Assessment of Water Shortage Situations in Lower Nam Pong Basin under Climate Change

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Abstract

Lower Nam Pong basin experiences scarcity of water demand for most part of the year. This paper aimed to evaluate the reliability and vulnerability of water resources in basin under a changing climate and growing water demand. To facilitate simulation, ECHAM5 and high temperature change scenarios was utilized in conjunction with Water Evaluation and Planning (WEAP) to allocate water for each sector to meet future water demand. Results show that the gap between demand and supply grew dramatically for high temperature change scenario with total water shortage of 13,530 MCM over 30 years while water shortage of ECHAM5 scenario was 1,347 MCM. Vulnerability for high temperature change scenario increased with values of 10.52 MCM/unsatisfactory day in which more than two times comparison to baseline. Additionally, the study confirmed that the WEAP model can be applied to assess water shortage for water resources planning in the Lower Nam Pong basin.

Keywords: WEAP, Reliability, Vulnerability, ECHAM5, High temperature change

Introduction

The National Water Management Plan of Thailand (2018 to 2037) launched six master plans for water resources management in basins. One of the plans is to manage water security for water use sectors. It recognizes the safe water for drinking and sanitation, followed by high priority allocation for domestic needs (including needs of industries), achieving food security and conserving ecosystem. The concept of Integrated Water Resources Management (IWRM) has been considered of implementing and formulating shared vision, management and planning strategies for sustainable water resources utilization and development. To achieve water management using IWRM concept, stakeholders and watershed manager need tools for quantitative analysis of water balance in the basin. The Water Evaluation and Planning (WEAP) model incorporates watershed-scale hydrological processes by introducing the concept of demand priorities and supply preferences. WEAP model is advanced, integrated modeling software that simulates and models water supplies, water demands and environmental requirement (Agarwal, Patil, Goyal, & Singh, 2019; Gao, Christensen, & Li, 2017).

The WEAP was applied to assess the impacts of climate change on water resources with competing water uses in Kaligandaki Gorge Hydropower Project area in Nepal (Sahukhal & Bajracharya, 2019). Shutayri and Juaidi (2019) employed the WEAP model to evaluate future urban water supply and demand by using various scenarios such as high population growth, reduce leaks from 25% to 10% and apply water conservation. Amin

Iqbal, Asghar, and Ribbe (2018) utilized WEAP model to develop management strategy to achieve water security and sustainability in the Upper Indus basin with different socio-economic and climate change scenarios. Referring Raamadan, Shalash, Fahmy, and Abdel-Aal (2019), WEAP was implemented on Mae Klong basin in Thailand under six scenarios to simulate water demand and resources and results show that water shortage has occurred in the dry period of 2014 and 2015 due to less rainfall in these years. Few studies in Thailand have concentrated on the importance of the economic water scarcity. That is the water management issue under the impact of climate change on domestic water use and the growth of industries. Thus, the aim of this study was to evaluate the reliability and vulnerability of water resources in the Lower Nam Pong basin under a changing climate and growing water demand.

Methods and Materials

The study area

The study area (Nam Pong basin) region contains two mains basins, Upper Nam Pong and Lower Nam Pong basins. It is located in the northeast part of Thailand as shown in Figure 1. The drainage areas of the Upper Nam Pong and Lower Nam Pong basins are 12,253 and 2,937 km^2, respectively. The average yearly rainfall is 1,133 millimeter (mm). The main reservoir namely Ubonratana dam exists in the Upper Nam Pong basin in which the storage capacity of 2,400 million cubic meter (MCM). The minimum, average and maximum inflow into the reservoir are 567, 2,500 and 5,425 MCM, respectively. The water is supplied to the Lower Nam Pong basin for domestic, irrigation of cultivated areas of 411.2 km^2 (257,000 rai) and industries. These encourage the economic growth of Khon Kaen province. So, the basin was selected for this research.

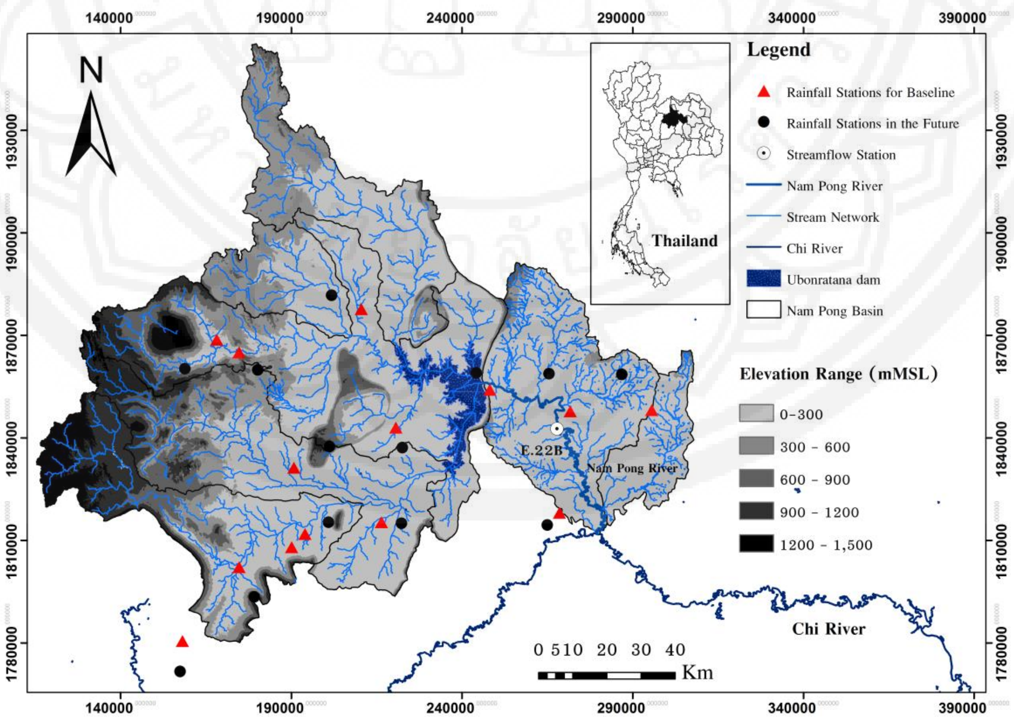

Figure 1 Nam Pong basin

Hydrological model

The hydrological model, Soil and Water Assessment Tool (SWAT) was employed for this study. It is a physical based, basin scale and continuous time model (Psomas, Panagopoulos, Konsta, & Mimikou, 2016). Data requirements are soil type, land use, digital elevation model (DEM) together with climatic and stream flow data. A watershed is divided into hydrologic respond units (HRUs) in which represent areas with homogenous land use and soil characteristics. Hydrological processes of HRUs include surface runoff, infiltration, evapotranspiration, lateral flow, percolation and return flow. The model includes SWAT-CUP combined with SUFI-2 method which uses to calibrate model parameters. The SWAT model was applied to estimate for both baseline and future lateral flow using climatic data during 1981 to 2015 and 2017 to 2046. Soil type and land use data in GIS format derived from Land Development Department. DEM data with spatial resolution of 30x30 m^2 collected from Royal Thai Survey Department was utilized in the model. For simulation of water balance in the future, the model was applied to calculate inflow into Ubonratana reservoir.

Water allocation using WEAP model

The Water evaluation and planning system (WEAP) was developed by the Stockholm Environmental Institute (SEI). It utilized to solve water allocation problems in many countries (Omar & Moussa, 2016). The advantages are microcomputer tool and user-friendly framework for policy analysis. The watershed is modeled by a network of nodes and links in which each node and link requires data depend on their representations. The basic water balance equation of WEAP is:

$$\text{Input (I)} - \text{Output (Q)} = \text{Change in storage } (\Delta S) \quad (1)$$

where inputs are rainfall, runoff, and groundwater influent, and outputs are evapotranspiration, irrigation use, domestic use, industrial use, and losses. The WEAP-MABIA module was employed to calculate reference evapotranspiration (Penmam-Monteith), irrigation requirements and scheduling, and soil water capacity.

The WEAP schematic of Lower Nam Pong basins is placed in Figure 2. The supply sides consist of water supply from Ubonrattana dam and 18 lateral inflows into the Lower Pong River. The Nongwai weir diverts water into the right and left main canals and supply water for irrigated areas of 43.75 km^2 (70,000 rai) and 119.69 km^2 (191,500 rai), respectively. Water demands were mainly classified into agricultural, industrial and domestic sectors together with ecology. Agriculture composed 19 pumping stations along the river and Nongwai irrigated areas in which grow rice in the wet season. For the dry season, farmers plant rice or field crops depend on water volume of Ubonratana reservoir. The domestic water consisted of 6 water treatment plants and the important plant is Provincial Waterworks Authority 6. This plant produces treatment water supply of 180,000 m^3/day to serves some areas of Khon Kaen province. There are many industries use water from the treatment plants, only 5 industries use raw water from Ubonrattana reservoir varying water volume of 0.02 to 16.61 MCM/year. Due to conservation of ecology, the reservoir releases discharge of 5 m^3/s into the river.

Mixed integer linear programming (MILP) in WEAP model is employed to solve the water allocation problem. The objective function is to maximize satisfaction of demand which subject to supply priorities, demand site preferences, mass balances and other constrains (Agarwal et al., 2019). Referring this study by meeting with the manager of Nongwai Irrigation Project, the priorities of water supply are domestic, ecology, industry and agriculture, respectively. The model was applied to allocate water for various sectors during 1981 to 2015 (baseline) and 2017 to 2046 (future).

Performance criteria

Two performance, Reliability and Vulnerability, criteria were used to evaluate the effect of different climate scenarios for water allocation. Reliability is probability of no deficit in the water supply during simulation which defined as:

$$\text{Reliability} = \frac{S}{N} \tag{2}$$

where S is the set of all satisfactory demand and N is the total number of simulation periods (Shutayri & Juaidi, 2019), in this study 30 years. The highest reliability index represents the best reliable water demand.

Vulnerability is the average of the water supply deficits experienced over the simulation period. This performance reveals the severity of failure which defined equation as:

$$\text{Vulnerability} = \frac{SH}{US} \tag{3}$$

Where SH is the sum of shortages and US is the number of times an unsatisfactory value occurred (Shutayri & Juaidi, 2019; Comair, Gupta, Ingenloff, Shin, & McKinney, 2013).

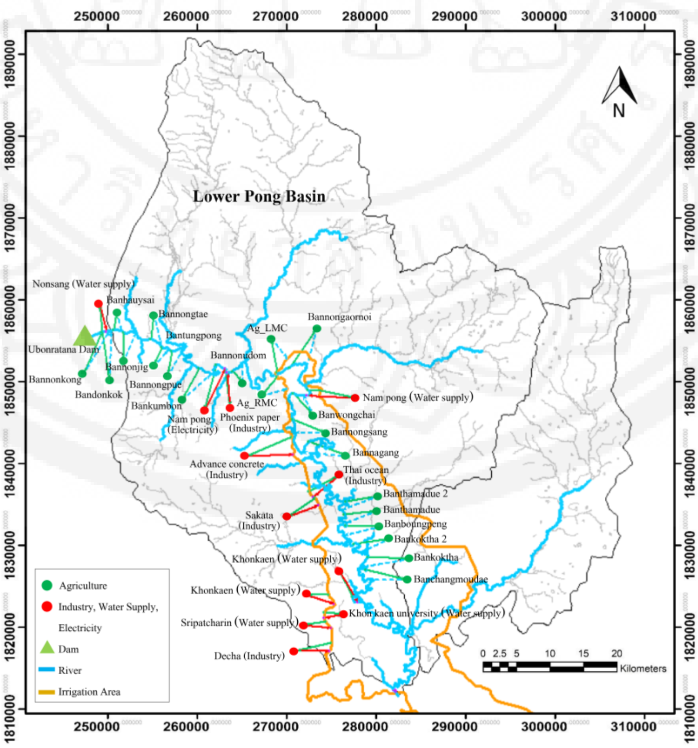

Figure 2 Schematization of nodes and links for Lower Nam Pong basin

Results

Calibration of SWAT and WEAP models

The SWAT model was employed to calculate lateral flow into the Pong River for both baseline and in the future. Also it was utilized to compute inflow into Ubonratana reservoir in the future. After the sensitivity analysis of sensitive parameters was simulated, the calibration process using daily time series were conducted for a period of 1996 to 2001 with R^2 of 0.7 and the Nash-Sutcliffe efficiency (NSE; Yaykiran, Cuceloglu, & Ekdal, 2019) of 0.69. The verification process for a period of 2006 to 2011, results were R^2 = 0.73 and NSE = 0.65. Additionally, performance efficiencies were in good for calibration and verification.

Simulation of water balance in the baseline (1986 to 2015), result of water volume in Ubonrat reservoir revealed agreement between observed and simulated water volume with R^2 of 0.64 as shown in Figure 3. Due to the upper and lower rule curve, the reservoir maintains the maximum and minimum water volume of 2,100 and 750 MCM, respectively. So, these criteria introduced different water volume between observed and simulated results for some duration of simulation. Figure 4 depicts water supply for irrigation of the left main canal during January to April each year. The calculated water supply agreed observed data with R^2 of 0.93 because there was no effect from input rainfall data.

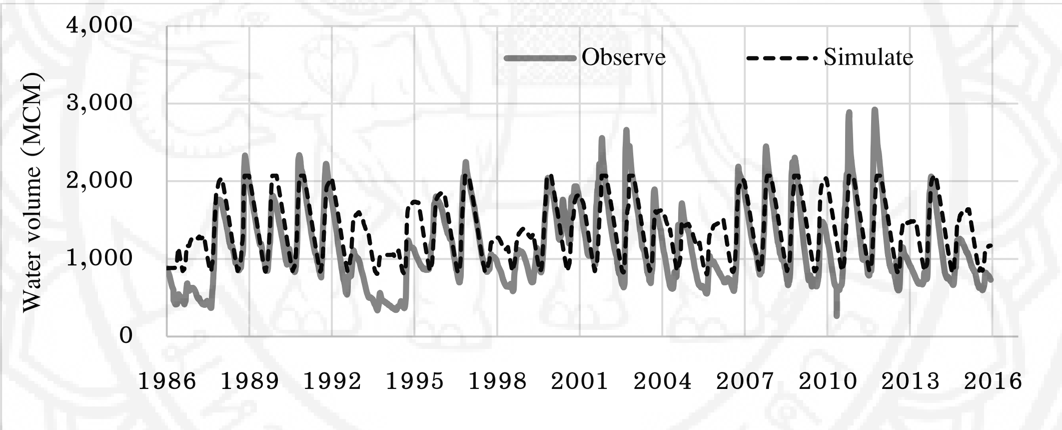

Figure 3 Observed and simulated water volume of Ubonratana reservoir

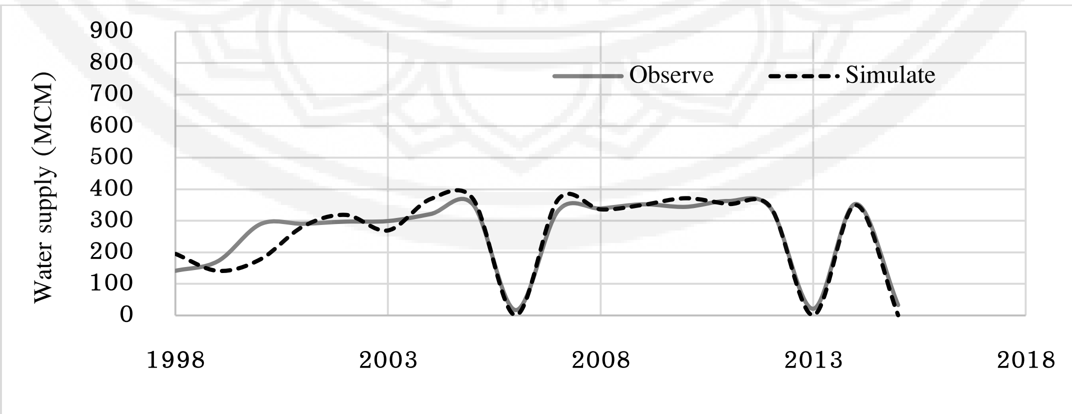

Figure 4 Water supply for irrigation of the left main canal

Simulation of water balance using WEAP model

Baseline scenario

The baseline scenario was simulated to allocate water supply for various activities such as domestic use, ecology, industry and agriculture during years of 1981 to 2015. There are six water treatment plants to produce clean water for domestic. Ubonratana reservoir directly supplies water for five industries. Agricultural water use composes pumped irrigation of 19 projects together with irrigated areas of right and left main canals (Nongwai Irrigation Project). Figure 5 depicts water demand and unmet demand for 30 years which unmet demand of 1,208.07 MCM existed for irrigated areas of Nongwai Irrigation Project. Nongwai Irrigation Project did not allow farmers to plant off-season rice in 1998 due to insufficient water supply from Ubonratana reservoir. The total unmet demand of 532 MCM revealed in 1993 in which agreed the observed information. Table 1 shows water shortage for right main canal of 1,118.72 MCM over 314 days. So, the reliability and vulnerability indexes were 91.28% and 3.56 MCM/unsatisfactory day.

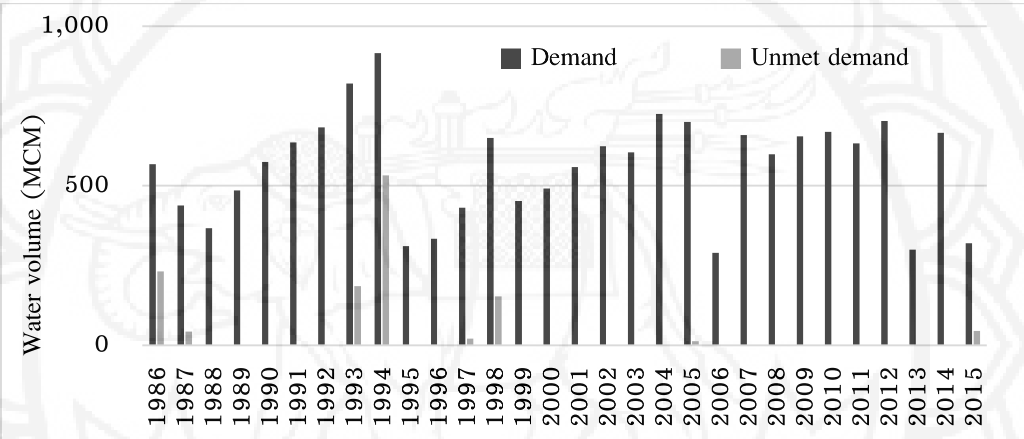

Figure 5 Water demand and unmet demand for baseline

Future scenario: Increase domestic water use and development of industrial zones

This scenario represents increase domestic water use by 50% (270,000 m^3/day) and development of three industrial zones located at Tambons Kudnamsai, Muandwhan and Koksung in 2035. Due to assumption that development of the world economic using balance of fossil and new technologies, climatic data of ECHAM5 and HadCM3Q13 scenarios were utilized to simulate water allocation of Lower Pong River basin in the future (2017 to 2046). The assumption of ECHAM5 is increase of temperature due to increase of carbon dioxide (Amnat, 2010; Guo, Jie, & Wei, 2012). The HadCM3Q13 (high temperature change) scenario introduces the change of high temperature (Amnat, 2010). Climatic data of ECHAM5 and HadCM3Q13 scenarios derived from Southeast Asia START Regional Center. The industrial zones areas of Kudnamsai, Muandwhan and Koksung are 42.08, 58.08 and 61.18 km^2, respectively. Referring interview a member of the Federation of Thai Industries, Khon Kaen Chapter, equipment industry was advised to produce for light rail road traffic (LRT) project and inland container depot (ICD). The estimation of water use for electronic devices of Kudnamsai, Muandwhan and Koksung industrial zones were 59, 86 and 82 MCM/ year, respectively.

Figure 6 and Table 1 show results of simulation of water allocation using ECHAM5 climatic data. The unmet demand revealed 10 years which mostly existed in the agricultural sectors such as pumped irrigation of 19 stations and Nongwai Irrigation Project. Refer to irrigated areas of Nongwai Irrigation Project, total unmet water volume was 1,341 MCM. The increase of water requirement for agriculture affected from evapotranspiration due to increase of temperature. The simulation revealed no unmet demand over 30 years of domestic and industry water use due to the average inflow into Ubonrattana reservoir and domestic water use was set as the first priority. The estimation of inflow into the reservoir revealed the maximum and minimum values of 791.07 and 3,601.14 MCM, respectively. This scenario affected no water shortage of domestic and industrial water use while facing some water shortage for agricultural sectors with reliability of 95.30%. The unmet demand of the right main canal of Nongwai Irrigation Project was 982.01 MCM which cover 169 days, so the index of vulnerability was 5.81 MCM/ unsatisfactory day.

Refer to high temperature change scenario, the unmet demand revealed water shortage over 30 years of simulation in which covered 4 sectors of water use (Figure 7). This scenario influenced less inflow into the reservoir comparison to the baseline. The maximum and minimum values were 117.31 and 2,074.33 MCM, respectively. Total unmet water volume of Nongwai Irrigation Project was 13,332.56 MCM. Domestic and industrial water use were affected water shortage volume of 4.49 and 122.93 MCM. The reliability index of agricultural sector (i.e., water supply which meets water demand) was approximately 64% in which considered unmet demand of 36%. The irrigated area of Nongwai Irrigation Project (right canal) faced water shortage of 1,280 day. So, the vulnerability index was 7.63 MCM/ unsatisfactory day which was greater than the baseline.

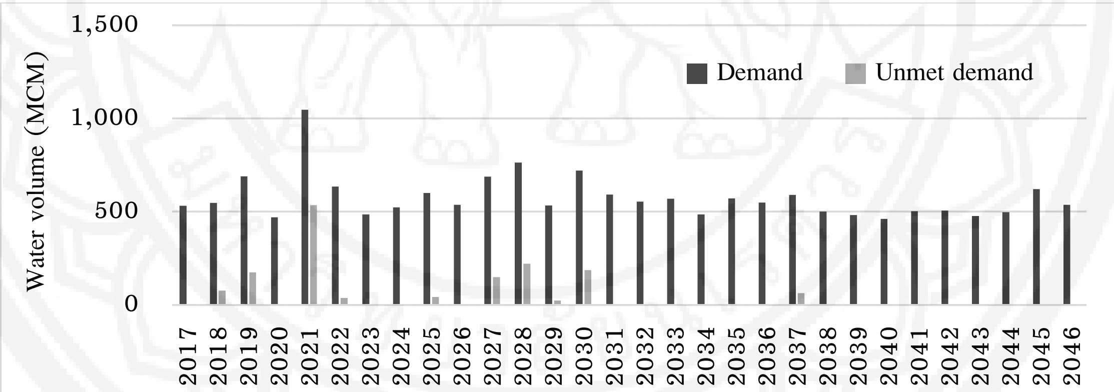

Figure 6 Water demand and unmet demand in the future of ECHAM5

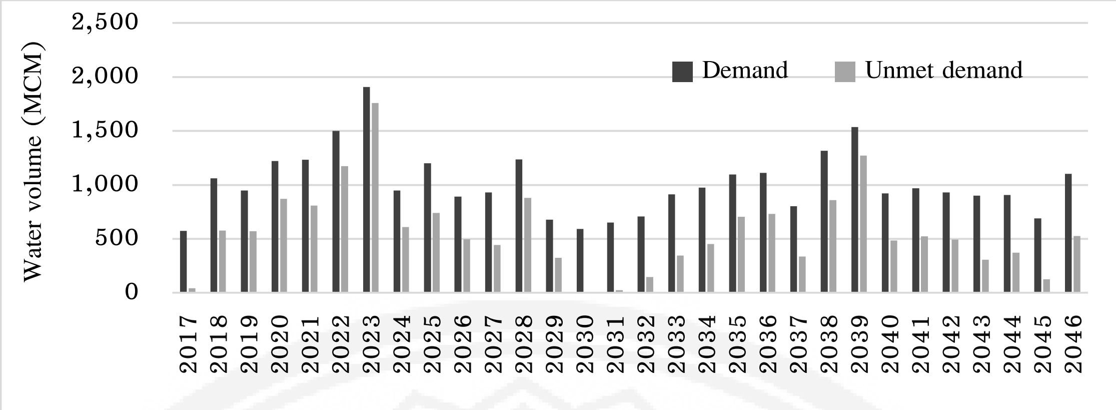

Figure 7 Water demand and unmet demand in the future of high temperature change

Table 1 Detailed water shortage, reliability and vulnerability

Scenario	Water sector	Water shortage (MCM)	Reliability (%)	Vulnerability (MCM/ unsatisfactory day)
Baseline	Pumped irrigation	0.03	97.73	0.003
	Nongwai Irrigation Project			
	Right canal	1,118.72	91.28	3.56
	Left canal	89.35	98.28	1.40
	Domestic use	1.90	98.80	0.01
	Industry	9.31	97.90	0.04
ECHAM5	Pumped irrigation	6.63	95.30	0.04
	Nongwai Irrigation Project			
	Right canal	982.01	95.30	5.81
	Left canal	358.99	95.30	2.12
	Domestic use	0	100	0
	Industry	0	100	0
High temperature change	Pumped irrigation	70.62	64.36	0.06
	Nongwai Irrigation Project			
	Right canal	9,763.55	64.45	7.63
	Left canal	3,569.01	64.45	2.79
	Domestic use	4.49	98.80	0.03
	Industry	122.93	60.34	0.01

Conclusion

The WEAP model was applied successfully for the Lower Nampong basin. A climate change scenario of ECHAM5 and HadCM3Q13 were employed to evaluate the performance criteria of domestic water use, industry and agriculture. Provincial Waterworks Authority 6 has planned to increase treatment water by 50% (270,000 m^3/day) in the future. The three industrial zones was planned to develop which use water volume of 227 MCM/ year. A high unmet demand existed in agricultural sector such as pumped irrigation and Nongwai Irrigation Project. Results of simulation using ECHAM5 scenario revealed reliability of 100% for domestic and industrial water use and 95.30% for agricultural water use. Vulnerability of agricultural sector appeared 7.97 MCM/unsatisfactory day over 30 years. Refer to high temperature change scenario, reliability for agriculture was 64.4% and values of vulnerability were 10.52 MCM/ unsatisfactory day in which was higher than the baseline values of 4.97 MCM/unsatisfactory day.

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