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Mekong River dry season changes due to hydropower dams and extractive processes: Making sense of contradictory community observations in Thailand, Laos and Cambodia

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ABSTRACT: The Mekong is amongst the most important rivers in the world with regard to biodiversity and livelihood. Over the last few decades, however, the river has experienced dramatic hydrological changes, mainly due to the construction of large hydropower dams on the mainstream Mekong and its tributaries. Other potentially crucial factors include sand mining, erosion, embankment construction, and water extraction. In March and early April of 2024, we organised focus group interviews to discuss the changes that have occurred during the dry season with local people living in different communities along the mainstream Mekong River: 32 villages in eight provinces in northern and northeastern Thailand, 9 villages in Champassak Province, southern Laos, and 3 villages in Stung Treng Province, northeastern Cambodia. In this paper, we present some of the results of this research, particularly focusing on water level and turbidity changes, as local people along the Mekong River have varied understandings regarding whether there is more or less water in the Mekong River during the dry season. We argue that riverbed incision resulting largely from hydropower dam development and sand mining have, in particular, led many people living along the Mekong between northeastern Thailand and central Laos to incorrectly believe that there is less water in the Mekong River during the dry season compared to the past, while dry season water releases from upriver hydropower dams have led those in northern Thailand, lower northeastern Thailand, southern Laos, and northeastern Cambodia to assess that there is now more water in the Mekong River.

KEYWORDS: Hydrology, sediment, local knowledge, water level, Mekong River, Thailand, Laos, Cambodia

INTRODUCTION

Everyone seems to agree that the Mekong River has undergone significant changes over the last few of decades (MRC, 2021; Eyler et al., 2024); indeed, hundreds of dams of various sizes have been built on the mainstream Mekong River and its tributaries (Eyler et al., 2024). But while such dams are bound to lead to some changes, there is a lack of consensus amongst the people living along the river regarding the changes that have occurred. Illustrative of this, one community leader living in a village adjacent to the mainstream Mekong River in Ubon Ratchathani Province, Thailand, told us in March 2024 that there had been significant disagreements and debate amongst villagers living along different stretches of the river regarding whether there was more or less water in the Mekong River during the dry season when compared to decades ago. This debate especially intensified when villagers from different locations along the Mekong River in Thailand attended networking meetings regarding the river. For example, those from

Nong Khai Province insisted that there was less water in the Mekong compared to decades earlier, while those from Ubon Ratchathani mostly believed that there was more water in the Mekong during the dry season. While this debate has been ongoing along the Mekong River in Thailand for some time, it has not yet been discussed in the literature. This paper is intended to fill that gap, including a consideration of the changes that have actually occurred and their causes.

The perceptions of different people regarding environmental change are crucial, and not just because such perceptions influence what people think the problems are and what causes them; they also determine what policies and policy changes are advocated for by different people and groups. Thus, public understandings of environmental policy need to be given sufficient consideration, even when those perceptions are inaccurate and not based on credible evidence (see Forsyth and Walker, 2008).

Whether there is actually more or less water in the Mekong mainstream during the dry season is crucial, as increased water can negatively impact various important habitats, such as flooded forests, and the many species that depend on these habitats, including various fish species and others (Baird and Thorne, 2023). Too little water can also have negative environmental and social impacts. These negative impacts can in turn adversely affect local livelihoods. Changes in water levels in the Mekong River also has important implications for the Mekong Delta in Vietnam, especially due to related changes in salt-water intrusion and erosion there.

The objective of this paper is to consider why villagers who all have close and long-term livelihood connections to the Mekong River differ in their understandings of whether there is more or less water flowing down the river during the dry season, depending where along it they live. We also consider how hydrological and sediment flow data can help to better understand these discrepancies. This question is justified because local people themselves are debating the status of dry season water levels. We argue that sediment transport changes along the mainstream Mekong River, combined with geological factors and sand mining, have resulted in people living at various locations along the river coming to contrasting conclusions regarding the dry season hydrological changes that have occurred, despite the upstream dams having measurable effects everywhere downstream along the mainstream Mekong River.

The paper proceeds as follows: In the next section we explain our methods. We then present the results of our focus group interviews with local people living along the Mekong River. Next, we present other hydrological, water extraction and turbidity data. We then consider erosion and riverbank embankments, hydropower development impacts, and sand mining impacts before finally discussing how local understandings of water levels during the dry season might be explained and what the implications of our findings are, both in terms of local perceptions and environmental changes along the Mekong.

METHODS

In recent years, remote sensing has become a powerful way to monitor changes to the environment. Indeed, it is now possible to track water surface area in reservoirs along the river using satellite imagery (see, for example, Vu et al., 2022; Eyler et al., 2024; Mahto et al., 2024). It can also be used to assess riverbank erosion (Kummu et al., 2008; Tha et al., 2022) and even to estimate numbers of sand mining operators on parts of the Mekong River (Hackney et al., 2021). But while satellite technology has immense value, it can also lead to erroneous assumptions, because while it allows us to observe changes, it cannot necessarily explain the reasons for many of those changes.

At the same time, because it has become much easier to gather data about hydrological changes in the Mekong from physical gauges and remote sensing technology, the views of people living along the river have not been sufficiently considered, leading to local conditions and explanations generally being overlooked. This study, therefore, is focused on how local people who live along the Mekong River perceive the changes the river has undergone over the last few decades, with an emphasis on the dry

season. However, we also rely on other expert and government interview data, as well as quantitative data.

Our methods are partially based on previous research that we conducted along the Mekong River in Stung Treng Province, northeastern Cambodia in June 2022 (Baird & Thorne, 2023). At that time, we interviewed local people living along the Mekong and made use of national hydrological data to understand how the river has changed during the dry season, and particularly why much of the seasonally inundated forests located within the Mekong riverbed and along its banks have died in recent years. This research was inspired by that previous work, with the idea of scaling up the study to learn from local people living along a much greater length of the river about how the Mekong River is changing and how such changes are affecting them. We come from a position of strongly agreeing with various other researchers who have pointed to the great value of local knowledge regarding various kinds of aquatic ecosystems (Haggan et al., 2007; Silvano et al., 2023; Hamelin et al., 2024), especially for complex tropical ecosystems where much less research has been conducted than in environments proximal to more industrialised parts of the world (Johannes et al., 2000). This is especially the case for people who spend large amounts of time interacting with and observing rivers and aquatic life as part of their everyday livelihood activities (Baird, 2006, 2007; Baird and Manorom, 2019). We wanted to take advantage of these people's deep local knowledge, and we tried to engage with them in a manner that was most conducive to obtaining accurate information (see Baird, 2006).

Our focus was on changes during the dry season, between February and April, when Mekong River waters are typically at their lowest. Historically reduced water levels during this season are especially important for the survival of flooded forests and other types of riverine vegetation. Carrying out the interviews during the dry season was advantageous, since when we spoke with villagers, often near the river, they could more easily show us what they were talking about. In addition, less agricultural activity occurs during this season, which made it easier for local people – most of whom are farmers and fishers – to participate in discussions without it interfering with their work.

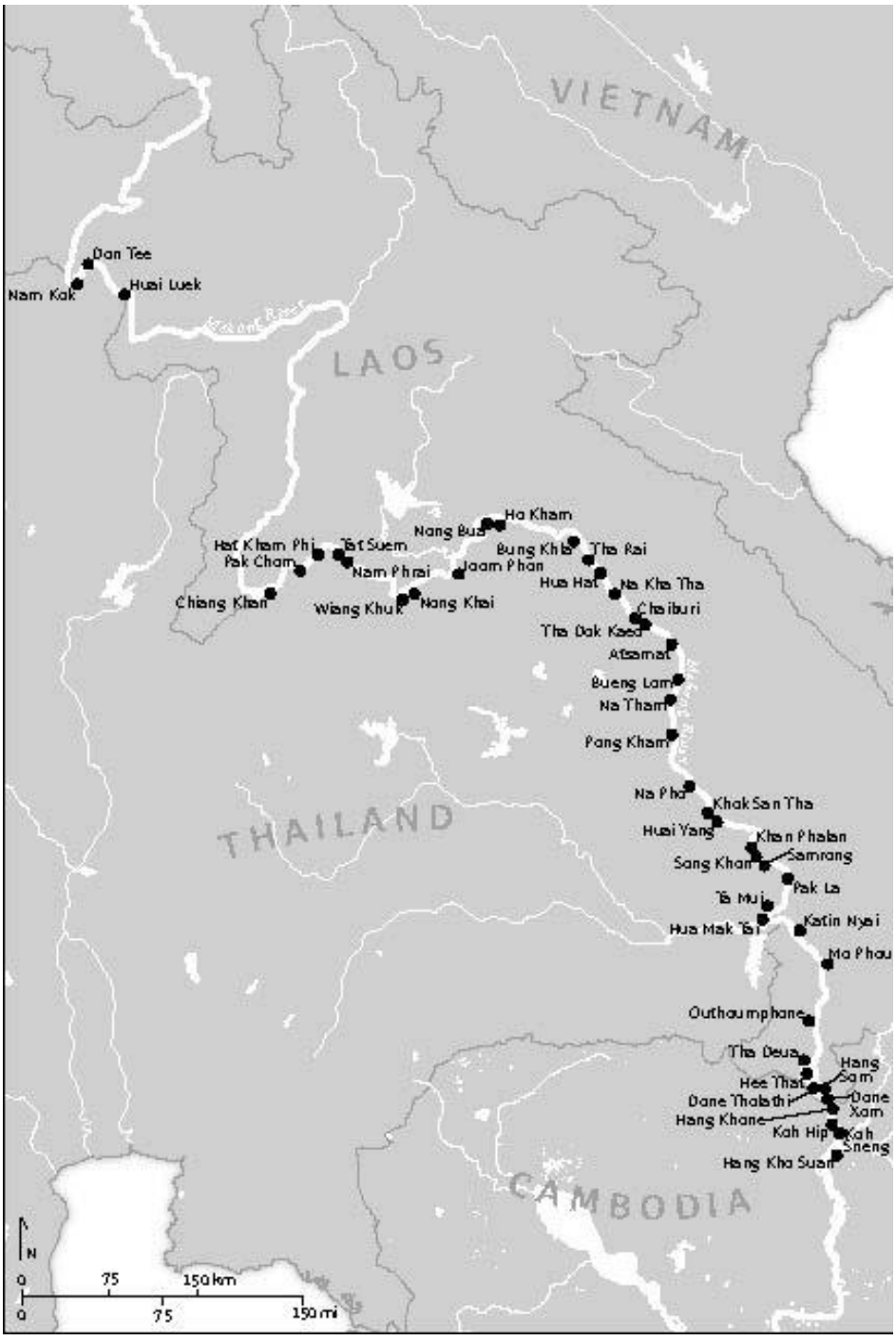
Thus, we set out a plan to visit villages along the Mekong River in Thailand, Laos, and Cambodia during March and April. We decided to visit villages along the river at intervals; we did not choose exact distances between villages but hoped to visit communities at intervals of less than 50 km away from each other. We visited two contiguous regions. One where the Mekong acts as the border of Northern Thailand and Laos; the other where the Mekong flows down from Laos to form the border with Thailand all the way to Stung Treng in Northern Cambodia. Villages were often chosen based on factors such as distance from each other, but some were chosen because we already had contacts there, or because of information that had been provided by non-government organisations (NGOs) and their allies working along the Mekong River. This meant that some residents were active members of NGO networks. However, in many villages we visited, we had no contacts.

During our community visits, groups of villagers, both men and women, mostly between their 40s and 70s, met us informally at different locations, ranging from open air structures adjacent to the Mekong to individual homes. The interviews were semi-structured, in that we had a pre-determined list of topics and general questions regarding dry season Mekong River changes in the area that we intended to ask in each community we visited. These focus group interviews were sometimes conducted in Central Thai, but were mainly done using various dialects of Lao, including Northern Lao, Isan Lao, Southern Lao, and Northeastern Cambodian Lao. The first author, who is fluent in all of these languages and dialects, led the interview and discussion process in the villages, with each group interview and discussion taking between one and two hours. In addition, we sometimes combined interviews with short walks, drives, or boat trips to observe aspects of the Mekong River, often accompanied by the villagers we were interviewing.

Interviews with locals were conducted in 32 villages in eight provinces (Chiang Rai, Loei, Nong Khai, Bueng Kan, Nakorn Phanom, Mukdahan, Amnat Charoen and Ubon Ratchathani) in northern and

northeastern Thailand, 9 villages in Champassak Province, southern Laos, and 3 villages in Stung Treng Province, northeastern Cambodia (Figure 1). (We decided not to interview people in northern and central Laos due to logistical limitations.) The village interviews were all done between March 1 and April 3, 2024. We started at the village farthest upstream (in Chiang Saen District) and gradually travelled downstream through Thailand before crossing into southern Laos and northern Cambodia, conducting the final interview just north of Stung Treng Town.

Figure 1. Map of the villages where focus group discussions were conducted along the mainstream Mekong River in March and April 2024.



Given that the villagers' responses were subjective, we did not expect them all to align with each other or to be necessarily factual. However, the people we interviewed were almost all rural farmers who have interacted with the river for livelihood reasons for most of their lives, especially for daily fishing activities and also when cultivating crops on islands and riverbanks along the river, so they have accumulated considerable in-depth knowledge about the river over time. What is particularly striking about the information we received from them is that people from multiple communities in the uppermost and lowermost parts of our study area reported higher water levels during the dry season, while many communities in the middle section of the study area reported lower water levels during the dry season. This consistency across multiple groups of people living along specific sections of the river increased our confidence in their reports, even if what was reported was initially contradictory.

While the foundations of this research were the village focus group interviews, we did not constrain ourselves to a single method. Apart from making observations and taking measurements in the field, we also interviewed local government officials during the same time period, particularly in Thailand. In addition, after the main fieldwork was completed, we conducted follow-up research. Information was collected about sand mining through interviews in Laos and Thailand, turbidity and other data such as water extraction statistics were collected from authorities in Thailand, and hydrology data was obtained from the Mekong River Commission (MRC) via the Stimson Center (see below). In particular, we looked at water gauge levels during the dry season months of February, March, and April at Chiang Saen (1960-2023), Nakhon Phanom (1924-2023), and Pakse (1923-2023). We examined the monthly average water levels for all the years of data available at each location (see Figures 2-4). Finally, we conducted a number of interviews with various Mekong hydrology experts to discuss our findings.

Ultimately, while our starting point was to utilise the local knowledge of people who have lived along the Mekong for most or all of their lives, we tried to make use of whatever information could contribute to answering our questions, so our research can best be described as applying mixed methods.

VILLAGER RESPONSES

The people we interviewed along the Mekong River provided a great deal of interesting and useful information regarding Mekong River changes. However, this paper is especially focused on their responses to a standard question that we asked in every community we visited: "Do you think that dry season water levels in the Mekong River Basin over the last few decades have increased or declined?" Crucially, during the interviews, we assumed that water levels and water discharge were correlated, and the interviewees also made the same assumption.

In 2022, when we conducted similar research along the Mekong River in Stung Treng Province, northeastern Cambodia, all the people we spoke with were certain that water levels had increased during the dry season in recent decades. Moreover, hydrological data from the Pakse station in southern Laos, the closest hydrological gauge upriver from Stung Treng, confirmed villager reports that water levels during the dry season had increased significantly over the previous 15-20 years or so, due to hydropower dam water releases upriver (Baird and Thorne, 2023). So we expected that local people living upstream in Laos and Thailand would also report increased water levels during the dry season.

Our 20 or so interviewees from Chiang Rai Province in northern Thailand did all report that dry season water levels have increased dramatically, sometimes as much as two to three meters higher. (It should be noted that the Xayaburi Dam in Laos is too far downstream to affect northern Thailand via the backwater effect.) Villagers in Loei Province, in northeastern Thailand, also reported higher water levels during the dry season. However, beginning in Tat Suem Village, Sangkhom District, Nong Khai Province, villagers began to report that there is now *less* water in the Mekong River during the dry season. This response surprised us, as it contradicted reports from the villagers upriver of Tat Suem and also seemed to contradict official hydrological data. However, we found that villagers from communities downstream from Tat Suem also reported that there is less water during the dry season than before. In fact, this was

consistently reported in 17 villages between Tat Suem Village and Pong Kham Village in Wan Yai District, Mukdahan Province, including villages in Nong Khai, Bueng Kan, and Nakorn Phanom Provinces, and part of Mukdahan Province. However, from Na Pho Village, Ton Tan District, in southern Mukdahan Province, down past Amnat Charoen and Ubon Ratchathani Provinces in northeastern Thailand, villagers once again reported that there is more water in the Mekong during the dry season compared to a few decades earlier. Locals in Champasak Province, southern Laos, and Stung Treng Province, northeastern Cambodia, also consistently reported more water in the Mekong during the dry season.

Villagers often justified their observations by basing them on riverine landmarks, such as particular large rocks or riverbank characteristics. By observing these locations year after year, they had developed relative understandings of annual changes in water levels.

We were initially perplexed. How could it be that people from the first six villages that we visited in Chiang Rai and Loei Provinces reported that there is more water during the dry season compared to the past, followed by the next 17 villages reporting that there is less water during the dry season, and then the last 21 villages downstream again reporting that there is more water during the dry season? We could not initially imagine how these findings could be correct; this would imply the presence of more water upstream, less water in the middle stretch of the river, and then more water again downstream in the same river. But neither could we simply dismiss these findings, as the reporting was consistent over many villages and different but adjacent geographical areas.

Crucially, these findings encouraged us to look for additional evidence that could help us understand what the villagers had reported to us. The following sections of the paper are devoted to making sense of the above-outlined puzzle, and we think that the findings are quite useful for understanding how the Mekong River has changed over the last few decades and why local people have reported particular changes.

MEKONG RIVER HYDROLOGICAL CHANGES DUE TO HYDROPOWER DAM DEVELOPMENT

The hydrological data for the Mekong River during the dry season within our study area indicate that the mainstream Mekong River south of China, at gauge stations located at Chiang Saen, Nakorn Phanom, or Pakse, has more water flowing down it during the dry season (specifically for the months of February, March, and April) than was the case before the Mekong dams in China began being built in the 1990s. Unfortunately, however, the exact amounts of water released downstream since the dams in China were constructed are not publicly available, so we only have the MRC hydrological data from the lower Mekong countries to work with.

Water levels at the three stations for February, March and April are shown in Figures 2-4. These figures also indicate when four of the key dams on the Lancang/Mekong River in China were commissioned: the Manwan Dam (1995), the Jinghong Dam (2008), the Xiaowan Dam (2010), and the Nuozhadu Dam (2012). For a detailed history of hydropower dam development in the Mekong River Basin, see Sneddon (2015), Soukhaphon et al. (2021), and Middleton (2022).

Figures 2-4 clearly indicate that the volume of water in the mainstream Mekong River during the height of the dry season, whether at Chiang Saen, Nakorn Phanom, or Pakse, has significantly increased since the early 1990s, and especially since the 2010s. Water volumes have decreased somewhat from their highest dry season levels over the last couple of years, although they are still higher than historical levels. The most recent change has been reported to be at least partially due to a lack of rain in the upper basin (Eyler et al., 2024).

Figure 2. Mekong River water volumes at Chiang Saen during the months of February, March, and April between 1960 and 2023. Commission dates of four of the main upstream dams are indicated (M = Manwan Dam [1995]; J = Jinghong Dam [2008]; X = Xiaowan Dam [2010]; N = Nuozhadu Dam [2012]).

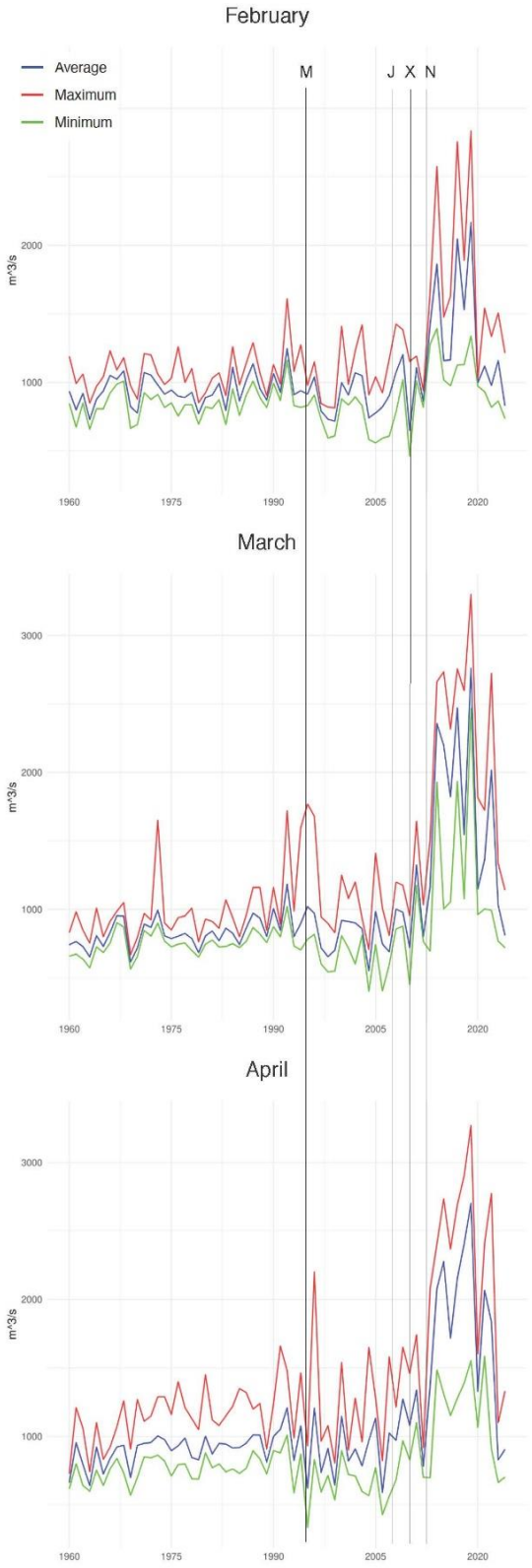


Figure 3. Mekong River water volumes at Nakorn Phanom during the months of February, March, and April between 1924 and 2023. Commission dates of four of the main upstream dams are indicated (M = Manwan Dam [1995]; J = Jinghong Dam [2008]; X = Xiaowan Dam [2010]; N = Nuozhadu Dam [2012]).

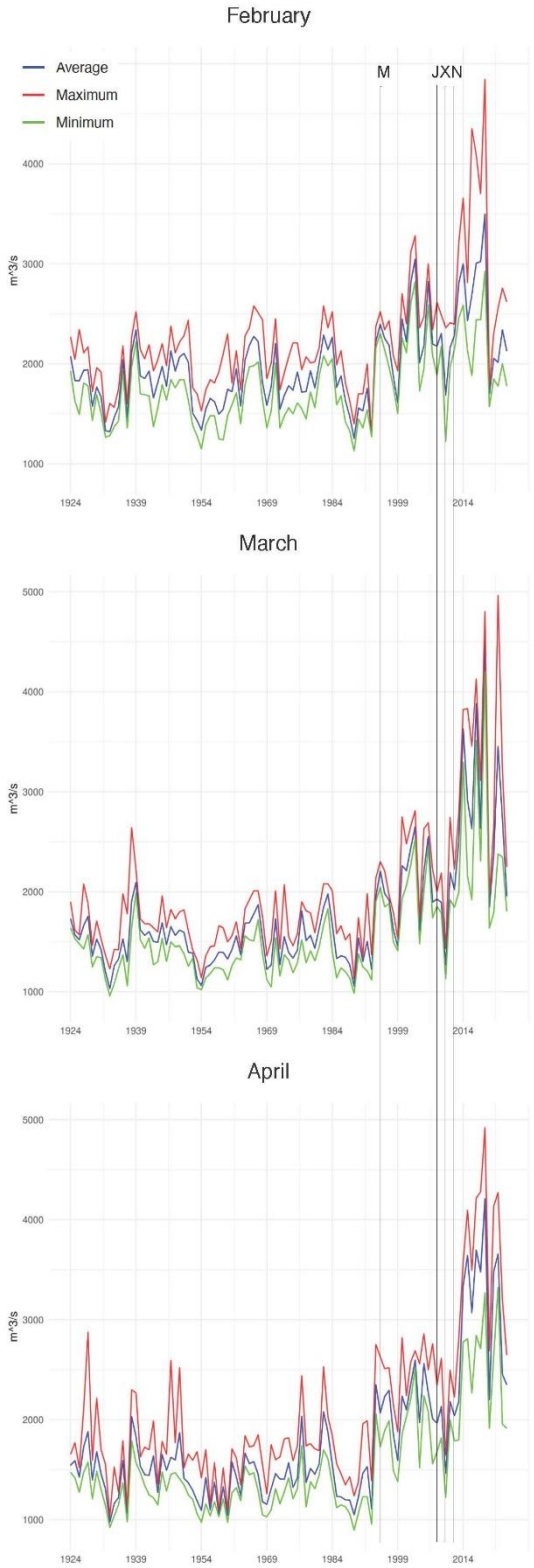
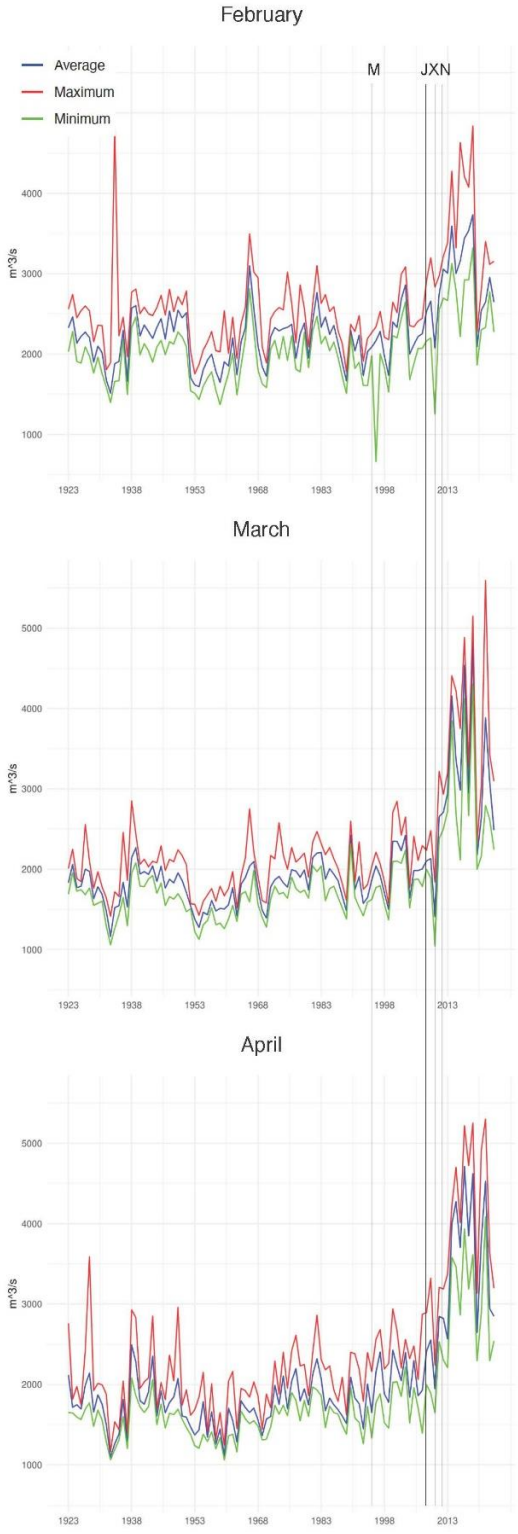


Figure 4. Mekong River water volumes at Pakse during the months of February, March, and April between 1923 and 2023. Commission dates of four of the main upstream dams are indicated (M = Manwan Dam [1995]; J = Jinghong Dam [2008]; X = Xiaowan Dam [2010]; N = Nuozhadu Dam [2012]).



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Hydropower dams can cause considerable daily fluctuations to downstream water flows (Wyatt and Baird, 2007; Morovati et al., 2024), something that local people widely reported during our fieldwork. However, other dams, including the Xiaowan and Nuozhadu Dams in China and some of the larger tributary dams in Laos, have large enough reservoirs to store water during the rainy season and gradually release it to produce electricity throughout the year, including during the dry season, resulting in overall increases in dry season flows (Eyler et al., 2024). This commonly occurs downstream of hydropower dams with large reservoirs (McCully, 2001).

There is compelling evidence that the construction and operation of large mainstream and tributary dams in China are the main cause of increased downstream flows during the dry season. Räsänen et al. (2012) reported that over a decade ago at Chiang Saen, in 2011, dry season water discharge had already increased from between 34 and 155% between December and May, and this was before all the present dams along the Lancang (Mekong) River in China had been built. These changes became even more pronounced by 2014, after more dams in China had been built, with water discharge at Chiang Saen between March and May increasing by between 121% and 187% (Räsänen et al., 2017). However, there has been significant tributary dam construction in Laos over the last couple of decades, with a large number still being built at present, and those dams are likely to be causing significant changes, although detailed research on this aspect has so far not been conducted. Dams have also caused serious downstream impacts along the tributaries (Claassen, 2004; Wyatt and Baird, 2007; Lacombe et al., 2014; Baird et al., 2015; Hecht et al., 2019; Middleton, 2022; RFA, 2024).

With all these changes occurring to the Mekong and its tributaries, one has to wonder about the accuracy of the water level calculations along the Mekong. That is beyond the scope of this study, but according to the head of the Thai Meteorological Department in Mukdahan, which monitors 25 gauges in Mukdahan and Nakhon Phanom Province, the gauges are frequently recalibrated for accuracy and are therefore believed to be fairly accurate.[1] We were not, however, in a position to verify this claim.

The hydrological data presented above is revealing, but it did not resolve the discrepancy between the villager reports about dry season water levels.

WATER EXTRACTION

Following the village-level fieldwork, we considered whether water extraction might help explain the different responses we received from villagers about dry season water levels.

First, there are large numbers of small and medium-sized pumps located on the Mekong River along the Thailand-Laos border, with water being pumped mainly for agricultural purposes but also for providing domestic water to many villages, towns, and cities located along the Mekong River. Crucially, according to the water utilisation rules agreed upon by member countries of the MRC, it is permitted to pump water from the Mekong River for agricultural and domestic purposes during the dry season, but only for use by communities located directly adjacent to the Mekong River. This rule is in place to prevent the over-extraction of water during the dry season. Projects designed to transfer water longer distances from the river must pass through the MRC public consultation process and international agreement in certain cases; up to now, no such projects have been officially proposed through the MRC process.

We were able to obtain some data about major Mekong water extraction on the Thai side of the border. Most of the total pumping capacity of 166 m^3/second reported involves two projects in Nong Khai Province: the Huai Luang Project in Phon Phisai District, which has the capacity to pump 150 m^3/second (90% of the total capacity), and the Huai Mong Project in Tha Bo District, which has a pumping capacity of 13.4 m^3/second (less than 8% of the total capacity). Thus, the remaining pumping capacity of all the other locations is just over 2% of the total (Government of Thailand, no date).

[1] Usap Phaensaen, Director of the Thai Meteorological Department, Mukdahan Province, March 18, 2024.

We were also able to obtain the 2013 data for domestic water supply pumping in Laos, although these data are imperfect because they do not cover water extraction from the Mekong River only but also from other bodies of water in Laos. Unlike the Thai data, which include information about pumping capacity per hour, the data from Laos do not include pumping capacity but only the actual amounts of water extracted. It was reported that in 2013, a total of 148 Mm^3 of water was pumped for domestic water usage. A significant amount of that total came from the Mekong. It is noticeable that 65 Mm^3 of that water, or 44% of the total, was extracted in Vientiane Prefecture. Savannakhet was second, at 53 Mm^3 extracted, which amounted to 36% of the total amount extracted nationally. Luang Prabang extracted the third most, at 6 Mm^3, amounting to just 4% of the total, and Champasak Province extracted the fourth most at 5 Mm^3, just 3%. All the other provinces in Laos combined only accounted for 13% of the total amount of water extracted in Laos (Lao PDR Government, 2013).

Considering that Mekong River's dry season flow is typically between 1000 m^3 and 5000 m^3 per second, and that the average extraction rate for domestic consumption throughout the region is less than 5 m^3 per second, which is only 0.5% of the 1000 m^3 per second flow at the river's lowest point, it seems likely that water extraction at present is not significantly affecting the dry season flow of the river. This is also the opinion of hydrologists who have worked on the Mekong River in recent years.[2]

MEKONG RIVER TURBIDITY AND SEDIMENT TRANSFER CHANGES

We now consider whether changes to sediment flow along the Mekong River can help explain the conflicting accounts by villagers about dry season water levels.

Historically, the Mekong River and its tributaries transported over 160 million metric tons of sediment to the South China Sea annually (Wild et al., 2015). About half of this was believed to have originated in China, although sediment fluxes in the Mekong River Basin are complex, with sediment sizes and types varying across the basin (Bravard et al., 2013). The literature on sediment flows along the Mekong River strongly indicates that sediment plays an important role in its productivity and ecosystem health (Bravard et al., 2014; Baran et al., 2015). Unfortunately, as the data below clearly show, the amount of sediment flowing down the Mekong River has dramatically declined since the early 1990s, largely due to sediment being trapped behind upriver dams (Kummu and Varis, 2007; Kummu et al., 2010; Sarkkula et al., 2010; Xue et al., 2011; Bravard et al., 2013; Wild et al., 2015; Binh et al., 2020a, 2020b; MRC, 2021; Chuenchom et al., 2023), combined with sand mining and other causes such as land-use changes and climate change (Bravard et al., 2013; Pokhrel et al., 2018). Increased deforestation in the upper basin has resulted in increased erosion (Lacombe et al., 2018), but there is very little rain during the dry season, so upland erosion at this time tends to be minimal. And even with this increased erosion taken over the course of the year, the *VietNamNet Bridge* (2015) reported that the amount of sediment flowing into the South China Sea had declined from 160 million tons historically to just 75 million tons in 2014. The amount of sediment flowing down the Mekong can only have been reduced further since then, as even more dams have been built. Efforts have been made to develop low sediment-trapping dams, but they have not been as successful at solving the problem as initially hoped (Schmitt et al., 2019).

We were able to obtain turbidity data for the 1990s and 2020s from Chiang Saen, Nong Khai, and Khong Chiam (Figures 5-7) from the Office of National Water Resources (ONWR) in Thailand. For each location, we graphed three years of turbidity data from the early 1990s and three from the early 2020s, in order to compare turbidity levels from before mainstream Mekong hydropower dams were constructed with the most recent period for which data were available, after many dams had been constructed. We chose three years for each period to average out any individual year exceptions that might have occurred.

[2] Timo Räsänen, *pers. comm.,* March 11, 2024.

Figure 5. Turbidity data from Chiang Saen, Chiang Rai Province, northern Thailand.

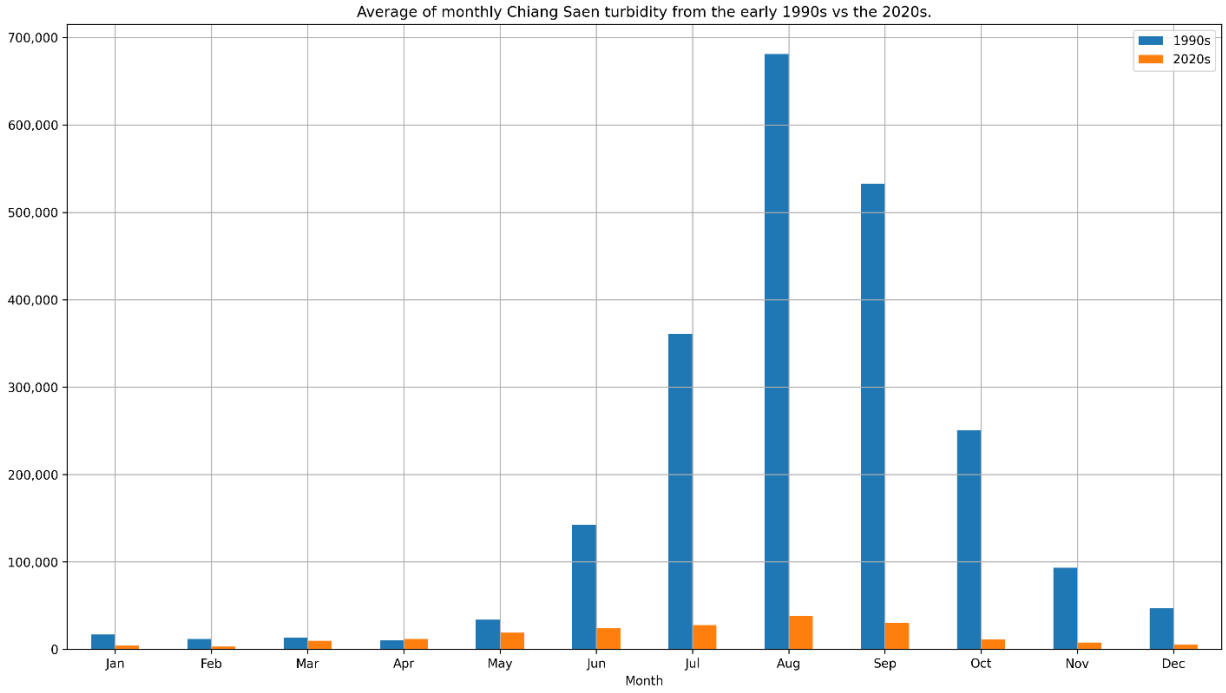


Figure 6. Turbidity data from Nong Khai, Nong Khai Province, northeastern Thailand.

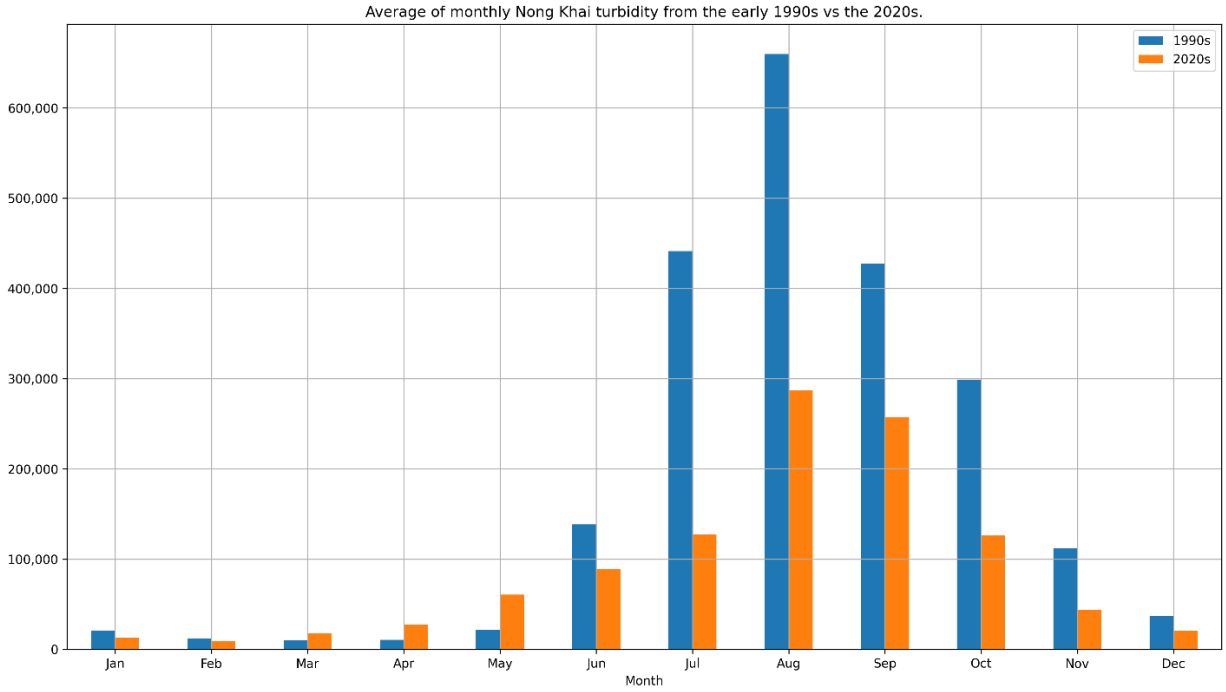
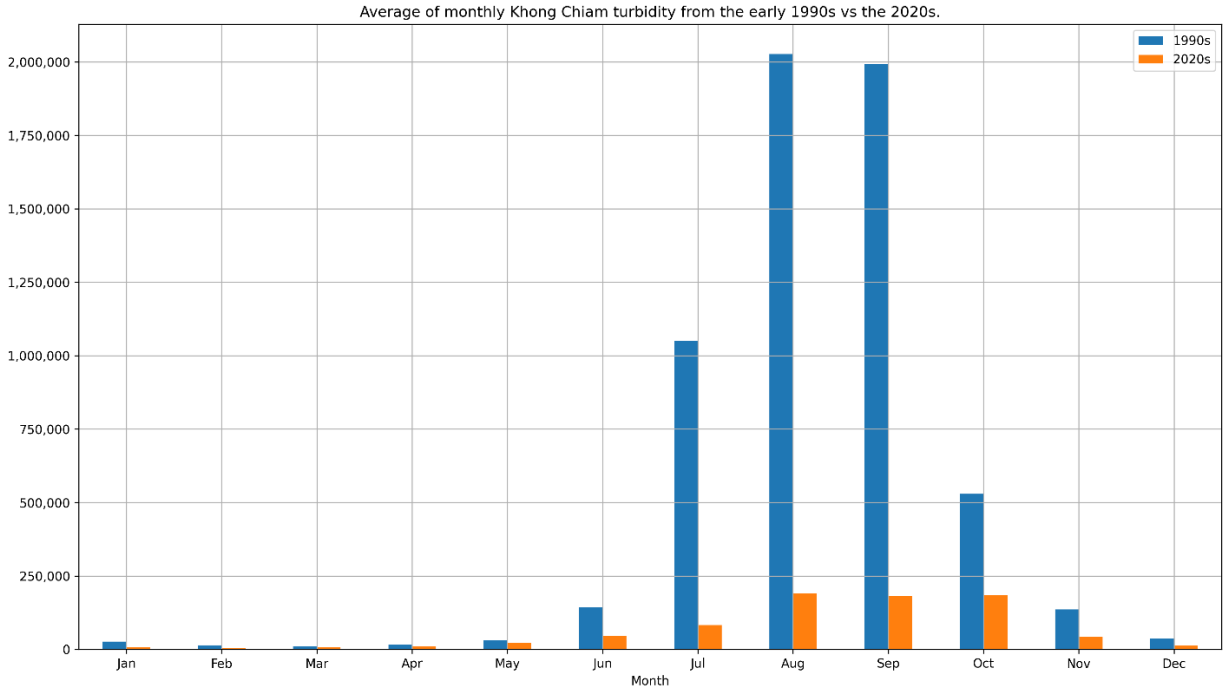


Figure 7. Turbidity data from Khong Chiam, Ubon Ratchathani Province, northeastern Thailand.



The Mekong River turbidity data presented in Figures 5-7 indicate that between the 1990s and the 2020s there has been a dramatic decline in the amount of sediment flowing through the Mekong River system. It appears to have been particularly significant at Chiang Saen (Figure 5), which makes sense, because Chiang Saen is just ~350 kilometers downstream from the Jinghong Dam, the closest dam to Thailand on the Lancang/Mekong mainstream Mekong River in China. There were no other large dams built on Mekong tributaries upriver from Chiang Saen prior to the construction of the Jinghong Dam.[3] Recently, the MRC Secretariat's CEO, Dr. Anoulak Kittikhoun, expressed serious concerns about the decline of the Mekong River's sediment load (Vongphachanh, 2023).

It is well known from other river basins around the world that the primary productivity of rivers declines significantly when dam construction deprives those rivers of sediment (Sarkkula et al., 2010). In some parts of the world, such as for the Rhine River in Europe, artificially produced sediment is being added to the river for the benefit of the river's ecology (Chardon et al., 2021; Mörtl and De Cesare, 2021; Krapesch et al., 2024). However, for the Mekong, there are no plausible ways of compensating for such a dramatic reduction in sediment (Sarkkula et al., 2010). There has not been much research done on the exact impacts of sediment and turbidity changes on aquatic life and livelihoods along the Mekong, but there is no doubt that the so-called "sandscape" of the Mekong River Basin is crucial (Rousseau and Marschke, 2023) to its ecosystem and plays an important role in the high productivity of the river. Baran et al. (2015) have reported that diminished sediment in the Mekong River is negatively impacting primary productivity, including fish stocks, respiration, nutrition, reproduction, and migration, as well as reshaping their habitats.

While there have been dramatic declines of sediment along the Mekong River in Nong Khai and Khong Chiam as well, it is noteworthy that there has been less of a decline in Nong Khai compared to Khong Chiam, something that warrants further research. In summary, however, these data indicate that there

[3] However, sediment is trapped not only by the Jinghong Dam but by all the dams in the cascade along the Lancang River and its tributaries in China.

has been a dramatic overall decline in sediment flowing down the Mekong River since hydropower dams in China started being constructed the 1990s. This is something that others have also reported (Kallio and Kummu, 2021).

RIVERBANK EROSION AND EMBANKMENT

The Mekong River hydrology literature clearly indicates that water flows have changed significantly over the last few decades. In particular, there is now more water flowing down the mainstream Mekong River during the low-flow part of the year (February, March, and April), and there is less water flowing down the Mekong during the rainy season (Eyler et al., 2024). Moreover, it is widely recognised that these changes have been due to hydropower development upriver, especially on the Lancang (Mekong) upper basin in China (Kummu and Sarkkula, 2008; Richter et al., 2010; Lauri et al., 2012; Räsänen et al., 2012, 2017; Li et al., 2017; Sabo et al., 2017; Arias et al., 2019; Hoang et al., 2019; Binh et al., 2020a, b; Eyler and Weatherby, 2020; Baird et al., 2021; Kallio and Kummu, 2021; Lu et al., 2021; RFA, 2022; Keithmaleesatti et al., 2022; Chen et al., 2024).

Riverbank erosion along the Mekong River has historically been much less than along many other large rivers in the world (Kummu et al., 2008), although some parts of the Mekong are more prone to erosion than others (Miyazawa et al., 2008). Over the last few decades, however, riverbank erosion has become a well-known negative impact of hydropower dam development (Darby et al., 2013; Hackney et al., 2020), whether in Thailand (Pattanamongkol, 2023), Cambodia (Tha et al., 2022, 2024), or in Vietnam (Tran et al., 2023; Hackney et al., 2020). Indeed, the rate of riverbank erosion on the Mekong along the Thailand-Laos border was much slower between 1961 and 1992, before any dams were built on the Mekong River, when compared to the period between 1992 and 2005, after dam construction began (Kummu et al., 2008). When sediment is trapped by dams, it commonly occurs that erosion downstream is increased due to what is known as the 'hungry water' phenomenon, when the capacity for erosion increases due to the sediment-depleted nature of the river (McCully, 2001; RFA, 2022). Our field interviews and observations along the Mekong River also indicate that there has been significant riverbank erosion along the Mekong River in Thailand, Laos, and Cambodia since the 1990s. Other researchers have also reported on this trend (Darby et al., 2013; Hackney et al., 2020; Tha et al., 2022, 2024; Tran et al., 2023), as have journalists in Vietnam (Tuyển, 2022), Cambodia (Flynn and Srey, 2022) and Thailand (Rujivanarom, 2023).

Riverbank erosion has, in turn, led to a substantial portion of the Mekong mainstream that serves as a border between Thailand and Laos being embanked by government agencies, especially on the Thai side of the border but also along parts of the Mekong River in Laos. A senior Lao PDR government official who works for the Ministry of Public Works and Transport reported, in June 2024, that 83% of the Mekong on the Thai side of the river has already been embanked, compared to only 12-13% on the Lao side.[4] There has been less in Laos due to river embankment being quite costly (Miyazawa et al., 2008; Rujivanarom, 2023).

Villagers who live along the Thai side of the river recognise that embanking the river has had some negative impacts on the environment by damaging riverbank vegetation and habitat. However, they generally feel that embankment has been necessary to prevent erosion, which has led to the loss of quite large amounts of land (Pattanamongkol, 2023). The Office of National Water Resources (ONWR) in Thailand reported that in 2012-2013, 44 km^2 of land was lost on the Thai side of the Mekong due to riverbank erosion. Since then, embankment construction has reduced erosion in some areas, but 46 km^2 of land was still lost between 2014 and 2018, presumably mainly in areas without embankments. Most recently, between 2018 and 2020, another 18-24 km^2 of land was eroded (Rujivanarom, 2023). Villagers

[4] Senior Government Official, Waterway Impact and Management Division, Ministry of Public Works and Transport, Lao PDR, *pers. comm.,* Vientiane, June 7, 2024.

on the Thai side report that riverbank erosion on the Lao side of the river is much worse than on the Thai side, since there are much fewer river embankments there.

So, while sediment trapping by dams and sand and gravel mining are removing sediment from the river, riverbank erosion would normally add more sediment to the river. However, it appears that thanks to the widespread embankments, much more sediment is being removed than is being added through erosion, thus leading to the lowering of the riverbed. This, in turn, could be what has led many along the middle stretch of the study area, where the substrate is much sandier than along other stretches of the river, to believe that there is less water in the Mekong River during the dry season than in the past, even if there is significant evidence to suggest that this is not the case.

HYDROPOWER DAMS AND SEDIMENT

Globally, the downstream impacts of hydropower dams are generally not taken as seriously as the impacts that occur in reservoir areas (Baird et al., 2021). Where they are, some have called for implementing environmental flow regimes, in which water is released from dams in such a way as to partially replicate natural flows (Dyson et al., 2003; Richter and Thomas, 2007; Baird and Quastel, 2015; Sabo et al., 2017). But it is well known that the construction of dams can dramatically alter the amount of sediment also flowing down rivers, leading to serious delta erosion (Goldsmith and Hilyard, 1984; McCully, 2001). This is a major concern in the Mekong Delta of Vietnam (*Vietnam News Service*, 2012; *VietNamNet Bridge*, 2015; Tuyển, 2022; Park, 2024). Lu et al. (2014) have confirmed that sediment transport is being obstructed more in the upper Mekong (Lancang) River in China than along any other sections of the Mekong River and that the obstruction began in 1993 during the construction of the Manwan Dam, the first Mekong mainstream dam built in China (see also Fu et al., 2008).

Recently, Chuenchom et al. (2023) have reported that existing dams (as of 2018) in the Mekong River Basin have the potential to trap around 61% of its sediment, and that the amount could expand to 69% of the sediment load if more dams included in government development plans are constructed. Chua and Xi (2022) have documented even more serious declines, reporting that the amount of sediment flowing down the Mekong River at Chiang Saen in northern Thailand has declined by 84% when comparing sediment levels recorded between 1965 and 1991 with those recorded between 2010 and 2019. In line with these and other previous findings (cf. Baird and Thorne, 2023), Binh et al. (2020b) have reported that between 2012 and 2015, sediment flow to the Mekong Delta in Vietnam declined by 74.1%, of which 40.2% was believed to be attributable to the six dams that had been constructed on the Lancang (mainstream Mekong) River in China at the time. Binh et al. (2020b) attributed 14.8% of the effect to sand mining.

In summary, there seems little doubt that the major reduction in recorded sediment in the Mekong since the 1990s is strongly related to the construction of many large dams along the mainstream Mekong and its tributaries. The MRC (2018) has predicted that if all the dams in the Mekong River Basin are constructed as planned, by 2040 there will be a reduction of over 96% in the amount of sediment entering the Mekong Delta. This will not only negatively impact the Mekong Delta ecosystem and the enormous numbers of people who depend on it; water and nutrients that enter the South China Sea from the Mekong River have historically contributed to the primary productivity of the coastal ecosystem and its large variety of fish species and other aquatic life (Rainboth et al., 2012). These findings are considered further below.

HYDROPOWER DAMS AND INCISION

'Incision' is a natural riverbed erosion process that frequently becomes accentuated due to human activities. Dam-induced incision has long been recognised, from the Colorado River in the United States (Grams et al., 2007) to the Yellow River in China (Li et al., 2021). In the case of the Mekong, the reduction

in sediment is contributing to incision; various hydrologists who have conducted related research in the Mekong region, including Christopher Hackney (cf. Wetzel, 2020),[5] Chris Darby (cf. Timmins, 2019), Timo Räsänen,[6] and Doan Van Binh[7] believe that the Mekong's riverbed has lowered due to erosion or incision. The Mekong Delta is sinking with it (Binh et al., 2021; Chua et al., 2024), making the Delta more vulnerable to sea level rise caused by human-induced climate change (Allison et al., 2017).

This incision, like the erosion already discussed, is likely to be a result of the "hungry water" effect, which often occurs when sediment-depleted water flows downstream and erodes more than it did previously in order to add sediment to its sediment-depleted water (McCully, 2001). In this case, the river has been depleted of sediment and as a result has caused increased downstream erosion and incision. However, it is also important to consider the impacts of sand mining, as we do below.

SAND MINING

Sand, gravel, and pebbles are extracted from rivers in various parts of the world for different reasons but especially for land reclamation and for producing concrete for construction. More development in the Mekong region has increased the demand for river sand and gravel, leading to the mining of the river's sediment and thus the reduction of the river's sediment load (Bravard et al., 2013).[8] The extraction of sediment in upstream areas results in less sediment in the river downstream.

The negative environmental impacts of 'sand mining', which is the extraction of sand or other sediment from rivers, has been known in Europe since the 1950s; also in the case of the Pearl River in China, the riverbed has been severely lowered due to sand mining (Bravard et al., 2013). Along the Mekong River, impacts have become evident in some areas since the 1990s (Bravard et al., 2013). However, sand mining has become increasingly controversial, both globally (Bendixen et al., 2019a, 2019b, 2021; Wetzel, 2020; Rentier and Cammeraat, 2022) and more recently in the Mekong River Basin, including in Thailand (Piman and Shrestha, 2017), Cambodia (Flynn and Srey, 2022; Rousseau and Marschke, 2023), Vietnam (Timmins, 2019; Hackney et al., 2020; Tuyển, 2022; Tran et al., 2023), and the Mekong more generally (Sarkkula et al., 2010; Bravard et al., 2013, 2014; Kondolf et al., 2014, 2018; Chua and Xi, 2022; Park, 2024).

Sand, gravel and pebble mining along the Mekong River is now widely recognised as being detrimental both to the environment and the livelihoods of those who depend on the river having a healthy ecosystem (Bravard et al., 2013; Kondolf et al., 2014; Hackney et al., 2020; Tran et al., 2023). Hackney et al. (2020), for example, have written about increased riverbank instability along the Mekong River due to sand mining, and Flynn and Srey (2022), like Asif and van Arragon (2024), have reported serious tensions between those who make their living from sand mining and fisheries along the Mekong River in Cambodia.

The Joint Committee for Management on the Mekong River and Heung River (JCMH) was co-established by the governments of Thailand and Lao PDR in order to regulate natural resource extraction, including sand mining, along the river border between the two countries (Rujivanarom, 2023). Incision and riverbed erosion are recognised as problems along the Mekong River in Laos and Thailand, and this is the main reason rules have been adopted prohibiting sand mining within 1000 m of the tips of islands

[5] Chris Hackney, *pers. comm*., April 18, 2024.

[6] Timo Räsänen, *pers. comm.,* March 11, 2024.

[7] Doan Van Binh, *pers. comm.,* April 10, 2024.

[8] Villagers living along the Mekong River in Thailand and Laos are quite aware that sand mining can lead to increased riverbank erosion. This may differ considerably from Vietnam, where Tran et al. report that many people living in the Mekong Delta are aware that sand mining has detrimental environmental impacts but are generally not aware that it increases riverbank erosion (2023). However, Tuyển (2022) reports that at least in some parts of the Mekong Delta, local people are quite aware of the impacts that sand mining is having on riverbank erosion.

and at least 100 m from the middle of islands, riverbanks, and sand bars. Sand extraction over two metres deep is also prohibited, while mining for pebbles is not supposed to go deeper than ten metres (Ministry of Public Works and Transport, Lao PDR, 2010). Moreover, the Thailand and Lao PDR governments (2006) have also prohibited sand mining within 1000 m of river embankments, due to concerns that incision and related riverbank erosion could damage this valuable infrastructure (Thailand and Lao PDR Governments, 2006; Rujivanarom, 2023).

Since the river is often less than two kilometres wide, this has made sand mining impossible along many parts of the Thai side of the Mekong River where river embankments have been constructed. This in turn has led to an increased amount of illegal sand mining along the Mekong River, at least in Thailand,[9] although to what degree remains uncertain. As a result of these tensions and the increase in illegal sand mining, the Thai National Committee on Sand Mining released a resolution allowing provincial administrations to revise sand mining zoning rules to fit local environmental and economic circumstances. However, illegal sand mining still persists (Rujivanarom, 2023).

There seems to be little doubt that parts of the Mekong riverbed are significantly lower than in the past, and that this is due to incision. However, the degree to which sand mining is responsible for this incision, compared to hydropower dam development and other causes, remains uncertain. Some villagers in Chiang Rai Province have reported that groundwater levels adjacent to the river have also declined, based on the depth of water in wells, but they attributed this to river embankment construction rather than riverbed lowering. Kondolf et al. (2018) believe that hydropower dam development is the main cause of changes in Mekong River sediment transport. However, they point out that it is not the only cause, and that sand mining, climate change, diking and water infrastructure development, and accelerated subsidence water pumping were also partially responsible. We would add that land-use change is another factor.

While it is widely recognised that large amounts of sand and gravel has been extracted from the Mekong River over the last few decades, one serious challenge is knowing the exact volume of extracted material. In Thailand, for example, the government gives out legal sand and gravel mining concessions to companies operating in different provinces, and the Department of Industry claims that there are about 140 sand mining companies registered in Thai provinces adjacent to the Mekong River (Rujivanarom, 2023). However, they do not collect data on the exact amounts of gravel and sand extracted.[10] In Lao PDR, sand and gravel concessions are approved by the government, and before concessions are granted, companies need to prepare management plans that include the estimated amount of sand and gravel that they will harvest annually. However, the government does not collect data on the actual amount of sand and gravel extracted in Laos either.[11]

In some areas, the number of sand mining operations on the Thai side of the Mekong has increased considerably in recent years, along with an increase in demand for sand. Some Thai sand miners are supposedly registered in Laos but operate near the Thai side of the border. One official has claimed that 80% of the sand extracted from the Mekong by these Thai operators is illegally exported back to Thailand (Rujivanarom, 2023). While Lao government officials in Vientiane stress that it is illegal to export sand

[9] Article 9 of The Thai Land Code Act stipulates that illegal sand mining can be punished by up to five years' imprisonment and a 20,000 baht fine (Rujivanarom, 2023).

[10] Official from the Public Land Management Sub-Bureau, Public Land Management Bureau, Department of Land, Thailand, *pers. comm*., Bangkok, June 11, 2024.

[11] Senior Government Official, Waterway Impact and Management Division, Ministry of Public Works and Transport, Lao PDR, *pers. comm.,* Vientiane, June 7, 2024.

and gravel from Laos and that no exceptions have been granted by the central government,[12] our fieldwork indicates that it is nonetheless taking place.

Villagers living along the Mekong River in northeastern Thailand have been reporting illegal Thai mining operations to Thai government officials for years, but not much has been done to combat it. Reportedly, illegal sand miners are frequently tipped off in advance about visits by government officials, giving them chances to evade apprehension. Local "influential people" also often protect illegal sand miners (Rujivanarom, 2023).

Bravard et al. (2013: 6) reported that 55.2 metric tons of sediment was extracted from the Mekong mainstream River in Laos, Thailand, Cambodia and Vietnam in 2011-2012. Of this, they reported that 90% was sand, 8% was gravel,[13] and 1% was pebbles.[14] Ultimately, Bravard et al. (2013: 6) found that Cambodia extracted 60% of the sediment, while Vietnam extracted 22%, Thailand extracted 13%, and Laos extracted 4%. These statistics were based on interviews with operators, and it was recognised that, as extraction companies, they may have underestimated the actual amounts. In Laos, for example, sand miners are supposed to pay a 10% tax to the government based on amounts extracted (President's Office, Lao PDR, 2005), which encourages underreporting.

Because of the sensitivity of the sand mining issues in the Mekong region (see also Bravard et al., 2013), none of the member governments of the MRC provide sand mining data to the MRC,[15] thus making regionally relevant research on sand mining difficult to conduct. Bravard et al. (2013: 5) also reported that, at the time of their study, "Official statistics from national agencies and the MRC were not readily available". Still, over the last few decades, there appears to have been an increase in the amount of sand and gravel being extracted from the Mekong River and its tributaries (Rujivanarom, 2023). Illustrative of this, MME, NERI, and ICMM (2011) reported that the amount of sand extracted in Laos increased from less than 300,000 m^3 per year in 2001 to over 1,000,000 m^3 in 2008, and interviews of sand miners on the Thai side of the Mekong in May-June 2025 clearly indicated that they were increasingly granted permission to extract sand and gravel on the Lao side of the river.[16] All of this indicates overall increases in extraction in recent years.

While many owners and managers of sand mining companies in various parts of the world are believed to rely on high-level political connections and sometimes exhibit degrees of organised criminal behaviour (Rentier and Cammeraat, 2022; Park, 2024), including in Cambodia (Global Witness, 2009; Flynn and Srey, 2022) and Thailand (Rujivanarom, 2023), many sand mining company owners and managers have worked in the industry for decades and have considerable knowledge about sediment flows and changes in river flows over time.

In June 2024, we interviewed someone who had been a manager of a sand mining company north of Vientiane for over thirty years. The results were useful for corroborating the hydrological and sediment data already presented here. He reported that when he started operating in the area during the early 1990s, after he had to move his operations from the Done Chanh area near Vientiane, there was typically six metres of sand build-up along the riverbed of the Mekong River at the end of the rainy season in front

[12] Senior Government Official, Waterway Impact and Management Division, Ministry of Public Works and Transport, Lao PDR, *pers. comm.,* Vientiane, June 7, 2024.

[13] No gravel extraction was reported in Vietnam, and only 10,000 m^3 of gravel was reported to have been extracted in Laos. It was reported that 857,740 m^3 of gravel was extracted in Thailand and 2,044,940 m^3 in Cambodia (Bravard et al., 2013: 6).

[14] Pebbles were reportedly only extracted in Laos, with no extraction being recorded for Thailand, Cambodia, or Vietnam (Bravard et al., 2013: 6). Pebbles are generally more rounded by hydrological erosion than gravel, although the terms are sometimes used interchangeably.

[15] Official at Mekong River Commission, *pers. comm.,* Vientiane, May 29, 2024.

[16] Interviews with sand miners in Ubon Ratchathani, Amnat Charoen, Mukdahan, and Nakorn Phanom Provinces, May-June 2025.

of his operation. However, by the 2000s, after the Chinese had completed dams in the upper Mekong, only three metres of sand remained. Then, when the Xayaburi Dam was built, the amount of sand accumulation downstream declined even further. At present there is reportedly only 80 cm remaining at the end of each rainy season.[17] This is despite the Xayaburi dam – unlike many other dams – having the ability to occasionally flush sediments, which improves the operating capacity of the dam (see Glijnis, 2022).

Recent developments in the creation of sand and gravel from crushed rock, called 'm-sand', may lessen levels of sand and gravel extraction in the future, but it is unclear how rapidly the transition to m-sand is occurring, and the cost of Mekong sand and gravel is still generally the cheapest option for builders.

In summary, sand mining is likely to be playing an important role in Mekong River changes, but it is difficult to assess its relative impact compared to sediment trapping behind dams.

CONCLUSION

A few important findings emerge from this study. First, as stated above, Mekong River villagers in the upper stretches of the study area, as well as the most downstream parts of the study area, believe that there is more water in the Mekong during the dry season, and people living along the middle stretch believe there is less water during the dry season. This odd situation can be explained by the hydrological and sediment flow changes caused by upriver dams and downstream incision, especially in areas with less bedrock, but we needed both local knowledge and the available associated data to reach this explanation. The additional data we collected indicate that there is a considerable lowering of the Mekong riverbed, likely due to a combination of river incision and sand and gravel mining – along the northern northeast Thai section of the of the river in particular, due to the sandier nature of the riverbed in this area. Incision certainly occurs within bedrock, but it obviously happens much more quickly with sand. Sand mining's importance relative to incision is hard to assess; more research is needed to quantify these changes and determine the exact cause.

Thus, while there is more water released during the dry season from the active storage of hydropower dams upstream, incision and sediment removal in the sandy areas of the Mekong have led many people living along these stretches of the River, in Nong Khai, Bueng Kan, Nakorn Phanom, and much of Mukdahan province, to believe that dry season levels have declined. Upstream and downstream from this section, villagers report that there is more water in the river during the dry season. We have considered whether changes along the Mekong tributaries in Laos might explain the circumstances, but even if that were the case, it would not get us closer to explaining why villagers perceive the situation differently along different stretches of the mainstream Mekong River. Moreover, most of the tributaries that have experienced major hydropower dam construction in recent years are in Laos and flow into the middle section of our study area (i.e. Theun/Kading, Hinboun, etc) – the area where dry season water levels were reported to be lower than those reported on paper. Since these dams would presumably add more water in the dry season, not less, they cannot explain what local people have reported.

Sediment transport along the mainstream Mekong River has dramatically declined since the 1990s, when hydropower dams on the Mekong River in China and elsewhere in the basin began being developed. This has led to serious downstream riverbed incision and riverbank erosion, leading to the lowering of the riverbed and encouraging riverbank embankment in order to reduce land loss. While some of these processes are likely to have counteracting effects, it appears that riverbed erosion, sediment extraction, and riverbed incision have been particularly impactful along the section of the river where the substrate is sandy.

[17] Sand mining company manager, Vientiane Prefecture, *pers comm.,* June 2, 2024.

Apart from providing important new information about hydrological changes and sediment flows along the Mekong River, this study addresses why people living along different stretches of the river have different perceptions about the hydrological changes that have taken place there. While the use of new technologies to better understand the Mekong is exciting, care needs to be taken to consider such information alongside local understandings of river changes. Ultimately, this study indicates that more efforts should be put into studying incision extent and impacts, especially along the Thailand-Laos border, and we contend that local knowledge, whether held by villagers or sand mine operators, can help, along with other methods, to better understand riverine changes. Furthermore, more regular, detailed bathymetric surveys along the Mekong will be particularly useful for ascertaining the state of the incision and the effects of the changes that have been wrought on the river through dam construction and other human activities. We tried to obtain such data from various sources, but we were not able to find anything that could be easily used to assess changes to the riverbed. In any case, there is still compelling evidence that in the middle part of our study area, the riverbed is sinking, resulting in the perception that there is now less water in the river during the dry season even though there is actually more.

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