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THE HYDROLOGICAL AND WATER LEVEL DATA IN YOM RIVER BASIN OF THAILAND

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Abstract. Yom River basin located in Northern Thailand, faces perennial droughts and floods with great impact on agriculture and the economy in the surrounding landscape. Therefore, the purpose of the present study is to study the hydrological nature of the Yom River basin, by descriptive statistics analysis using daily water level data from four water level measurement stations, from April 1, 2007, to March 31, 2020.

The lower part of Mae Nam Yom river is almost half of the Yom River basin area. The water allocation plan in 2019-2020 for six reservoirs suggests usable water of 116.5 million m^3, with the water allocated at the beginning of the rainy season more than during the dry season. During the dry season most of the water was allocated for agriculture. In most areas of Yom River basin, there are droughts and floods happened not more than 3 times in the last 10 year. The daily water level data of all four water level measurement stations showed relatively clear seasonal variations. The daily water level peaked every hydrological year during the rainy season. The average annual water level was the highest in 2011 (258.92 ± 1.09, 183.26 ± 1.64, 145.56 ± 1.89, and 96.20 ± 2.17 m(MSL)), and the lowest in 2015, except at the Y.1C station in 2019 (258.01 ± 0.49, 182.10 ± 0.61, 144.01 ± 1.24, and 94.50 ± 0.56, m(MSL)). The average monthly water level started to rise since May, with its highest peak value is in September (259.67 ± 0.86, 184.27 ± 1.14, 146.21 ± 1.39, and 97.09 ± 1.57 m(MSL)). The average monthly water level is low from December to April (dry season), the lowest values are from February to March (257.82 ± 0.19, 181.65 ± 0.12, 143.91 ± 0.32, and 94.31 ± 0.20, m(MSL)).

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1. INTRODUCTION

Among 25 main basins of Thailand, The Yom River basin, located in Northern Thailand, with tropical wet and dry or even savanna climate throughout the year. It is river basin covers 24,046.89 km^2. In 2014, the Yom River basin received average annual precipitation of about 1,179 mm, and average annual runoff of about 5,261 million mm^3 and an average annual runoff of fewer than 2,500 mm^3 per year per person, which is less than average annual runoff in Thailand per year per person (3,496 m^3) ([1]).

Over the past 40 years, Thailand has suffered from many weather extremes. Severe droughts problems, such as in 1999, occur in almost every region of Thailand causing severe economic damage in both agriculture and argo-industries based upon agriculture raw materials ([1]). Moreover, the Land Development Department reports that the frequency of drought in the Yom River basin in 2013, an area with a drought frequency of not more than 3 times in 10 years 907.75 km^2, a drought frequency of 4-5 times in 10 years 701.3 km^2, and a drought frequency greater than or equal to 6 times in 10 years 229.34 km^2 ([2]).

Floods are the other weather extreme that occur in almost every Thai province many times and causes damage to life, property, and economy, such as in 2011, where Thailand has suffered economic losses of 1.44 million THB. The reasons vary from natural causes to human activities ([1]). Moreover, the Land Development Department reports that the frequency of flood in Yom River basin in 2013, Yom River basin had an area with a flood frequency of not more than 3 times in 10 years 2,454.06 km^2, a flood frequency of 4-7 times in 10 years 1,334.25 km^2, and a flood frequency greater than or equal to 8 times in 10 years 541.90 km^2 ([3]).

The agricultural trade system of Thailand causes a large consumption of water for agriculture. The increase in population, expansion of the community area, and development of the industrial and economic area result in increased water demand leading to the urge of protecting water resources. Regarding the Yom River basin in 2014, was found that 3,089 million m^3 water was used for irrigation, 1,850 million m^3 as non-irrigated agricultural water, 71.65 million m^3

water for consumption and tourism, 17.99 million m^3 covering the industrial water demand, and ecological water demand of 160 million m^3 ([1]).

The streamflow of a river represents an integrated basin response to climatic factors with a dominant precipitation ([4]). Streamflow changes are being complicated by climate change and intensified human activities ([5, 6]). This creates instability in the formation of hydrological models.

Due to the problem in the Yom River basin above-mentioned, the researchers were interested in studying the hydrological nature and the descriptive statistics of the Yom River basin. That can reflect such problems to serve as important information in planning and managing water resources in the Yom River basin more effectively in the future. Different geographical conditions of the Yom River basin, the upstream higher than the downstream, including the nature of the Yom River in the downstream narrower than the upstream region provoked, the interest to study the hydrological nature of the Yom River basin, its impact on agriculture and the economy, and descriptive statistics.

2. Study Region and Dataset

Yom River basin covers a surface area of approximately 24,046.89 km^2, between the latitude 14 50′ N to 18° 25′ N and the longitude 99° 16′ E to 100° 40′ E. Yom River basin consisted of 11 major sub-river basins and covers administratively 11 provinces, 45 districts, 286 sub-district, and 2,028 villages, as shown in Table 1 - 2 and Fig. 1.

Yom River originates from the Khun Yuam mountain in Phi Pan Nam Range in Pong district and Chiang Muan district, Phayao province, at high slope of 180-360 m(MSL). Then, the stream flow into a large lowland in Phrae province and continues down south through the lowland Sukhothai province. In this area, it flows parallel to the Nan River, at a lower slope of 50-180 m(MSL). Flowing through Phichit province it confluence with Nan River in Nakhon Sawan province at a low slope of 20-50 m(MSL). The length of the Yom River is approximately 735 km ([7]).

The water resources situation of the Yom River basin in 2014, received an average annual precipitation of about 1,179 mm ([1]). Most of the rain falls between mid-May to mid-October, which is during the rainy season or the southwest monsoon blowing over Thailand. Based on

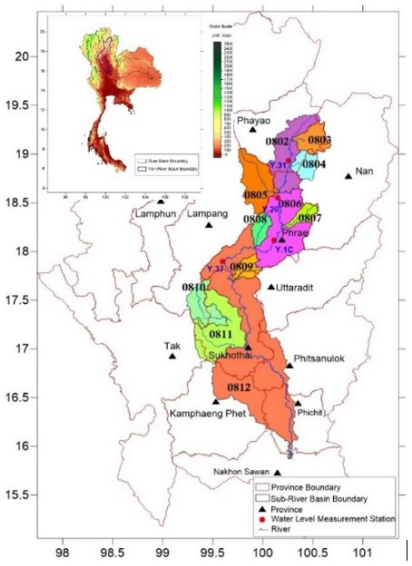

Fig. 1 The topography of Yom River basin

data in 2011, the Yom River basin has not a large-scale water reservoir development project yet. There are only six completed reservoirs with a capacity of more than 8.6 million m^3, the total water storage capacity of 271.8 million m^3 ([7, 8, 9]). For retrieving daily water level data in m(MSL) four water level measurement stations were selected over the length of Yom river: Ban Thung Nong [Y.31] station, Ban Huai Sak [Y.20] station, Ban Nam Khong [Y.1C] station, and Ban Wang Chin [Y.37] station. Data was collected from the Upper Northern Region Irrigation Hydrology Center (Royal Irrigation Department) from April 1, 2007 to March 31, 2020, over 13 hydrological years or 4,649 days, as shown in Table 3 and Fig. 1 ([10, 11, 12, 13, 14, 15]).

3. METHODOLOGY

3.1. Hydrological year. A hydrological year is a term commonly used in hydrology to describe 12 months. It differs from the calendar year because of the precipitation that falls. Due to meteorological and geographical factors, the definition of the hydrological year varies. The hydrological year of Thailand was defined as the period between April 1 of one year and March 31 of the next.

3.2. Descriptive Statistics. Generally, the field of statistics is divided into two major divisions: descriptive and inference statistics ([16]). This study focuses on the study of descriptive

Table 1 The major sub-river basin of the Yom River basin.

The sub-river basins in the Yom River basin	The area in the Yom River basin (km^2)	
Upper Part of Mae Nam Yom (0802)	2,111.04	(8.78 %)
Mae Nam Khuan (0803)	870.74	(3.62 %)
Nam Pi (0804)	656.66	(2.73 %)
Mae Nam Ngao (0805)	1,753.86	(7.29 %)
Middle Part of Mae Nam Yom (0806)	3,066.51	(12.75 %)
Nam Mae Kham Mi (0807)	456.18	(1.90 %)
Nam Mae Ta (0808)	518.24	(2.16 %)
Huai Mae Sin (0809)	531.00	(2.21 %)
Nam Mae Mok (0810)	1,071.02	(4.45 %)
Nam Mae Ram Phan (0811)	2,617.79	(10.89 %)
Lower Part of Mae Nam Yom (0812)	10,393.84	(43.22 %)
Total	**24,046.89**	**(100 %)**

Table 2 Details for the area of the Yom River basin.

Provinces of the Yom River basin	Area of the province (km^2)	Area in the Yom River basin			Yom River basin covers administrative districts			
		Area in the Yom River basin (km^2)	Percentage of the area in the Yom River basin	Percentage of the area of the province	Province	District	Sub-district	Village
Kamphaeng Phet	8,541.34	1,862.60	7.75	21.81	1	6	28	236
Tak	17,271.22	195.36	0.81	1.13	1	1	2	6
Nakhon Sawan	9,567.04	20.56	0.09	0.21	1	1	2	11
Nan	12,215.06	527.55	2.19	4.32	1	3	6	28
Phayao	6,182.16	2,513.50	10.45	40.66	1	2	10	108
Phichit	4,341.96	1,633.43	6.79	37.62	1	7	36	301
Phitsanulok	10,524.94	1,529.61	6.36	14.53	1	4	30	179
Phrae	6,490.81	6,426.15	26.72	99.00	1	8	74	433
Lampang	12,488.39	2,616.56	10.88	20.95	1	3	13	96
Sukhothai	6,670.29	6,606.01	27.47	99.04	1	9	82	620
Uttaradit	7,855.21	115.55	0.48	1.47	1	1	3	10
Total		**24,046.89**	**100**		**11**	**45**	**286**	**2,028**

Table 3 Water level measurement stations.

Code	Name	Location (sub-district, district, province)	Latitude	Longitude	Height of the water area. (m(MSL))
Y.31	Ban Thung Nong	Sa, Chiang Muan, Phayao	18° 57' 20" N	100° 16' 01" E	253.465
Y.20	Ban Huai Sak	Tao Pun, Song, Phrae	18° 35' 03" N	100° 09' 17" E	179.411
Y.1C	Ban Nam Khong	Pa Maet, Mueang Phrae, Phrae	18° 07' 59" N	100° 07' 39" E	140.704
Y.37	Ban Wang Chin	Wang Chin, Wang Chin, Phrae	17° 54' 00" N	99° 56' 24" E	91.428

statistics of the Yom River basin and serves as basis for further studies of inference statistics in the future. By doing the statistical analysis as follows:

Arithmetic Mean

$$\overline{y_i} = \sum_{k=1}^{K} \frac{y_{ik}}{n_{y_i}} \qquad i = 1,2,\ldots,I; k = 1,2,\ldots,K \tag{1}$$

Standard deviation

$$s_i = \sum_{k=1}^{K} \frac{(y_{ik} - \overline{y_i})^2}{n_{y_i} - 1} \qquad i = 1,2,\ldots,I; k = 1,2,\ldots,K \tag{2}$$

Minimum

$$y_{\min_i} = \min\{y_{ik}\} \qquad i = 1,2,\ldots,I; k = 1,2,\ldots,K \tag{3}$$

Maximum

$$y_{\max_i} = \max\{y_{ik}\} \qquad i = 1,2,\ldots,I; k = 1,2,\ldots,K \tag{4}$$

where

$\overline{y_i}$ = The arithmetic mean or average of daily water level data of month or year i^{th}

y_{ik} = The k^{th} daily water level data of month or year i^{th}

n_{y_i} = The number of daily water level data of month or year i^{th}

s_i = The standard deviation of daily water level data of month or year i^{th}

$y_{\min_i}$ = The minimum of daily water level data of month or year i^{th}

$y_{\max_i}$ = The maximum of daily water level data of month or year i^{th}

4. Results and Discussion

4.1. The hydrological nature of the Yom River basin. The upper Yom River basin has a higher slope height than the lower Yom River basin as shown in Fig. 2. The lower part of Mae Nam Yom (0812) has the largest catchment area. With a catchment area of 10,393.84 km^2, which accounts for 43.22 percentage of the Yom River basin area, this area is almost half of the catchment area in the Yom River basin (24,046.89 km^2) as shown in Table 1, Fig. 1 and Fig. 3.

The Yom River basin covers administratively 11 provinces, 45 districts, 286 sub-district, 2,028 villages. The area of the province is in the Yom River basin of 6,606.01 and 6,426.15 km^2, 99.04 percentage of the Sukhothai province area and 99.00 percentage of the Phrae province area, which accounted for 27.47 and 26.72 percentage of the Yom River basin area, respectively. These two provinces combined equal more than 50 percentage of the area in the Yom River basin as shown in Table 2, Fig. 1 and Fig. 4.

In 2019, the Yom River basin is one large-sized reservoir and five medium-sized reservoirs with a total storage capacity of 295.62 million m^3 as shown in Table 4 and Fig. 5. The reservoir with the largest capacity, which is the only large-sized reservoir of the Yom River basin, Mae Mok reservoir, has a storage capacity of 110.00 million m^3, and represents 37.21 percentage of the Yom River basin's total water storage capacity.

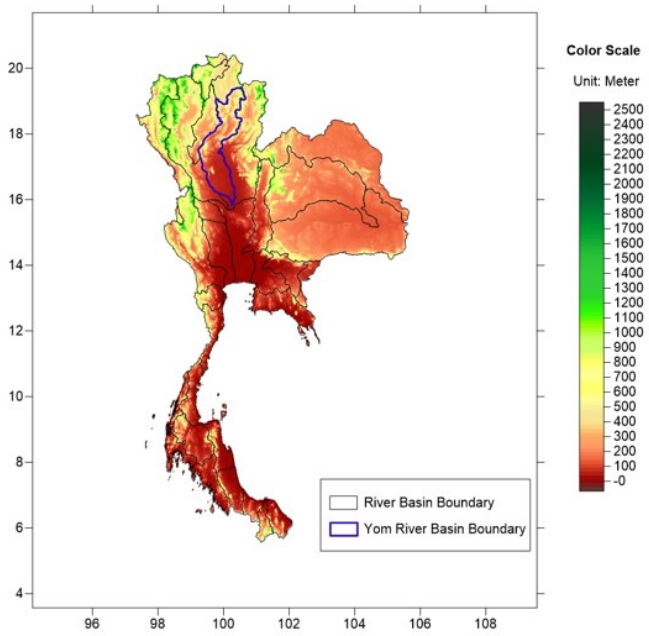

Fig. 2 Digital Elevation Model (DEM) map in Thailand.

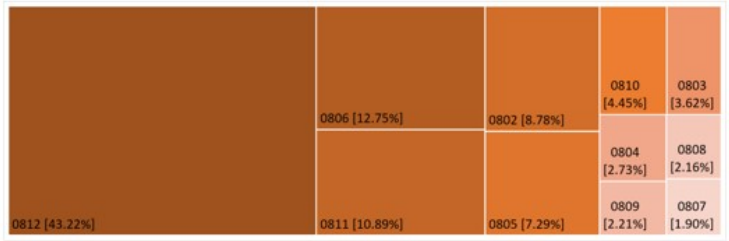

Fig 3 The proportion of the catchment areas of the major sub-river basin of the Yom River basin.

Data of water consumption in the Yom River basin was collected from the annual report of the Royal Irrigation Department. Water allocation plan for the dry season in irrigated areas in the period 2019 - 2020, beginning on November 1, 2019, to July 30, 2020 ([17]).

The water budget (usable water) allocation plan from large and medium-sized reservoirs of the Yom River basin with water volume of the usable water at 116.5 million m^3 is depicted

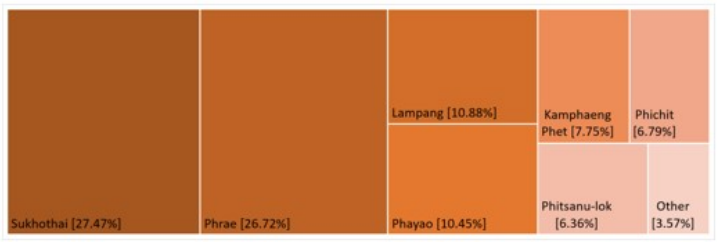

Fig. 4 The proportion of the catchment areas of the administrative district of the Yom River basin.

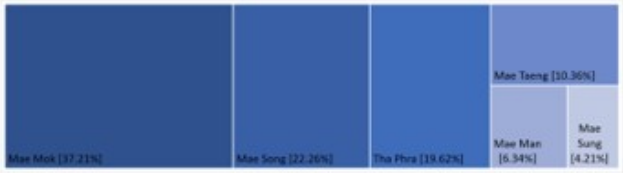

Fig. 5 The Yom River basin's water storage capacity

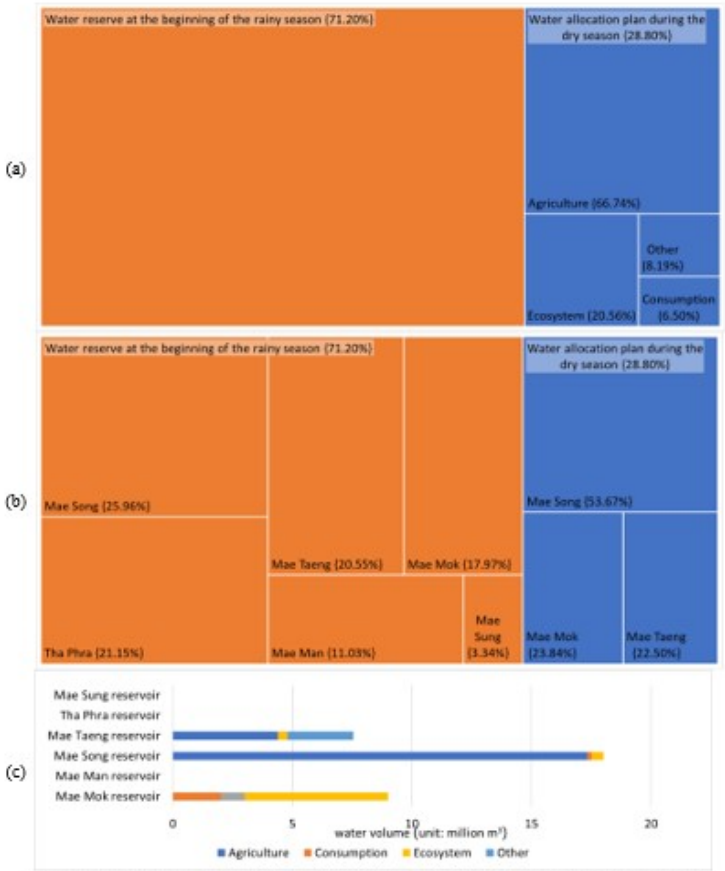

Fig. 6 Water allocation plan for large and medium-sized reservoirs for the Yom River basin during the dry season in 2019 – 2020. (a) Classified by water consumption type, (b) Classified by reservoir, (c) Classified by reservoir and water consumption type.

in Table 4 and Fig. 6. At the beginning of the rainy season the Yom River carries a volume of 82.97 million m^3, and the water volume to the water allocation plan during the dry season counts

a volume of 33.65 million m^3, which accounted for 71.20 and 28.80 percentage of the water volume of the usable water. During the dry season, water allocated for agriculture a volume of 21.73 million m^3, which accounted for 66.74 percentage of the water volume according to the water allocation plan during the dry season, as shown in Table 4 and Fig. 6(a).

The water allocation plan during the dry season, focusses on only three reservoirs, namely Mae Mok Reservoir, Mae Song Reservoir, and Mae Taeng Reservoir, with a volume of 8, 18.01, and 7.55 million m^3, which accounted for 23.84, 53.67, and 22.50 percentage of the water volume, respectively. At the beginning of the rainy season, the Mae Song Reservoir contributed with a volume of 21.54 million m^3, that accounted for 25.96 percentage of the water as shown in Table 4 and Fig. 6(b).

The water from Mae Song and Mae Taeng Reservoirs was mainly designated for agriculture more than from other reservoirs. The Mae Song Reservoir has a volume of 17.33 million m^3, which accounted for 96.22 percentage of the water volume according to the water allocation plan during the dry season of Mae Song Reservoir, and the Mae Taeng Reservoir has a volume of 4.4 million m^3, which accounted for 58.28 percentage of the water volume as shown in Table 4 and Fig. 6(c).

The Yom River basin has eleven water resources development projects under the supervision of the Regional Irrigation Office 3 and 4, with a total irrigated area of 4,912.3312 m^2. The Royal Irrigation Department has allocated water in the dry season of a total volume 662.91 million m^3. During the dry season, the water allocation plan sets the main part for agriculture at a volume of 504.34 million m^3, which accounted for 76.08 percentage of the water volume. Secondly, the part for the ecosystem is intended at a volume of 107.57 million m^3, which accounted for 16.23 percentage of the water volume as shown in Table 5 and Fig. 7(a).

Only Phichit Provincial Irrigation Office allocates the water for various purposes. Under the water resources development project Mae Yom Operation and Maintenance Project the main water allocation happened through the Kamphaeng Phet Provincial Irrigation Office. The water volume was 210.50, and 167.62 million m^3, and represents 31.75, and 25.29 percentage of the water volume as shown in Table 5 and Fig. 7(b).

The Phitsanulok Provincial Irrigation Office, Mae Yom Operation and Maintenance Project, and Sukhothai Operation and Maintenance Project allocated water to only one purpose: agriculture. The Kamphaeng Phet Provincial Irrigation Office, Sukhothai Provincial Irrigation Office, Phrae Provincial Irrigation Office, and Tho Thong Daeng Operation and Maintenance Project allocated water mainly for agriculture from the same water resource development projects at a volume of 155.27, 9.31, 28.25, and 85.30 million m^3, respectively, as shown in Table 5 and Fig. 7(c).

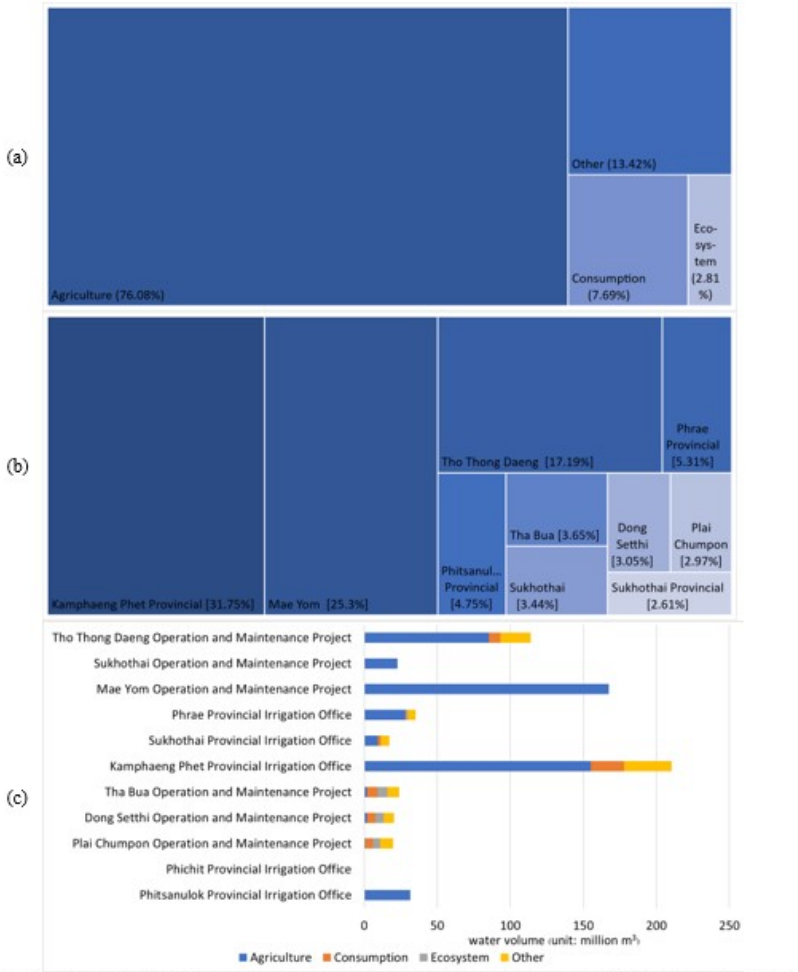

Fig. 7 Water allocation plan for each project irrigation area for the Yom River basin during the dry season in 2019 - 2020. (a) Classified by water consumption type, (b) Classified by the reservoir, (c) Classified by the reservoir and water consumption type.

The frequency of recurring droughts and floods in the Yom River basin ([2, 3]), is depicted in Table 6 and Fig. 8.

Recurring droughts in the Yom River basin were measured over 10 years in 2013 with a drought frequency of not more than 3 times 907.75 km^2, with a drought frequency of 4-5 times

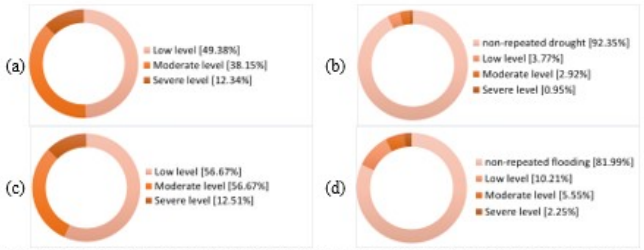

Fig. 8 The frequency of recurring droughts and floods in the Yom River basin in 2013. (a) The recurring drought area, (b) The recurring drought area compared with the Yom River basin area, (c) The recurring flood area, (d) The recurring flood area compared with the Yom River basin area.

Table 4 Water allocation plan for large and medium-sized reservoirs for the Yom River basin during the dry season in 2019/2020.

Reservoir	Storage capacity (million m³)	Usable water (1/11/2019) (million m³)	Water allocation plan during the dry season (million m³)					Water reserve at the beginning of the rainy season (million m³)
			Agriculture	Consum ption	Ecosystem	Other	Total	
Mae Mok Reservoir	110 [37.21%]	22.91 [19.66%] {100%}	-	2 [91.74%] (25.00%)	6 [86.96%] (75%)	-	8 [23.84%] (100%) {34.92%}	14.91 [17.97%] {65.08%}
Mae Man Reservoir	18.75 [6.34%]	9.15 [7.85%] {100%}	-	-	-	-	-	9.15 [11.03%] {100%}
Mae Song Reservoir	65.8 [22.26%]	39.55 [33.94%] {100}	17.33 [79.75%] (96.22%)	0.18 [8.26%] (1.00%)	0.5 [7.25%] (2.78%)	-	18.01 [53.67%] (100%) {45.54%}	21.54 [25.96%] {54.46%}
Mae Taeng Reservoir	30.62 [10.36%]	24.6 [21.11%] {100%}	4.4 [20.25%] (58.28%)	-	0.4 [5.80%] (5.30%)	2.75 [100%] (36.42%)	7.55 [22.5%] (100%) {36.42%}	17.05 [20.55%] {30.69%}
Tha Phra Reservoir	58 [19.62%]	17.55 [15.06%] {100%}	-	-	-	-	0	17.55 [21.15%] {100%}
Mae Sung Reservoir	12.45 [4.21%]	2.77 [2.38%] {100%}	-	-	-	-	0	2.77 [3.34%] {100%}
Total	**295.6 [100%]**	**116.5 [100%] {100%}**	**21.73 [100%] (64.74%)**	**2.18 [100%] (6.50%)**	**6.9 [100%] (20.56%)**	**2.75 [100%] (8.19%)**	**33.56 [100%] (100%) {28.80%}**	**82.97 [100%] {71.20%}**

Note: [α] is a representation of α percentage of the water volume in the reservoir.
(α) is a representation of α percentage of the water volume according to the water allocation plan during the dry season in each reservoir.
{α} is a representation of α percentage of the water volume of the usable water.

701.3 km^2, and with a drought frequency greater than 5 times 229.34 km^2, which accounted for 49.38, 38.15, and 12.34 percentage of the total area with the repeated drought, and represents 3.77, 2.92, and 0.95 percentage of the Yom River basin area. The recurring drought area of all three levels has a total area of 1,838.39 km^2 as shown in Table 6 and Fig. 8(a-b).

Recurring floods in the Yom River basin were measured over 10 years in 2013 with a flood frequency of not more than 3 times 2,454.06 km^2, with a flood frequency of 4-7 times 1,334.25 km^2, and with a drought frequency greater than 7 times 541.90 km^2, which accounted for 56.67,

Table 5 Water allocation plan for irrigation area project for the Yom River basin during the dry season in 2019/2020.

Offices	Water allocation plan during the dry season (million m^3)				
	Agriculture	Consumption	Ecosystem	Other	Total
Phitsanulok Provincial Irrigation Office	31.52 [6.25%] (100%)	-	-	-	31.52 [4.75%] (100%)
Phichit Provincial Irrigation Office	-	-	-	-	0
Plai Chumpon Operation and Maintenance Project	0.71 [0.14%] (3.60%)	5.15 [10.10%] (26.13%)	4.95 [26.58%] (25.11%)	8.9 [10.01%] (19.71%)	19.71 [2.97%] (100%)
Dong Setthi Operation and Maintenance Project	1.73 [0.34%] (8.57%)	5.86 [11.49%] (29.02%)	5.63 [30.24%] (27.89%)	6.97 [7.84%] (34.52%)	20.19 [3.05%] (100%)
Tha Bua Operation and Maintenance Project	1.84 [0.36%] (7.64%)	7.14 [14%] (29.66%)	6.94 [37.27%] (28.83%)	8.15 [9.16%] (33.86%)	24.07 [3.65%] (100%)
Kamphaeng Phet Provincial Irrigation Office	155.27 [30.79%] (73.76%)	22.46 [44.04%] (10.67%)	-	32.77 [36.84%] (15.57%)	210.50 [31.75%] (100%)
Sukhothai Provincial Irrigation Office	9.31 [1.85%] (53.78%)	2 [3.92%] (11.55%)	-	6 [6.75%] (34.66%)	17.31 [2.61%] (100%)
Phrae Provincial Irrigation Office	28.25 [5.60%] (80.21%)	0.55 [1.08%] (11.56%)	1.1 [5.91%] (3.12%)	5.32 [5.98%] (15.11%)	35.22 [5.31%] (100%)
Mae Yom Operation and Maintenance Project	167.62 [33.24%] (100%)	-	-	-	167.62 [25.29%] (100%)
Sukhothai Operation and Maintenance Project	22.79 [4.52%] (100%)	-	-	-	22.79 [3.44%] (100%)
Tho Thong Daeng Operation and Maintenance Project	85.3 [16.91%] (74.84%)	7.84 [15.37%] (6.88%)	-	20.84 [23.43%] (18.28%)	113.98 [17.19%] (100%)
Total	**504.34 [100%] (76.08%)**	**51 [100%] (7.69%)**	**18.62 [100%] (2.81%)**	**88.95 [100%] (13.42%)**	**6,62.91 [100%] (100%)**

Note: [α] is a representation of α percentage of the water volume in the Office.
(α) is a representation of α percentage of the water volume according to the water allocation plan during the dry season in each Office.

Table 6 The frequency of recurring droughts and floods in the Yom River basin in 2013.

Frequency of recurring droughts or recurring floods in 10 years	Drought or flood area (km^2)	Percentage of Drought or flood area	Percentage of Yom River basin area
Low level: drought frequency of < 4 times	907.75	49.38	3.77
Moderate level: drought frequency of 4-5 times	701.3	38.15	2.92
Severe level: drought frequency of > 5 times	229.34	12.34	0.95
Total area with the repeated drought	1,838.39	100	7.65
Total area with the non-repeated drought	22,208.50		92.35
Low level: flooding frequency of < 4 times	2,454.06	56.67	10.21
Moderate level: flooding frequency of 4-7 times	1,334.25	30.81	5.55
Severe level: flooding frequency of > 7 times	541.9	12.51	2.25
Total area with the repeated flooding	4,330.21	100	18.01
Total area with the non-repeated flooding	19,716.68		81.99
Yom River basin area	**24,046.89**		**100**

30.81, and 12.51 percentage of the total area with the repeated flood, and represents 10.21, 5.55, and 2.25 percentage of the Yom River basin area. The recurring flooding area of all three levels has a total area of 4,330.21 km^2 as shown in Table 6 and Fig. 8(c-d).

4.2. Water Level of the Yom River basin. Covering a period of 13 hydrological years from April 2007 to March 2020, daily water level was measured at all four water level measurement

stations: Ban Thung Nong [Y.31] station, Ban Huai Sak [Y.20] station, Ban Nam Khong [Y.1C] station and Ban Wang Chin [Y.37] station. The data showed a regular pattern as depicted in the time series plot in Fig. 9. That is to say, the daily water level data of all four water level measurement stations have relatively clear seasonal variations. There is a peak of the daily water level every hydrological year, which occurs during the rainy season or the southwest monsoon covering Thailand. According to the analyzed data, it was found that in 2011, the daily water level of all four water level measurement stations was the highest of all 13 hydrological years of study.

As shown in Table 7 and Fig. 10, the average annual water level of all four water level measurement stations peaked in 2011, the year with a heavy flood in Thailand. The average annual water level of the four water level measurement stations was the lowest in 2015, except at the Ban Nam Khong [Y.1C] station in 2019. The standard deviation of the lowest peak average annual water level was lesser than the highest peak average annual water level of all four water level measurement stations.

At Ban Thung Nong [Y.31] station, the minimum annual water level at less than 257.87 m(MSL), which fell to its lowest value at 257.35 m(MSL) occurred in 2009. Extreme measurements were found in the extreme hydrological year 2011, where the maximum annual water level of more than 260.28 m(MSL) peaked at 263.57 m(MSL) the lowest average annual water level was measured at 258.92 $\pm$ 1.09 m(MSL) in 2011, as well as the highest water level at 258.92 $\pm$ 1.09 m(MSL) as shown in Table 7 and Fig. 10(a).

At Ban Huai Sak [Y.20] station, the minimum annual water level at less than 181.65 m(MSL) had the lowest value at 181.41 m(MSL) occurred in 2019. The maximum annual water level of more than 185.07 m(MSL), highest at 189.73 m (MSL) occurred in 2011. The lowest average annual water level is 182.1 $\pm$ 0.61 m(MSL), measured in 2015, and the highest peak at 183.26 $\pm$ 1.64 m(MSL) occurred in 2011 as shown in Table 7 and Fig. 10(b).

At Ban Nam Khong [Y.1C] station, the minimum annual water level at less than 144.03 m(MSL) with the lowest value at 143.30 m(MSL) occurred in 2019. The maximum annual water level of more than 146.89 m(MSL) with the peak value at 153.78 m(MSL) occurred in 2011. The lowest average annual water level at 144.01 $\pm$ 1.24 m(MSL) was measured in 2019,

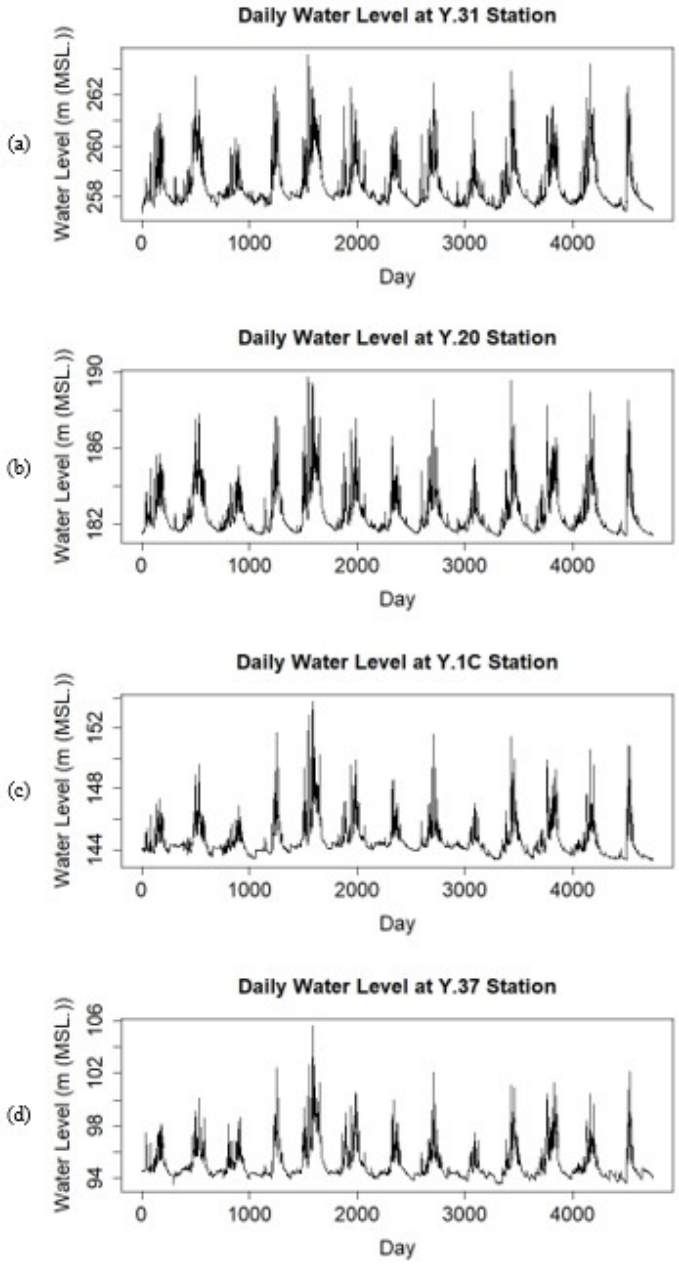

Fig. 9 Time series plot of daily water level of all four water level measurement stations. (a) Y.31 station, (b) Y.20 station, (c) Y.1C station, (d) Y.37 station.

and the highest value at 145.56 $\pm$ 1.89 m(MSL) occurred in 2011 as shown in Table 7 and Fig. 10(c).

At Ban Wang Chin [Y.37] station, the minimum annual water level at less than 94.27 m(MSL), assessed with the lowest peak value at 93.54 m(MSL) occurred in 2016. The maximum annual water level of more than 97.5 m(MSL) with its highest value at 105.63 m(MSL) occurred in

Table 7 Descriptive statistics of annual water level data of all four water level measurement stations.

Hydrological year	Annual Water Level (m(MSL))					
	Y.31 station			Y.20 station		
	Minimum	Mean ± S.D.	Maximum	Minimum	Mean ± S.D.	Maximum
2007	257.35	258.27 ± 0.67	261.25	181.49	182.43 ± 0.86	185.71
2008	257.60	258.62 ± 0.93	262.70	181.64	182.76 ± 1.17	187.77
2009	257.66	258.19 ± 0.40	260.28	181.52	182.24 ± 0.67	185.07
2010	257.61	258.40 ± 0.85	262.31	181.48	182.40 ± 1.19	187.63
2011	257.87	258.92 ± 1.09	263.57	181.61	183.26 ± 1.64	189.73
2012	257.76	258.54 ± 0.74	262.28	181.65	182.69 ± 1.02	187.57
2013	257.61	258.24 ± 0.63	260.72	181.54	182.30 ± 0.81	186.60
2014	257.64	258.41 ± 0.89	262.44	181.54	182.57 ± 1.16	188.56
2015	257.49	258.01 ± 0.49	261.34	181.45	182.10 ± 0.61	185.45
2016	257.53	258.41 ± 0.91	262.92	181.42	182.55 ± 1.18	189.52
2017	257.63	258.49 ± 0.93	261.56	181.59	182.82 ± 1.28	188.24
2018	257.65	258.51 ± 0.96	263.18	181.56	182.69 ± 1.15	188.94
2019	257.42	258.07 ± 0.85	262.30	181.41	182.18 ± 1.20	188.49
	Y.1C station			Y.37 station		
	Minimum	Mean ± S.D.	Maximum	Minimum	Mean ± S.D.	Maximum
2007	143.78	144.41 ± 0.61	147.33	93.55	94.97 ± 0.85	98.14
2008	143.55	144.63 ± 0.99	149.63	94.08	95.22 ± 1.08	100.07
2009	143.41	144.19 ± 0.59	146.89	93.98	94.90 ± 0.80	98.66
2010	143.72	144.54 ± 1.16	151.71	93.99	95.06 ± 1.39	102.37
2011	144.03	145.56 ± 1.89	153.78	94.27	96.20 ± 2.17	105.63
2012	144.02	144.98 ± 1.07	149.89	93.98	95.39 ± 1.37	100.57
2013	143.93	144.58 ± 0.69	148.60	93.88	94.85 ± 0.97	99.96
2014	143.94	144.76 ± 1.06	151.62	94.04	95.00 ± 1.10	102.07
2015	143.35	144.20 ± 0.54	147.04	93.78	94.50 ± 0.56	97.50
2016	143.37	144.52 ± 1.25	151.43	93.54	94.95 ± 1.38	101.08
2017	143.60	144.75 ± 1.25	149.89	93.93	95.43 ± 1.54	101.29
2018	143.41	144.43 ± 1.08	150.60	93.80	95.05 ± 1.07	100.43
2019	143.30	144.01 ± 1.24	150.86	93.65	94.69 ± 1.26	102.11

2011; whereas the lowest average annual water level is 94.5 $\pm$ 0.56 m(MSL) occurred in 2015, and the highest peak at 96.2 $\pm$ 2.17 m(MSL) in 2011 as shown in Table 7 and Fig. 10(d).

Monthly water level data of all four water level measurement stations are depicted in Table 8 and Fig. 11. The average monthly water level of all four water level measurement stations starts to rise since April. The highest peak value rises in September during the rainy season (mid-May to mid-October). The lowest peak value occurs between February to March, during the summer season (mid-February to mid-May). The average monthly water level is low from approximately December to April, which is during the dry season (mid-October to mid-May). The standard deviation of the lowest average monthly water level meters less than the highest peak average monthly water level of all four water level measurement stations.

At Ban Thung Nong [Y.31] station, the minimum monthly water level at less than 258.10 m(MSL) has the lowest peak value at 257.35 m(MSL) occurred in April. The maximum monthly water level of more than 258.28 m(MSL), highest at 263.57 m(MSL) measured in June. The lowest average monthly water level is 257.82 $\pm$ 0.19 m(MSL) occurred in March,

Table 8 Descriptive statistics of monthly water level data of all four water level measurement stations.

Month	Monthly Water Level (m(MSL))					
	Y.31 station			Y.20 station		
	Minimum	Mean ± S.D.	Maximum	Minimum	Mean ± S.D.	Maximum
January	257.68	257.92 ± 0.13	258.30	181.60	181.86 ± 0.15	182.58
February	257.56	257.84 ± 0.17	258.78	181.50	181.73 ± 0.13	182.58
March	257.47	257.82 ± 0.19	258.28	181.41	181.65 ± 0.12	182.12
April	257.35	257.84 ± 0.21	258.71	181.42	181.74 ± 0.24	182.98
May	257.56	258.09 ± 0.50	261.53	181.45	182.25 ± 0.74	187.15
June	257.48	258.16 ± 0.62	263.57	181.51	182.33 ± 0.88	189.73
July	257.42	258.66 ± 0.99	262.28	181.43	182.85 ± 1.15	188.24
August	257.96	259.54 ± 1.05	263.18	182.04	184.03 ± 1.41	189.52
September	258.10	259.67 ± 0.86	262.44	182.10	184.27 ± 1.14	188.56
October	258.02	258.83 ± 0.59	261.21	182.08	183.28 ± 0.85	187.59
November	257.89	258.24 ± 021	259.82	181.89	182.40 ± 0.32	184.36
December	257.71	258.03 ± 0.13	258.81	181.67	182.02 ± 0.17	182.87
	Y.1C station			Y.37 station		
	Minimum	Mean ± S.D.	Maximum	Minimum	Mean ± S.D.	Maximum
January	143.45	143.94 ± 0.27	144.58	93.55	94.33 ± 0.19	94.85
February	143.34	143.91 ± 0.32	144.47	93.80	94.31 ± 0.20	94.82
March	143.30	143.94 ± 0.36	144.56	93.78	94.32 ± 0.20	94.80
April	143.37	144.05 ± 0.34	145.03	93.54	94.38 ± 0.30	95.44
May	143.41	144.33 ± 0.70	149.40	93.63	94.74 ± 0.87	99.41
June	143.43	144.33 ± 0.91	152.83	93.85	94.83 ± 1.01	102.64
July	143.32	144.74 ± 1.14	150.05	93.65	95.30 ± 1.27	100.81
August	143.61	146.01 ± 1.70	153.78	94.38	96.67 ± 1.80	105.63
September	144.26	146.21 ± 1.39	151.62	94.48	97.09 ± 1.57	102.11
October	143.88	145.14 ± 0.89	150.23	94.44	95.87 ± 1.07	101.30
November	143.64	144.34 ± 0.34	145.65	94.13	94.85 ± 0.41	98.62
December	143.43	144.00 ± 0.29	145.14	93.93	94.38 ± 0.23	95.99

and the highest peaked at 259.67 $\pm$ 0.86 m(MSL) in September as shown in Table 8 and Fig. 11(a).

At Ban Huai Sak [Y.20] station, the minimum monthly water level less than 182.10 m(MSL), with the lowest peak value at 181.41 m(MSL) occurred in March. The maximum monthly water level of more than 182.12 m(MSL), reached highest peak value at 189.73 m(MSL) in June. Lowest average monthly water level at 181.65 $\pm$ 0.12 m(MSL) occurred in March, and the highest value at 184.27 $\pm$ 1.14 m(MSL) occurred in September as shown in Table 8 and Fig. 11(b).

At Ban Nam Khong [Y.1C] station, the minimum monthly water level with less than 144.26 m(MSL), was the lowest value at 143.30 m(MSL) in March. The maximum monthly water level of more than 144.47 m(MSL), peaking highest at 153.78 m(MSL) occurred in August. The lowest average monthly water level fell to 143.91 $\pm$ 0.32 m(MSL) in February, and the highest peaked at 146.21 $\pm$ 1.39 m(MSL) in September as shown in Table 8 and Fig. 11(c).

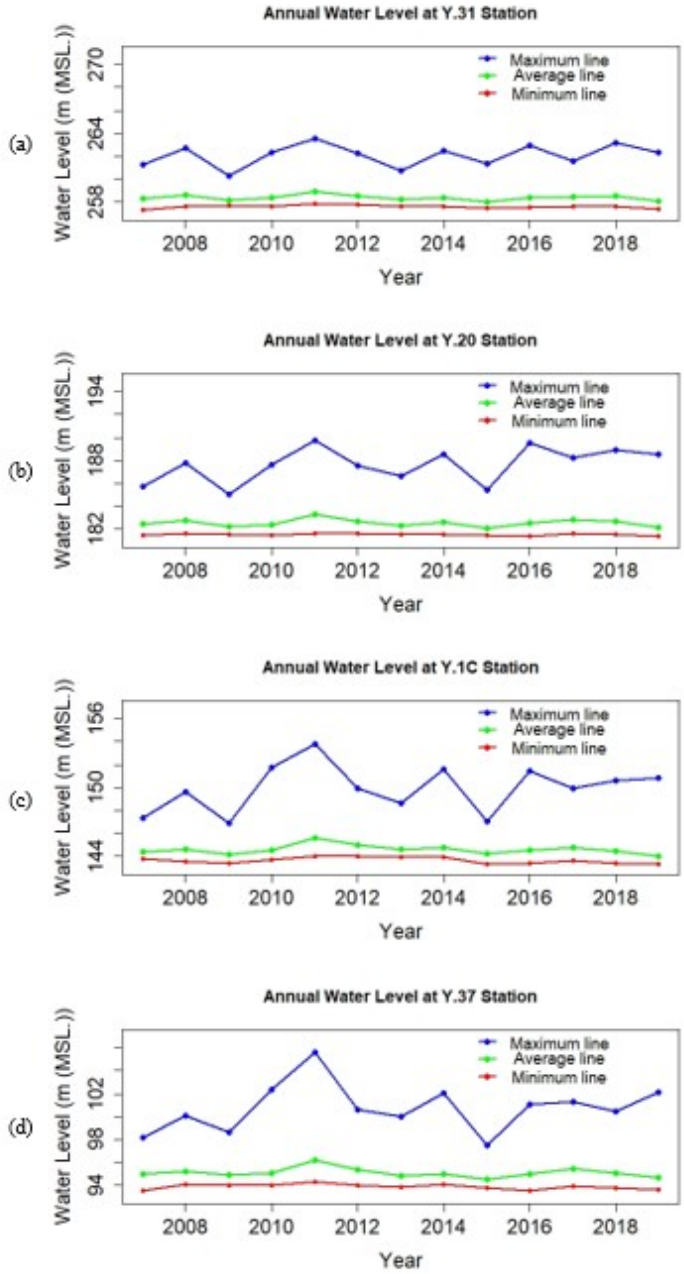

Fig. 10 Descriptive statistics of annual water level data of all four water level measurement stations. (a) Y.31 station, (b) Y.20 station, (c) Y.1C station, (d) Y.37 station.

At Ban Wang Chin [Y.37] station, the minimum monthly water level at less than 94.48 m(MSL), showed lowest peak value at 93.54 m(MSL) in April. The maximum monthly water level of more than 94.80 m(MSL), as the highest peak value at 105.63 m(MSL) occurred in August. The lowest average monthly water level is 94.31 ± 0.20 m(MSL) in February, and the highest peak at 97.09 ± 1.57 m(MSL) in September as shown in Table 8 and Fig. 11(d).

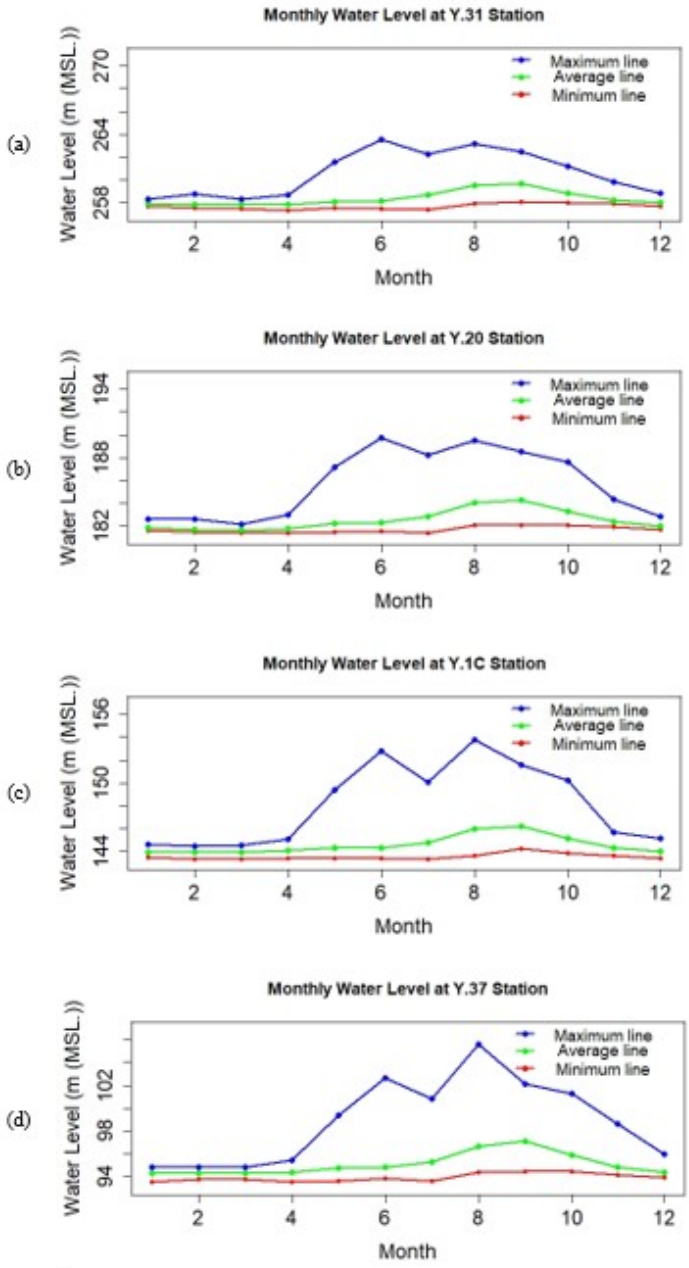

Fig. 11 Descriptive statistics of monthly water level data of all four water level measurement stations. (a) Y.31 station, (b) Y.20 station, (c) Y.1C station, (d) Y.37 station.

5. CONCLUSIONS

5.1. The hydrological nature of the Yom River basin. Yom River originates from the Khun Yuam mountain in Phi Pan Nam Range in Pong district and Chiang Muan district, Phayao province at a length of approximately 735 km while covering a surface area of approximately 24,046.89 km^2. Yom River basin consists of 11 major sub-river basins and stretches through

11 provinces. The lower part of Mae Nam Yom has the largest catchment area, with almost half of the catchment area of the overall Yom River basin. The Sukhothai and Phrae provinces are almost fully covered the Yom River basin. These two provinces combined compile more than 50 percentage of the Yom River basin area. The upper Yom River basin has a slope height greater than the lower Yom River basin, with the slope gradually decreasing from the upper Yom River basin to the lower Yom River basin.

The Yom River basins form one large-sized reservoir and five medium-sized reservoirs with a total storage capacity of 295.62 million m^3. The water allocation plan has the water volume of the usable water of 116.5 million m^3 and allocates water into two parts: The water volume at the beginning of the rainy season with a volume of 82.97 million m^3, and during the dry season with a volume of 33.65 million m^3, accounting for 71.20 and 28.80 percentage of the water volume of usable water, respectively. Most of the water allocation during the dry season was planned for agriculture. There are only three reservoirs, namely Mae Song Reservoir, Mae Mok Reservoir, and Mae Taeng Reservoir. The water allocation of Mae Song and Mae Taeng Reservoirs was more than any other reservoirs allocated in agricultures with most of the water partially from Mae Song Reservoir at the beginning of the rainy season.

The Yom River basin has eleven water resources development projects have a total irrigated area of 4,912.3312 m^2 and a total water volume of 662.91 million m^3. During the dry season, most of the water is designated to agriculture, and secondly for the ecosystem and other consumptions. The water source development project with the most water allocation is the Kamphaeng Phet Provincial Irrigation Office. Inferior position holds the Mae Yom Operation and Maintenance Project, and the Tho Thong Daeng Operation and Maintenance Project, respectively. The Phitsanulok Provincial Irrigation Office, Mae Yom Operation and Maintenance Project, and Sukhothai Operation and Maintenance Project allocated water only to agriculture. The Kamphaeng Phet Provincial Irrigation Office, Sukhothai Provincial Irrigation Office, Phrae Provincial Irrigation Office, and Tho Thong Daeng Operation and Maintenance Project allocated more to agriculture than any other type in the same water resource development projects.

The Yom River basin faces recurring droughts and floods in the past ten years. The recurring drought area of all three levels covers a total area of 1,838.39 km^2, and the recurring flood area

of all three levels covers a total area of 4,330.21 km^2. Floods and droughts tend to happen more at low levels than at other levels.

5.2. Water Level of the Yom River basin. The daily water levels at four water level measurement stations, namely Ban Thung Nong [Y.31] station, Ban Huai Sak [Y.20] station, Ban Nam Khong [Y.1C] station, and Ban Wang Chin [Y.37] station, were analyzed over a period of 4649 days between April 1, 2007, to March 31, 2020. The average annual water level and average monthly water level calculated for all four water level measurement stations. The following conclusions and recommendations could be made:

1. The daily water level data of all four water level measurement stations have relatively clear seasonal variations. There is a peak of the daily water level every hydrological year, which occurs during the rainy season or the southwest monsoon covering Thailand. According to the studied data, it was found that in 2011, the daily water level of all four water level measurement stations was the highest of all 13 hydrological years of study.

2. The average annual water level of all four water level measurement stations peaked the highest in 2011 at 258.92 $\pm$ 1.09, 183.26 $\pm$ 1.64, 145.56 $\pm$ 1.89, and 96.20 $\pm$ 2.17 m(MSL), respectively, the year of heavy flooding in Thailand. The average annual water level of the four water level measurement stations showed the lowest value in 2015, except at Ban Nam Khong [Y.1C] station in 2019, but has a similar value as in 2015 at 258.01 $\pm$ 0.49, 182.10 $\pm$ 0.61, 144.01 $\pm$ 1.24, and 94.50 $\pm$ 0.56, m(MSL), respectively; including the maximum annual water level with highest value in 2011. The standard deviation of the lowest peak average annual water level was less than the highest peak average annual water level of all four water level measurement stations.

3. The average monthly water level of all four water level measurement stations rises since May. The highest peak values in September at 259.67 $\pm$ 0.86, 184.27 $\pm$ 1.14, 146.21 $\pm$ 1.39, and 97.09 $\pm$ 1.57 m(MSL), respectively, happened during the wet season (mid-May to mid-October). Similarly, the lowest value are measured from February to March, during the summer season (mid-February to mid-May). The average monthly water level is low from approximately December to April with the lowest peak values at 257.82 $\pm$ 0.19, 181.65 $\pm$ 0.12, 143.91 $\pm$ 0.32, and 94.31 $\pm$ 0.20, m(MSL), respectively, which is during the dry season from mid-October to

mid-May; including the maximum monthly water level at its highest peak occurring in June and August, and the minimum monthly water level with the lowest peak value occurring in March and April. The standard deviation of the lowest average monthly water level was less than the highest peak average monthly water level of all four water level measurement stations.

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CONFLICT OF INTERESTS

The author(s) declare that there is no conflict of interests.

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