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Technical report

JOINT OBSERVATION AND EVALUATION OF THE EMERGENCY WATER SUPPLEMENT FROM CHINA TO THE MEKONG RIVER

Mekong River Commission
and
Ministry of Water Resources of China

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Contents

List of figures

List of tables

Executive Summary

Recent meteorological and agricultural drought conditions over the Mekong Basin have worsened and triggered China to implement its emergency water supplement from its cascades dams in the Lancang River to the Mekong River by increasing the water discharge from Yunnan's Jinghong Reservoir. China decided to implement its **emergency water supplement in a 'three-phase plan'**: (1) from **9 March to 10 April 2016**, with an average daily discharge of no less than 2,000 m^3/s; (2) from **11 April to 20 April 2016** with the discharge of no less than 1,200 m^3/s; and (3) from **21 April to 31 May 2016** with the discharge of no less than 1,500 m^3/s. The Mekong River Commission acknowledges this action by China, in which China has also stated that it implemented the water supplement at a challenging time, especially within the context where China itself was also suffering from drought, which has affected its household water supply and agricultural production.

The China's Ministry of Water Resources and Mekong River Commission Secretariat then co-organised experts from both sides to conduct a Joint Observation and Evaluation of the Emergency Water Supplement from China and its effect of easing the drought situation in the Mekong Basin.

The scope of the Joint Observation and Evaluation covers: (1) Temporal Scope – dry season of 2016, which runs from 1 December 2015 to 31 May 2016 and especially during the emergency water supplement period from 15 March to 15 May 2016; and (2) Spatial Scope – from Jinghong hydrological station on the Lancang River to the Mekong Delta.

In this study, an agreement was reached on exchange and sharing of 21 hydrological stations for water level and 7 stations for discharge on the Mekong mainstream from the Mekong River Commission Secretariat; and 1 station for water level and discharge on the Lancang mainstream and 1 station for water level and discharge on the main tributary of Man An, from China.

The analyses cover (1) Cause of the drought in the Lancang-Mekong Basin considering temperature, rainfall, flows, soil moisture and water stress; (2) Overall influence of Lancang cascade reservoirs operation on dry season volume of the Mekong River; (3) Hydrological influence of the emergency water supplement in 2016 on water level, discharge and volume of the Mekong mainstream; (4) Net contribution of the water supplement to discharge of the Mekong River; (5) Variation of water level and discharge of the Mekong mainstream during the water supplement; (6) Flow propagation along the mainstream; and (7) Salinity variation in the Mekong Delta during the period of the emergency water supplement.

The Joint Observation and Evaluation of the Emergency Water Supplement from China to the Mekong River were jointly and objectively conducted with the Mekong River Commission Secretariat and Ministry of Water Resources of China. In the course of this study, besides regular hydrological data sharing in the flood season from China, additional daily water level and discharge for the dry season of 2016 and its long term average of 1960-2009 and 2010-2015, from both sides were exchanged and used in the analyses of this report. Similarly, methodology of the analyses were jointly developed and adopted. Analyses were carried out and the results were exchanged, discussed and agreed. The contents of the Joint Report were also jointly developed.

It is found that the **emergency water supplement from China increased water level** and **discharge** along the Mekong mainstream and **decreased salinity intrusion** in the Mekong Delta. The following are the key findings from this study:

- **Reduced rainfall amount and inflow discharge** to the Lancang Basin have been observed in the dry season of 2016. Likewise, the Mekong Basin has been experienced by abnormally dry conditions with **high temperature** and **less rainfall**. These meteorological and agricultural droughts are strongly believed to be impacted by the **super El Niño 2015-2016**. Monitoring of flow conditions on the mainstream suggests that water level and discharge in the dry season of 2016 at Vientiane/Nong Khai and Stung Treng in December 2015 were few days below the long term minimum of 1960-2009. However, thanks to the emergency water supplement from China, the **water level** and **discharge** at most stations along the Mekong mainstream were most of the time **above the long term average** and even higher than the long term maximum in March and April 2016.
- Total volume released at Jinghong was **12.65 billion m^3**: 6.10 billion m^3 from 9 March to 10 April 2016, 1.07 billion m^3 from 11 April to 20 April 2016, and 5.48 billion m^3 from 21 April to 31 May 2016.
- During the period of the emergency water supplement in March and April 2016, the monthly discharges at Jinghong were 1,280 m^3/s and 985 m^3/s respectively, larger than the average of 1960-2009, and 704 m^3/s and 442 m^3/s respectively, higher than the average of 2010-2015.
- The emergency water supplement from China arrived at **Chiang Saen on 11 March** and increased till 14 March 2016. This pattern reached **Luang Prabang on 14 March**, **Chiang Khan on 17 March**, **Nong Khai on 19 March**, **Nakhon Phanom on 22 March**, **Mukdahan on 23 March**, **Pakse on 25 March**, **Stung Treng on 27 March**, **Kratie on 28 March** and **Tan Chau on 1 April 2016**. Similarly, the emergency water supplement **increased water level** or **discharge** along the Mekong mainstream to an overall extent of **0.18-1.53 m** or **602-1,010 m^3/s**. Equally, the maximum salinity in the Mekong Delta decreased by 15% and 74%, and the minimum salinity decreased by 9% and 78% according to observation stations.
- Monitoring at Chiang Khan suggests that additional water of 300 m^3/s for one day on top of the emergency water supplement from China was detected on 27 March 2016. This additional water arrived at Nong Khai on 28 March, at Nakhon Phanom on 31 March, at Mukdahan on 1 April, at Pakse on 3 April and at Stung Treng on 4 April 2016. Immediately after the peak of the additional water, a drop in discharge of 300 m^3/s was recorded on 31 March 2016.
- Total **volume in the dry season of 2016** (December 2015 to May 2016) at Jinghong presented huge portion (**40%-89%**) of the total volume at different stations along the Mekong mainstream. Additionally, the volume from 10 March to 10 April 2016, which was first period of the emergency water supplement, claimed significant portion, specifically 99% at Chiang Saen, 92% at Nong Khai and 58% at Stung Treng. Similarly, **net contribution of the water supplement** in term of discharge to total discharge was **47% at Jinghong**, **44% at Chiang Saen**, **38% at Nong Khai** and **22% at Stung Treng**. This contribution also alleviated salinity intrusion in the Mekong Delta.

Recommendation

During conduct of the Joint Observation and Evaluation, discussion and exchange between the Mekong River Commission Secretariat and China were sincere with warmth and friendliness. Both parties respected each other views with mutual understanding. It is therefore recommended this kind of study and working attitude should continue to boost strong foundation for further cooperation between China, Mekong River Commission Secretariat and its Member Countries.

This good spirit of cooperation should keep its momentum and be extended to further study on Hydrological Impact of the Lancang Hydropower Cascade on Downstream Floods and Droughts. Likewise, future direction of the study should also focus on positive and negative impact of water resources and hydropower development in the tributaries of the Mekong mainstream.

Limitation of the study

Due to limited data and time constraints at the time of the study, the detailed calculations could not be performed; only monthly average computations were normally conducted. Additionally, processes, impacts and linkages of (meteorological, agricultural, hydrological and socio-economic) droughts and relationship between the drought and global extreme events, namely the El Niño or La Niña were not thoroughly performed. Moreover, detailed evaluation was hampered by limited data from the release of reservoirs on the tributaries of the Mekong River and good quality of hydrological data including rating curves before 2009. Similarly, flow contribution from the Tonle Sap Lake and flow distribution in the Mekong and Bassac Rivers downstream Phnom Penh were not included. Furthermore, several assumptions, including travelling time in the section between Kratie and the Mekong Delta, were used in the analyses. It is also recognised that fully comprehensive salinity analysis in the Mekong Delta could not be performed without additional effort on salinity modelling. In sum, the analyses in this report focused mainly on general hydrological situation and average condition of flows on the Lancang-Mekong mainstream.

1 Background

Observation of global land and ocean temperature reveals that Years 2015-2016 are the warmest years of record. The El Niño[1] 2015-2016 is recorded to be the strongest and has already created weather chaos around the world including the Lancang-Mekong Basin, which have been hit by abnormally dry conditions. Consequently, the countries in the Lancang-Mekong Basin have all suffered in various degrees from the drought caused by the effects of the super El Niño since the end of 2015. Equally, the Mekong Delta is particularly subjected to the most severe drought over the past century, the water level of Mekong River has dropped to the lowest level, which brings considerable damage to the agricultural production of the region and affect living conditions and livelihood of the riparian residents.

The recent drought conditions over the Mekong Basin have worsened and triggered China to implement its emergency water supplement from its cascades dams in the Lancang River to the Mekong River by increasing the water discharge from Yunnan's Jinghong Reservoir. China decided to implement its emergency water supplement in a 'three-phase plan': (1) from 9 March to 10 April 2016, with an average daily discharge of no less than 2,000 m^3/s; (2) from 11 April to 20 April 2016 with the discharge of no less than 1,200 m^3/s; and (3) from 21 April to 31 May 2016 with the discharge of no less than 1,500 m^3/s.

To objectively evaluate the effect of the emergency water supply from China to the Mekong River, the Ministry of Water Resources of China (MWR) and the Mekong River Commission Secretariat (MRCS) have agreed to conduct a Joint Observation and Evaluation.

In light of this, expert teams of the Mekong River Commission Secretariat (MRCS), representatives from some of its Member Countries, and China met from 4 to 5 May in Vientiane to discuss and explore a possibility to conduct the Joint Observation and Evaluation of China's emergency water supplement to the Mekong River and a future joint research project. This initiative is to allow the Mekong River Commission (MRC) and China, a Dialogue Partner since 1996, to evaluate jointly the effect of the emergency water supplement from China for the dry season[2] of 2016 that runs from 1 December 2015 to 31 May 2016, to gather this important experience, and to build a good foundation of further Lancang-Mekong water resources cooperation. After the meeting, both sides have jointly developed a work plan of the study, analysed and evaluated the effect of the water supplement, and written a technical reporting (this report) documenting the findings from the study.

[1] The El Niño-Southern Oscillation (ENSO) cycle is a scientific term that describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific (approximately between the International Date Line and 120 degrees West). La Niña is sometimes referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. These deviations from normal surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate (source: NOAA – United States National Oceanic and Atmospheric Administration, http://oceanservice.noaa.gov/facts/ninonina.html, accessed on 31 May 2016).

[2] For the purpose of the Joint Observation and Evaluation, the dry season is considered from 1 December to 31 May.

2 Profile of the Lancang-Mekong Basin

The Lancang-Mekong[3] River originates from Yushu Tibetan Autonomous Prefecture in Qinghai Province of China, and runs out of China from Xishuangbanna Dai Autonomous Prefecture in southern Yunnan Province. The Lancang-Mekong River flows through Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam, before emptying into the sea in the west of Ho Chi Minh City.

The Lancang-Mekong River ranks the 10th in the world's great rivers on the basis of mean annual flow at the mouth[4]. The Lancang-Mekong can be divided into two parts: the Upper Basin in China where the river is called the Lancang, and the Mekong Basin from Yunnan downstream from China to the Sea. The Lancang Basin covers an area of 164,400 km^2, with an annual average volume of 64 billion m^3, accounting for 20.7% of the total Lancang-Mekong Basin area[5] of 795,000 km^2 and 13.5% of the total Lancang-Mekong annual average volume of 475 billion m^3, respectively. Additionally, the difference in elevation from the source (Tibetan plateau) to the mouth of the river is 5,060 m with an average gradient of 1.04 ‰, most of the steep slope occurs along the Lancang River within the territory of China, where the river flows through steep alpine valley. Compared with the flat broad basin in the downstream, the Lancang Basin is relatively narrow.

About half of the total length of the Lancang-Mekong River of about 4,900 km is located in the territory of China. This section of the river flows through narrow areas of high mountains and deep valleys, thus, the volume of the Lancang River accounts only for 13.5% of the annual total volume. The flow regime of the river is mainly influenced by the Monsoon rains that occur every year in the downstream Southeast Asia, especially in Lao PDR, where the basin area covers mainly tropical rainforest and farmland.

The last 170 km of the Lancang River within the territory of China and the section flowing through Myanmar to the border of Thailand, the river transits from section with steep to mild slope, and flows through broad fertile valley. After leaving the territory of China, the river flows along the border of Lao PDR and Myanmar, passes through the border of Lao PDR and Thailand in the downstream of Chiang Saen.

The construction of cascade reservoirs in the mainstream in the middle and lower reaches of the Lancang River has been completed. The Xiaowan Reservoir and Nuozhadu Reservoir have especially the multi-year regulating capacity, with regulating storage of 21.2 billion m^3 in total. By scientifically operating and regulating, the Lancang River cascade reservoirs are capable to balance the water discharge/volume between the wet season and dry season, benefiting the Mekong River on the aspects of flood control, irrigation, navigation and so on.

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[3] In documents of the Mekong River Commission, the Lancang-Mekong River/Basin is simply the Mekong River/Basin, composing of two parts: the Upper Mekong River/Basin (Lancang River/Basin in China) and Lower Mekong River/Basin. Exceptionally, in this document, the Lower Mekong River/Basin refers to the Mekong River/Basin.

[4] Mekong River Commission (MRC) 2005. Overview of the Hydrology of the Mekong Basin. Mekong River Commission, Vientiane, November 2005. 73 pp.

[5] The total Lancang-Mekong Basin area of 795,000 km^2 is used in MRC publications (e.g. Overview of the Hydrology of the Mekong Basin), however, China suggests the total Lancang-Mekong Basin area of 812,400 km^2.

The Lancang-Mekong Basin can be generally divided into 6 major zones: zone one represents the Lancang Basin in China, and five zones are in the Mekong Basin, coincident with the five fluvial geomorphological reaches along the mainstream. The rationale behind the number and extent of these six reaches of the Lancang-Mekong mainstream encompasses a range of considerations, which include hydrological regime, physiography, landuse, existing, planned and potential resource developments as well as the perceived nodes along the mainstream at which there exist discernable transformations in hydrological response and where the impacts of existing and potential resource developments are likely to be detectable.

Zone 1 – Lancang River in China. The Lancang Basin is mainly characterized by steep alpine valley, located in the under-developed region with extremely inconvenient transportation and deficient natural resources, except extraordinary rich hydropower resources. Water use rate is about 3% in this area, and the water consumed is less than 1% of the total volume of the Lancang-Mekong Basin. This zone contributes about 13.5% volume of the Lancang-Mekong River. The runoff normally comes from rainfall, snowmelt and groundwater. This zone has distinguishing wet season and dry season. The dry season lasts from November to April, during which the volume mainly depends on the snowmelt and groundwater. Additionally, there are currently six hydropower projects on the mainstream of the Lancang River, which could generally increase the volume of the Lancang River by 70% in the dry season and reduce it by 30% in the rainy season. This helps flood mitigating and drought relieving with a proper regulation.

Zone 2 – Chiang Saen to Vientiane/Nong Khai. The additional hydrological contributions to it are generated almost entirely in Lao PDR. This reach is well defined physiographic sub-region of the lower basin being almost entirely mountainous and covered with natural and mostly undisturbed land cover. There is little scope for extensive agricultural development comparative in scale to that further downstream nor are there any plans for any significant water resources developments. Pre-feasibility and feasibility studies of the hydropower potential here, for example, has centred upon small run of river schemes (no regulation beyond diurnal pondage). Although this zone could hardly be described as pristine, the hydrological response from it is certainly the most natural and undisturbed within the basin. In addition, however, it is at the downstream boundary of this zone that virtually every relevant facet of the basin starts to undergo rapid transition.

Zone 3 – Vientiane/Nong Khai to Pakse. The upstream boundary of Zone 3 is the point at which the broader picture of Mekong hydrology changes from one dominated in both wet and dry seasons by the Zone 1 to one increasingly influenced by the contributions from the large left bank tributaries in Lao PDR, namely the Nam Ngum, Nam Theun, Nam Hinboun, Se Bang Fai, Se Bang Hieng and Se Done rivers. Also entering the mainstream within this zone extending to Pakse, is the Mun/Chi system from the right bank and Thailand. The Mun and Chi Rivers are highly developed low relief, agricultural basins with comparatively low runoff potential and significant reservoir storage for dry season irrigation. The left bank Lao tributaries are under steady development in terms of agricultural water demand and hydropower development.

Zone 4 – Pakse to Kratie. The major hydrological contributions to the mainstream in this reach coming from the Sekong, Sesan and Srepok catchments, jointly the largest hydrological sub-component of the basin. Over 25% of the mean annual flow volume on the Mekong mainstream at Kratie originates from these three river basins, which are therefore a crucial element in the hydrological dynamics of this part of the system, not least with respect to the Tonle Sap Lake flow reversal.

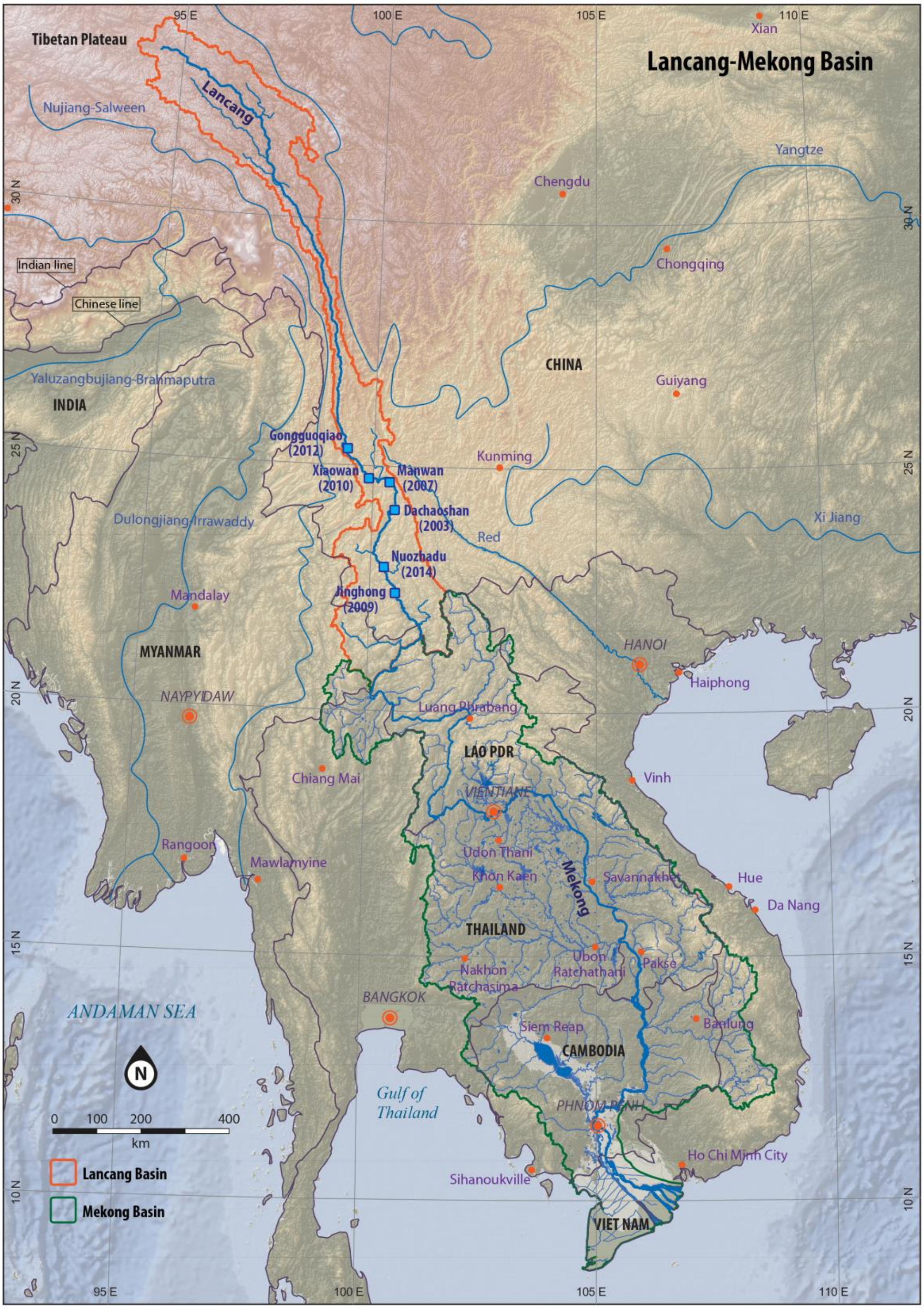

Figure 1 | Map of the Lancang-Mekong Basin.

The Lancang-Mekong Basin is the Mekong Basin in MRC documents, composing of two parts: the Upper Mekong Basin (Lancang Basin in China) and Lower Mekong Basin. Exceptionally, in this document, the Lower Mekong Basin refers to the Mekong Basin. The Gongguoqiao Reservoir started fully operational in 2012, Xiaowan in 2010, Manwan in 2007, Dachaoshan in 2003, Nuozhadu in 2014 and Jinghong in 2009.

Zone 5 – Kratie to Phnom Penh. This reach encompasses the hydraulic complexities of the Cambodian floodplain, the Tonle Sap Lake and River. By this stage over 95% of the total flow has already entered the Mekong system and the balance of emphasis moves from hydrology and water discharge to the critical assessment of water level, overbank storage and flooding and the hydrodynamics that determine the timing, duration and volume of the seasonal flow reversal into and out of the Tonle Sap Lake.

Zone 6 – Phnom Penh to the sea. This stretch defines lower Cambodia, the flow bifurcations and the delta region in Viet Nam, with the total volumes of flow entering the latter observed as the sum of those recorded at Tan Chau and Chau Doc.

3 Data and methodology

Due to time constraint and resources limitation, only water level and discharge of the key hydrological stations along the Lancang-Mekong mainstream before and after the emergency water supplement are analysed to evaluate the effect of the emergency water supplement. The evaluation covers the generic analysis of the drought in the Lancang-Mekong Basin, analysis of influential factor contribution to flows of the Mekong River, hydrological influence analysis and descriptive benefit analysis of the emergency water supplement.

3.1 Scope

The scope of the Joint Observation and Evaluation covers:

- **Temporal Scope**: dry season[6] of 2016, which runs from 1 December 2015 to 31 May 2016 and especially during the emergency water supplement period from 15 March to 31 May 2016.
- **Spatial Scope**: from Jinghong hydrological station on the Lancang River to the Mekong Delta.

3.2 Data exchange and sharing

The Joint Observation and Evaluation of Emergency Water Supplement from China to the Mekong River boost the cooperation of the MRC and China to the next level by enhancing hydrological data exchange and sharing from both parties[7]. In this study, an agreement of hydrological data exchange and sharing was reached for 21 hydrological stations for water level and 7 stations for discharge on the Mekong mainstream from the MRCS; and 1 station for water level and discharge on the Lancang mainstream and 1 station for water level and discharge on the main tributary of Man An, from China. Location of the hydrological stations on the Lancang-Mekong mainstream is illustrated in Figure 2.

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[6] For the purpose of the Joint Observation and Evaluation, the dry season is considered from 1 December to 31 May.

[7] Currently, time schedule for hydrological data exchange and sharing between the MRC and China covers the period of the flood season, which runs from 1 June to 31 October every year.

Data exchange and sharing from the MRCS

- Daily water level (21 hydrological stations) and discharge data (7 hydrological stations) from 1 December 2015 to 15 May 2016 at the hydrological stations along the Mekong mainstream
- Newly developed rating curves at the seven hydrological stations along the Mekong mainstream
- Long term average monthly data of water level (21 hydrological stations) and discharge (7 hydrological stations) for 1960-2009 at the hydrological stations along the Mekong mainstream
- Long term average monthly data of water level (21 hydrological stations) and discharge (7 hydrological stations) for 2010 to 2015 at the hydrological stations along the Mekong mainstream
- Coordinate with the Member Countries for daily discharge of reservoirs that contribute to the emergency water supplement for March-May 2016[8]

Data exchange and sharing from the China

- Daily water level and discharge data from 1 December 2015 to 15 May 2016 at Jinghong station
- Daily water level and discharge data from 1 December 2015 to 15 May 2016 at Man An station
- Long term average monthly data of water level and discharge for 1960-2009 at Jinghong station
- Long term average monthly data of water level and discharge for 2010-2015 at Jinghong station

Apart from the above data exchange and sharing, salinity concentration in Soc Trang was also provided from Viet Nam to China.

3.3 Methodology

The effect of the emergency water supplement from China was evaluated by analysing daily water level and discharge in the dry season 2016, which runs from 1 December 2015 to 31 May 2016, and especially emphasises the period of the emergency water supplement of 15 March – 31 May 2016 and long term average of dry season flow conditions of 1960-2009 and 2010-2015. The evaluation focused on the generic analyses of the drought in the Lancang-Mekong Basin, influential hydrological factors of Mekong water flow/volume, and socio-economic benefits of the emergency water supplement. More specifically, the evaluation covered the following:

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[8] Only monthly reservoir regulation information during January to April 2016 of Nam Ngum 1 Hydropower Project has been successfully collected in due time.

- Cause of the drought in the Lancang-Mekong Basin was assessed by considering monitoring data of temperature, rainfall, flows, soil moisture, water stress and status of the El Niño 2015-2016.
- Overall influence of Lancang cascade dams operation on dry season volume of the Mekong River was analysed by comparing long term average of dry season discharge, then converted to volume of 1960-2009 and 2010-2015.
- Hydrological influence of the emergency water supplement in 2016 on water level, discharge and volume of the Mekong mainstream was investigated using monthly average of water level, discharge and volume of the dry season of 1960-2009, 2010-2015 and 2016. Additionally, contribution of volume at Jinghong and volume from stretch along the Mekong mainstream was also studied.
- Net contribution of the emergency water supplement to discharge of the Mekong River was performed using technique of discharge hydrograph separation and adjustment.
- Analysis of variation of water level and discharge of the Mekong mainstream during the water supplement was carried out by placing daily observed water level and derived discharge in the dry season of 2016 with its daily long term average, minimum and maximum of the dry season of 1962-2009 and comparing to individual dry season of 2010-2015.
- Flow propagation along the Mekong mainstream was conducted using variation of daily water level and discharge, and sequence of its events, including the emergency water supplement.
- Salinity variation in the Mekong Delta during the period of the emergency water supplement was analysed using daily maximum and minimum salinity concentration at seven monitoring sites in the Mekong Delta.

Figure 2 | Location of hydrological stations along the Lancang-Mekong River.

The Lancang-Mekong River is simply the Mekong River in MRC documents, composing of two parts: the Upper Mekong River (Lancang River in China) and Lower Mekong River. Exceptionally, in this document, the Lower Mekong River refers to the Mekong River.

4 Implementation of the emergency water supplement from the Lancang River

China decided to implement a 'three-phase plan' of emergency water supplement to the Mekong River by notifying the MRCS and its Member Countries on 15 March 2016. The plan covers (1) from 9 March to 10 April 2016, with an average daily discharge of no less than 2,000 m^3/s; (2) from 11 April to 20 April 2016 with the discharge of no less than 1,200 m^3/s; and (3) from 21 April to 31 May 2016 with the discharge of no less than 1,500 m^3/s.

On 15 March 2016, the discharge from Jinghong Reservoir increased to 2,190 m^3/s, marking officially the beginning of the emergency water supplement from cascade reservoirs of the Lancang River. From 9 March to 10 April 2016, the volume at Jinghong accumulated to 6.10 billion m^3, with daily average discharge of 2,170 m^3/s, which was increased by 1,570 m^3/s comparing with the discharge without dam regulation.

To respond to the need of security-related activities for the Water Splashing Festival of Dai people[9] in Xishuangbanna from 11 April to 20 April 2016, the discharge of Jinghong Reservoir was regulated to 1,200 m^3/s. From 00:00 on 11 April 2016, the discharge of Jinghong Reservoir was regulated in a smooth way and decreased gradually from 2,100 m^3/s to 1,200 m^3/s, guaranteeing safe navigation in the downstream and meeting the need of related activities during the Water Splashing Festival. The discharge from Jinghong Reservoir was then reached approximately 1,200 m^3/s at 05:00 on 11 April 2016. From 11 April to 20 April 2016, the volume at Jinghong accumulated to 1.07 billion m^3, with daily average discharge of 1,234 m^3/s, which was increased by 363 m^3/s comparing to the discharge without dam regulation.

The discharge of Jinghong Reservoir was then controlled to no less than 1,500 m^3/s from 21 April to 31 May 2016. The accumulated volume of this period was 5.48 billion m^3.

From 9 March to 31 May 2016, the total released volume at Jinghong was found to be 12.65 billion m^3.

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[9] The Dai people belong to an ethic group that is spread widely in the southwest of China, but is concentrated in the southern part of Yunnan Province. Jinghong is the capital city of Xishuangbanna Dai Autonomous Prefecture. The biggest festival of the Dai people is the New Year celebrations (or Water Splashing Festival) held during the sixth month of the Dai calendar, usually falling in the middle of April. The New Year celebrations last for 3 days. Due to historical reasons, the New Year for the Dai people of Xishuangbanna is from April 13 to 15. During the festival, visitors can experience exciting water splashing activities, and other activities, such as cock fighting, dragon boat racing, and water lantern floating (China Highlights: http://www.chinahighlights.com/video/the-water-splashing-festival.htm, accessed on 09 June 2016).

5 Analysis of cause of the drought in the Lancang-Mekong Basin

Cause of the drought in the Lancang-Mekong Basin was assessed by considering status of the El Niño 2015-2016 and monitoring data of temperature, rainfall, flows, soil moisture, and water stress.

5.1 Rainfall and inflow discharge to the Lancang Basin

From November 2015 to April 2016, the average rainfall in the upstream catchment of Jinghong was 166.9 mm by statistical analysis according to the measured rainfall in the Lancang Basin, which was decreased by 19% comparing with an average rainfall of 206.4 mm of the same period.

Moreover, inflow discharge to Xiaowan Reservoir and Nuozhadu Reservoir from November 2015 to March 2016 was calculated and then compared to the long term average values, the results are presented in Table 1. The inflow discharges to Xiaowan Reservoir and Nuozhadu Reservoir were found to be reduced by 14%-38% and 10%-38% respectively, comparing to the long term average values of the same period.

In short, from the aspects of measured rainfall and inflow discharge to Xiaowan Reservoir and Nuozhadu Reservoir, it generally suggests that the Langcang Basin was experienced shortage of inflows from November 2015 to March 2016.

Table 1 | Conditions of inflow discharge to Xiaowan Reservoir and Nuozhadu Reservoir from November 2015 to March 2016.

Inflow discharge (m^3/s)	November	December	January	February	March
Xiaowan Reservoir					
Inflow to Xiaowan in 2016	537	409	324	326	351
Inflow to Xiaowan without upstream dams in 2016	544	404	321	321	360
Long term average inflow of 1960-2006	875	553	420	380	418
Ratio of reduction to long term average	-38%	-27%	-24%	-16%	-14%
Nuozhadu Reservoir					
Inflow discharge to Nuozhadu in 2016	1,110	1,240	1,230	731	901
Inflow to Nuozhadu without upstream dams in 2016	933	692	535	501	459
Long term average inflow discharge of 1960-2006	1,500	915	668	559	536
Ratio of reduction to long term average	-38%	-24%	-20%	-10%	-14%

5.2 Drought in the Mekong Basin

The drought phenomenon is usually grouped into four types[10]:

- **Meteorological or climatological drought**, which focuses on the degree of 'dryness' in terms of an accumulated rainfall deficit.
- **Agricultural drought**, which expresses the rainfall shortfall primarily in terms of its impact upon crop production through insufficient soil moisture. It generally applies to rainfed agriculture, though irrigated crops can be affected when the water resources themselves become restricted or too expensive.
- **Hydrological drought** refers to shortages in both surface water and groundwater. This can take the form of critically low river flow, drawn-down reservoir storage and deeper groundwater levels, which make pumped abstraction too expensive or mechanically impossible.
- **Socio-economic drought** associates the supply and demand consequences for economic goods. Energy outputs from hydropower schemes can be curtailed due to low stream flow and low levels of reservoir storage. There are industrial, agricultural, environmental and social consequences from any curtailment of water supply and water use during droughts.

Meteorological drought is the prime mover in the sequence. The first consequence of an accumulated rainfall deficit is a reduction in soil moisture storage, which once it reaches a critical level, will have impacts upon crops and animal grazing. Agricultural impacts are therefore the first to appear and in most cases provide the first confirmation that there is in fact a drought of any sort at all. These impacts can vary from crop to crop, from farm to farm, from region to region and they depend upon the crop and its resistance to moisture stress, the stage in its growth, whether there are alternative water supplies other than rainfall, and whether livestock can be provided with alternative grazing.

As the rainfall and moisture deficit continues to accumulate, hydrological drought begins to manifest itself. Firstly natural stream flows decrease and fall below normal[11], ultimately causing a water resources shortfall as reservoirs and other sources of water supply become drawn down. If the event has a long duration and particularly in the case of multi-year droughts, groundwater levels fall and abstraction can become too expensive, too damaging or even mechanically impossible.

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[10] Wilhite, D. A. & Glantz, M. H., 1985. Understanding the drought phenomenon: the role of definitions, Water International, 10(3), pp. 111–120. World Meteorological Organization. December 2009. Experts agree on a universal drought index to cope with climate risks. Press release No. 872.

[11] Hydrological drought or historically severe drought is defined in the context of the 1995 Mekong Agreement and the Procedures for the Maintenance of Flows on the Mainstream (PMFM) as when the daily flows during the dry season are less than the lower bound of the Annual Recurrence Interval (ARI) 1:20 of the historically observed daily flows of the historical period of 1960-2009. The ARI is defined as the average annual rate of occurrence of an event. In this case, a Lognormal distribution applied the General Extreme Value (GEV) is used in the calculation of the ARI. For example, ARI 1:5 (equivalent to 20 times in 100 years, meaning 80% probability of exceedance) daily flow is the mean daily flow that is not equalled or exceeded one in five years in the record under consideration. In the context of the ARI, the mean daily flow is equal to the flow of 50% probability of exceedance.

Finally, drought becomes apparent as a socio-economic process of water shortage and its impacts. There may be food price increases due to reduced domestic agricultural output and (possibly) their replacement with more expensive imports. There may be power rationing due to reduced generating capacity and some industries that are high consumers of water (petrochemicals, metallurgical, bottling plants) might have to reduce production, with secondary consequences for employment, prices, the availability of goods and national economic growth.

As adequate data and information on this domain were not available in the Mekong Basin countries, this section could not be fully developed; however, a general observation of the drought situation is compiled using various sources as presented in Annex A.

The cause of drought in this study was investigated using the status of the El Niño 2015-2016, temperature, rainfall, soil moisture and water index as described in below section.

El Niño 2015-2016 and El Niño 1997-1998

The El Niño 2015-2016 is strong and appears likely to equal the event of 1997-1998 (Figure 3), the strongest El Niño on record, according to the World Meteorological Organization. The super El Niño of 2015-2016 was highly on alert. Data from NASA[12] reveals side-by-side comparisons of Pacific Ocean sea surface height anomalies[13] of what was happening to the Pacific Ocean El Niño signal with the famous El Niño 1997-1998 (which peaked in November 1997). The El Niño 2015-2016, which peaked in January 2016, was longer lasting than the 1997-1998 episode and was larger in area. The El Niño of 2015-2016 was similar to the El Niño of 1997-1998, but not an exact repeat. Each El Niño episode had a unique timing and variations in impacts. It should be noted that the El Niño of 2015-2016 was a continuing El Niño that first appeared in 2014-2015[14]. Comparing 2015-2016 conditions with 1997-1998, a large area of the northeastern tropical Pacific (north of the equator) still contained a large area of positive heat content (warmer than normal).

Temperature

Average temperature departure from the normal average, illustrated in Figure 4, shows that during mid-January between 11 and 20 January 2016, the Mekong Basin received a high temperature starting from middle part of the basin towards southern part of the region

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[12] Jet Propulsion Laboratory, United States National Aeronautics and Space Administration (NASA): https://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/, accessed on 7 June 2016.

[13] Height of the sea surface is caused by both gravity (which doesn't change much over 100's of years), and the active (always changing) ocean circulation. The normal slow, regular circulation (ocean current) patterns of sea-surface height move up and down (warming and cooling and wind forcing) with the normal progression of the seasons: winter to spring to summer to fall. The differences between what is normal for different times and regions are called anomalies or residuals. The year-to-year and, even, decade-to-decade changes in the ocean that indicate climate events such as the El Niño, La Niña and Pacific Decadal Oscillation are dramatically visualized by these data. Sea surface height is the most modern and powerful tool for taking the 'pulse' of the global oceans (NASA: https://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/, accessed on 7 June 2016).

[14] United States National Aeronautics and Space Administration (NASA), http://www.nasa.gov/feature/goddard/nasa-studying-2015-el-nino-event-as-never-before, accessed on 8 June 2016.

between 3-5 °C above the normal average[15]. However, the condition lasted for only around two weeks. Northeast Thailand, Lao PDR and North Viet Nam, nevertheless, experienced lower temperature than the average in February 2016. The temperature started rising up again in early March across the region and intensifying in some areas with severe condition in April 2016. It is considered that the region received highest temperature at national records.

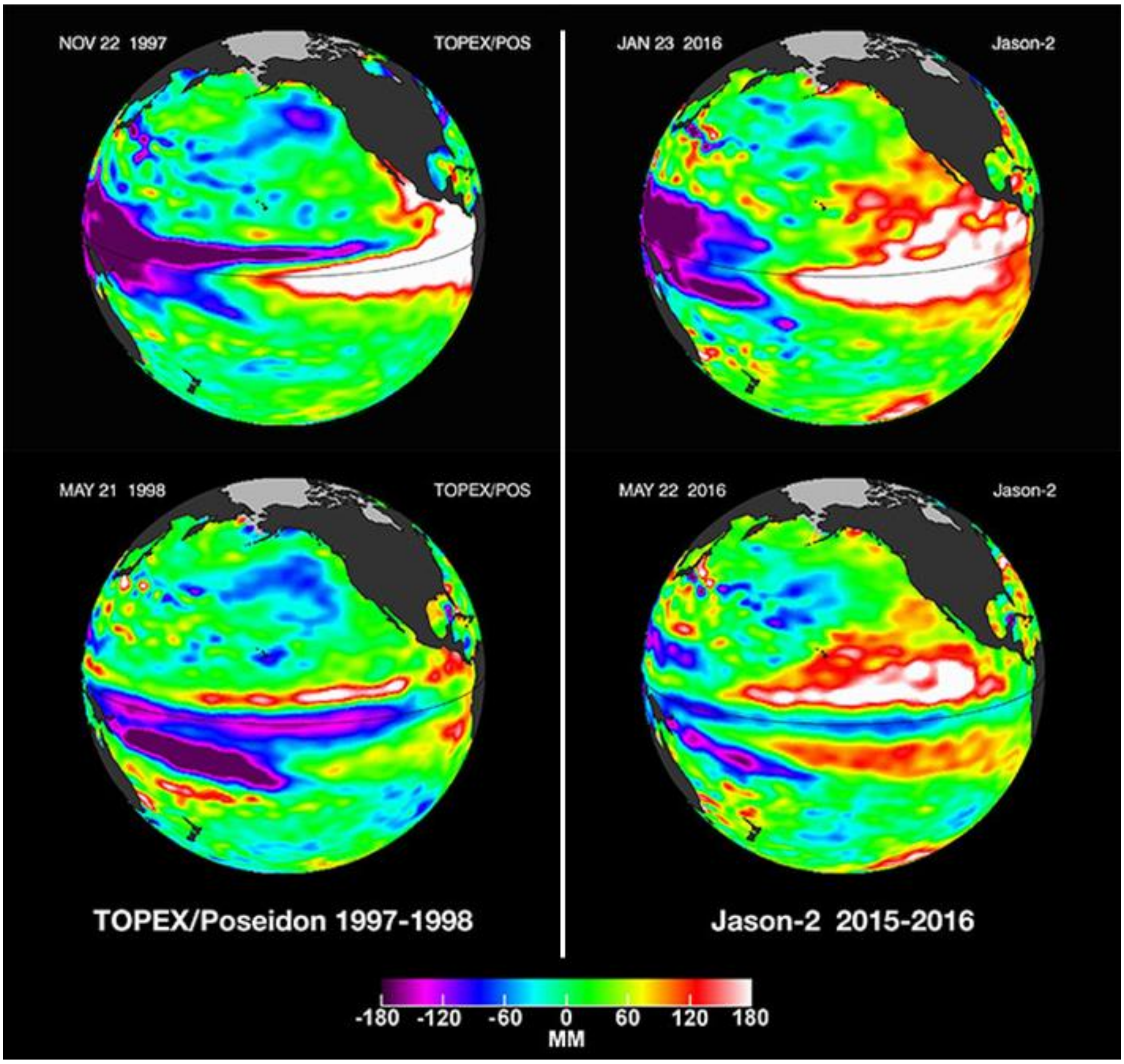

Figure 3 | Side-by-side comparisons of Pacific Ocean sea surface height anomalies caused by the El Niño 1997-1998 and El Niño 2015-2016.

These images show sea surface height anomalies with the seasonal cycle (the effects of summer, fall, winter, and spring) removed. The differences between what is normal for different times and regions are called anomalies or residuals. When oceanographers and climatologists view these 'anomalies' they can identify unusual patterns and can tell how heat is being stored in the ocean to influence future planetary climate events. Each image is a 10-day average of data, centered on the date indicated.

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[15] Average daily air temperature is calculated for each grid cell by averaging the twenty-four 1-hourly air temperatures. The dekadal average air temperature is then estimated by averaging the ten daily air temperatures for each grid cell. The temperature data is derived from satellite weather data from the Air Force Weather Agency (AFWA).

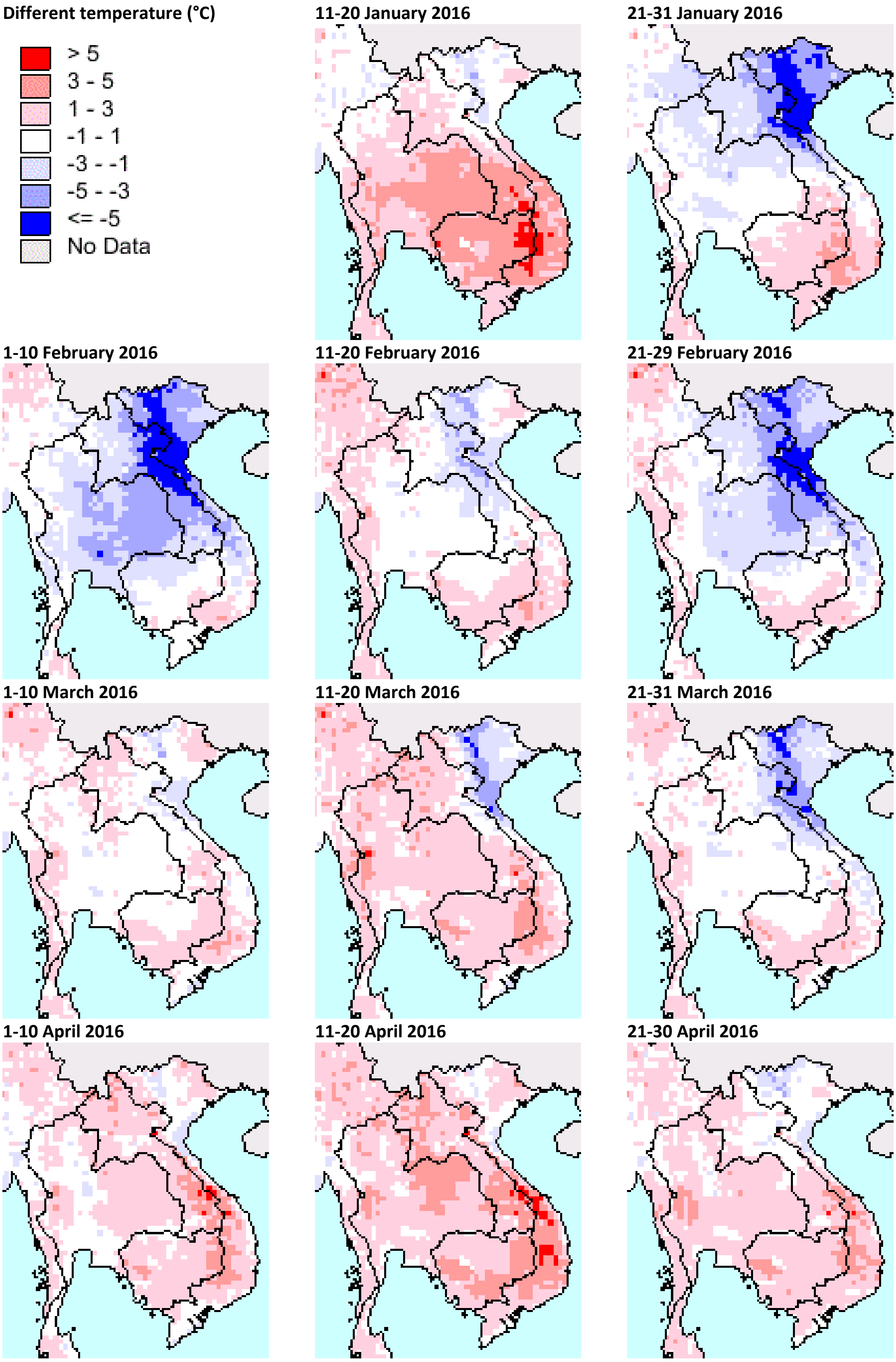

Figure 4 | Average temperature departure from normal, from the United States Air Force Weather Agency (AFWA) for January-April 2016.

Rainfall

Satellite rainfall from the Tropical Rainfall Measuring Mission (TRMM) presented in Figure 5 reveals rainfall conditions over the Mekong Basin from January to April 2016. The observation shows the northern part of Lao PDR received small amount of rainfall in January 2016. There was almost no rain over the Mekong Basin in February and March 2016. In April, most areas of the Mekong Basin, except for the Mekong Delta, received some small amount of rainfall between 20 to 200 mm. Lao PDR received the most accumulated rainfall between 50-200 mm in April, especially in the north and middle parts of the country. Point rainfall at the ground was also observed at all hydrological stations (Figure 2). Rainfall amount for March-May 2016 was mainly concentrated in late April and early May as recorded at Luang Prabang, Chiang Khan and Nakhon Phanom. It is shown that only small amount of rainfall was observed over the Mekong Basin, as depicted in Figure 6.

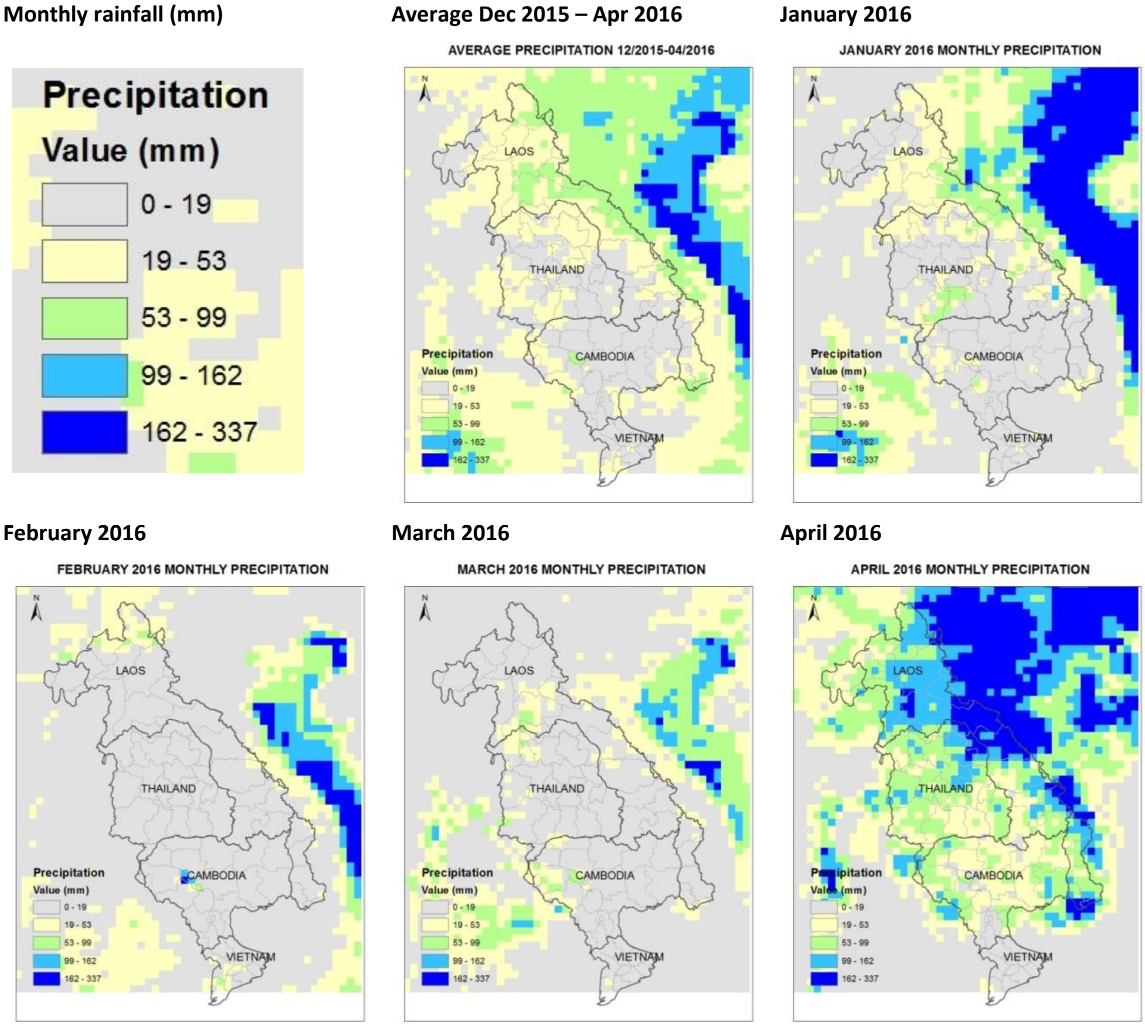

Figure 5 | Monthly rainfall over the Mekong Basin from the Tropical Rainfall Measuring Mission (TRMM) for January-April 2016.

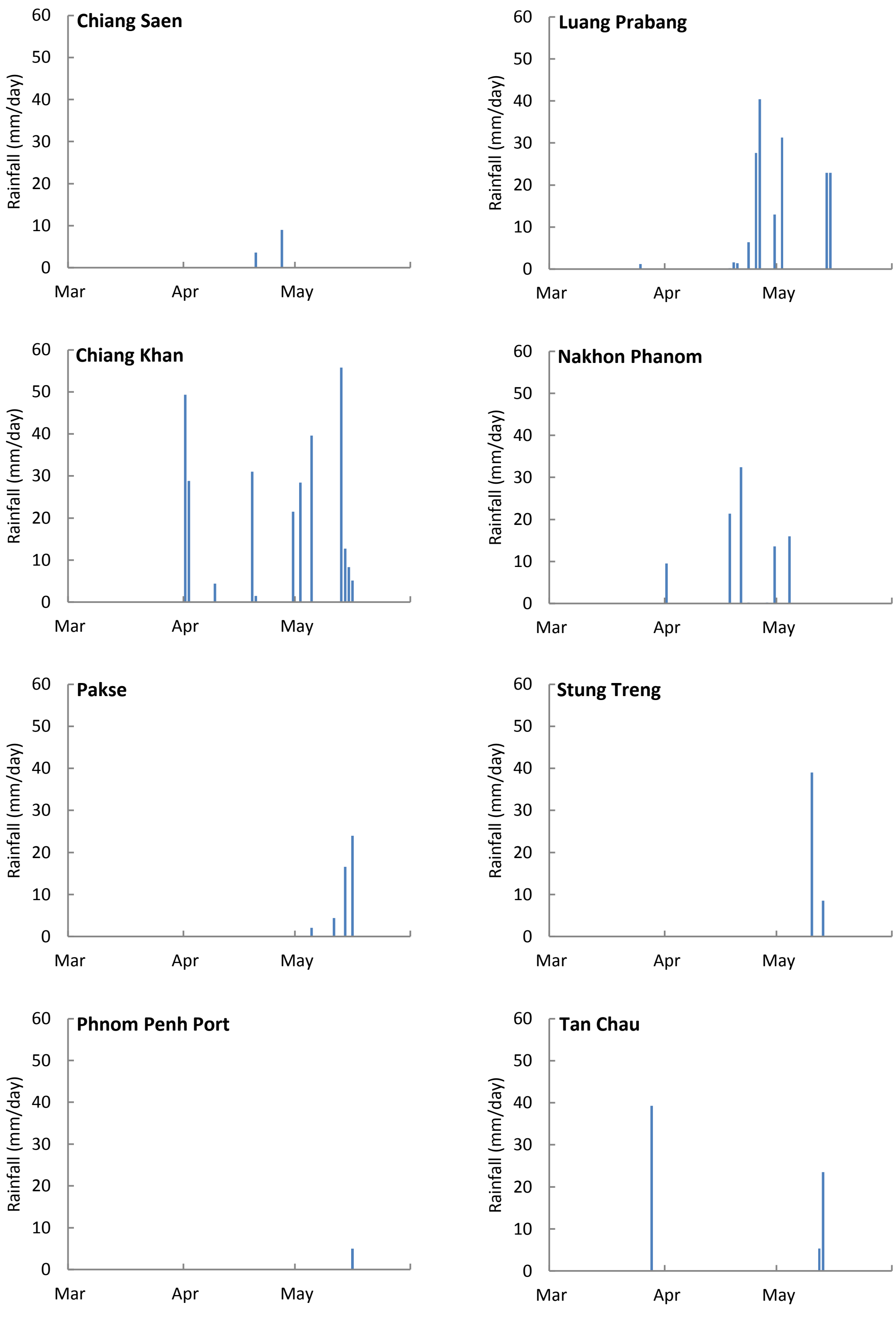

Figure 6 | Rainfall observation at eight representative stations in the Mekong Basin from 1 March to 15 May 2016.
Location of observation stations can be found in Figure 2. Rainfall amount for March-May 2016 was mainly concentrated in late April and early May as recorded at Luang Prabang, Chiang Khan and Nakhon Phanom. Only small amount of rainfall was observed over the Mekong Basin during March-May 2016.

Subsurface soil moisture

Subsurface soil moisture[16] levels are best used to monitor an established crop. The subsurface soil moisture is assumed to hold 0-400 mm/m of water depending on the soil's water-holding capacity (based on soil texture and soil depth).

Subsurface soil moisture started getting worse in March 2016 in Thailand, Cambodia and Mekong Delta (Figure 7). The moisture content remained less than 25 mm making unfavourable condition for the crops. The dry condition intensified in the following months of April. Only some small part of the east Thailand received some moisture in fourth week of April as the rain pours down (Figure 5). Western part of Lao PDR had a better soil moisture condition throughout the dry season 2016.

Normalised Difference Water Index

The Normalized Difference Water Index[17] (NDWI) or water stress for agriculture is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. Map of the NDWI depicted in Figure 8 shows that, starting from fourth week of January 2016, the water stress value was already at moderate level in northeast Thailand and around floodplain of the Tonle Sap Lake of Cambodia. The condition became worse in February to end of April, which would damage a large area of agricultural production in northeast Thailand and Cambodia. The water stress conditions became less serious towards the end of April in these two countries, thanks to rainfall over the Mekong Basin. However, it looks relatively good for Lao PDR and Mekong Delta during January-April 2016.

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[16] The soil moisture model assumes rainfall enters the two soil layers by first filling the surface soil layer and then filling the lower soil layer. Moisture is extracted from the two soil layers by evapotranspiration, whereby water is first depleted from the top layer and then extracted from the subsurface layer. When the water-holding capacity of both soil layers is reached, excess rainfall is lost from the model and treated as runoff or deep percolation. Subsurface soil moisture levels ranging from: >100 mm indicates an abundance or at least favourable amount of moisture in the subsoil; <100 mm indicates the subsurface soil moisture storage is short but can still support a well-established crop; and <25 mm has very little subsurface soil moisture and the crop could be severely stressed and reduce yields, especially if it occurs when the top layer has little or no significant soil moisture and the crop is at a critical stage of growth.

[17] The Normalized Difference Water Index (NDWI) is a satellite-derived index from the Near Infrared (NIR) and Short Wave Infrared (SWIR) channels. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR and SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content. The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. The SWIR reflectance is therefore negatively related to leaf water content.

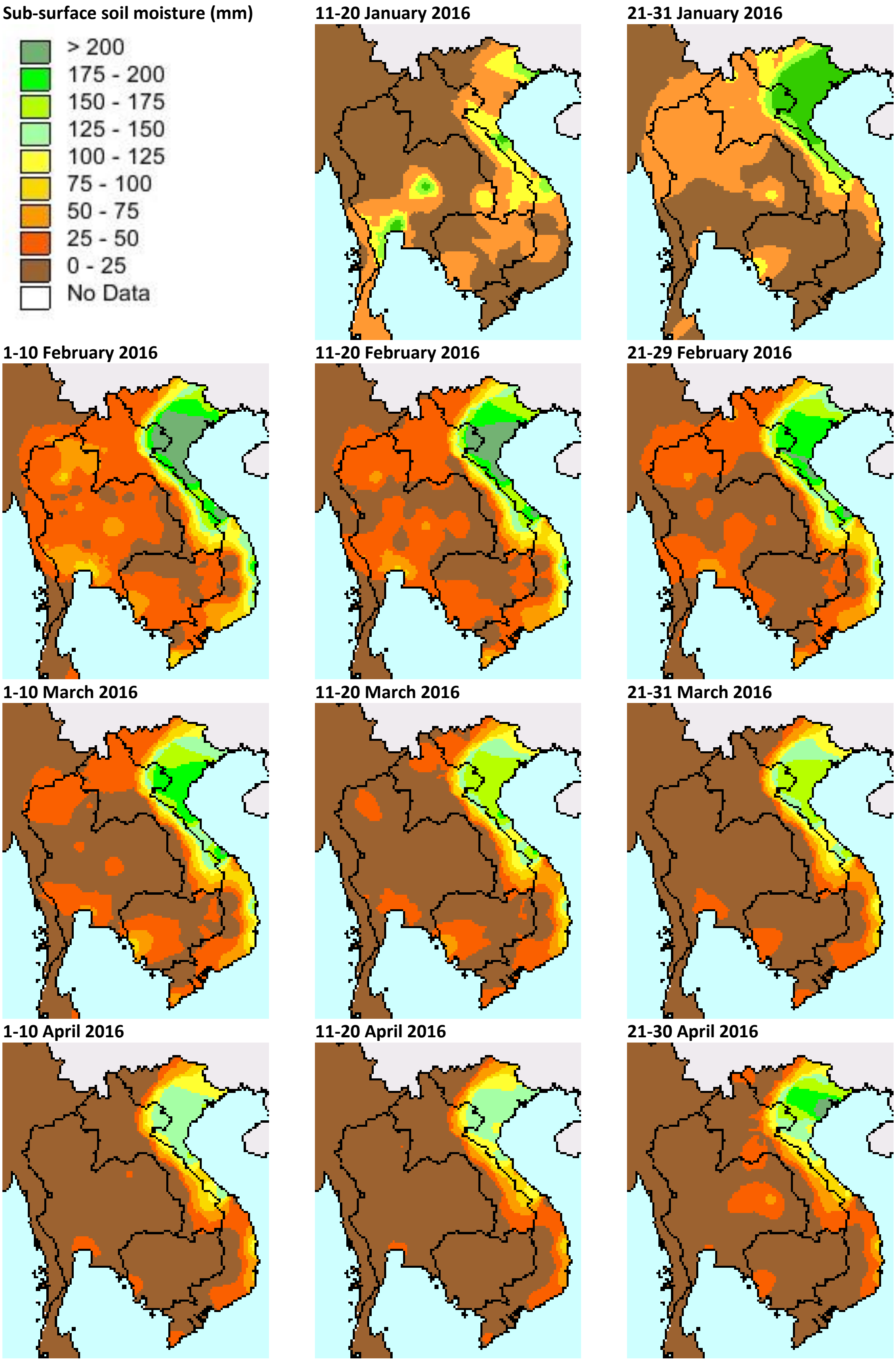


Figure 7 | Subsurface soil moisture monitoring from the World Meteorological Organisation (WMO) for January-April 2016.

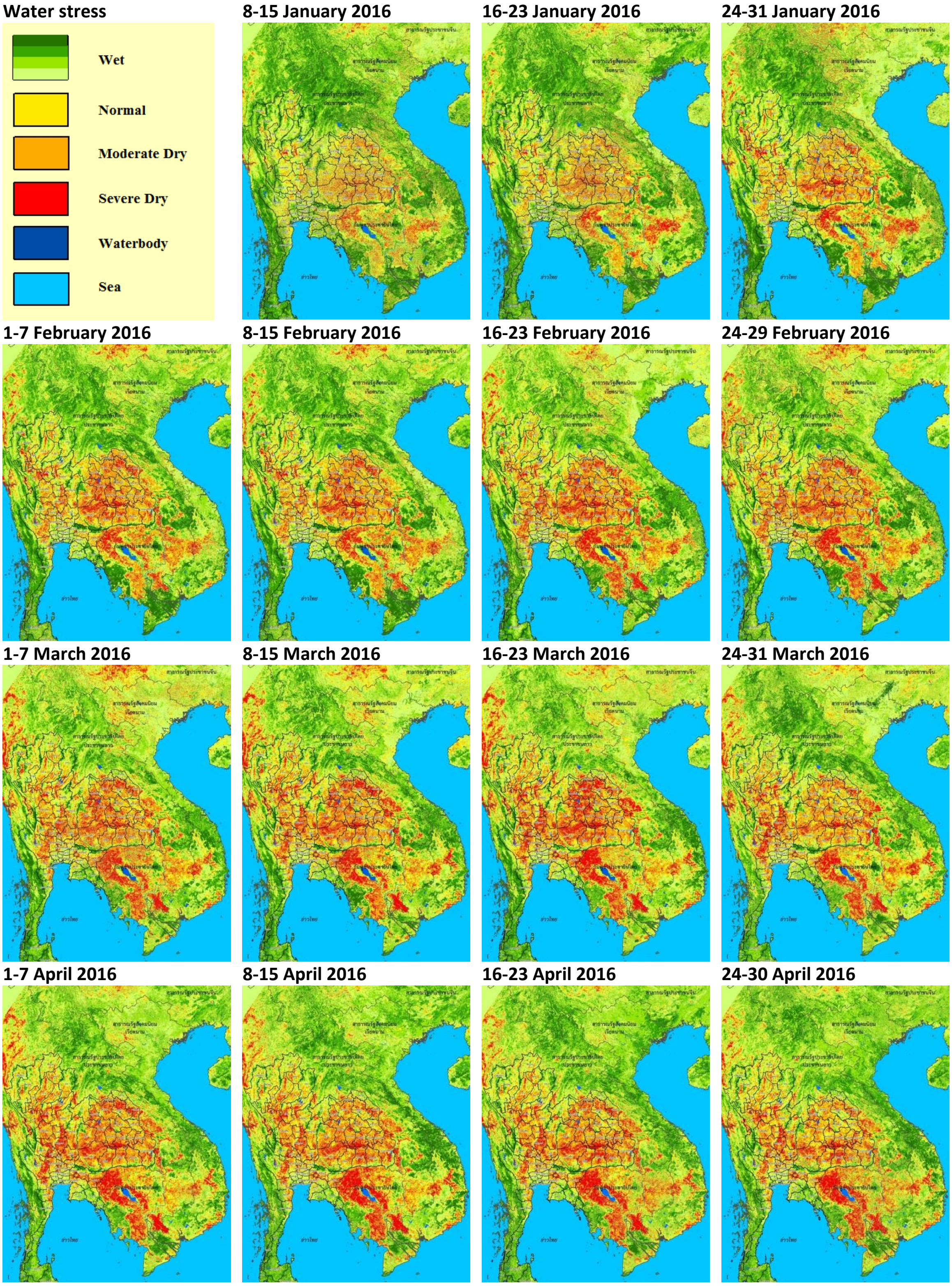


Figure 8 | Normalised Difference Water Index (Water Stress for Agriculture) from Geo-Informatics and Space Technology Development Agency (GISTDA) for January-April 2016.

6 Influence of Lancang cascade reservoir operation on dry season volume of the Mekong River

Overall influence of Lancang cascade reservoir operation on dry season volume of the Mekong River was analysed by comparing long term average of dry season discharge, then converted to volume of 1960-2009 and 2010-2015.

The Xiaowan Reservoir started to store water in the flood season of 2009 with the first power unit put into use in September 2009. During this period, the hydropower plant only functioned to minimum power generation. Until July 2010, the stored water level reached the dead level and the Xiaowan Reservoir began to perform its regulation and storage capacity. Likewise, the Nuozhadu Reservoir started to generate power in September 2012. These two large reservoirs balance the Lancang flows between the rainy and dry seasons with its storage capacity and regulation. Hence, it is widely accepted that Year 2010 is considered as a dividing time point, when considerable influence of the Lancang cascade on flows of the Mekong mainstream in the dry season grows.

6.1 Annual volume of the Lancang River

Main cascade reservoirs of the Lancang River were completed between 2010 and 2015. The Gongguoqiao Reservoir started fully operational in 2012, Xiaowan in 2010, Manwan in 2007, Dachaoshan in 2003, Nuozhadu in 2014 and Jinghong in 2009. Therefore, the volume at Jinghong hydrological station before 2009 could be considered as the **'natural condition'** without influence of operation of the reservoirs. An amount of 13.0 billion m^3 was reduced at Jinghong, with an average annual volume of 56.2 billion m^3 for 1960-2009 and 43.2 billion m^3 for 2010-2015.

From 2010 to 2015, Gongguoqiao and Nuozhadu Reservoirs started to store water with a total dead storage of 10.68 billion m^3, which means a contribution of 1.78 billion m^3 annually (10.68 billion m^3 over 6 years of 2010-2015) to the variation of average annual volume at Jinghong. It only represents about 4% (1.78 billion m^3 of 43.2 billion m^3) of average annual volume of 2010-2015. Besides the storage of the Lancang Reservoirs, the average annual volume of 2010-2015 reduced by 11.2 billion m^3 (13.0 billion m^3 minus 1.78 billion m^3), which was about 20% (11.2 billion m^3 of 56.2 billion m^3) of the average value of 1960-2009. This reflects a reduction of 20% of annual volume at Jinghong which is typically caused by climate variability.

6.2 Impact of cascade dams on dry season volume of the Mekong River

Using monthly average discharge of 1960-2009 and 2010-2015, average volume for the dry season (Dec-May) was evaluated at Jinghong and seven other hydrological stations along the Mekong River. The results show that the operation of the Lancang cascade dams increased dry season volume at Jinghong from 11.82 billion m^3 (or 21% of annual volume of 1960-2009) to 17.77 billion m^3 (or 41% of annual volume of 2010-2015), contributing 5.95 billion m^3 (or 20%). Likewise, overall increase in dry season volume were observable between 4% and 12% at hydrological stations along the Mekong mainstream, as presented in Table 2. However, it is important to note that the increase was also partly attributed to regional climate condition (rainfall) and contribution from tributaries.

Table 2 | Average volume for the dry season and its ratio to annual volume along the Lancang-Mekong mainstream.

Station	Average volume of the dry season (billion m³) and ratio to annual volume (%)		
	1960-2009	2010-2015	Increase
Jinghong	11.82 (21%)	17.77 (41%)	5.95 (20%)
Chiang Saen	17.79 (21%)	24.22 (33%)	6.43 (12%)
Luang Prabang	23.99 (19%)	28.15 (27%)	4.17 (7%)
Nong Khai	26.57 (18%)	31.48 (24%)	4.90 (5%)
Nakhon Phanom	34.85 (15%)	45.90 (19%)	11.06 (4%)
Mukdahan	35.59 (14%)	52.59 (20%)	17.00 (5%)
Pakse	41.74 (13%)	56.02 (18%)	14.28 (5%)
Stung Treng	51.41 (13%)	62.06 (17%)	10.65 (4%)

7 Hydrological influence of the emergency water supplement to the Mekong River

Hydrological influence of the emergency water supplement in 2016 on water level, discharge and volume of the Mekong mainstream was investigated using monthly average of water level, discharge and volume of the dry season of 2016, 1960-2009 and 2010-2015. Moreover, contribution of volume at Jinghong and from stretch along the Mekong River was also studied.

7.1 Influence on discharge of the Mekong River

The monthly average discharge in the dry season from December 2015 to May 2016 at Jinghong and seven key stations along the Mekong mainstream was calculated from daily derived discharge at these stations and illustrated in Figure 9. Moreover, a comparison between the monthly average discharge of the dry season of 2016, 1960-2009 and 2010-2015 was conducted. The results of this analysis are presented in Figure 10.

It is observed that flow patterns of 2010-2015 at all interested stations were generally higher than that of 1960-2009. However, pattern of two-month (March and April) minimum discharges of 1960-2009 was typically replaced by one-month (February) minimum flows of 2010-2015.

Particularly for the dry season of 2016, it is found that discharges in December 2015 at all stations, except for Jinghong and Mukdahan, were lower than the average discharges of 1960-2009. This was because of low inflows to the Lancang-Mekong River during this month. In January 2016, discharges at most stations were between the average discharges of 1960-2009 and 2010-2015, while discharges at Jinghong were higher than those of 2010-2015 and discharges at Nong Khai and Stung Treng were lower than those of 1960-2009. Furthermore, discharges in February 2016 at stations downstream Chiang Saen were above the average discharge of 2010-2015. This observable pattern happened as there was a bump of flows at Jinghong in mid-January and that bump travelled down the Mekong mainstream. It is important to note that February was considered as the lowest month of the dry season as reflected in the general pattern of the dry season of 2010-2015. Additionally, discharges for March-April 2016 at most stations were higher than average discharge of 2010-2015, indicating the implementation of the emergency water supplement from China. Finally, discharges in May 2016 at all stations, except at Jinghong, were between the average of 1960-2019 and 2010-2015.

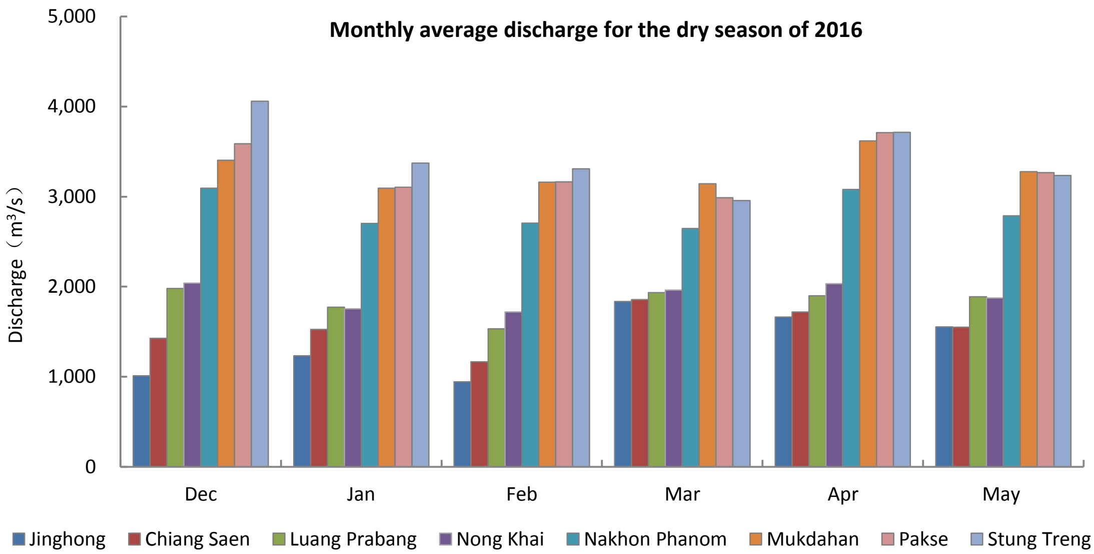


Figure 9 | General pattern of monthly average discharge along the Lancang-Mekong mainstream for the dry season of 2016.

During the period of the emergency water supplement in March and April 2016, the monthly average discharges at Jinghong were 1,280 m^3/s and 985 m^3/s, respectively, larger than the average of 1960-2009, and 704 m^3/s and 442 m^3/s larger than the average of 2010-2015. Meanwhile, discharges at key stations along the Mekong mainstream were also increased to a different extent, as shown in Table 3. Therefore, with a proper operation of the Lancang cascade dams, the discharge along the Mekong mainstream increased considerably in these two months of March-April, which were the period of minimum discharge for 1960-2009. More specifically, monitoring records in 2016 reveal a further increase in discharge even higher than the average of 2010-2015. This implies the emergency water supplement undoubtedly helps mitigate the prolonged meteorological and agricultural droughts in the Mekong Basin.

Table 3 | Monthly average discharge in March and April 2016 and average increased discharge comparing to the average discharge of 1960-2009 and 2010-2015.

Station	Discharge for 2016 (m^3/s)		Increased discharge comparing to 1960-2009		Increased discharge comparing to 2010-2015	
	March	April	March	April	March	April
Jinghong	1,830	1,660	1,280	985	704	442
Chiang Saen	1,860	1,720	1,020	806	427	231
Luang Prabang	1,930	1,900	871	789	394	307
Nong Khai	1,960	2,030	782	789	282	287
Nakhon Phanom	2,650	3,080	1,070	1,510	234	588
Mukdaham	3,140	3,620	1,520	2,000	259	610
Pakse	2,990	3,710	1,120	1,860	113	632
Stung Treng	2,960	3,710	774	1,570	-80	344

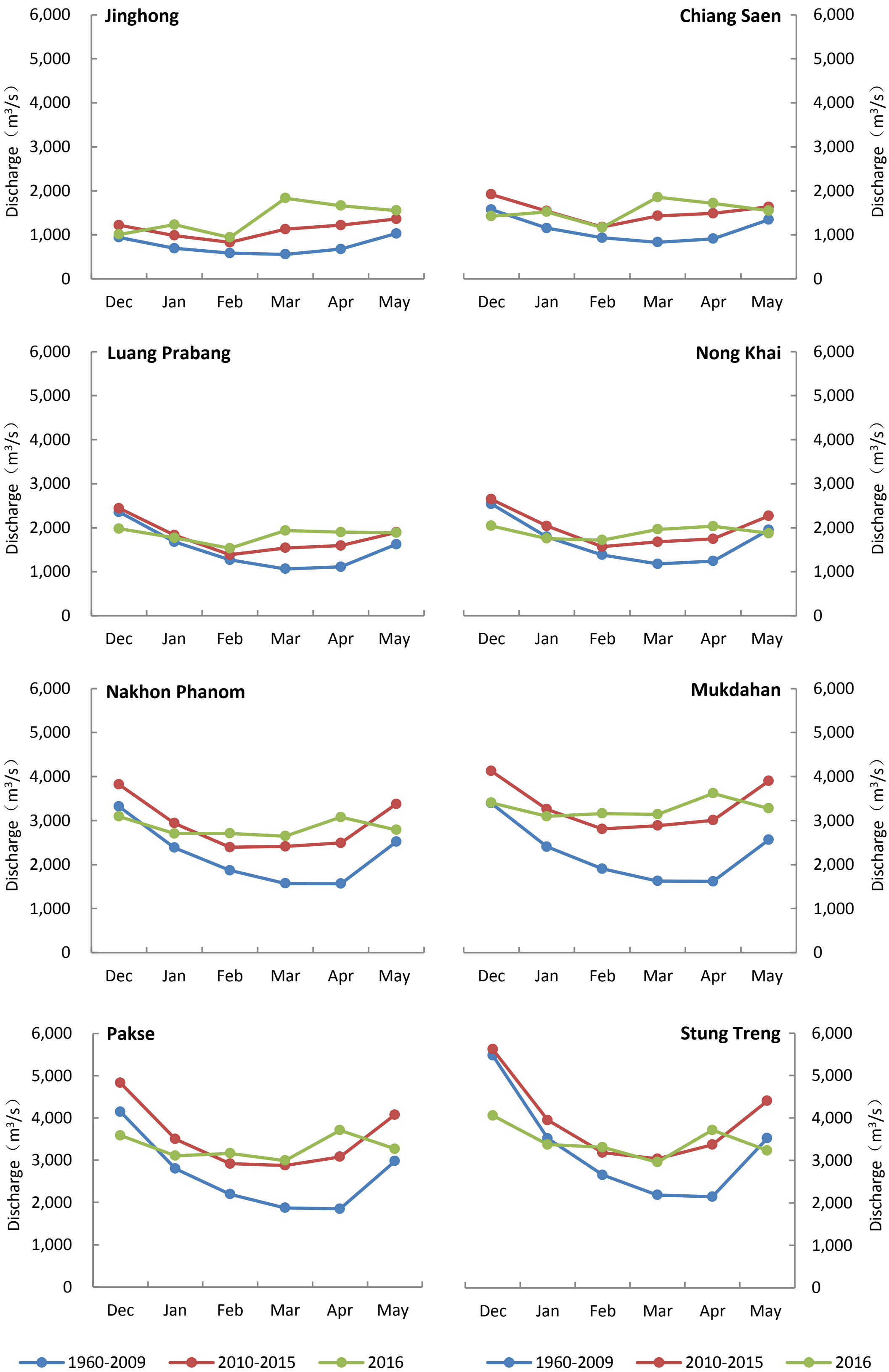


Figure 10 | Comparison of monthly average discharge along the Lancang-Mekong mainstream for the dry season of 2016, 1960-2009 and 2010-2015.

7.2 Influence on water level of the Mekong River

For the purposes of comparison between the long term average of 1960-2009 and 2010-2015, the monthly average water level in the dry season of 2016 (December 2015 to May 2016) along the Lancang-Mekong mainstream was calculated from the daily water level and the results are presented in Table 4.

In December 2015, the water levels at most stations along the Lancang-Mekong River were generally lower than the average value of 1960-2009. However, from January to May 2016, the water levels at all stations were typically higher than the average of 1960-2009. As shown in Table 9, water level in March 2016 at the hydrological stations rose to an overall extent of 0.18-1.53 m.

Table 4 | Monthly average water level in the dry season of 2016 and deviation of average water levels of 2016, 1960-2009 and 2010-2015.

Station	December	January	February	March	April	May
Average water level in 2016 (m local datum)						
Jinghong	535.54	535.82	535.43	536.62	536.43	536.36
Chiang Saen	2.38	2.47	2.05	2.84	2.70	2.53
Luang Prabang	4.99	4.60	4.19	4.89	4.83	4.84
Nong Khai	2.29	1.88	1.78	2.16	2.25	2.07
Nakhon Phanom	1.88	1.59	1.56	1.54	1.87	1.66
Mukdahan	2.09	1.89	1.92	1.92	2.22	2.01
Pakse	1.50	1.27	1.29	1.21	1.56	1.35
Stung Treng	2.81	2.61	2.59	2.48	2.71	2.57
Deviation of average water level between 2016 and 1960-2009 (m)						
Jinghong	-0.15	0.62	0.47	1.73	1.32	0.66
Chiang Saen	0.16	0.82	0.77	1.74	1.46	0.63
Luang Prabang	-0.64	0.03	0.37	1.52	1.38	0.47
Nong Khai	-0.76	-0.29	0.18	0.90	0.91	-0.16
Nakhon Phanom	-0.47	0.00	0.41	0.63	0.94	-0.09
Mukdahan	-0.41	0.03	0.41	0.61	0.93	0.11
Pakse	-0.43	0.01	0.35	0.46	0.82	0.04
Stung Treng	-0.33	0.03	0.32	0.41	0.68	0.05
Deviation of average water level between 2016 and 2010-2015 (m)						
Jinghong	-0.29	0.33	0.23	1.00	0.63	0.35
Chiang Saen	-0.52	-0.03	0.01	0.53	0.29	-0.06
Luang Prabang	-0.65	-0.10	0.31	0.77	0.58	0.04
Nong Khai	-0.67	-0.38	0.17	0.45	0.43	-0.46
Nakhon Phanom	-0.47	-0.17	0.22	0.22	0.48	-0.38
Mukdahan	-0.40	-0.10	0.22	0.19	0.41	-0.35
Pakse	-0.55	-0.19	0.12	0.07	0.31	-0.37
Stung Treng	-0.42	-0.17	0.04	-0.02	0.11	-0.33

7.3 Influence on volume of the Mekong River

Accumulated volume in the dry season of 2016 at Jinghong was 21.69 billion m^3, with an average increase of 3.92 billion m^3 and 9.87 billion m^3 over the long term average of 2010-2015 and 1960-2009, respectively. Moreover, the accumulated volume in the dry season of 2016 at other stations along the Mekong mainstream was larger than the long term average of 1960-2009. Table 5, Figure 11, and Figure 12 show that the accumulated volume in the dry season of 2016 and its deviation between that of 2010-2015 and 1960-2009.

Since the emergency water supplement was implemented by increasing the discharge of Jinghong Reservoir, the accumulated volume from Lancang River in the dry season of 2016 occupied a larger percentage of the volume in the Mekong River than the past years. The ratio, at which the accumulated volume at Jinghong occupied the volume at different stations along the Mekong mainstream, is presented in Table 5. The accumulated volume in the dry season of 2016 at Jinghong presented huge portion (40%-89%) of the accumulated volume at different stations along the Mekong mainstream. Furthermore, it is considered that the increase in volume in the Mekong River was 20% and 10%, compared to average accumulated volume of 1960-2009 and 2010-2015, respectively.

The stretch between Jinghong and Chiang Saen provided similar order of average contribution in 1960-2009 and 2010-2015, as indicated in Table 6. However, it is obviously seen that this stretch generated relatively low flow in the dry season of 2016. Furthermore, several tributaries on the left bank of the Mekong River between Chiang Saen and Luang Prabang contributed to volume in the mainstream.

Additionally, contribution from the stretch between Luang Prabang and Nong Khai was barely changed for 1960-2009 and 2010-2015 and flows in the dry season of 2016 were noticeably low.

For the stretch between Nong Khai and Nakhon Phanom, there are many large tributaries from the left bank of the Mekong mainstream, including Nam Ngum. This major water producing area contributed substantial flows to the mainstream. The volumes in the dry season for 2010-2015 and 2016 were found to increase when comparing to the average volumes of 1960-2009.

Although the section between Nahkon Phanom to Mukdahan has only a small catchment of about 1,800 km^2, and produced relatively small amount of contribution in the dry season of 1960-2009, the water yield of 2010-2015 and 2016 was found about 9 times higher than the average of 1960-2009. It is suggested that hydrological data and rating curves of 1960-2009 at these two stations should be carefully revisited.

Flows of the mainstream of the stretch between Mukdahan and Stung Treng come from two major tributaries of the Mun-Chi of the right bank and Sekong-Sesan-Srepok of the left bank. This section was traditionally water producing areas, however, the water volume produced in the dry season of 2010-2015 and 2016 was found to be less than the average 1960-2009, particularly in 2016.

Table 5 | Volume in the dry season of 2016, 1960-2009 and 2010-2015 along the Lancang-Mekong mainstream.

Station	Volume of the dry season (billion m³)			Deviation of volume between (billion m³)		
	1960-2009 (% Jinghong)	2010-2015 (% Jinghong)	2016 (% Jinghong)	2016 and 1960-2009	2016 and 2010-2015	2010-2015 and 1960-2009
Jinghong	11.82 (100%)	17.77 (100%)	21.69 (100%)	9.87	3.92	5.95
Chiang Saen	17.79 (66%)	24.22 (73%)	24.33 (89%)	6.54	0.11	6.43
Luang Prabang	23.99 (49%)	28.15 (63%)	28.94 (75%)	4.95	0.79	4.17
Nong Khai	26.57 (44%)	31.48 (56%)	29.90 (73%)	3.33	-1.57	4.90
Nakhon Phanom	34.85 (34%)	45.90 (39%)	44.66 (49%)	9.81	-1.25	11.06
Mukdahan	35.59 (33%)	52.59 (34%)	51.69 (42%)	16.10	-0.90	17.00
Pakse	41.74 (28%)	56.02 (32%)	52.01 (42%)	10.28	-4.01	14.28
Stung Treng	51.41 (23%)	62.06 (29%)	54.19 (40%)	2.78	-7.88	10.65

Table 6 | Contribution of volume in the dry season of 2016, 1960-2009 and 2010-2015 at different stretch along the Lancang-Mekong mainstream.

Stretch between	Volume of the dry season (billion m³)			Deviation of volume between (billion m³)		
	1960-2009	2010-2015	2016	2016 and 1960-2009	2016 and 2010-2015	2010-2015 and 1960-2009
Jinghong and Chiang Saen	5.97	6.45	2.63	-3.33	-3.81	0.48
Chiang Saen and Luang Prabang	6.20	3.94	4.61	-1.58	0.68	-2.26
Luang Prabang and Nong Khai	2.59	3.32	0.96	-1.62	-2.36	0.73
Nong Khai and Nakhon Phanom	8.27	14.43	14.76	6.48	0.33	6.15
Nakhon Phanom and Mukdahan	0.74	6.69	7.03	6.29	0.34	5.95
Mukdahan and Pakse	6.15	3.43	0.33	-5.82	-3.10	-2.72
Pakse and Stung Treng	9.67	6.04	2.17	-7.50	-3.87	-3.63

During the emergency water supplement from 10 March to 10 April 2016 (32 days), discharges at Jinghong stayed at about 2,000 m^3/s, with an accumulated volume of 6.00 billion m^3. Taking the travelling time into consideration, ratio at which the volume at Jinghong contributes to the total accumulated volume of the hydrological stations was calculated. The results are shown in Table 7. The total accumulated volume at Stung Treng is found to be 10.30 billion m^3 for the period between 27 March and 27 April (moving band of 32 days). Thus, the volume of the emergency water supplement in 2016 at Jinghong claims 58% of that at Stung Treng.

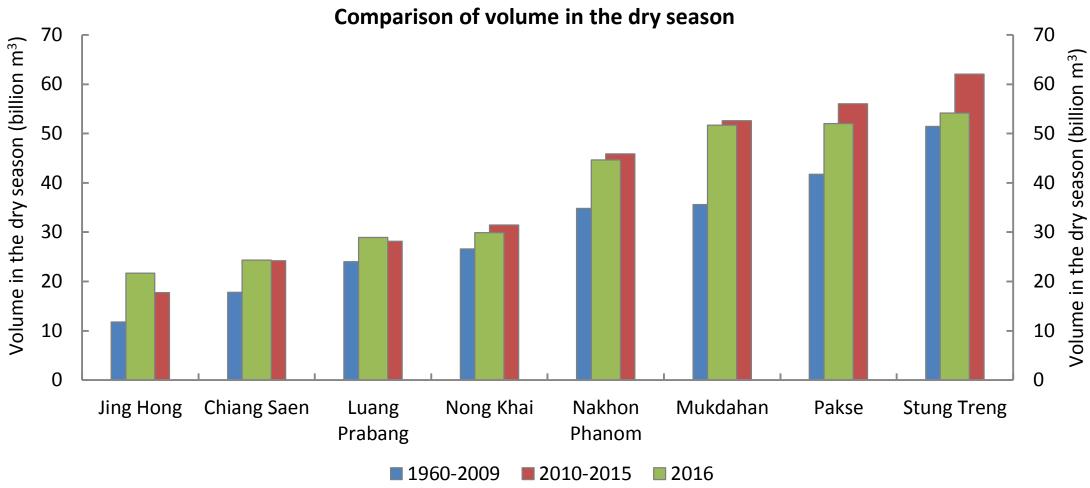


Figure 11 | Accumulated volume in the dry season at stations along the Lancang-Mekong mainstream.

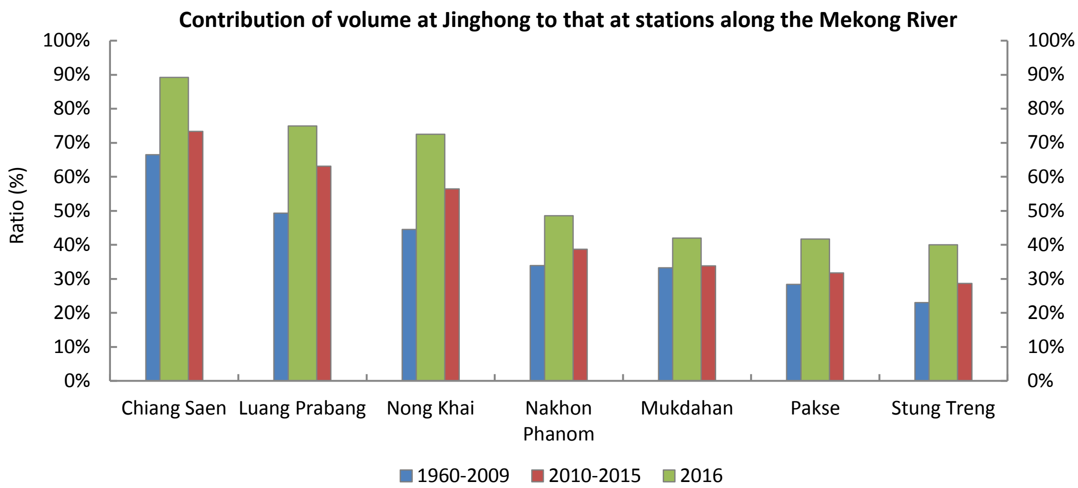


Figure 12 | Contribution of volume in the dry season at Jinghong to that at stations along the Mekong mainstream.

Table 7 | Contribution of accumulated volume at Jinghong to that at stations along the Mekong mainstream during the emergency water supplement of 2016.

Station	Travelling time	Moving band of 32 days	Discharge (m^3/s)	Volume (billion m^3)	Ratio of Jinghong
Jinghong	+0 day	10 Mar to 10 Apr	2,170	6.00	100%
Chiang Saen	+1 day	11 Mar to 11 Apr	2,199	6.08	99%
Luang Prabang	+4 days	14 Mar to 14 Apr	2,237	6.18	97%
Nong Khai	+9 days	19 Mar to 19 Apr	2,361	6.53	92%
Nakhon Phanom	+12 days	22 Mar to 22 Apr	3,262	9.02	67%
Mukdahan	+13 days	23 Mar to 23 Apr	3,748	10.36	58%
Pakse	+15 days	25 Mar to 25 Apr	3,781	10.45	57%
Stung Treng	+17 days	27 Mar to 27 Apr	3,726	10.30	58%

8 Net contribution of the emergency water supplement to discharge of the Mekong River

Major influential factors of flows of the Mekong mainstream considered in this study are rainfall, water supplement from China, water releases from water infrastructure in the Mekong Basin, water withdrawal along the Mekong mainstream.

Overall monthly satellite rainfall over the Mekong Basin is presented in Figure 5 and ground rainfall observation at representative stations is depicted in Figure 6. It is understood that only small amount of rainfall was observed over the Mekong Basin. Additionally, since data and information of water releases from water infrastructures in the Mekong Basin and water withdrawal along the Mekong mainstream were not available at the time of this analysis, it is considered that the water supplement was a lumped sum of the emergency water supplement from China, lateral inflow and outflow of the Lancang-Mekong mainstream.

Analysis of the influential factors of flows of the Mekong mainstream was performed using hydrograph separation and hydrograph adjustment during the period of the emergency water supplement of March-May 2016. A simple hydrograph separation method[18] was applied by drawing a horizontal line between the beginning of rising limb of the hydrograph, which marked the arrival of the water supplement, and the end of falling limb of the hydrograph. This method was used to separate discharge of the water supplement from 'regular discharges'. On the other hand, the hydrograph at Jinghong was adjusted using discharge offset and travelling time to the hydrograph at Chiang Sean, Nong Khai and Stung Treng. These two methods were used for a cross-check in this analysis. It is found that discharge difference between these methods at all

[18] Gupta R. S. 2008, Hydrology and Hydraulic System, Third Edition, Waveland Press, United States.

selected stations was relatively small and within the error margin of the accuracy of its rating curves[19]. Results of the analysis are illustrated in Figure 13 and summarised in Table 8.

Examining the hydrograph at Jinghong for March-May 2016 reveals that there were two distinct bands of the emergency water supplement from China: (1) steady flows of 2,200 m^3/s from 10 March to 10 April 2016 and (2) steady flows of 1,500 m^3/s from 21 April to 31 May 2016. These bands propagated along the Mekong mainstream as seen at Chiang Saen, Nong Khai and Stung Treng (Figure 13). The first band of 32 days was particularly investigated. Net contribution of the emergency water supplement at a given station was evaluated as a difference between average discharges of the moving band and the 'regular discharges' at the station (Table 8). The net contribution of the emergency water supplement is found to be 1,024 m^3/s (or 47% of total discharges during the water supplement) at Jinghong, 962 m^3/s (or 44%) at Chiang Saen, 906 m^3/s (or 38%) at Nong Khai, and 818 m^3/s (or 22%) at Stung Treng.

[19] Difference between hydrograph separation and hydrograph adjustment is found: 91 m^3/s – 50 m^3/s = 41 m^3/s and Root Mean Square Error (RMSE) of the rating curve of 158 m^3/s (75 measurement points with discharge ranging between 720 m^3/s and 6,977 m^3/s) at Chiang Saen; 309 m^3/s – 250 m^3/s = 59 m^3/s and RMSE of 400 m^3/s (85 points with discharge ranging between 884 m^3/s and 15,928 m^3/s) at Nong Khai; and 1,762 m^3/s – 1,650 m^3/s = 112 m^3/s and RMSE of 328 m^3/s (129 points with discharge ranging between 2,232 m^3/s and 39,971 m^3/s) at Stung Treng.

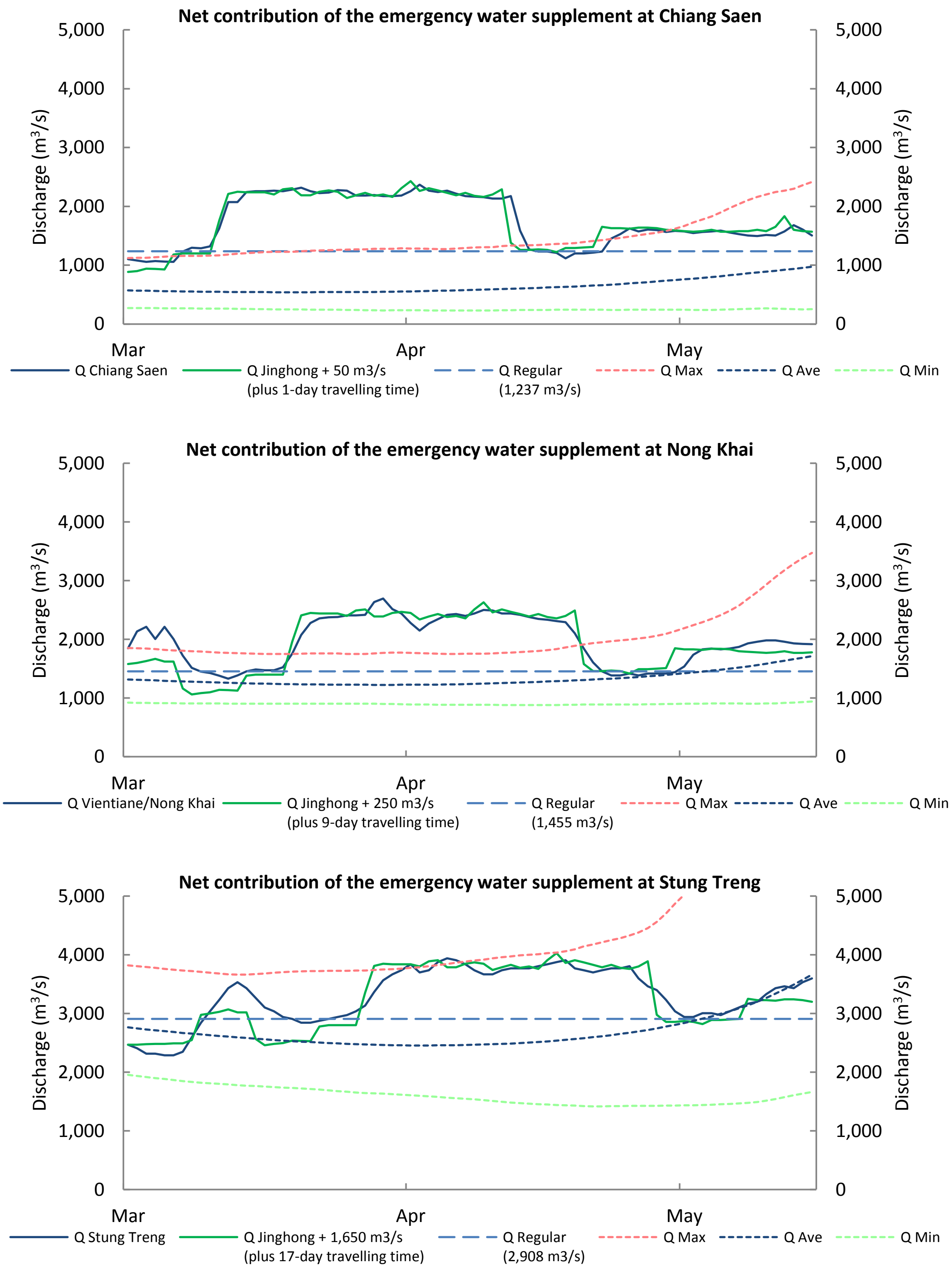


Figure 13 | Net contribution of the emergency water supplement at Chiang Saen, Nong Khai and Stung Treng from 1 March to 15 May 2016.

Water supplement is a lumped sum of the emergency water supplement from China, lateral inflow and outflow of the Lancang-Mekong mainstream during the investigation period. Q Max, Q Ave and Q Min are the maximum, average and minimum of historical records of 1962-2009.

Table 8 | Analysis of net contribution of the emergency water supplement at Chiang Saen, Nong Khai and Stung Treng for March-May 2016.
Water supplement is a lumped sum of the emergency water supplement from China, lateral inflow and outflow of the Lancang-Mekong mainstream during the investigation period.

Hydrograph separation for 'regular discharges' at	**Discharge (m^3/s)**
Jinghong (5 days: 5-9 Mar)	1,146
Chiang Saen (5 days: 6-10 Mar)	1,237
Nong Khai (5 days: 13-17 Mar)	1,455
Stung Treng (5 days: 21-25 Mar)	2,908
Difference of 'regular discharge' between	
Jinghong and Chiang Saen	91
Jinghong and Nong Khai	309
Jinghong and Stung Treng	1,762
Contribution of catchment area between	
Jinghong and Chiang Saen	91
Chiang Saen and Nong Khai	218
Nong Khai and Stung Treng	1,453
Hydrograph adjustment between	
Jinghong and Chiang Saen (travelling time: +1 day)	50
Jinghong and Nong Khai (travelling time: +9 days)	250
Jinghong and Stung Treng (travelling time: +17 days)	1,650
Average discharge of the moving band of the emergency water supplement at	
Jinghong (32 days: 10 Mar to 10 Apr)	2,170
Chiang Saen (32 days: 11 Mar to 11 Apr)	2,199
Nong Khai (32 days: 19 Mar to 19 Apr)	2,361
Stung Treng (32 days: 27 Mar to 27 Apr)	3,726
Net contribution and ratio to total discharges during the water supplement at	
Jinghong	1,024 (47%)
Chiang Saen	962 (44%)
Nong Khai	906 (38%)
Stung Treng	818 (22%)

9 Variation of daily water level and discharge at mainstream stations

Analysis of variation of water level and discharge of the Mekong mainstream during the emergency water supplement was carried out by placing daily observed water level and derived discharge in the dry season[20] of 2016 with its daily long term average, minimum and maximum of 1962-2009 and comparing to individual dry season of 2010-2015.

Being the most upstream hydrological station in the Mekong Basin, Chiang Saen is critically important to capture flow behaviour of the Lancang Basin. Particularly in the dry season, the flow behaviour observed at Chiang Saen can be clearly seen propagating along the mainstream down to Kratie, since rainfall rarely pours down in the Mekong Basin during the dry season to attribute to change in flow pattern downstream of Chiang Saen. Chiang Saen is therefore selected for an observation on impact of the emergency water supplement from China on flow conditions. Furthermore, three important stations, namely Vientiane/Nong Khai, Pakse and Stung Treng are also part of this analysis. Location of the hydrological stations is illustrated in Figure 2.

Variation of daily observed water level and rated discharge was analysed using daily long term average, minimum and maximum of 1962-2009. To provide a comprehensive picture of overall flow conditions, flow patterns of individual year of 2010-2015 are also included in this assessment. Flows at Chiang Saen are presented and discussed in details in this section and those at Vientiane/Nong Khai, Pakse and Stung Treng are illustrated in Annex B.

Daily monitoring at Chiang Saen for the dry season of 2010-2016, presented in Figure 14, reveals that increased regulation of mainstream flows, particularly from operations of water infrastructures in the Lancang Basin, has been apparent since 2012, with minimum flows well above the long term average of 1962-2009. Flows were most of the time steady and higher than the long term average in general and above the long term maximum in particular from February to April. Dry season flows in 2013 and 2014 were most of the time higher than the long term maximum flows and a large variation between low and high flows were more obvious.

An extreme event of December 2013 was evidently observed at Chiang Saen. The cause of the extreme event was attributed to the abnormal high rainfall in the downstream section of Jinghong station in the Lancang Basin and northern part of the Mekong Basin. This extreme event at Chiang Saen is unique in historically observed records of 1962-2016. Furthermore, regulated flows became even more obvious in the dry seasons of 2014 and 2015, where elevated flows were clearly seen at Chiang Saen particularly during February-April[21].

Observation at Chiang Saen in the dry season of 2016 reveals that flows below the long term average of 1962-2009 was recorded in December and followed by four major flow peaks in mid-December, mid-January, end-February and mid-March to mid-April. Magnitude of flow variation

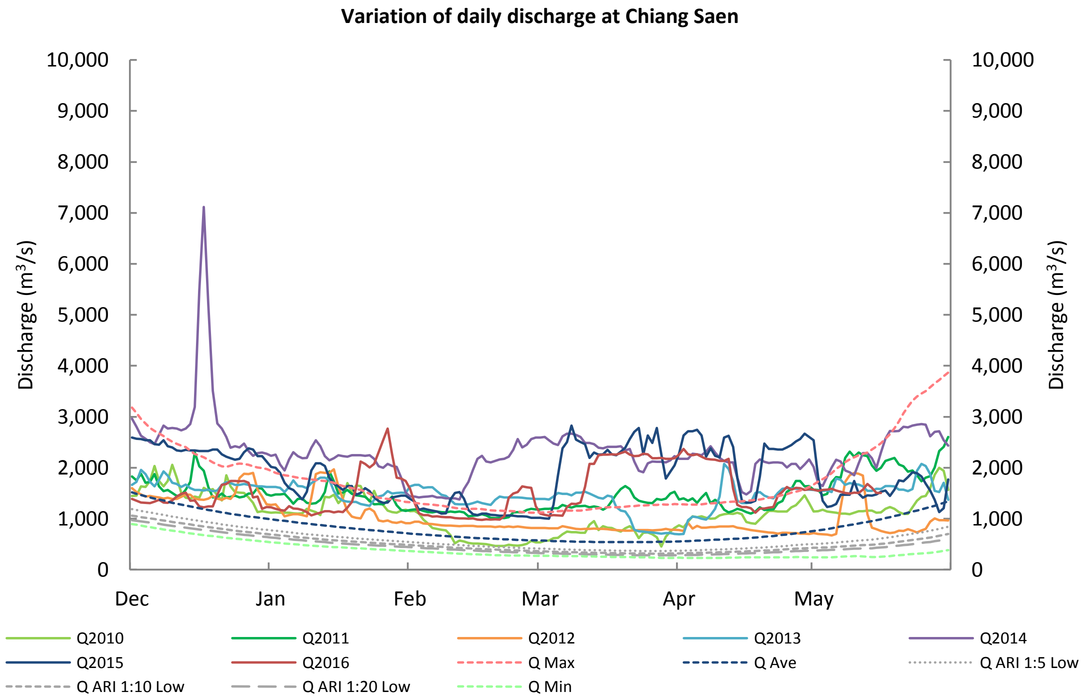
[20] For the purpose of the Joint Observation and Evaluation, the dry season is considered from 1 December to 31 May.

[21] More details of flow analysis for 2008-2015 along the Mekong mainstream could be found in Implementation Report of the PMFM for 2011-2015, March 2016.

of the dry season of 2016 was observed similar to those of 2014 and 2015, except that flow peaks shift according to time. This flow pattern was still observable at Stung Treng (Figure 14 and Figure 15).

China notified the Mekong River Commission Secretariat that China decided to implement emergency water supplement to the Mekong River by increasing the discharge at Jinghong Reservoir. As depicted in Figure 14, flow monitoring on the mainstream at Chiang Saen reveals that flows started rising from 2.26 m (or 359.37 m mean sea level or 1,319 m^3/s) on 10 March 2016, to 2.62 m (or 359.73 m msl or 1,625 m^3/s) on 11 March 2016, to 3.10 m (or 360.21 m msl or 2,075 m^3/s) on 12-13 March 2016, then to 3.27 m (or 360.38 m msl or 2,245 m^3/s) on 14 March 2016 and after that the flows remained steady at 3.25 m (or 360.36 m msl or 2,230 m^3/s) until 12 April 2016. Discharge recorded at Chiang Saen is in the same order of discharge reported by China at Jinghong.

In the letter dated on 8 April 2016, China informed the Mekong River Commission Secretariat that discharge at Jinghong was regulated to 1,200 m^3/s for 11-20 April 2016 to celebrate the New Year of Buddhist calendar of the Dai people in Yunnan Province. Similar to last three years, flows at Chiang Saen were therefore dropped for ten days of 12-22 April 2016, decreasing from 3.20 m (or 360.31 m msl or 2,174 m^3/s) on 12 April to 2.20 m (or 359.31 m msl or 1,271 m^3/s) on 14 April, continuing until 22 April 2016. This pattern has been observed at Chiang Saen since the dry season of 2013. Then, flows increased to 2.42 m (or 359.53 m msl or 1,452 m^3/s) on 23 April, to 2.62 m (or 359.73 m msl or 1,625 m^3/s) on 25 April, and steadily continued to 31 May 2016.



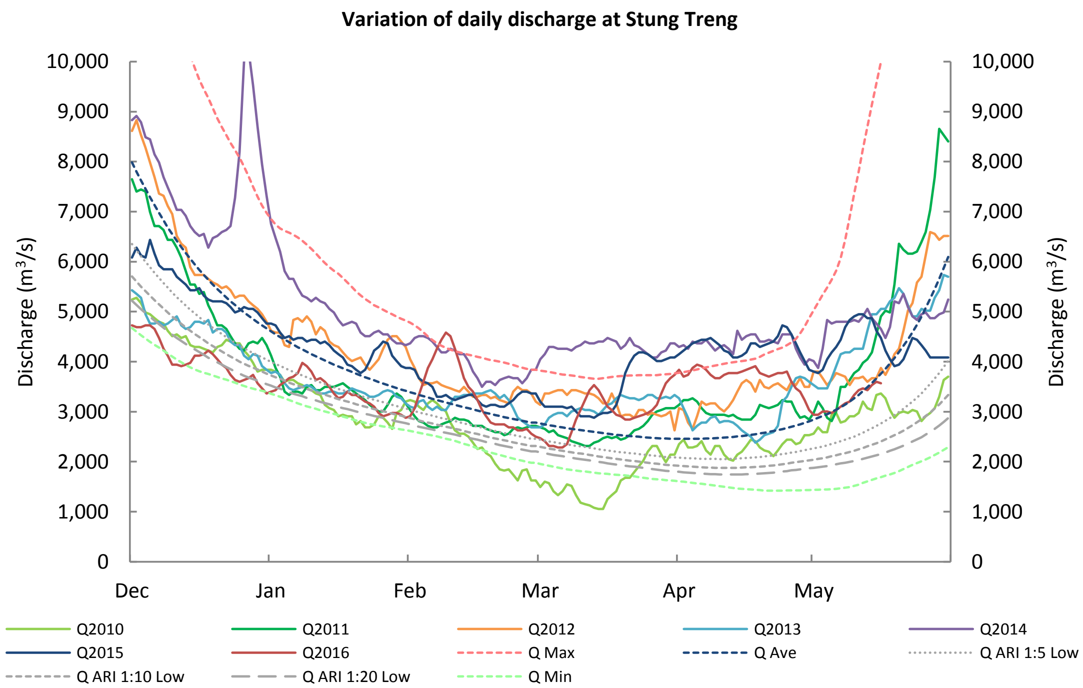
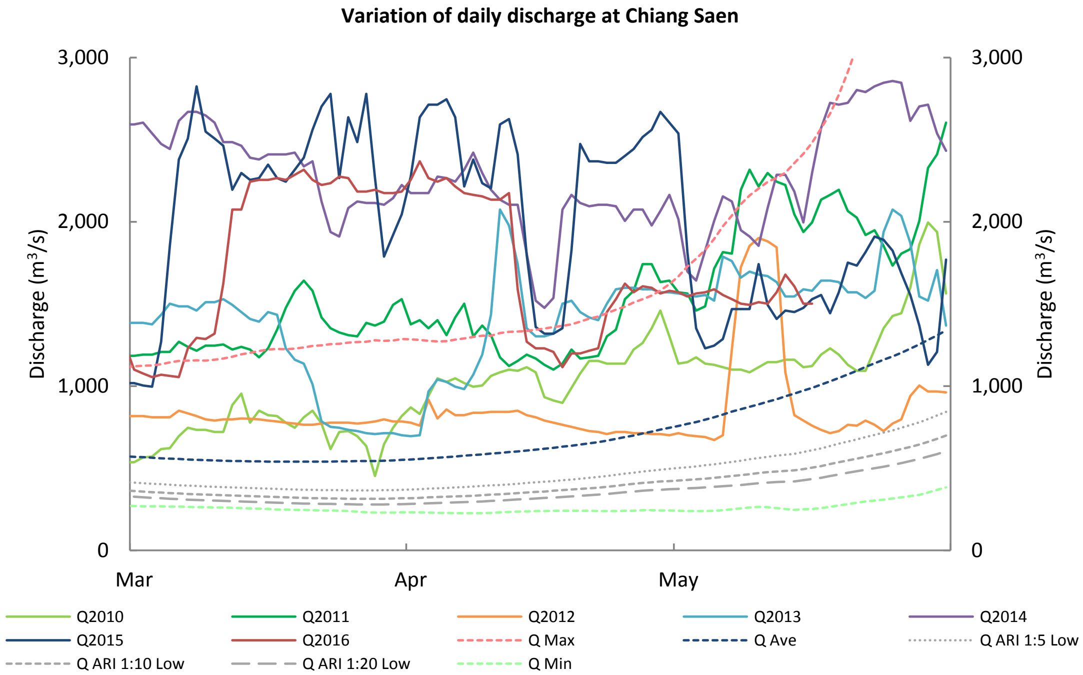


Figure 14 | Variation of daily discharge monitoring at Chiang Saen and Stung Treng for individual dry season of 2010-2016, comparing to the long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang River. Q Max, Q Ave and Q Min are the maximum, average and minimum of historical records of 1962-2009.



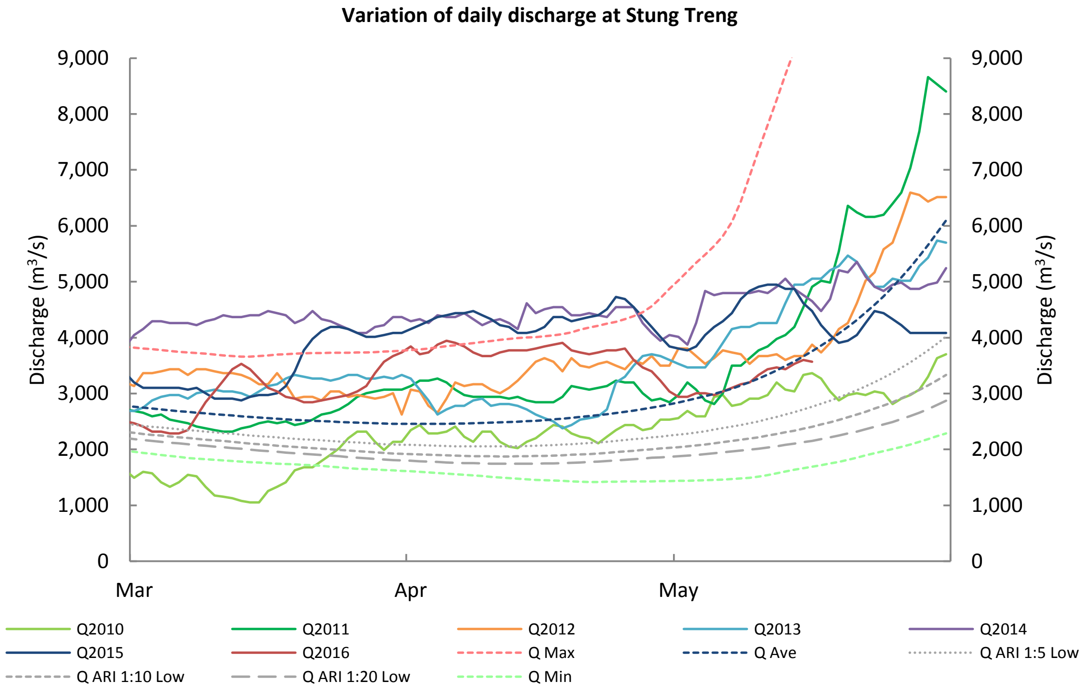


Figure 15 | Variation of daily discharge monitoring at Chiang Saen and Stung Treng for individual March-May of 2010-2016, comparing to the long term average, minimum and maximum of 1962-2009. *The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang River. Q Max, Q Ave and Q Min are the maximum, average and minimum of historical records of 1962-2009.*

10 Flow propagation along the Mekong mainstream

Flow propagation along the Mekong mainstream was conducted using variation of daily water level and discharge, and sequence of its events, including the emergency water supplement. Variation of water level and discharge at Jinghong during the emergency water supplement was generally planned as follows:

- 9 to 11 March 2016 – increasing to 2,000 m^3/s;
- 12 March to 10 April 2016 – staying at 2,200 m^3/s;
- 11 to 12 April 2016 – decreasing to 1,200 m^3/s;
- 13 to 20 April 2016 – staying at 1,200 m^3/s;
- 21 April 2016 – increasing to 1,500 m^3/s; and
- 22 April to 31 May 2016 – staying at 1,500 m^3/s.

As shown in Figure 16, the discharge at Jinghong from March 9 to March 11 was gradually increased to 2,160 m^3/s, with an obvious rise of water level from 535.76 m to 537.05 m. For an analysis on the travelling time, the beginning time of the emergency water supplement was thus deemed as 9 March 2016.

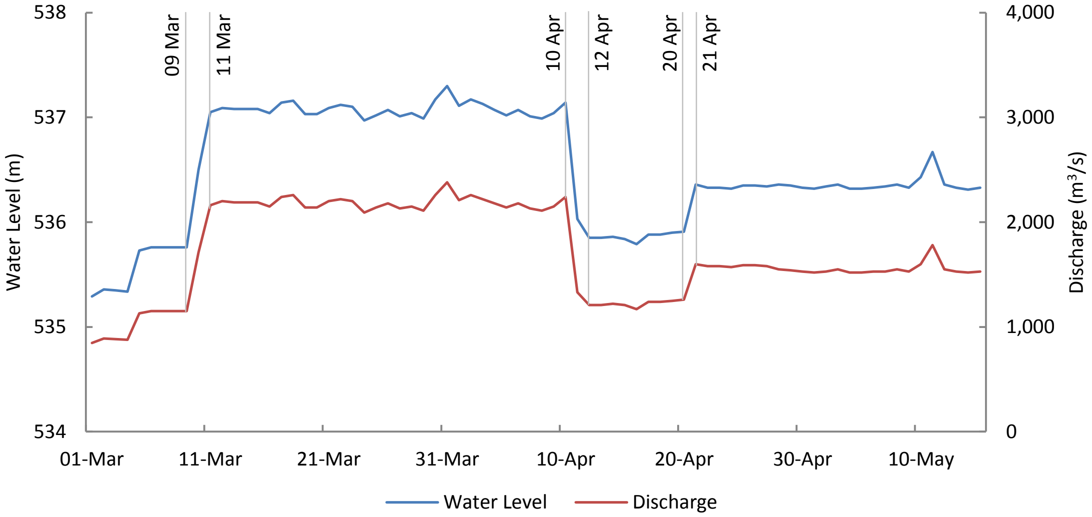


Figure 16 | Variation of daily water level and discharge at Jinghong from 1 March to 15 May 2016.

Propagation of the flow pattern along the mainstream was investigated using daily observed water level at 22 hydrological stations (1 station in the Lancang River and 21 stations in the Mekong River) and discharge at 8 hydrological stations (1 in the Lancang River and 7 in the Mekong River). Location of the hydrological stations is illustrated in Figure 2. Rated discharge was derived from the observed water level using newly developed rating curves by taking advantages of 'Discharge and Sediment Monitoring Project for 2008-2014', implemented by the MRC's Information and Knowledge Management Programme (IKMP).

For general flow conditions, characteristics of rapid fluctuation of daily observed water level and rated discharge of the Mekong mainstream for the dry season between Chiang Saen to Pakse follows the flow pattern observed in Chiang Saen. This is because the flow pattern is not typically perturbed by runoff generated from intense rainfall, which does not usually occur in the basin during the dry season. The pattern becomes smoother and less variable as the Mekong River entering Cambodia, at Stung Treng since the flows from the Tonle Sap Lake dominated the flows in the Mekong River during this period. For particular dry season flow conditions of 2016, where flow volume stored in the Tonle Sap Lake was relatively low, patterns of variation of daily water level and discharge observed at Chiang Saen could be still seen at Tan Chau and Chau Doc (Figure 17 and Figure 18).

The emergency water supplement arrived at Chiang Saen on 11 March and started increasing till 14 March (3 days). As presented in Table 9 and depicted in Figure 17, Figure 18, Figure 19 and Figure 20, this pattern reached Luang Prabang on 14 March, Chiang Khan on 17 March, Nong Khai on 19 March, Nakhon Phanom on 22 March, Mukdahan on 23 March, Pakse on 25 March, Stung Treng on 27 March and Kratie on 28 March 2016.

Due to flow conditions downstream Kratie are normally influenced by the outflow of the Tonle Sap Lake and tide of the sea, using variation of water level to mark arrival time of the emergency water supplement in this area is not obvious. It took 18 days for the emergency supplement water to travel a total length of 2,147 km from Jinghong to Kratie. Thus, this suggested a moving velocity of 1.4 m/s (or 5 km/h). It is assumed that the moving velocity was slowed down to 1 m/s in floodplain area. It would take around 4 days to travel 324 km between Kratie and Tan Chau. This is therefore believed that the emergency water supplement arrived to Tan Chau on 1 April 2016 with a travelling time from Jinghong of 22 days.

Moreover, monitoring at Chiang Khan suggests that additional water of 300 m^3/s for one day on top of the emergency water supplement was detected on 27 March 2016. This additional water arrived at Nong Khai on 28 March, at Nakhon Phanom on 31 March, at Mukdahan on 1 April, at Pakse on 3 April and at Stung Treng on 4 April. Immediately after the peak of the additional water at Chiang Khan, a drop in flows of 300 m^3/s was recorded on 31 March 2016.

Table 9 | Propagation of the emergency water supplement of 2016 along the Mekong mainstream.

Station	River kilometre	Water supplement arrival	Variation*	Increment
Jinghong	2,707 km	10 to 11 March (+0 day)	535.76 m (1,150 m^3/s) to 537.05 m (2,160 m^3/s)	+1.29 m (+1,010 m^3/s)
Chiang Saen	2,364 km	11 to 14 March (+1 day)	2.26 m (1,319 m^3/s) to 3.27 m (2,245 m^3/s)	+1.01 m (+926 m^3/s)
Luang Prabang	2,010 km	14 to 17 March (+4 days)	4.06 m (1,454 m^3/s) to 5.50 m (2,295 m^3/s)	+1.44 m (+841 m^3/s)
Chiang Khan	1,715 km	17 to 20 March (+7 days)	3.91 m to 5.44 m	+1.53 m
Nong Khai	1,549 km	19 to 22 March (+9 days)	1.57 m (1,526 m^3/s) to 2.70 m (2,359 m^3/s)	+1.13 m (+833 m^3/s)
Nakhon Phanom	1,221 km	22 to 25 March (+12 days)	1.35 m (2,385 m^3/s) to 1.95 m (3,183 m^3/s)	+0.60 m (+798 m^3/s)
Mukdahan	1,128 km	23 to 26 March (+13 days)	1.85 m (3,024 m^3/s) to 2.29 m (3,729 m^3/s)	+0.44 m (+705 m^3/s)
Pakse	866 km	25 to 28 March (+15 days)	1.20 m (2,954 m^3/s) to 1.58 m (3,743 m^3/s)	+0.38 m (+789 m^3/s)
Stung Treng	683 km	27 to 31 March (+17 days)	2.54 m (3,135 m^3/s) to 2.72 m (3,737 m^3/s)	+0.18 m (+602 m^3/s)
Kratie	560 km	28 March to 1 April (+18 days)	6.93 m to 7.23 m	+0.30 m

* Variation of daily observed water level or rated discharge starts one-day earlier than the arrival of the emergency water supplement.

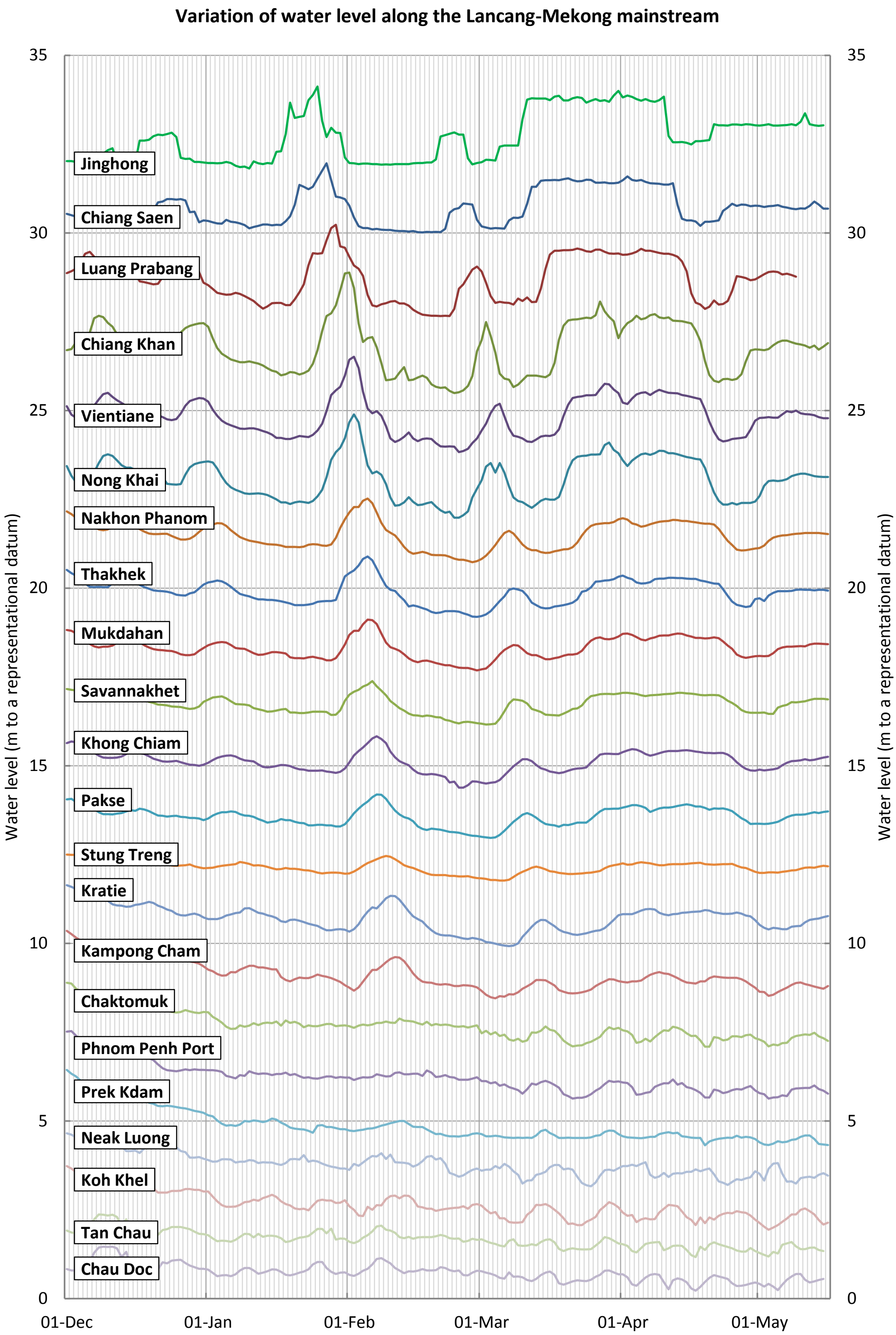


Figure 17 | Propagation of daily water level along the Lancang-Mekong mainstream for the dry season of 2016.
It is critically important to note that water level is referenced to a representational datum for presentation purposes only. Location of hydrological stations can be found in Figure 2.

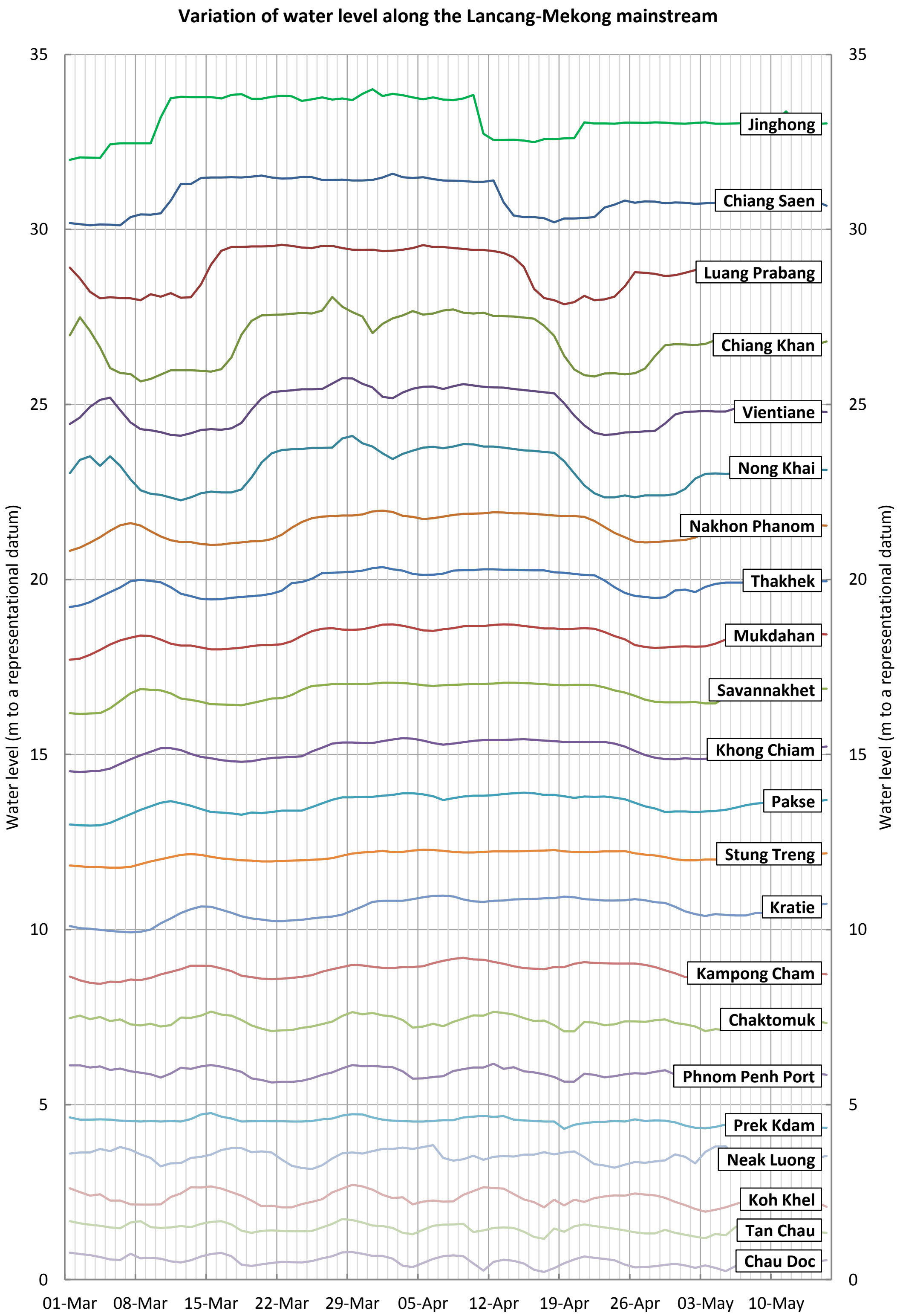


Figure 18 | Propagation of daily water level along the Lancang-Mekong mainstream for March-May of 2016.

It is critically important to note that water level is referenced to a representational datum for presentation purposes only. Location of hydrological stations can be found in Figure 2.

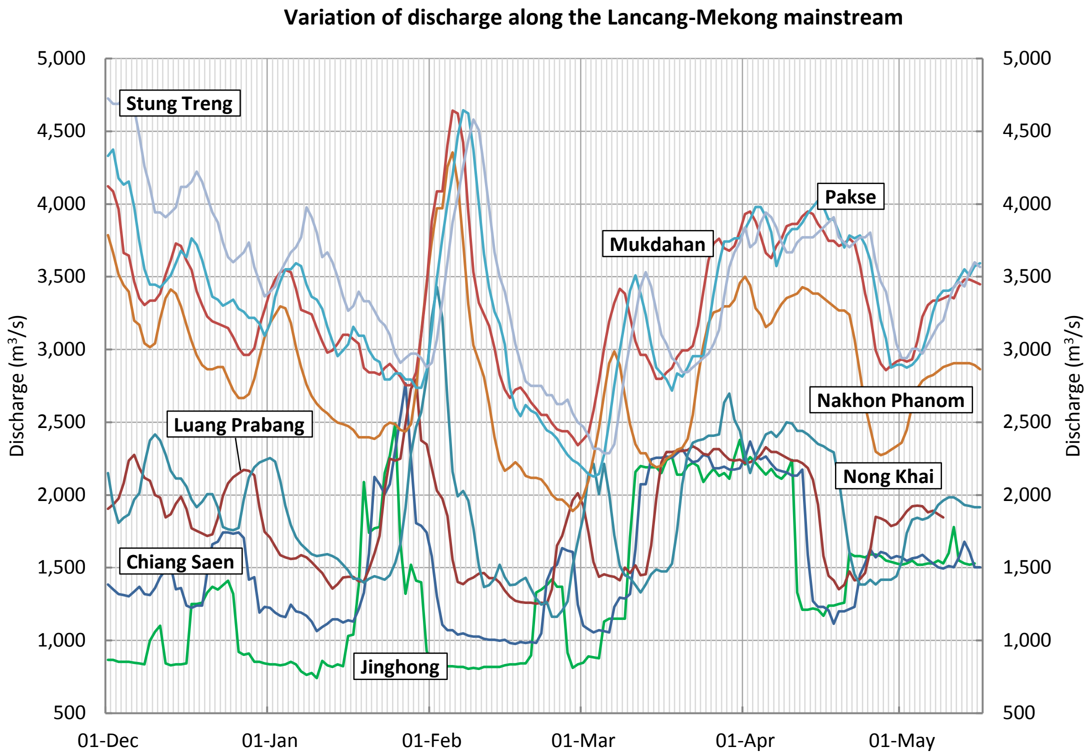


Figure 19 | Propagation of daily discharge at some selected hydrological stations along the Lancang-Mekong mainstream for the dry season of 2016.

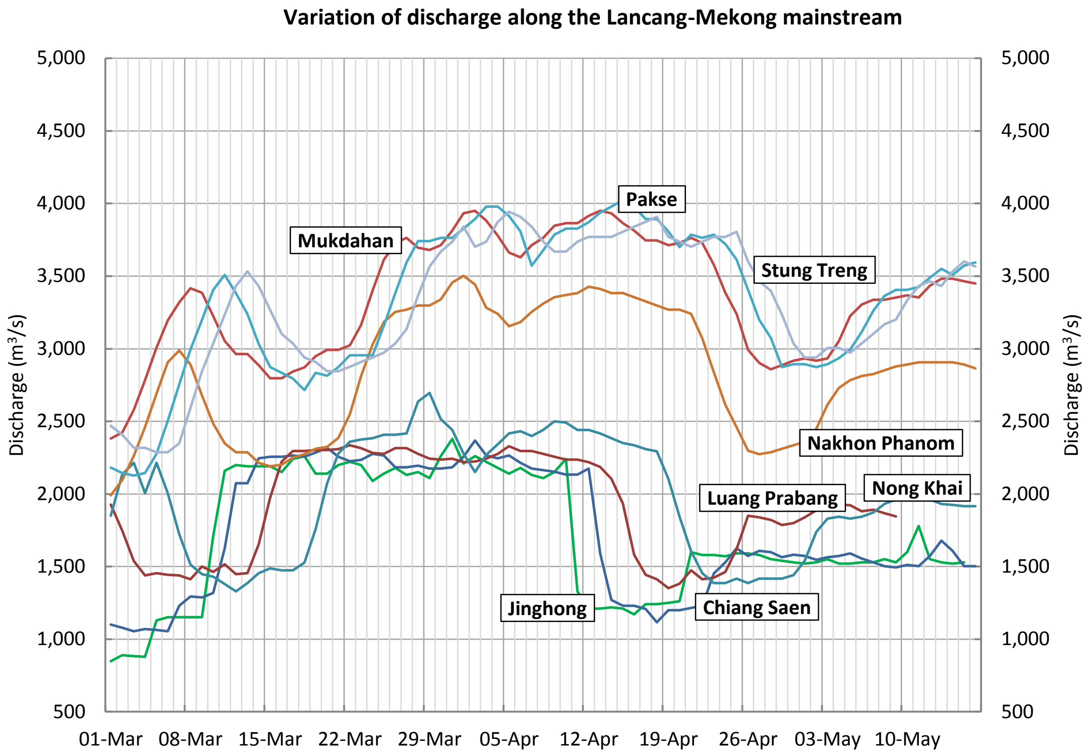


Figure 20 | Propagation of daily discharge at some selected hydrological stations along the Lancang-Mekong mainstream for March-May 2016.

11 Salinity variation in the Mekong Delta

As adequate data and information on benefits of the emergency water supplement on reducing the meteorological agricultural drought affected area were not available at the time of this study, general observation of the benefits of easing the drought was compiled using various sources as presented in Annex A. Thus, analysis in this section was limited to salinity variation at in Soc Trang Province.

Soc Trang Province locates 231 km from Ho Chi Minh city, 60 km from Can Tho, close to Tra Vinh, Vinh Long, Hau Giang, Bac Lieu, with coastline of 72 km coastline and alluvial flat of 30,000 ha. It has an ocean climate and two seasons, rainy season from May to November, and dry season from December to May. The average temperature is between 26°C and 28°C. The economy is agriculture dominated, with cropland of 259,799 ha, among which 94% is rice field. The other cropland is covered by maize, Mung beans, jackfruit, coconut trees, green onion and garlic etc.

Salinity intrusion distance reached up to 80 km in March 2016 in Soc Trang Province. There are seven salinity monitoring stations in Soc Trang Province, namely Tran De, Long Phu, Dai Ngai, An Lac Tay on the main river, Soc Trang city, Nga Nam and Than Phu on canals. Tran De locates near the river mouth and An Lac Tay is about 40 km from the river mouth (Figure 21).

Salinity variation in the Mekong Delta during the period of the emergency water supplement was analysed using daily maximum and minimum salinity concentration at the seven monitoring sites in the Mekong Delta. Based on the results of flow propagation analysis, the water supplement from the Lancang reservoirs reached the Mekong Delta in early April 2016. The salinity of March and April were compared at An Lac Tay, Dai Ngai , Long Phu, Tran De and Soc Trang city. Figure 22 shows that there was a 4-day low salinity at early April at all the stations, though it was in rising tide period. The maximum salinity in April was between 2.2‰ and 6.4‰ less than that in March. The most prominent reduction occurred at An Lac Tay, from 8.0‰ in March to 2.1‰ in April (Table 10). The maximum salinity at Dai Ngai decreased from 13.8‰ in March to 7.4‰ in April. The maximum salinity decreased by 15% and 74%, and the minimum salinity decreased by 9% and 78% according to observation stations. Hence, the emergency water supplement from China played an important role in controlling seawater intrusion and reducing salinity, which would help protect ecosystem and environment in the Mekong Delta.

Table 10 | Observation of salinity in March and April 2016 in Soc Trang Province.

Salinity (‰)	Tran De		Long Phu		Dai Ngai		An Lac Tay		Soc Trang City	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Salinity in March	27.4	5.6	23.1	4.1	13.8	0.9	8.0	0	9.0	3.0
Salinity in April	23.4	5.1	17.2	1.4	7.4	0.2	2.1	0	6.8	1.2
Salinity reduction	-4	-0.5	-5.9	-2.7	-6.4	-0.7	-5.9	0	-2.2	-1.8
Reduction ratio	-15%	-9%	-26%	-66%	-46%	-78%	-74%	-	-24%	-60%

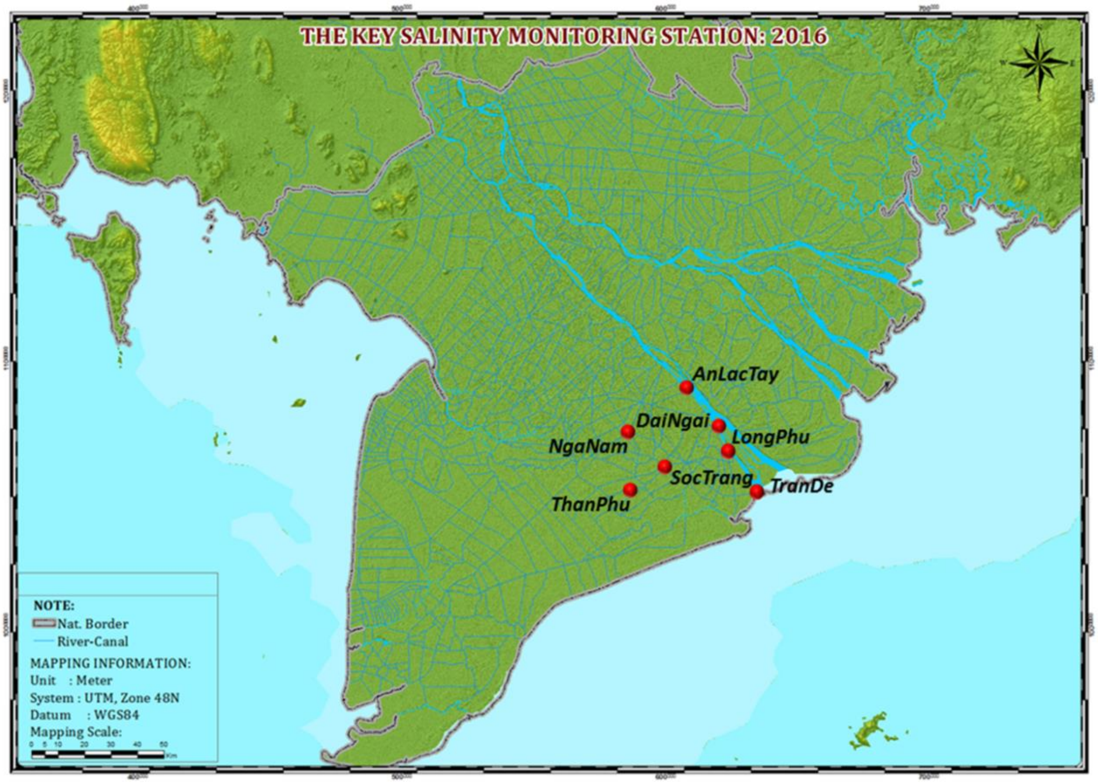


Figure 21 | Salinity monitoring stations in the Mekong Delta.

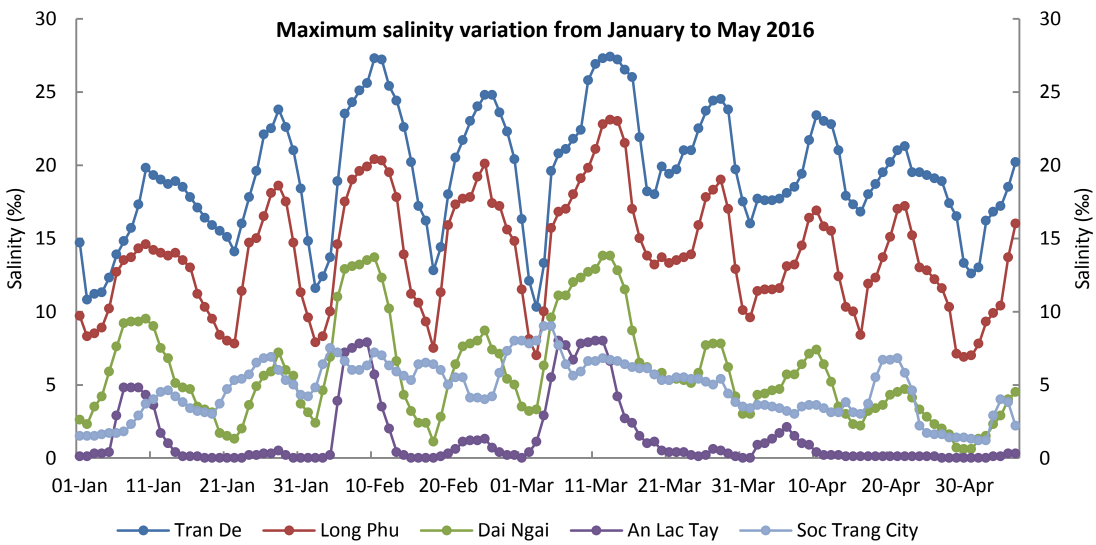


Figure 22 | Maximum salinity variation from 1 January to 6 May 2016 at the monitoring stations in the Mekong Delta.

12 Conclusions

Recent meteorological and agricultural drought conditions over the Mekong Basin have worsened and triggered China to implement its emergency water supplement from its cascades dams in the Lancang River to the Mekong River by increasing the water discharge from Yunnan's Jinghong Reservoir. The emergency water supplement was implemented with a 'three-phase plan': (1) from 9 March to 10 April 2016, with an average daily discharge of no less than 2,000 m^3/s; (2) from 11 April to 20 April 2016 with discharge of no less than 1,200 m^3/s; and (3) from 21 April to 31 May 2016 with discharge of no less than 1,500 m^3/s. The Mekong River Commission acknowledges this action by China, in which China has also stated that it implemented the water supplement at a challenging time, especially within the context where China itself was also suffering from drought, which has affected its household water supply and agricultural production.

The Joint Observation and Evaluation of the Emergency Water Supplement from China to the Mekong River were jointly and objectively conducted with the Mekong River Commission Secretariat and China. In the course of this study, besides regular hydrological data sharing in the flood season from China, additional hydrological data and information (daily and long term average of water level and discharge) for the dry season of 2016 from both sides were exchanged and used in the analyses of the Joint Report of this study. Equally, methodology of the analyses were jointly developed and adopted. Analyses were carried out and the results were exchanged, discussed and agreed. The contents of the Joint Report were also jointly developed. It is found that the **emergency water supplement from China increased water level** and **discharge** along the Mekong mainstream and **decreased salinity intrusion** in the Mekong Delta. The following are the key findings from this study:

- **Reduced rainfall amount and inflow discharge** to the Lancang Basin have been observed in the dry season of 2016. Likewise, the Mekong Basin has been experienced by abnormally dry conditions with **high temperature** and **less rainfall**. These meteorological and agricultural droughts are strongly believed to be impacted by the **super El Niño 2015-2016**. Monitoring of flow conditions on the mainstream suggests that water level and discharge in the dry season of 2016 at Vientiane/Nong Khai and Stung Treng in December 2015 were few days below the long term minimum of 1960-2009. However, thanks to the emergency water supplement from China, the **water level** and **discharge** at most stations along the Mekong mainstream were most of the time **above the long term average** and even higher than the long term maximum in March and April 2016.
- Total volume released at Jinghong was **12.65 billion m^3**: 6.10 billion m^3 from 9 March to 10 April 2016, 1.07 billion m^3 from 11 April to 20 April 2016, and 5.48 billion m^3 from 21 April to 31 May 2016.
- During the period of the emergency water supplement in March and April 2016, the monthly discharges at Jinghong were 1,280 m^3/s and 985 m^3/s respectively, larger than the average of 1960-2009, and 704 m^3/s and 442 m^3/s respectively, higher than the average of 2010-2015.
- The emergency water supplement from China arrived at **Chiang Saen on 11 March** and increased till 14 March 2016. This pattern reached **Luang Prabang on 14 March**, **Chiang Khan on 17 March**, **Nong Khai on 19 March**, **Nakhon Phanom on 22 March**, **Mukdahan on 23 March**, **Pakse on 25 March**, **Stung Treng on 27 March**, **Kratie on 28 March** and **Tan**

Chau on 1 April 2016. Similarly, the emergency water supplement **increased water level** or **discharge** along the Mekong mainstream to an overall extent of **0.18-1.53 m** or **602-1,010 m^3/s**. Equally, the maximum salinity in the Mekong Delta decreased by 15% and 74%, and the minimum salinity decreased by 9% and 78% according to observation stations.

- Monitoring at Chiang Khan suggests that additional water of 300 m^3/s for one day on top of the emergency water supplement from China was detected on 27 March 2016. This additional water arrived at Nong Khai on 28 March, at Nakhon Phanom on 31 March, at Mukdahan on 1 April, at Pakse on 3 April and at Stung Treng on 4 April 2016. Immediately after the peak of the additional water, a drop in discharge of 300 m^3/s was recorded on 31 March 2016.
- Total **volume in the dry season of 2016** (December 2015 to May 2016) at Jinghong presented huge portion (**40%-89%**) of the total volume at different stations along the Mekong mainstream. Additionally, the volume from 10 March to 10 April 2016, which was first period of the emergency water supplement, claimed significant portion, specifically 99% at Chiang Saen, 92% at Nong Khai and 58% at Stung Treng. Similarly, **net contribution of the water supplement** in term of discharge to total discharge was **47% at Jinghong**, **44% at Chiang Saen**, **38% at Nong Khai** and **22% at Stung Treng**. This contribution also alleviated salinity intrusion in the Mekong Delta.

Recommendation

During conduct of the Joint Observation and Evaluation, discussion and exchange between the Mekong River Commission Secretariat and China were sincere with warmth and friendliness. Both parties respected each other views with mutual understanding. It is therefore recommended this kind of study and working attitude should continue to boost strong foundation for further cooperation between China, Mekong River Commission Secretariat and its Member Countries.

This good spirit of cooperation should keep its momentum and be extended to further study on Hydrological Impact of the Lancang Hydropower Cascade on Downstream Floods and Droughts. Likewise, future direction of the study should also focus on positive and negative impact of water resources and hydropower development in the tributaries of the Mekong mainstream.

Limitation of the study

Due to limited data and time constraints at the time of the study, the detailed calculations could not be performed; only monthly average computations were normally conducted. Additionally, processes, impacts and linkages of (meteorological, agricultural, hydrological and socio-economic) droughts and relationship between the drought and global extreme events, namely the El Niño or La Niña were not thoroughly performed. Moreover, detailed evaluation was hampered by limited data from the release of reservoirs on the tributaries of the Mekong River and good quality of hydrological data including rating curves before 2009. Similarly, flow contribution from the Tonle Sap Lake and flow distribution in the Mekong and Bassac Rivers downstream Phnom Penh were not included. Furthermore, several assumptions, including travelling time in the section between Kratie and the Mekong Delta, were used in the analyses. It is also recognised that fully comprehensive salinity analysis in the Mekong Delta could not be performed without additional effort on salinity modelling. In sum, the analyses in this report focused mainly on general hydrological situation and average condition of flows on the Lancang-Mekong mainstream.

Annex A – Observation of drought situation in the Mekong Countries from various sources

It is critically important to note that data and information in this annex is generally compiled from various sources including local and regional newspapers and governmental websites.

The meteorological and agricultural drought in 2016 is the direct result of the disruption of normal global weather patterns by one of the strongest El Niño events ever recorded. However, the longer than normal duration of this event had caused large rainfall deficits to build up in many places. Besides the lack of rain, the current El Niño conditions had also increased average daily temperatures across the region. The exceptionally hot conditions also caused high evapotranspiration and agricultural stress in crops already affected by low rainfall, resulting in further crop losses and poor yields, especially in rain-dependent agricultural areas. Overall conditions of drought in the Mekong countries are presented in Figure A1.

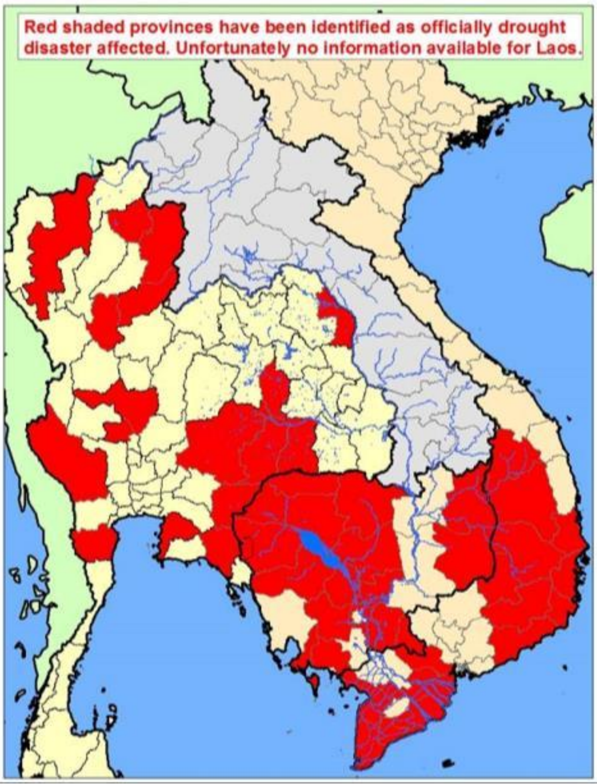


Figure A1 | Overall meteorological and agricultural drought situation in the Cambodia, Lao PDR, Thailand and Viet Nam.
Data and information are obtained from various sources as cited in respective sections.

Cambodia

The increase of air temperature was causing animal lives and disease. The prolonged El Niño event had caused a significant increase of air temperature. It was found that 42.6°C set in Preah Vihea on 15 April 2016 has broken the national record. Such high heat with serious drought condition has caused many lives of cattle and animals including fish and put rural villagers at risk. In April 2016, more than 300 cows and buffaloes were found dead due to disease in Stung Treng Province and 70 tons of fish in Kampong Thom were lost due to high temperature with too low water level in the protected Chhmar River. Likewise, in early May, 50 black monkeys died from lack of water in a protected area in Battambang province[22].

[22] Global Voices: https://globalvoices.org/2016/05/09/animals-cant-escape-cambodias-worst-drought-in-50-years-either/, accessed on 18 May 2016.

Two and half million people in Cambodia lack of water in 16 affected drought provinces. National Committee for Disaster Management (NCDM) said, on 24 April 2016, that the drought was causing water shortages in 16 provinces[23]: Kompong Cham, Kandal, Kompong Thom, Prey Veng, Kompong Speu, Svay Rieng, Preah Sihanouk, Kampot, Battambang, Banteay Meanchey, Oddar Meanchey, Pursat, Siem Reap, Preah Vihear, Mondolkiri and Ratanakkiri. About 2.5 million people in Cambodia were affected by lack of water and 500,000 people have not yet been reached by Cambodian Government aid (as of May 2016). Moreover, the Ministry of Education of Cambodia also estimated that 2,500 schools out of a total of 10,000 were lack of water supply[24], as depicted in Figure A2.

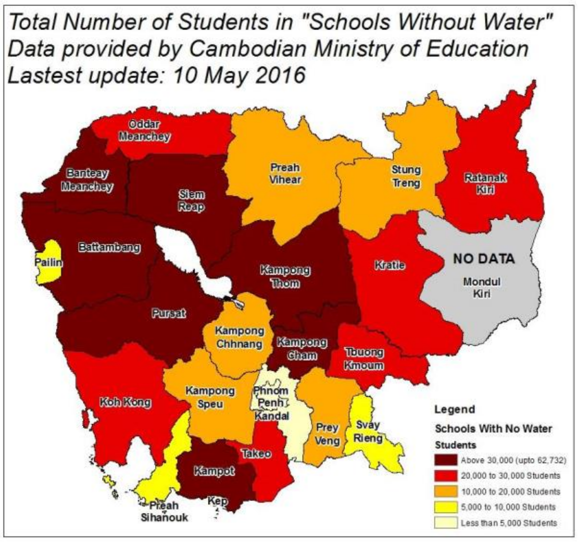


Figure A2 | Schools lack of water affected by the meteorological and agricultural drought in Cambodia.
Data and information are from the Ministry of Education, Youth and Sport of Cambodia.

Lao PDR

Observation of overall rainfall, temperature and water stress indices presented in the main report reveals that Lao PDR started dry out in Southern part including Savannakhet, Saravane, Sekong, Champassak, and Attapeu provinces starting from January 2016. However, the situation became better in February. Lao PDR received most rain in the North than other parts of the LMB in April making the vegetation condition wetter.

Thailand

Following section are presented by the information from the webpage of the Royal Thai Government[25].

The Royal Thai Government held a press briefing on 'Public-Private Alliance on Combating of Drought', and called on all sectors to conserve water as much as possible. The Royal Thai Government continues to undertake measures in preventing and tackling drought in a bid to ensure sufficient water supply throughout the dry season. The Thai Government also urged people to consume water wisely, and called on farmers to cooperate with the Government. The following are highlight of the press briefing:

The **Royal Irrigation Department** stated that 2016 was another year in which drought situation was severe with very little amount of water budget. As a consequence of the great flood in

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[23] Kathmandu Today: http://kathmandutoday.com/2016/04/187963.html, accessed on 17 May 2016.

[24] United Nations - Office for the Coordination of Humanitarian Affairs: https://data.humdata.org/dataset/cambodia-education, accessed on 18 May 2016.

[25] The Royal Thai Government webpage: http://www.thaigov.go.th/index.php/en/government-en1/item/99721-99721.html, accessed on 25 May 2016.

2011, large volume of water led to increase of rice cropping which had consumed about 18,153 million m^3. Approximately 14,861 million m^3 was released for that purpose resulting in a huge drop in overall water budget volume.

The **Geo-Informatics and Space Technology Development Agency (GISTDA)** revealed that satellite images had been used for the analysis of Government agencies' water allocation plan. The GISTDA had also constantly monitored off-season rice growing situation, and found that in 2013-2014, up to 15 million rai of land were used for off-season rice cropping. The Thai Government, therefore, urged farmers to reduce growing off-season rice, and replace with drought-resistant crops, as well as take alternate jobs. This resulted in major reduction of off-season rice cropping, especially in the Chao Phraya River Basin where it went down to only around 3 million rai.

The **Department of Water Resources** added that compared to the previous years, drought situation in 2015 was not as critical as that in 2013, which was the most severe. Drought situation nationwide has not reached the critical stage except Nakhon Ratchasima, Buriram, and Surin which were just near the critical state. Nevertheless, the Thai Government had carried out operations under 2015-2026 Water Resources Management Strategy which comprises (1) Strategy on water consumption management; (2) Strategy on promotion of water security in production sector (agriculture/industry); (3) Strategy on flood management; (4) Strategy on water quality management; (5) Strategy on restoration and conservation of denuded watershed forests and prevention of land erosion; and (6) Strategy on general management. The Thai Government had also implemented district-based water consumption management in 928 districts across the country to determine exact amount and demand for water consumption in a bid to ensure efficiency in water management which led to national security, prosperity, and sustainability.

The **Department of Agricultural Extension** stated that the Cabinet had ordered Ministry of Agriculture and Cooperatives to provide assistance to farmers in the repetitive drought-affected areas, and to implement agricultural development and revenue generation schemes in a bid to alleviate adverse effects of the drought during 2014/2015 in 3,051 sub-districts (Tambons) of 58 provinces. Approximately 2.87 million farming households had been benefited with sufficient water sources during the dry season, more employment opportunities as labours, more agricultural facilities, reduction of production cost, and higher quality crops.

The **Ministry of Agriculture and Cooperatives** revealed that volume of total usable water in 481 large and medium-scale reservoirs was 16,870 million m^3 or 33%. Usable water volume in 4 major dams in the Chao Phraya River basin

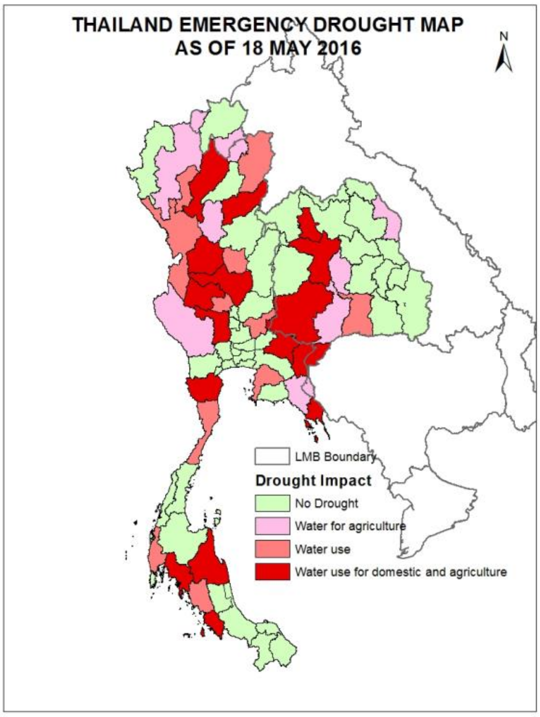

Figure A3 | Recent situation of the meteorological and agricultural drought in Thailand.
Data and information are from the Department of Disaster Prevention and Mitigation, Ministry of Interior of Thailand.

(Bhumibhol, Sirikit, Kwae Noi Bumrung Dan, and Pa Sak Jolasid) standed at 3,489 million m^3 or 19% in total; in water sources outside the irrigated areas nationwide 182.10 million m^3 or 52% of total capacity (as of 20 January 2016); and in 4,789 smaller reservoirs across the country 1,072.55 million m^3, 59% of the total capacity (as of 21 January 2016).

The Thai Government is putting effort in implementing water management measures, which may result in insufficient water for agricultural purpose, especially for water-consuming crop growing and off-season rice cropping. The Government called on fellow farmers to understand and cooperate by following its advice, and put priority in public interests. The public were also urged to consume water wisely. Drought disaster this time was a challenge that has impacted all.

In addition to the above, Figure A3 illustrates recent situation of the drought in Thailand[26].

Viet Nam

According to the Ministry of Agriculture and Rural Development, in the Mekong Delta saltwater had made its way to paddy fields two months sooner than in previous years as the rainy season began late last year but ended earlier than usual[27].

Saltwater had travelled 90 kilometres inland in many parts of the Mekong Delta. Eleven out of 13 provinces in the Mekong Delta confirmed saltwater had impacted on agriculture and caused fresh water shortages[28]. In addition, Salinity measured in local shrimp farms, covering 130,000 ha of water surface, surpassed 35 ppt. Shrimp cannot live in water where salinity is higher than 40 ppt[29].

Furthermore, reports from the provinces in the central highlands, south-central and Mekong Delta regions showed that more than 390,000 households had run short of fresh water as of 13 April 2016 and water shortages had wreaked havoc on over 240,000 ha of rice, more than 18,000 ha of other crops, 55,600 ha of orchards, and 100,000 ha of industrial trees. Around 4,600 ha of fisheries had been damaged[30].

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[26] Department of Disaster Prevention and Mitigation, Ministry of Interior of Thailand: http://122.155.1.143/th/index.php, accessed on 18 May 2016.

[27] News VietNamNet: http://english.vietnamnet.vn/fms/society/155698/drought--saltwater-intrusion-cause-hefty-losses.html, accessed on 25 May 2016.

[28] News VietNamNet: http://english.vietnamnet.vn/fms/society/155698/drought--saltwater-intrusion-cause-hefty-losses.html, accessed on 25 May 2016.

[29] News VietNamNet: http://english.vietnamnet.vn/fms/society/155668/social-news-28-4.html, accessed on 25 May 2016.

[30] News VietNamNet: http://english.vietnamnet.vn/fms/society/155668/social-news-28-4.html, accessed on 18 May 2016.

The Ministry of Agriculture and Rural Development said at a meeting on drought in Soc Trang Province (4 May 2016) that around 225,800 households in the Mekong Delta had run short of water for daily use by the end of April 2016, 70,800 households higher than in early March 2016. Additionally, as indicated in Figure A4, the number of households in dire need of water includes 86,200 in Ben Tre, 43,000 in Soc Trang, 25,000 in Kien Giang, 21,400 in Tra Vinh, 15,500 in Long An, 14,500 in Ca Mau, 7,000 in Tien Giang, 3,200 in Bac Lieu, and 5,000 in each of Vinh Long and Hau Giang[31].

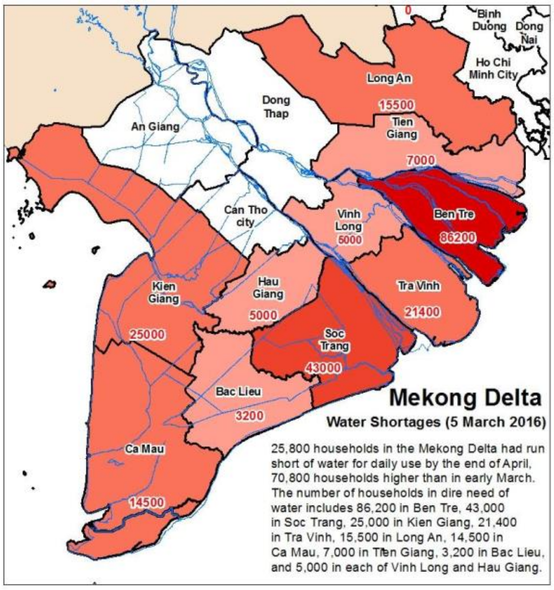

Figure A4 | Overall meteorological and agricultural drought situation in Viet Nam. *Data and information are obtained from various sources as cited in this section.*

Moreover, the Viet Nam Mekong committee (VNMC) said that the emergency water supplement from China would be enough to resolve the problem caused by the meteorological and agriculture drought and seawater intrusion[32]. The VNMC also added that without this emergency water supplement from China, the seawater would had intruded 50 km in Song Co Chien with salt concentration of 1‰, 45 km in Song Cua Dai and 70 km in Son Hau. The water supplement helped to reduce invaded distance of 8 km in Song Co Chien, 10 km in Song Cua Dai and 7 km in Song Hau.

Besides the direct economic effects, the emergency water supplement also deepens the friendship between China and the Mekong River Commission Secretariat and its Member Countries, especially China and Viet Nam. A statement was made by the Vietnamese Minsitry of Foreign Affairs on 14 March 2016 to express that Viet Nam welcomes China's increased outflow to Mekong River[33]. Other Mekong countries also expressed their appreciation for the emergency water supplement from China[34].

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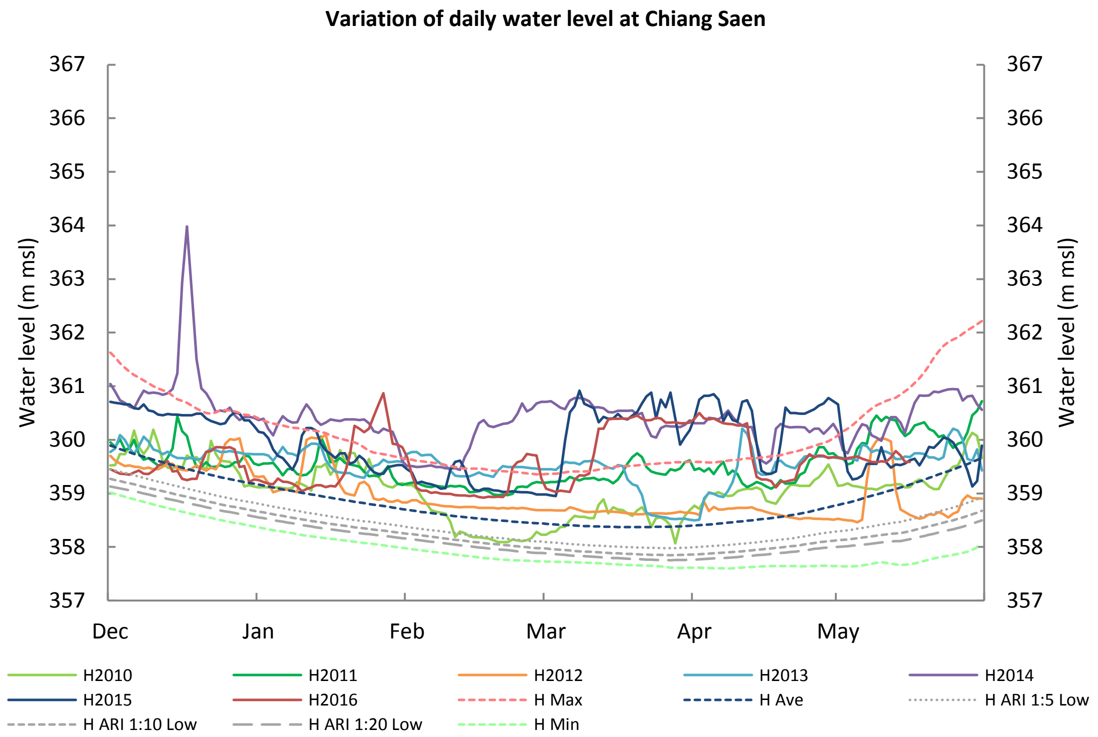
[31] Vietnam Breaking News: http://www.vietnambreakingnews.com/2016/05/many-mekong-delta-households-in-dire-need-of-fresh-water/, accessed on 18 May 2015.

[32] China Daily: http://world.chinadaily.com.cn/2016-04/06/content_24314806.htm, accessed 21 April 2016.

[33] http://english.vietnamnet.vn/fms/government/152455/vietnam-welcomes-china-s-increased-outflow-to-mekong-river.html

[34] State Council of China webpage: http://www.gov.cn/xinwen/2016-04/13/content_5063533.htm?cid=303, accessed on 13 April 2016.

Annex B – Variation of daily water level and discharge monitoring for 2010-2016



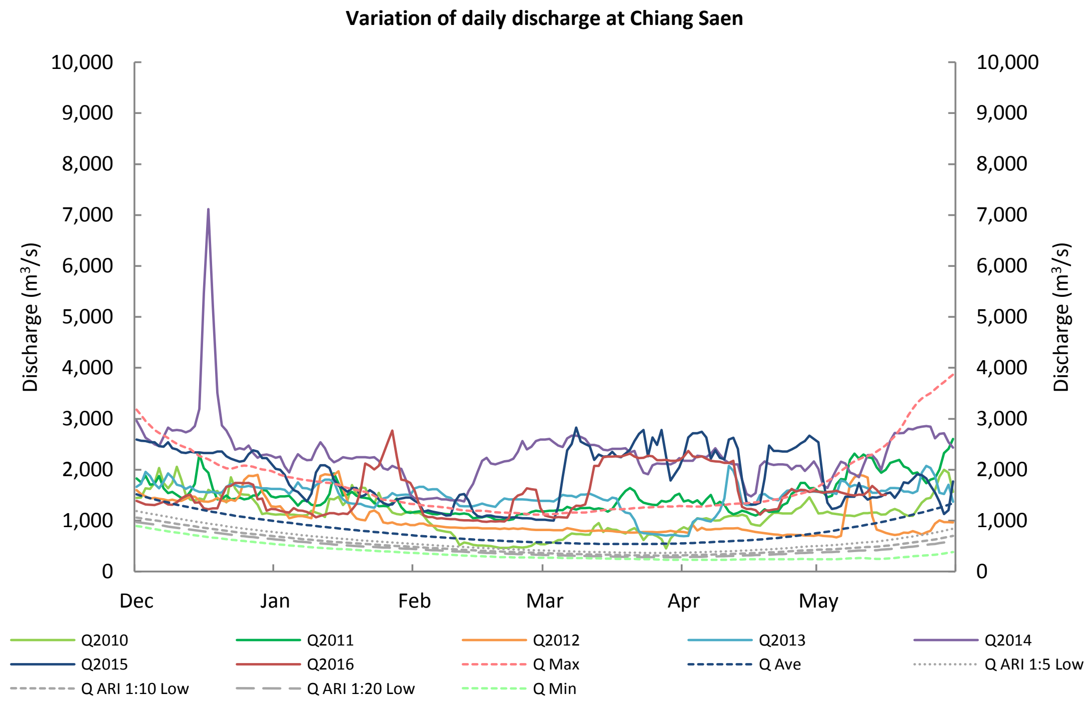
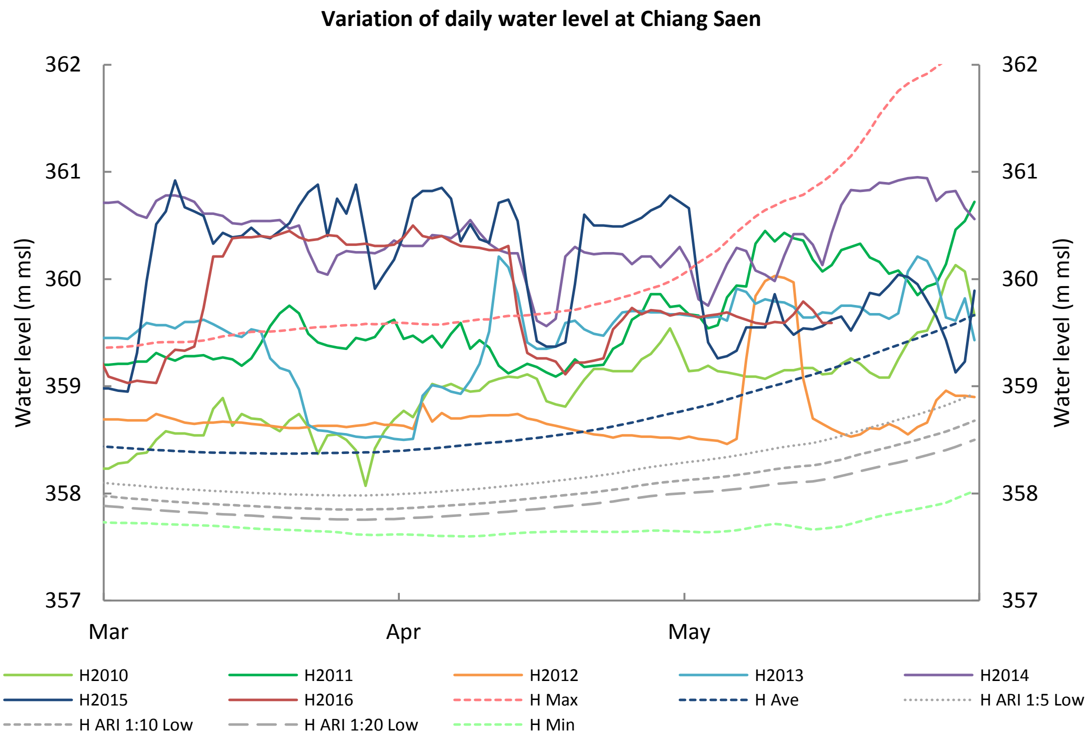


Figure B1 | Variation of daily water level and discharge at Chiang Saen for individual dry season of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].



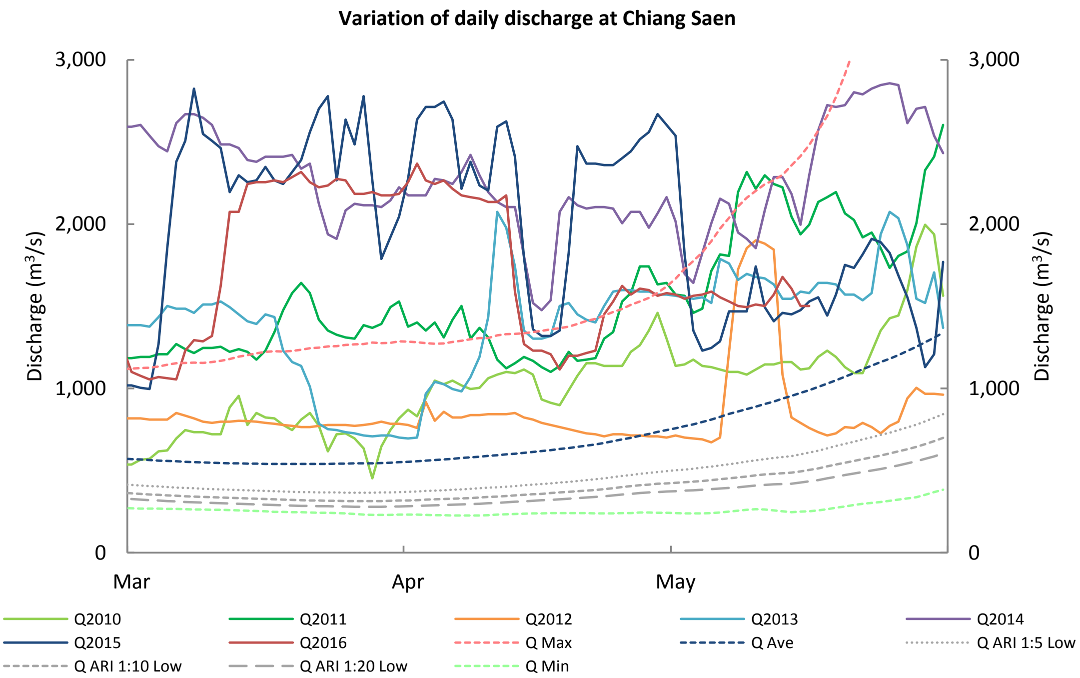
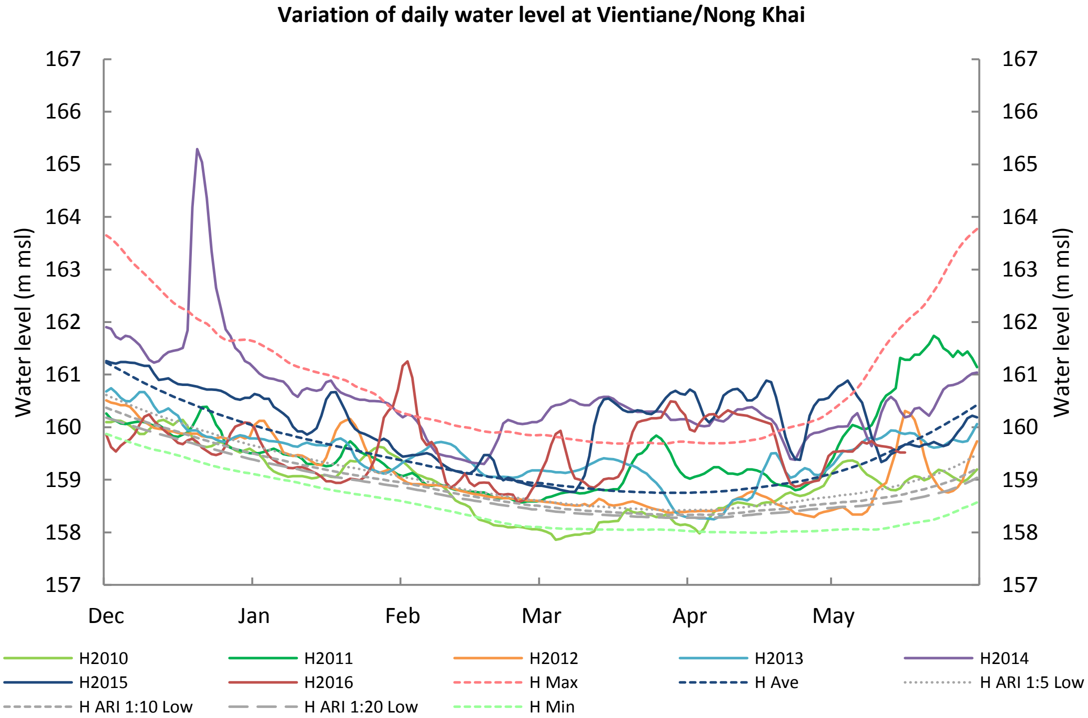


Figure B2 | Variation of daily water level and discharge at Chiang Saen for individual March-May of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].



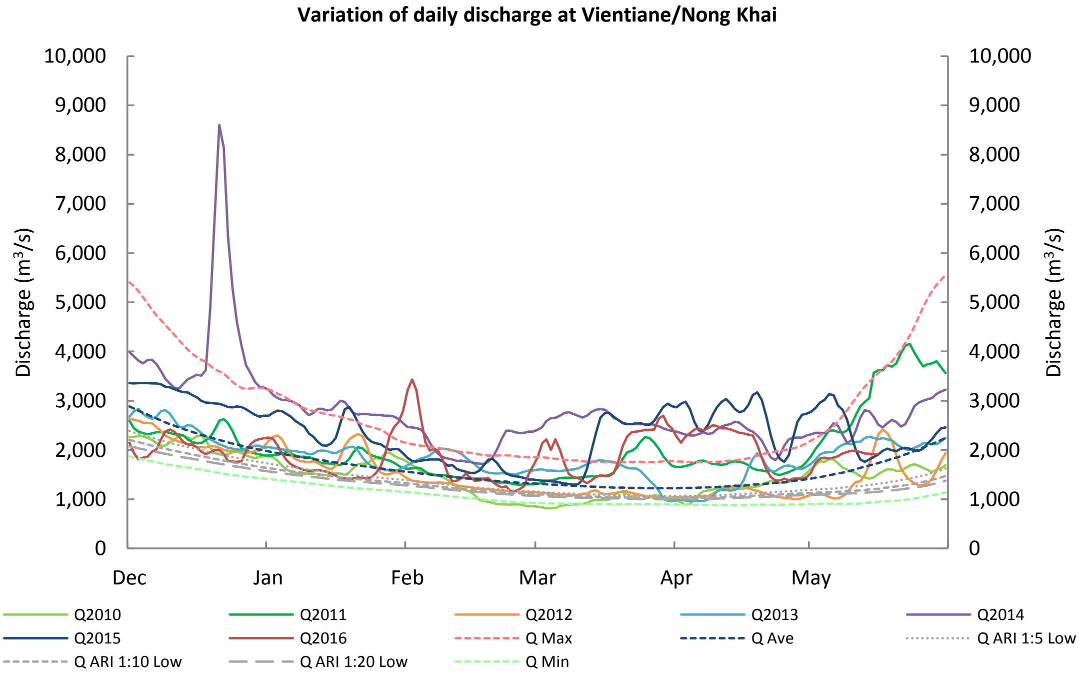
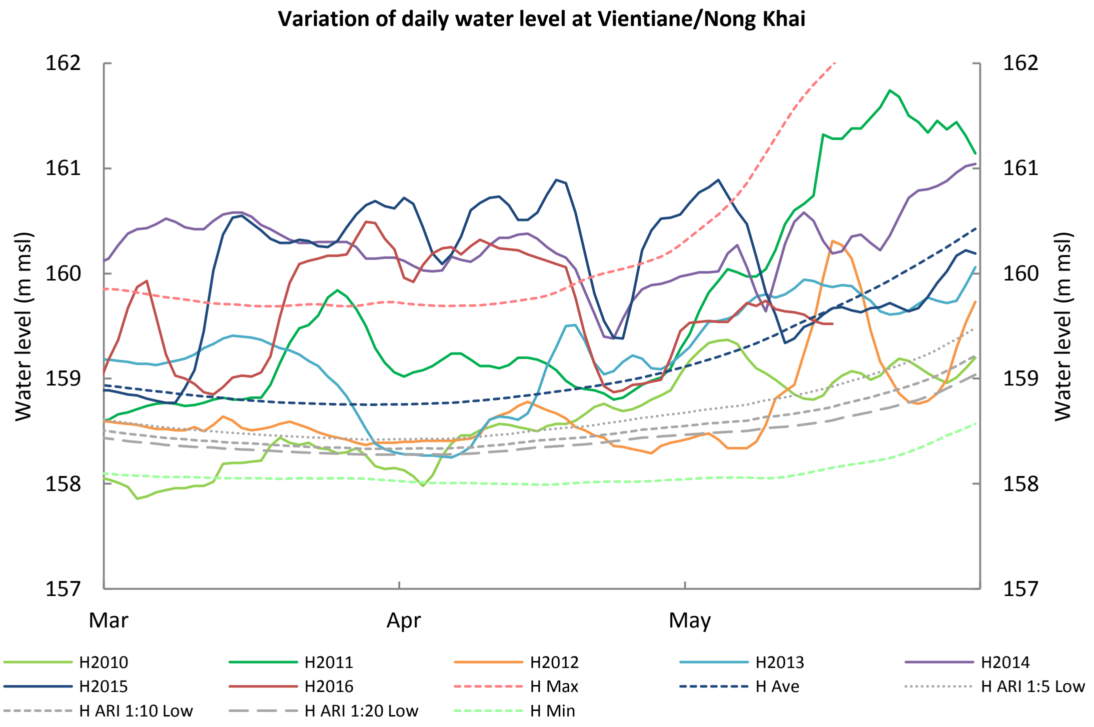


Figure B3 | Variation of daily water level and discharge at Vientiane/Nong Khai for dry season of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].



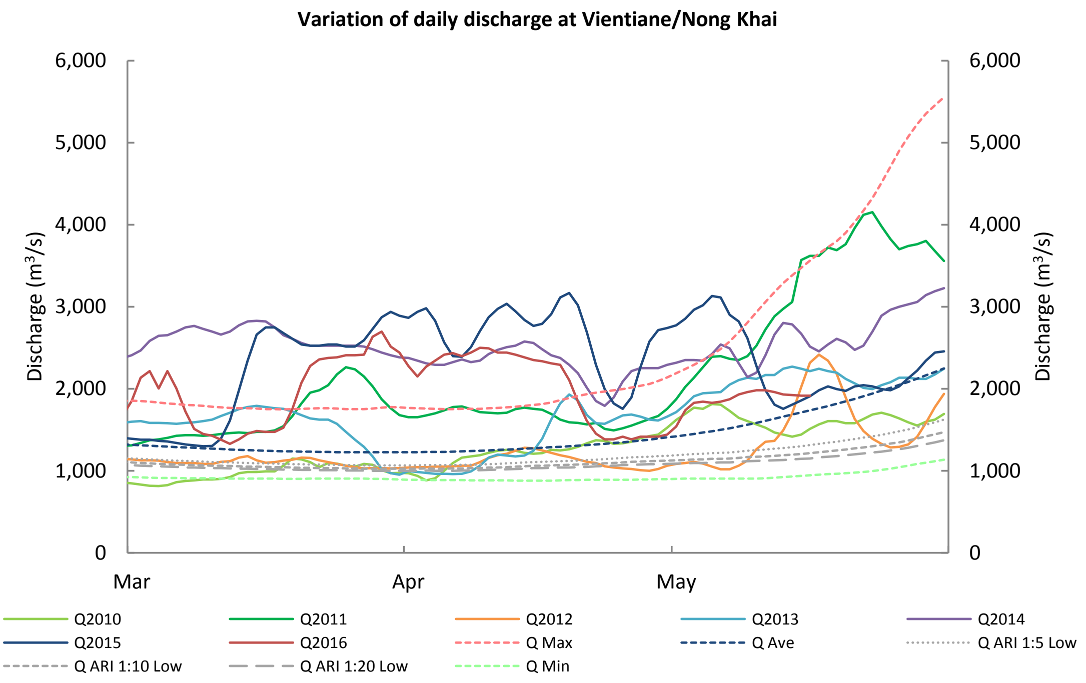
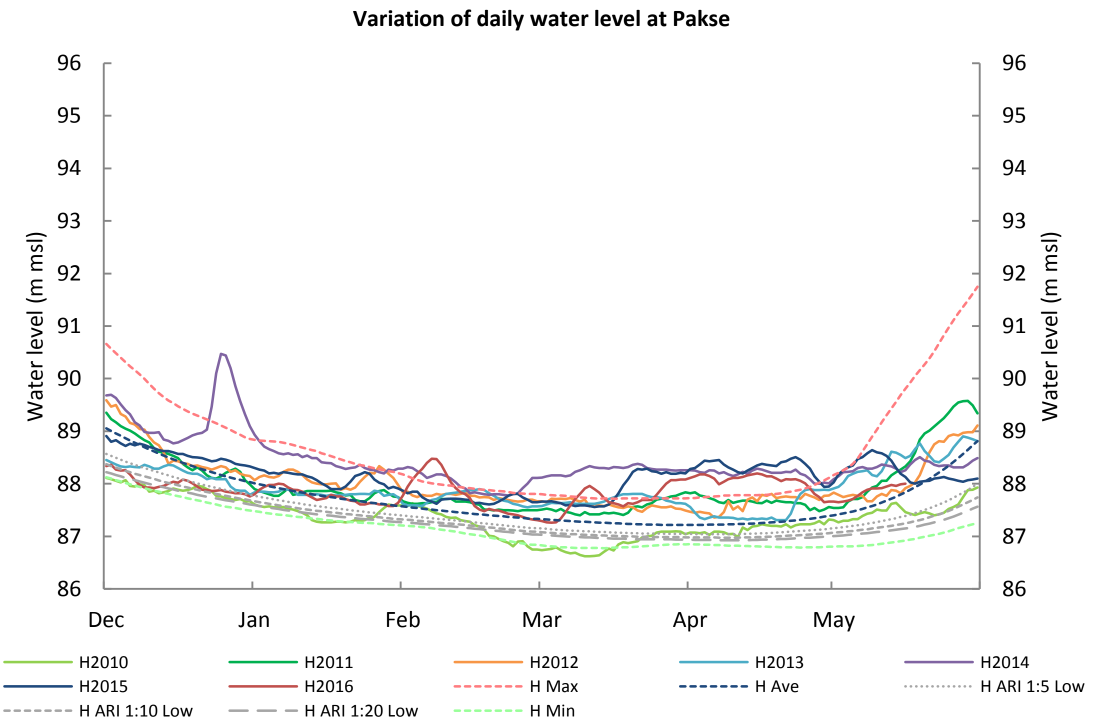


Figure B4 | Variation of daily water level and discharge at Vientiane/Nong Khai for individual March-May of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009. *The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].*



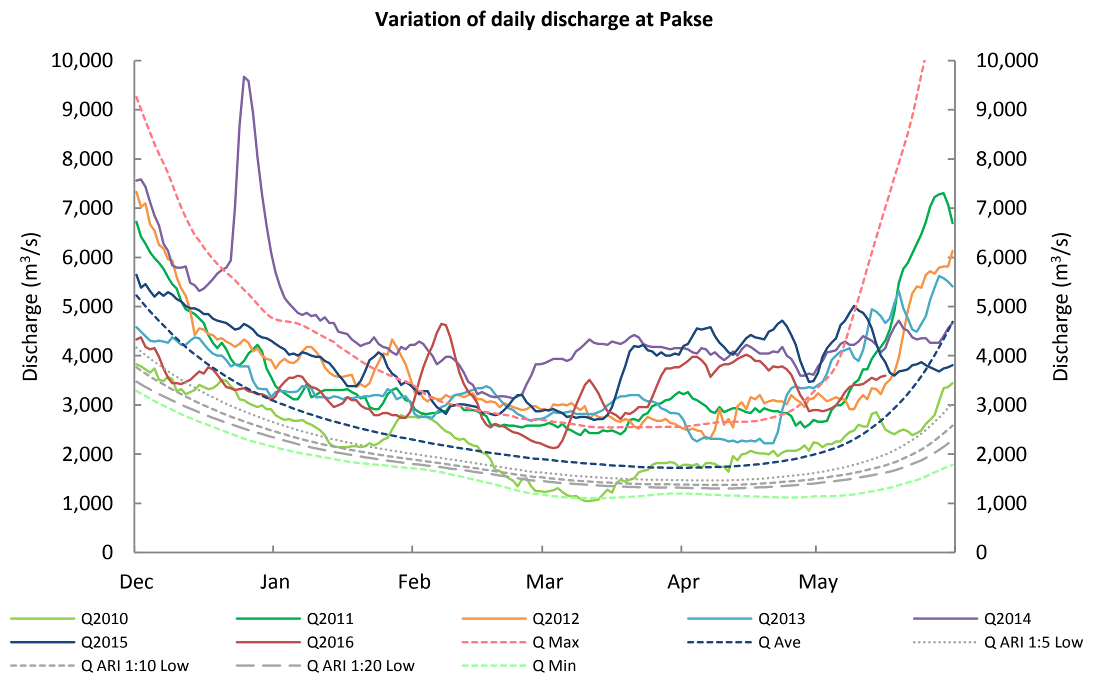
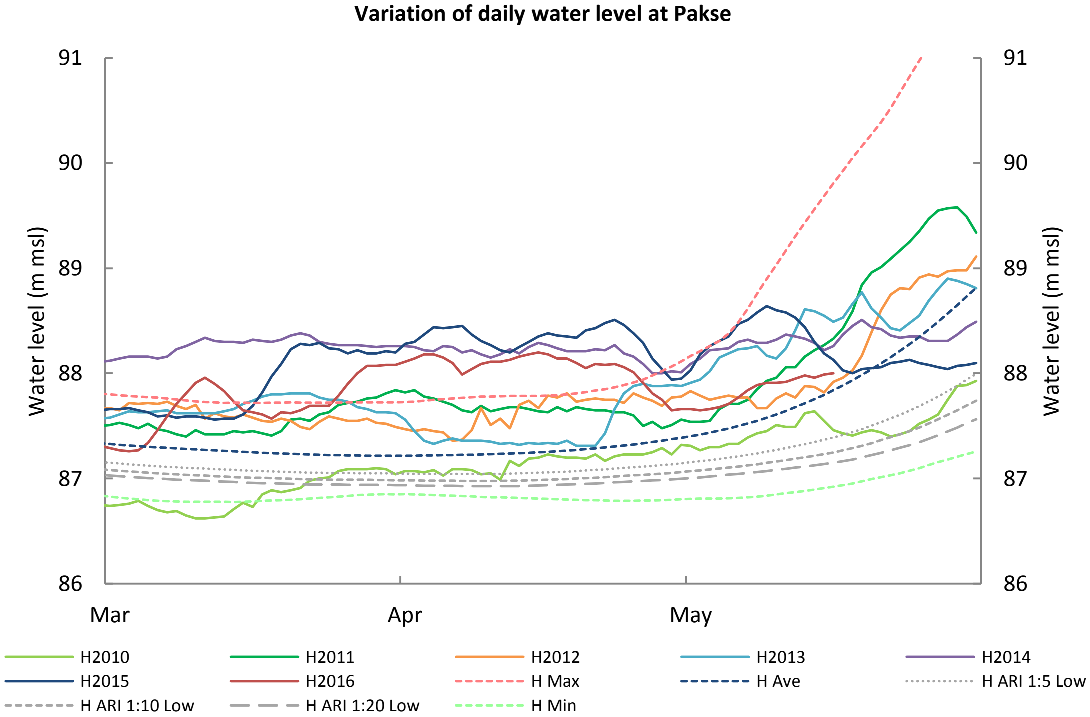


Figure B5 | Variation of daily water level and discharge at Pakse for individual dry season of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].



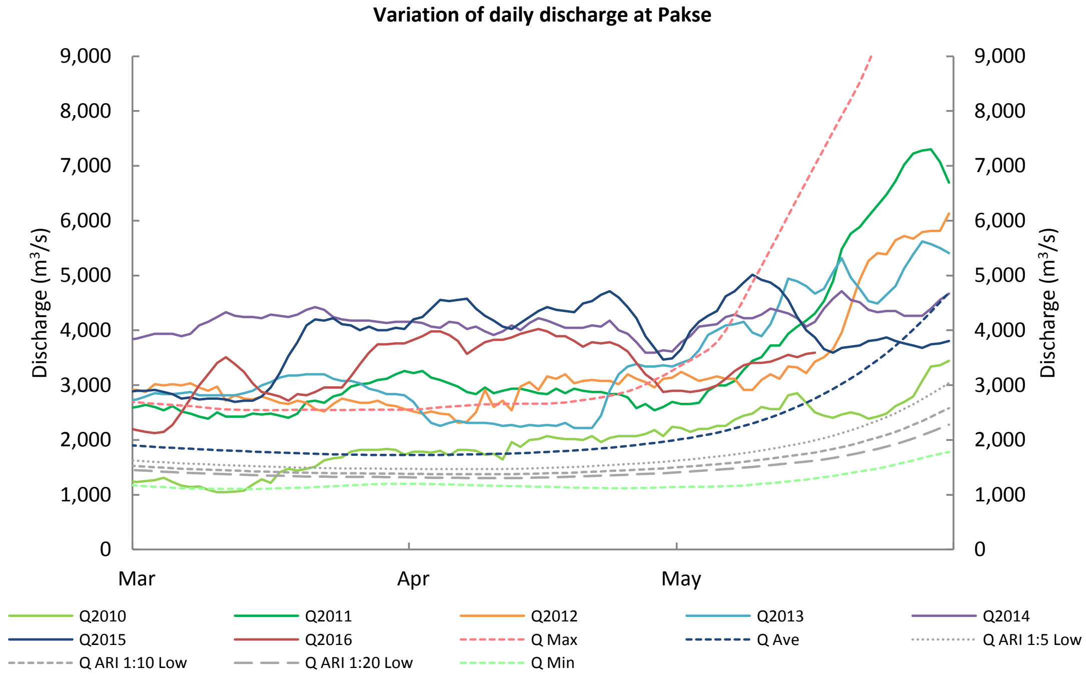
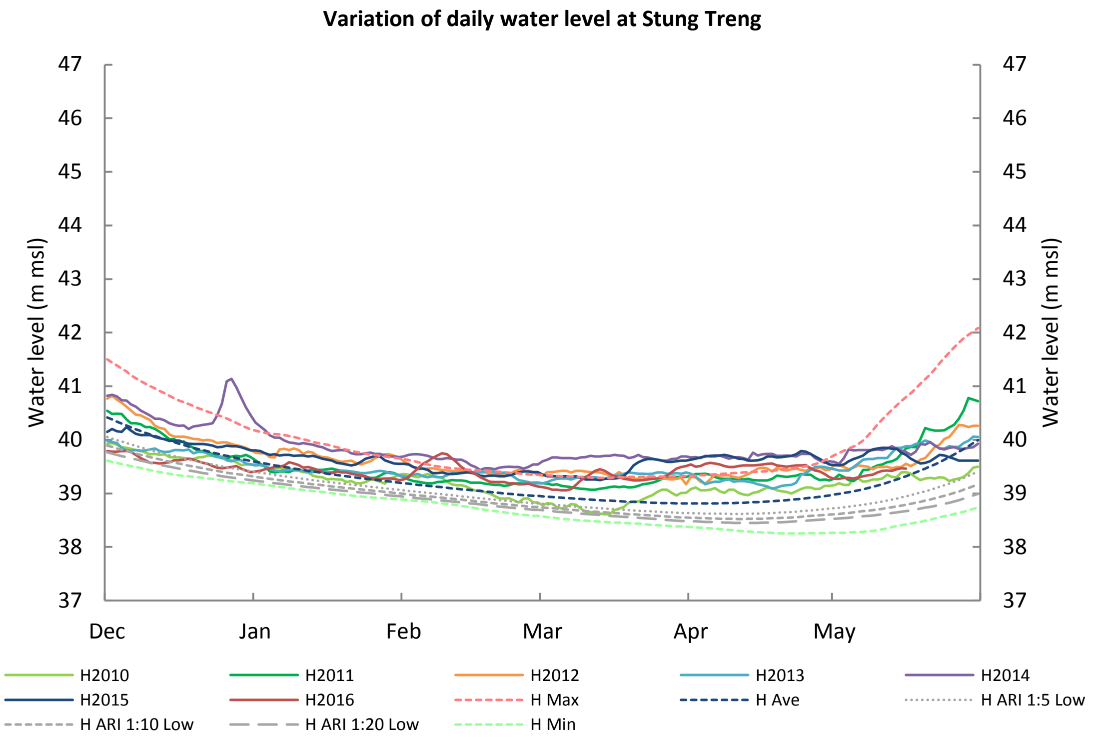


Figure B6 | Variation of daily water level and discharge at Chiang Saen for individual March-May of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].



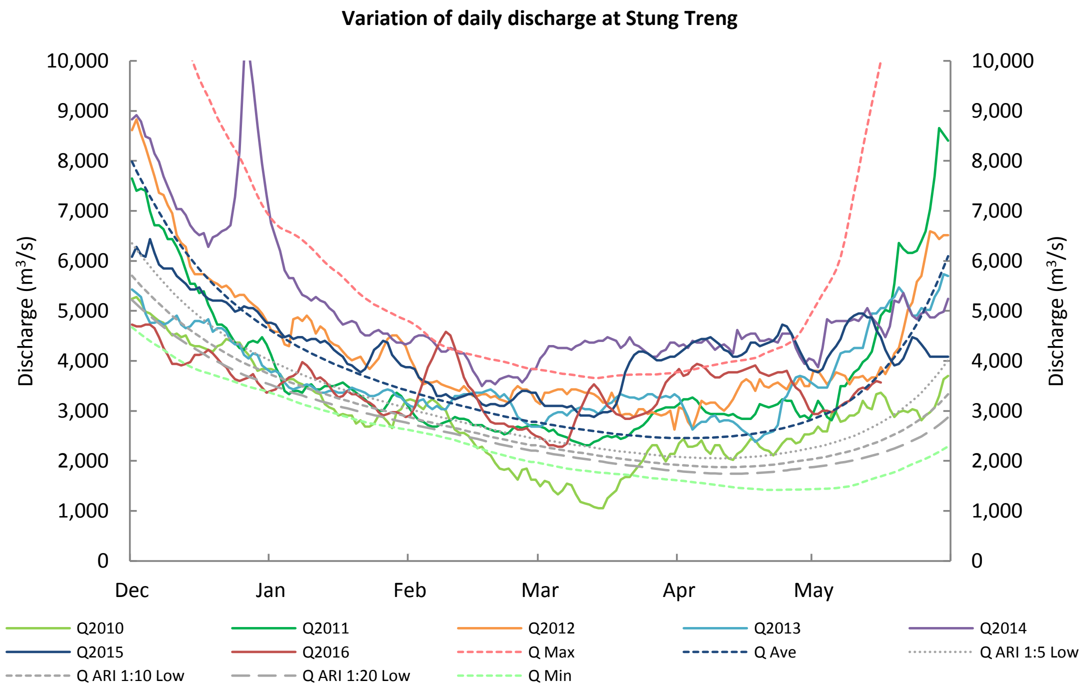
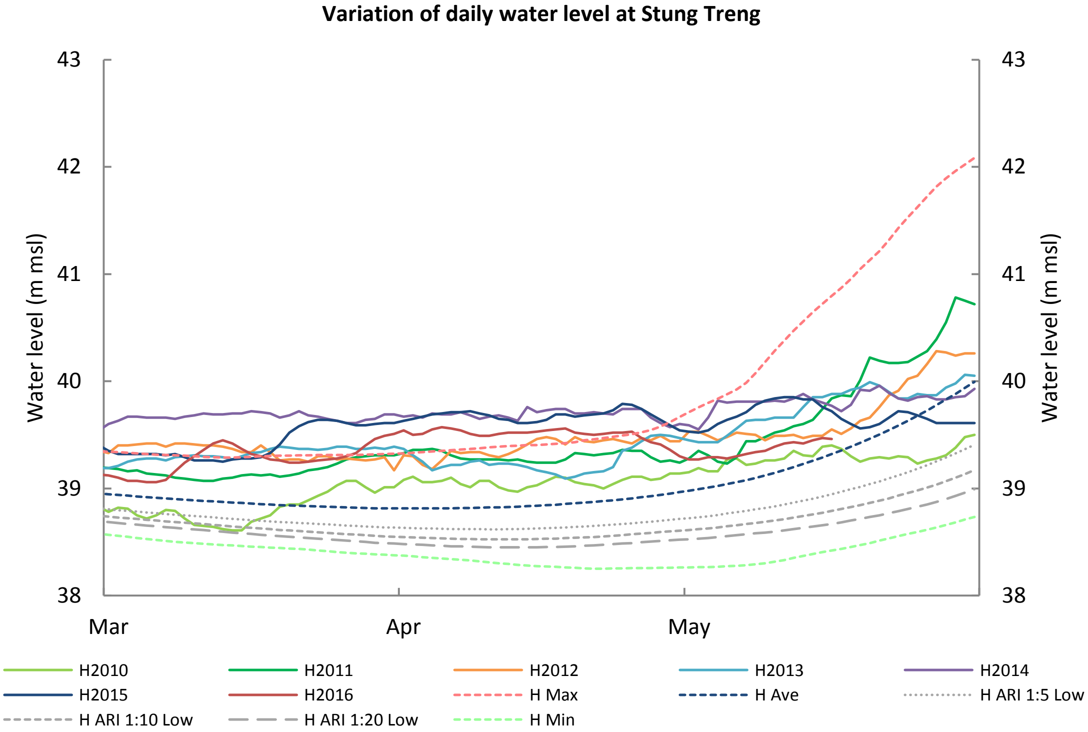


Figure B7 | Variation of daily water level and discharge at Stung Treng for individual dry season of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].



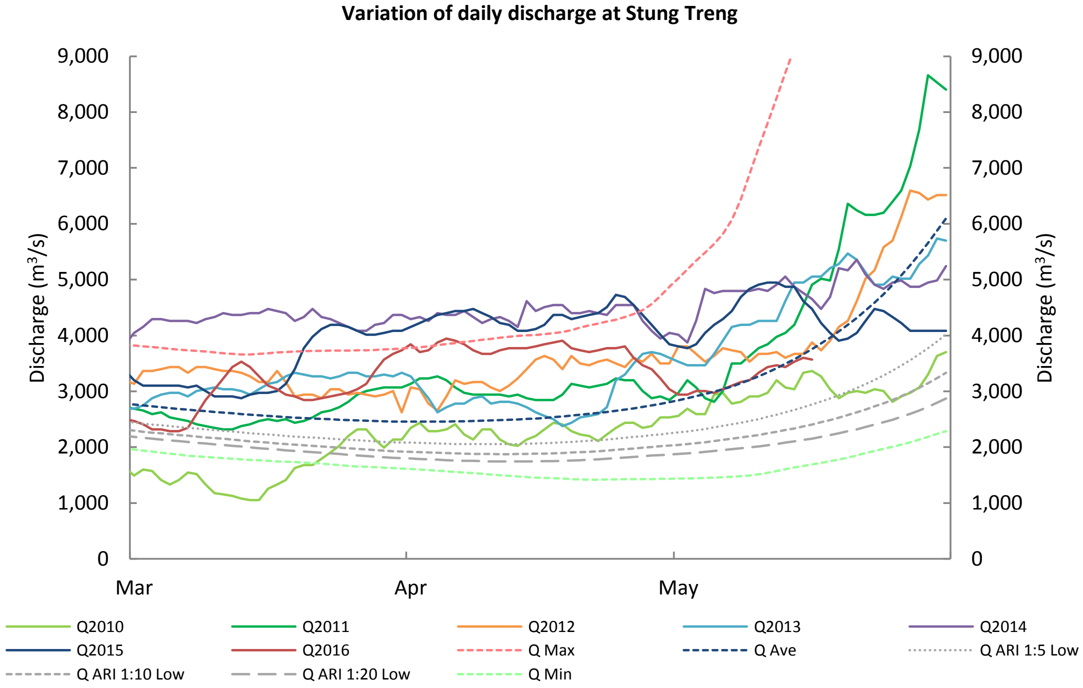


Figure B8 | Variation of daily water level and discharge at Stung Treng for individual March-May of 2010-2016, comparing to the daily long term average, minimum and maximum of 1962-2009.
The daily discharge of 2010-2011 is depicted in greenish colour tone to present flow conditions before major observable changes, while discharge of 2012-2016 is illustrated in various distinct colours to reflect flow fluctuation impacted by regulation in the Lancang Basin. Daily observed water level at a given year is represented by 'H' with [YEAR], while daily rated discharge is represented by 'Q' with [YEAR].

Mekong River Commission
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中国水利
CHINA WATER