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ANALYSIS OF HYDROLOGIC VARIABLE CHANGES RELATED TO LARGE SCALE RESERVOIR OPERATION IN THAILAND

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The objective of this study is to investigate the trend of hydrologic variable changes by applying the Mann-Kendall statistical trend test to daily historical record of reservoir operations data such as inflow to dam reservoirs, release from dam reservoirs, dam storage as well as precipitation and temperature. The five large scale dam reservoirs located in the northern, central and western parts of Thailand are selected to analyze the trend of the Ping River basin having the Bhumibol dam, the Nan River basin having the Sirikit dam, the Pasak River basin having the Pasak Jolasid dam and the Mae Klong River basin having the Srinagarind and Vajiralongkorn dams. Through the analysis, we found that the temperature and precipitation show increasing trends except the Ping River basin; water resources availability in terms of inflow to the Bhumibol dam and Pasak Jolasid dam shows decreasing trend during dry season; the inflow of all reservoirs in rainy season had increasing trends; and dam release of the all reservoirs shows significant increasing trends in the dry season. Furthermore, water storage for the Bhumibol dam were found decreasing trends throughout the year while the Srinagarind dam was detected increasing trends. Also, the increasing trends of water shortage in the Bhumibol and Pasak Jolasid dam, and raising trend of excess storage volume in the Sirikit dam and both dams in the Mae Klong River Basin were observed.

Key Words: *Trend Analysis, Mann-Kendall Trend Test, Reservoir Operation, Thailand*

1. INTRODUCTION

Climate change causes clear temperature increase for decades or even longer periods (IPCC, 2013)[1)], which significantly affects various hydrologic processes in time and space distribution patterns and quantity of precipitation and evapotranspiration. There are numerous earlier studies which focus on trend analysis of atmospheric and hydrologic variables in quantity and quality using historical data and GCM data. For example, Tao *et al.*[2)] analyzed the trends of streamflow in the Tarim River basin during the past 50 years using historical data, and Duong *et al.*[3)] examined the impact of river discharge changes by using a distributed river flow routing model and GCM datasets in the Indochina Peninsula region.

In the Southeast Asian countries such as Thailand, agriculture is the main source of the economy and it ensures the well-being of the people. Therefore proper planning of water resource development as well as the utilization based on uncertainty in climate change impact is very necessary. Tebakari *et al.*[4)] found the impact of two large-scale reservoir operation on flow regimes before and after reservoir development, which reveals the great change of natural flow to stabilized flow through the year. Now water demands are highly interacted among various sectors, so unless the water resources are managed with a balance approach of supply and demand, its sustainability will become at risk.

In this study, the trend of various hydrologic variables related to dam reservoir operations such as inflow to dam reservoirs, release from dam reservoirs, dam storage as well as precipitation and temperature using long historical record are examined with the Mann-Kendall test. The trend analysis results provide information to propose adaptive dam release operation rules under changing climate, which will be combined with GCM data analysis for challenges and responses to extreme climatic events.

Table 1 Characteristic features of selected reservoirs.

Name	BB	SK	SR	VRK	PS
Location	17°14′33″N 98°58′20″E	17°45′50″N 100°33′48″E	14°24′31″N 99°07′42″E	14°47′58″N 98°35′49″E	14°51′41″N 101°03′58″E
CatchmentArea (km2)	26,386	13,130	10,880	3,720	12,292
Max.Storage (MCM)	13,462	9,510	17,745	8,860	785
Mean Inflow (MCM)	5,783	5,780	4,790	5,585	2,725
Opening Year	1964	1974	1980	1984	1999
Period (years)	50	40	34	30	15

2. MATERIALS AND METHODS

River basins in Thailand are studied, which are located in the Southeast Asia with an area 513,115 km^2. The basins experience tropical climate with clear dry and wet seasons defined as follows: the dry season starts from November until April and the rainy season starts from May until October in the central and northern part of Thailand. In the western river basins dry season starts from January until June and rainy season begins July until December.

(1) Study areas and data collection

The five large scale dam reservoir basins located in the northern, western and central parts of Thailand as shown in **Fig. 1** are selected to analyze the historical trend of precipitation, temperature, dam inflow, dam release, and storage. The five basins are the Ping River basin with the Bhumibol dam (BB), the Nan River basin with the Sirikit dam (SK), the Pasak River basin with the Pasak Jolasid dam (PS), and the Mae Klong River basin with the Srinagarind dam (SR) and Vajiralongkorn dam (VRK).

Daily temperature and precipitation data were collected from 25 meteorological stations for the period of 1980-2011; and time series of daily dam inflow, dam release and storage data were obtained from the Electricity Generating Authority of Thailand (EGAT) and Thai Royal Irrigation Department (RID) for the period of starting reservoir operation. The reservoir characteristics are given in **Table 1.** The spatial distribution of the selected meteorological stations in Thailand is shown in **Fig. 1**.

(2) Trend analysis methods

Detecting trends in hydrologic, climatic, water quality and other natural time series has been an active topic for more than three decades now. Statistical tests for the detection of significant trends in hydrologic and climatologic time series can be classified as parametric and non-parametric methods. The parametric trend tests require sample data to be independent and distributed according to a certain

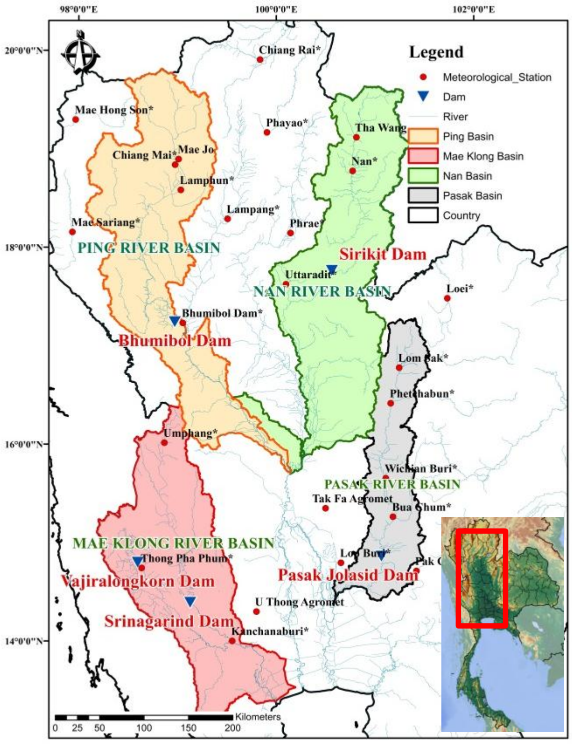

Fig.1 Location map of large scale reservoirs and meteorological stations in Thailand.

distribution function, while the non-parametric tests need only that the data to be independant[5].

The Mann-Kendall trend test[6), 7)] is one of the widely used non-parametric tests to detect significant trends in time series. The Mann-Kendall trend test is based on the correlation between the ranks of time series and their time order. The statistics *S* calculated as equation (1) represent the number of positive differences minus the number of negative differences for all the differences considered as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\left(x_j - x_i\right) \qquad (1)$$

where n is the number of total data points, x_i and x_j are the data values in time series i and j ($j>i$), respectively, and sgn (x_j-x_i) is the sign function as

$$\mathrm{sgn}\left(x_j - x_i\right) = \begin{cases} +1, & if \;\; x_j - x_i > 0 \\ 0 & if \;\; x_j - x_i = 0 \\ -1 & if \;\; x_j - x_i < 0 \end{cases} \qquad (2)$$

The variance of the Mann-Kendall statistic is calculated by equation (3) as

$$Var\,(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (3)$$

where n is the number of total data points, m is the number of tied groups. The tied group means a simple data having the same value. The t_i indicates the number of ties of extent *i*. In case of the sample size $n > 10$, the standard normal test statistic Z_S is estimated by equation (4) as

$$Z_S = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0\ \ if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \end{cases} \tag{4}$$

The positive values of Z_S show increasing trends while negative Z_S values present decreasing trends. In this study the 1% and 5 % significance level α were used. When $|Z_S| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. Therefore, the null hypothesis of no trend is rejected if $|Z_S|$> 1.96 and $|Z_S|$ > 2.576 at the 5% and 1 % significance level respectively.

(3) Data analysis

The observation data used in this study consists of daily precipitation, temperature, daily dam inflow, dam release and storage volume. The daily precipitation, dam inflow and dam release flow data were summed up for monthly, seasonally, and yearly and developed monthly, seasonally and annual time series data for the trend analysis. The daily temperature data were averaged monthly, seasonally, and yearly and developed for each time series data. Similarly the dam storage volume time series were averaged at the end of each month. After compiling of all-time series data on each parameter, the monthly time series in the designed month was selected to generate new time series for the Mann-Kendall trend analysis.

In addition, the seasonal analysis was also conducted by dividing the dry season (November to April) and the rainy season (May to October) for the northern and central of study area. The season for the western of study area is delayed, so the calculation was chosen for the dry season (January to June) and the rainy season (July to December) for each hydrologic parameter.

3. RESULTS AND DISCUSSION

(1) Analysis of temperature and precipitation trend

Results of applying the statistical tests for seasonal and annual temperature and precipitation trend over the period 1980-2011 are presented in **Table 2** and

Table 2 Results of the statistical tests for seasonal and annual temperature and precipitation over the period 1980-2011.

Station	Temperature			Precipitation		
	Dry Season	Wet Season	Annual	Dry Season	Wet Season	Annual
Bhumibol Dam	0.214	-0.714	-0.018	0.712	-0.188	-0.021
Chiang Mai	0.464	-2.194*	-1.053	-0.335	-0.314	-0.649
Chiang Rai	1.963*	0.839	1.731	0.251	-0.565	-0.523
Lampang	2.569**	0.036	1.855	0.126	-0.628	-0.607
Lamphun	0.788	-1.632	-0.263	-0.068	1.564	1.19
Mae Hong Son	-0.244	-0.732	-0.619	0.555	0.795	0.795
Mae Jo	2.963**	0.691	2.904**	0.34	-1.216	-1.112
Phayao	-0.338	0.319	0.638	-0.187	2.108*	1.836
Mae Sariang	0.143	-1.07	-0.749	1.13	0	0.251
Nan	1.035	0.125	0.517	0.272	0.188	0.293
Phrae	-0.393	-0.624	-0.232	1.193	0.649	0.733
Tha Wang Pha	-0.892	1.035	0.91	0.054	0.715	0.412
Uttaradit	1.427	-0.125	0.5	0	-1.047	-1.214
Phetchabun	1.285	0.178	1.285	2.156*	0.9	1.465
Pak Chong	2.623**	-0.963	1.267	0.921	2.219*	2.623**
Lom Sak	2.177*	-0.125	1.409	0.076	0.195	0.433
Lop buri	0.178	0.071	0.107	0.23	-1.088	-0.481
Loei	1.249	-0.624	0.892	0.586	1.005	1.235
Bua Chum	0.393	0.225	0.161	-0.303	0.195	-0.206
Wichian Buri	2.814**	2.176*	2.701**	1.741	0.108	0.966
Tak Fa	0.696	-0.731	0.232	0.954	1.047	1.17
Kanchanaburi	-0.892	1.873	0.232	-0.147	-0.586	-0.356
Thong Pha Phum	0.731	2.301*	1.855	0.52	0.011	0.412
Uthong	-1.82	0.464	-0.892	-3.181**	2.972**	-0.544
Umphang	0.535	-1.356	-0.393	1.363	0.824	1.761

Bold Character represent trends identified with

*Statistically significant trends at 5% significance level (1.960)

**Statistically significant trends at 1% significance level (2.576)

Dashed line indicate the separation of gauging station on each basin

Fig. 2. In **Table 2**, the Z_S values in equation (4) are presented. The positive values represent the increasing trend and the bold values show statistically significant at the 5% or 1% significant level.

All of metrological stations showed the slight significant increasing trends except some stations near to the BB dam stations while the other stations trends present increasing trend in terms of temperature and rainfall. For the results of the temperature trend, the Wichianburi and Maejo stations in the Pasak River basin and the Ping River basin showed insignificant increasing trends at the 1% significance level of temperature in all seasons.

The other metrological stations have slightly increasing and decreasing trends in the dry and rainy seasons. The mean temperature in the Pasak, Nan and Mae Klong River basins showed the increasing trend, which means the evapotranspiration trend in those river basins would increase because the temperature is a main factor of evapotranspiration component. The precipitation trends of the Pasak, Nan and Mae Klong River basins also slightly increase as similar trends with the temperature.

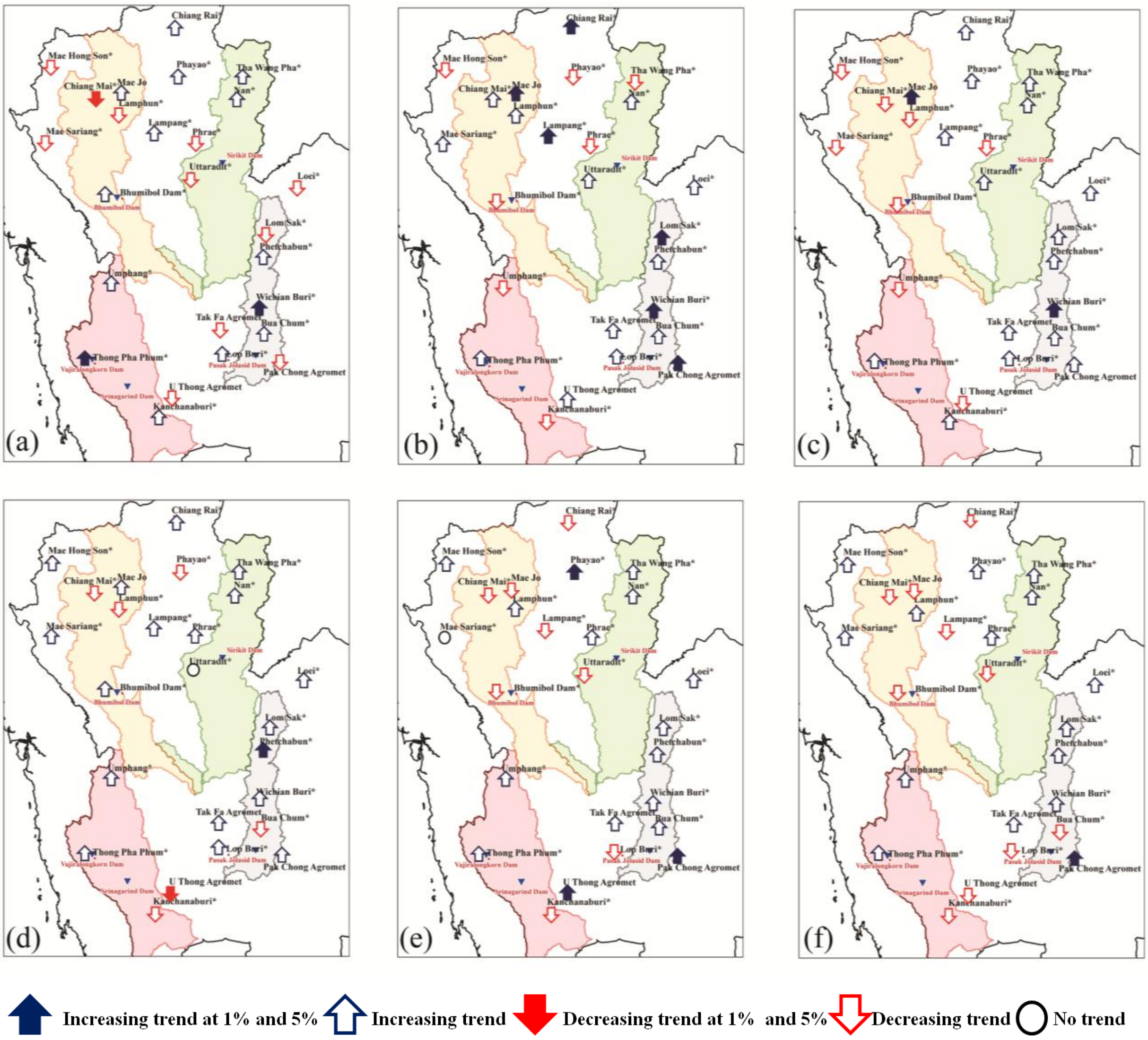

Fig.2 Spatial distribution of meteorological stations with increasing, decreasing and no trends for seasonal and annual data during the period 1980-2011. (a) mean temperature in dry season (b) mean temperature in rainy season (c) annual mean temperature (d) precipitation in dry season (e) precipitation in rainy season (f) annual precipitation

(2) Analysis of inflow trend

The output of the analyzed inflow series was summarized in **Table3**. The inflow series of the SK dam at the Nan River basin and the SR dam at the Mae Klong River basin were found significant increasing trends throughout the year, which were corresponding with the increasing precipitation trends. Both increasing and decreasing trends were detected at the BB, PS and VRK dams. The VRK and BB dam have a strong significant decreasing trend at the 1% significance level in early dry season. The Pasak reservoir was found only three months of slightly increasing trends comparing with other nine month significant decreasing trends, even though the precipitation trends in the Pasak River basin have been detected increasing trends in all stations that cover the basin. This suggests the higher evapotranspiration rate occurred correspond to the results of the increasing mean temperature trend in the Pasak River basin, which caused the decreasing amount of water resources in the basin.

(3) Analysis of release flow trend

The monthly, seasonal and annual trends of dam release flow obtained by the Mann-Kendall test are given in **Table 4**. According to these results, the significant increasing trend at the 1% significance level of dam release flow during the dry season were found except the Pasak dam, however the dam release flow of the Pasak dam has a little significant increasing trend especially on December and January at the 1% significance level. The inflow trends of the BB and SK dams during the early rainy season (May to July) found increasing trends as shown in **Table 3.** Therefore, the release of the BB, SK and PS dams in the rainy season have significant decreasing trend to store the flood flows in the Ping, Nan and Pasak Rivers. In brief, the results show generally increasing significant trends in the dry season of release flow in all reservoirs for high water demand, and decrease trends in the BB, SK, and PS dams to store water in the rainy season.

Table 3 Results of the statistical tests for monthly, seasonal and annual inflow over the period from the starting operation to 2013.

Month/Season	Test statistic (Zs)				
	BB	SK	PS	SR	VRK
Jan	**-2.141***	1.27	0	0.415	**-2.12***
Feb	-1.824	**2.552***	-1.204	0.978	**-2.345***
Mar	-0.351	0.804	-0.985	1.038	-0.769
Apr	-0.97	0.781	0.109	0.326	**-2.157***
May	1.029	0.874	-0.495	0.83	0.732
Jun	0.151	0.408	-0.594	0.86	0.071
Jul	0.46	0.92	-1.188	**1.986***	**2.212***
Aug	-0.067	0.804	-0.891	**2.194***	1.249
Sep	-0.033	1.014	0.495	1.393	1.855
Oct	0.184	0.478	0.891	1.127	0.928
Nov	-1.422	0.384	-1.188	0.296	0.036
Dec	**-2.894****	**2.598****	**-2.078***	0.385	0
Dry Season	-1.939	1.766	-1.642	1.334	0.319
Rainy Season	0.151	0.851	0.396	1.186	**2.07***
Annual	-0.233	0.702	0.495	1.512	**1.97***

Bold character represent trends identified with
*Statistically significant trends at 5% significance level (1.960)
**Statistically significant trends at 1% significance level (2.576)
Dashed line indicate the separation between dry and wet seasons

(4) Analysis of storage trend

Results of the Mann-Kendall test to the monthly storage volume at the end of each month are presented in **Table 5**. As shown, the majority of the monthly trends in the BB dam have a significant decreasing trend due to reservoir operation based on the existing rule curve while the SR dam shows an increasing trend throughout the year. The SK and VRK dams remain the similar trends of increasing trends in rainy season and of decreasing trends in dry season as a natural condition. The water storage trend of the Pasak dam found strongly decreasing trend at the 1% significance level in late dry season due to increased water consumption as indicated in **Table 4**.

(5) Insufficient and excess storage volume

Insufficient and excess storage volumes were also evaluated from the beginning of each dam operation. The insufficient storage volume means the amount of volume below the lower rule curve while the excess volume represents the total of volume exceeding the upper rule curve. The explanation of the insufficient and excess storage volume is illustrated in **Fig. 3**. The results of this analysis are summarized in **Table 6**. At the BB dam, increasing of insufficient storage volume trends was detected, which is corresponding to the results of section (2) and (3) for the analysis of reduced inflow and increasing outflow trends results.

Table 4 Results of the statistical tests for monthly, seasonal and annual dam release flow over the period starting from the operation to 2013.

Month/Season	Test statistic (Zs)				
	BB	SK	PS	SR	VRK
Jan	**3.543****	**4.928****	**3.266****	**3.579****	**2.72****
Feb	**4.215****	**3.944****	1.683	**4.092****	**4.858****
Mar	**2.595****	**2.179***	1.584	**3.765****	**3.395****
Apr	1.457	0.478	-0.792	**2.846****	**4.221****
May	-1.405	-0.711	0	**3.172****	**2.532***
Jun	-1.69	-0.151	0	2.046*	-0.469
Jul	**-2.476***	-1.456	-0.693	**2.075***	0.206
Aug	**-2.108***	-1.34	-0.693	1.66	1.069
Sep	**-3.279****	**-2.039***	-0.792	0.049	-0.019
Oct	-2.509*	-1.2	0.891	**3.143****	1.427
Nov	-0.569	-0.198	-0.891	**2.787***	**2.676****
Dec	1.941	**3.111****	**2.771****	**3.41****	**2.034***
Dry Season	**2.957****	**3.29****	0.766	**3****	**3.358****
Rainy Season	**-2.225***	-1.13	0.099	1.832	1.356
Annual	0.353	1.379	0.396	**3.13****	**2.72****

Bold character represent trends identified with
*Statistically significant trends at 5% significance level (1.960)
**Statistically significant trends at 1% significance level (2.576)
Dashed line indicate the separation between dry and wet seasons

Table 5 Results of the statistical tests for monthly, seasonal and annual storage over the period starting from the operation to 2013.

Month	Test statistic (Zs)				
	BB	SK	PS	SR	VRK
Jan	-1.491	-0.012	**-1.971***	1.186	1.294
Feb	**-2.112***	-0.827	**-2.847****	1.127	0.807
Mar	**-2.629****	-1.456	**-2.956****	0.889	0.619
Apr	**-2.801****	-1.619	**-3.175****	0.741	-0.169
May	**-2.681****	-1.503	-1.534	0.415	-0.694
Jun	**-2.422***	-1.107	-1.782	0.682	-0.178
Jul	**-1.982***	-0.641	-1.881	0.652	0.107
Aug	-1.664	0.128	**-2.573****	1.275	1.534
Sep	-1.577	0.454	-1.089	1.571	1.249
Oct	-1.284	0.618	1.386	1.601	1.463
Nov	-0.957	0.757	1.089	1.423	1.427
Dec	-1.112	0.734	-0.693	1.156	1.463

Bold character represent trends identified with
*Statistically significant trends at 5% significance level (1.960)
**Statistically significant trends at 1% significance level (2.576)
Dashed line indicate the separation between dry and wet seasons

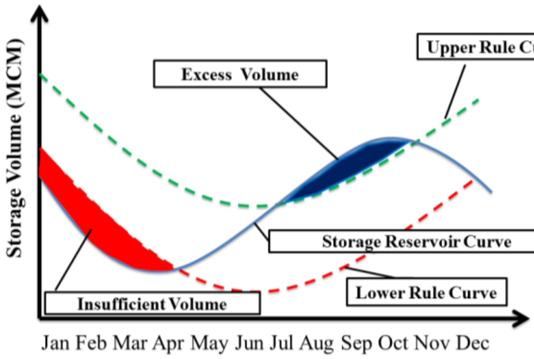

Fig. 3 Explanation of insufficient and excess storage volume.

The PS dam also had significant inflow and outflow trend results similar with the BB dam nevertheless the results of insufficient and excess storage volume results of the PS dam have indistinct. The SK, SR and VRK dams show gradually rising trends of excess storage volume which are the same as inflow trends of preceding section that represent the water resources in those areas would be increased.

The number of insufficient events in the BB, SK and SR reservoirs found biennial on average. The PS dam has a small capacity comparing with other dams, so many insufficient and excess events were detected within fifteen years. However, the VRK dam was also found the excess events with fourteen times to cope with floods. According to the dam characteristics in **Table.1**, the large scale reservoirs such as the BB and SR dams have an advantage to address the floods for four and two events, respectively.

4. CONCLUSIONS

The trends of hydrologic variables were analyzed statistically based on long term historical data by using the Mann-Kendall trend test. Our findings are summarized as follows:

- Through the analysis, we found that the temperature and precipitation trends show increasing trends nevertheless at the Ping River basin temperature and precipitation trends show decreasing trends.
- The water resources availability in terms of inflow to the BB and PS dam shows decreasing trend during the dry season. The inflow of all reservoirs in the rainy season has increasing trends.
- For dam release from the reservoirs, generally increasing significant trends appear in the dry season in all reservoirs. Only the BB and SK dam have decreasing trends during the rainy season.

Table6 Results of insufficient and excess storage volume.

Dam		Number of Event	Zs	
BB	Insufficient	24	1.15	Increasing
	Excess	4	-	-
SK	Insufficient	28	-0.01	Decreasing
	Excess	14	0.99	Increasing
PS	Insufficient	10	0.00	No Trend
	Excess	17	0.72	Increasing
SR	Insufficient	17	-0.03	Decreasing
	Excess	2	-	-
VRK	Insufficient	8	-1.86	Decreasing
	Excess	14	0.00	No Trend

- As a result, dam storage for the BB dam was found dramatically decreasing trends throughout the year while the SR dam was detected increasing trends.
- These insufficient and excess storage results indicate the increasing trends of water shortage in the BB and PS dam and also the rising trend of flood in the SK, SR and VRK reservoirs.

The further study will be combined with the analysis of the historical data and GCM outputs for development a new rule curve for adaptive dam reservoir operation.

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REFERENCES

1) IPCC: Summary for Policymakers: the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1–30, 2013.
2) Tao, H., Gemmer, M., Bai, Y., Su, B. and Mao, W.: Trends of streamflow in the Tarim River Basin during the past 50 years: human impact or climate change? *Journal of Hydrology*, Vol. 400 (1-2), pp.1-9, 2011.
3) Duong, D. T, Tachikawa, Y. and Yorozu, K.: Changes in river discharge in the Indochina Peninsula region projected using MRI-AGCM and MIROC5 datasets. *Journal of Japan Society of Civil Engineers*, Ser. B1 (Hydraulic Engineering), Vol. 70. No.4, pp.115-120, 2014.
4) Tebakari, T, Yoshitani, J and Suvanpimol, P.: Impact of large-scale reservoir operation on flow regime in the Chao Phraya River basin, Thailand. *Hydrological Processes*, Vol.26, pp.2411-2420, 2012.
5) Milan, G. and Slavisa, T.: Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and Planetary Change*, Vol. 100, pp. 172-182, 2013.
6) Kendall, M.G.: Rank Correlation Methods, Griffin, London, UK, 1975.
7) Mann, H.B.: Nonparametric tests against trend, *Econometrica* 13, pp. 245-259, 1945.

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