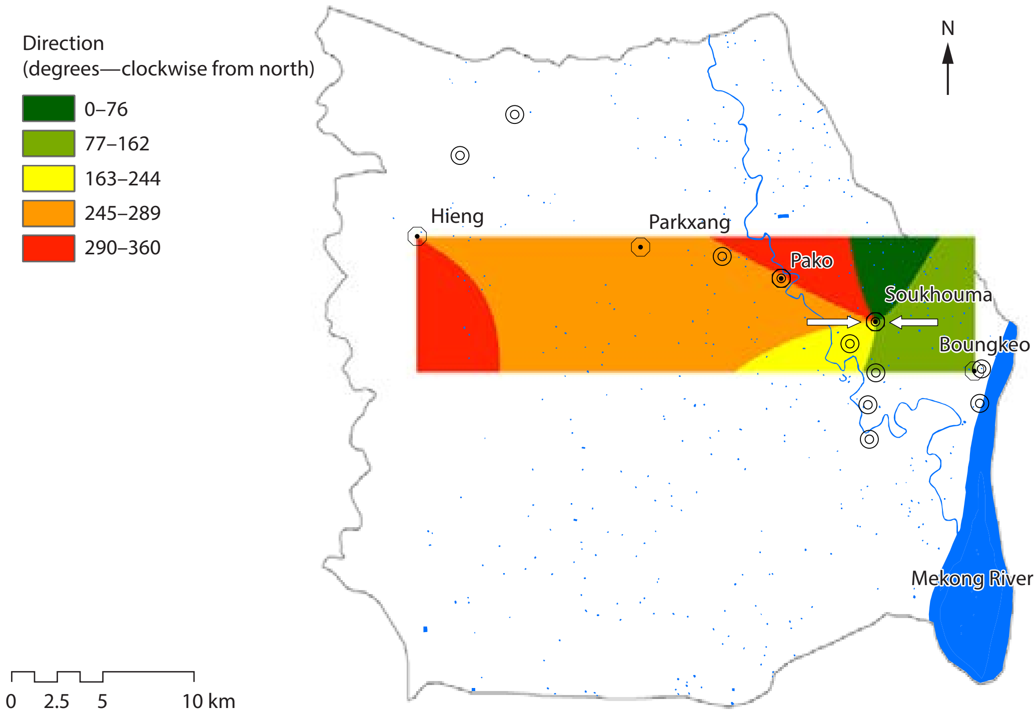

Figure 8. Modelled groundwater flow direction in the Soukhouma district, September 2012

These studies will also provide better knowledge about system behaviour at a more local scale, which will inform policy and guidelines on the specific installation of groundwater infrastructure, such as well depth for specific uses, distance between wells and distance to environmental assets (e.g. wetlands and rivers).

Risks regarding capacity of the system to deliver water to domestic users

Greater rates of groundwater extraction will increase the depth to watertables at times when recharge or other inputs of groundwater are limited, except in the case of groundwater bodies of exceptional size. Figure 6 illustrates the high seasonality of the depth to groundwater; greater consumptive use will result in further decline in watertable height, especially in the dry season. Watertable heights may drop to depths greater than the average depth of household domestic wells, preventing affected households from being able to pump water. Evidence obtained through the household survey showed that this is already occurring in some villages in northern Champassak province, although the exact cause is unknown.

Although the primary objective of developing groundwater policies is to ensure sustainable resource use, it is also important to establish access priorities for environmental needs, basic human needs (domestic supply), industrial use and irrigation. Accompanying policies for managing any conflicts arising are also needed. Mechanisms should be put in place to adequately protect higher priority uses from the potential adverse impacts from lower priority uses.

Licensing, metering and measurement

Future sustainable groundwater resource use, particularly where demand exceeds supply, will mean higher user costs and more bureaucracy. To achieve equitable access and use, certain procedures governing use are mandatory, including:

- establishment and maintenance of a regional register of infrastructure and individual bore capacity
- licensing of users, and allocation of volumetric entitlements
- calculation, or preferably metering, of water use.

Conclusion

Almost without exception, the experience of most countries regarding groundwater use has been that development and use has preceded the development of legislation governing use. Under these circumstances, the development of legislation that focuses on returning usage to sustainable levels commonly occurs in an environment of conflict and acrimony—with users losing both access to water and part of their investment. With groundwater use in southern Laos in its infancy and with growing demand, it would seem opportune to develop legislation that will ensure sustainable and equitable future access to groundwater reserves. However, as effective legislation cannot be developed in the absence of data, there is an immediate need for knowledge of the lower Mekong alluvial aquifer in a form that enables informed policy development. Although some studies focusing on the Mekong alluvium have been recently conducted, there is a need for wider and more strategic investment—incorporating scenario modelling—to enable the development of a regional groundwater model. The existence of such a tool may allow for the establishment of rules for access and use, so that future growth in use is legislated for without compromising the resource.

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