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Assessing the Effect of Incorporating Environmental Water Requirement in the Water Stress Index for Thailand

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Abstract: Human and environmental demands for water are both important; therefore, two approaches are proposed for assessing water scarcity using the water stress index. In one of them, the human demand for water explicitly includes environmental water as one of the components (WSI_{e1}), whereas in the other, environmental water is explicitly reserved by subtracting it from the water availability (WSI_{e2}). The results obtained from using the two approaches in the case of Bang Pakong watershed correspondingly contribute to the explanation of the existing stress situation, especially in the dry season. The stressful results were noticed during December to February for both approaches as a result of less available water and higher environmental water requirement. The assessment of environmental water requirement (EWR) in this study was quantified according to low and high flow periods. The two approaches perform well for assessing water scarcity in the Bang Pakong watershed; however, the result interpretation using the WSI_{e1} approach is more serious than the WSI_{e2} approach in terms of water scarcity potential beyond the critical threshold. In conclusion, priority of water allocation is the key consideration for selecting the approach. Higher priority for the environment favors the use of WSI_{e2} for policy making whereas for a lower priority, the use of WSI_{e1}. In case of Thailand, the WSI_{e2} approach would be recommended in order to put the EWR as the first priority. Then, water allocation priorities can be rearranged only for human demands for water while the EWR is already safeguarded by setting it aside.

Keywords: water stress index; environmental water requirement; freshwater use impact; Thailand

1. Introduction

Water crises have been increasingly observed in various parts of the world including Thailand. All regions of Thailand are being affected by floods and droughts almost every year. This issue is taken into consideration by assessing the impact of freshwater use on freshwater resources. The same amount of freshwater used in different areas may create different potential impacts on freshwater resources. To measure the level of water stress for each area, all demands for water are taken into account along with the availability of freshwater. Not only do humans need water for satisfying their demands, but water is also required by the environment, especially a river or watershed system, to maintain its functions and ecosystem services. This environmental water is affected by the overuse of freshwater resources as well as water scarcity [1] and it requires concern at different scales of analysis from large to small [2]. Environmental Water Requirement (EWR) appears to have been concerned at a global scale when the study of Smakhtin et al. [3] suggested that EWR needs to be addressed seriously in water resources management and development. Several countries have addressed this by developing the environmental flow guidelines to support their water resource management plans [4]. In reality, EWR varies based on environmental conditions and the period of time for maintaining river functions and ecosystem services. Accounting for EWR in the characterization of freshwater resource impact has also been strongly recommended by Fingerman et al. [5].

The water stress index (WSI) proposed by Pfister et al. [6] has been widely applied as a characterization factor for assessing water scarcity. The WSI was first developed based on the ratio of water withdrawal to water availability (WTA). Human demand for water is explicitly accounted for in the water withdrawal while environmental demand for water is implicitly incorporated via the thresholds of WSI. However, as freshwater is necessary for both human and environmental activities, environmental demand for water should also be taken into account explicitly in the WSI. Thus, explicitly accounting for EWR in the WTA will allow the flexibility to change or modify the EWR based on context. Therefore, this study highlights the importance of EWR as a separate and distinct sector in the WTA. EWR is the minimum amount of water required for maintaining the desired condition of rivers and ecosystems for providing their functions and services, especially the regulatory services to maintain river ecosystem conditions and natural protection. Thailand is divided into 25 major watersheds, each requiring a different amount of EWR for different purposes at different times. Thus, to allow changing the EWRs based on the local conditions, the explicit incorporation of EWR in the WSI and its application for the case of Thailand was studied by Nilsalab and Gheewala [7]. The EWR was taken into account in the WSI according to the existing practices under the Royal Irrigation Department (RID) of Thailand. In a later study, two general approaches for the explicit incorporation of EWR in the WSI were proposed by Nilsalab et al. [8]. One of these two approaches was adjusted specifically for Thailand in the earlier study [7]; therefore, the other one will be provided in this study. Accordingly, the proposed two approaches are discussed with the aim to draw out the implications of applying the two approaches through the assessment of a significant watershed in Thailand. This is a continuing work to support the use of the WSI with reference to EWR (WSI_e) [8] as a characterization factor for assessing the potential impact of water scarcity due to freshwater use. Freshwater taken from areas having high WSI_e potentially leads to increasing the severity of water scarcity to downstream users. This gives an idea about how much additional stress or pressure will be generated in that area. The application of WSI_e as a characterization factor for assessing the impact of freshwater use on freshwater resources was performed first to see how it works. This study focuses on improving the method to be suitable for a specific country and assist in the selection of an appropriate approach. Lastly, the influence of climate change is also taken into consideration for the recommended approach. This is because the spatial and temporal distribution of freshwater resources are expected to be affected by changes in rainfall and temperature patterns due to climate change [9].

2. Methodology Approach

The Bang Pakong watershed (see Figure 1), divided into four sub-watersheds covering over Nakhon Nayok, Chonburi, Chachoengsao, Prachinburi, and Saraburi, was selected as the case study for applying the WSI with reference to EWR, or WSI_e, proposed by Nilsalab et al. [8]. The Bang Pakong watershed has experienced progressive seawater intrusion and a decline in water quality [10–12].

The proposed two approaches for accounting EWR in the demand to availability (DTA) ratio of the WSI_e are based on a human perspective (the water demand explicitly includes EWR as one of the components, WSI_{e1}) and an environmental perspective (EWR is explicitly reserved by subtracting it from the water availability, WSI_{e2}). For both the approaches, the stress situation is defined to start occurring after the demands for water are equal to the water availability. This implies an impact on freshwater resources and its potential is measured directly from the excess demand instead of the predefined threshold. The WSI_{e1} (based on human perspective) includes both human and environmental demands for water. When these demands are equal to the water availability, the stress situation occurs because there is no available water for any excess demand. This is not the same when applying the WSI_{e2} (based on the environmental perspective) because the environmental water is potentially available for the excess demand of humans (though at the expense of the environment); thus, the impending stress situation is defined. Accordingly, it could be implied that the severity of stress situation by WSI_{e1} would be more serious than that assessed by WSI_{e2}. Furthermore, water allocation is generally based on a priority setting scheme for the water demand sectors. Applying the two approaches implies that the lowest priority sector will be the first sector suffering from the stress situation.

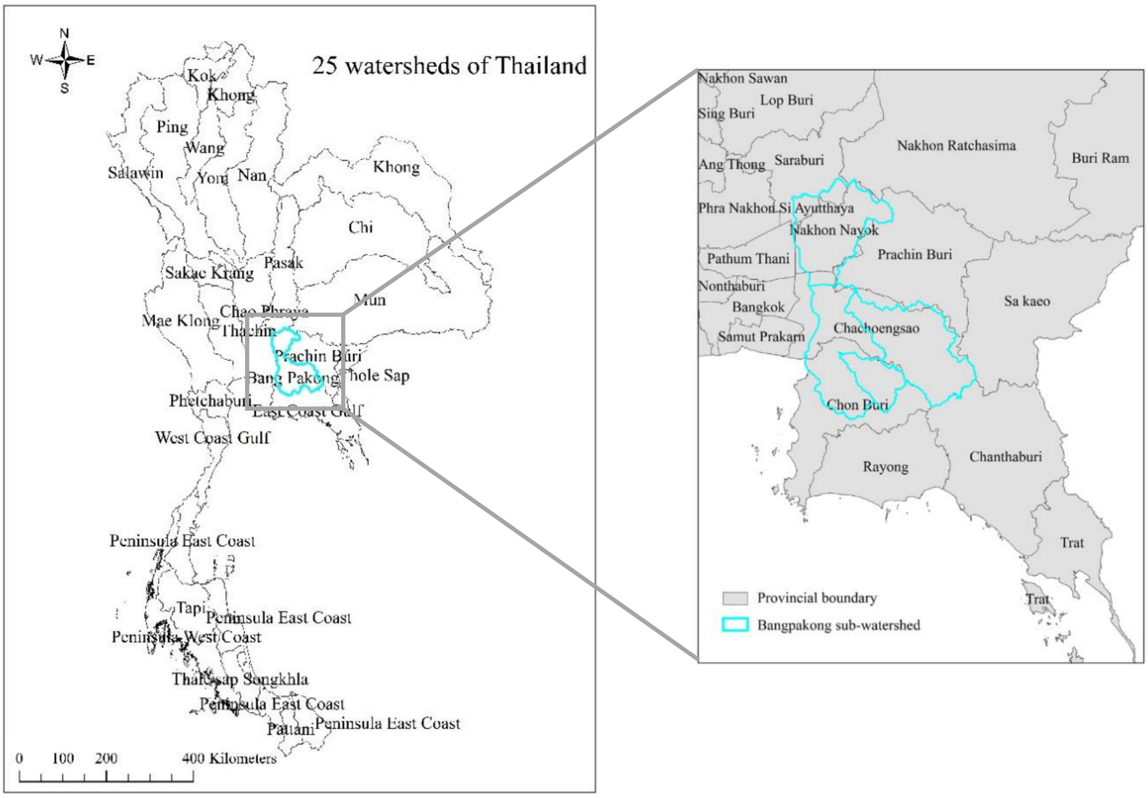

Figure 1. Bang Pakong watershed.

The stress situation is defined by the DTA ratio and calculated with a logistic function to obtain continuous values of the WSI_e, the ranges obtained are 0.01 to 2 for the WSI_{e1} and 0.01 to 1 for the WSI_{e2} resulting from different ways of the EWR incorporation. The occurrences of stress situation or a critical point are indicated at DTA equal to 1 for the WSI_{e1} and 0.5 for the WSI_{e2}. Hence, the levels of stress situation are classified at the values of WSI_{e1} and WSI_{e2} ranging from 1 to 2 and 0.5 to 1, respectively (see Table 1). Three levels of approaching stress are categorized below and three beyond the critical point [7]. The severity of a stress situation is classified into three levels based on the proposed water pressure ranges in Frischknecht et al. [13]. Three levels before approaching the critical threshold, especially watch and warning levels, are established from the minimum and maximum of EWR in Pastor et al. [14]. The variable monthly flow (VMF) method of Pastor et al. [14] is developed based on a hydrology-based method which is the most used one for calculating the EWR [15]. The VMF method is verified with three renowned hydrology-based methods including the Smakhtin, Tennant, and Tessmann methods and 11 local case studies using model simulation.

Table 1. Classifications of WSI_{e1} and WSI_{e2}.

$WSI_{e,1}$	$WSI_{e,2}$	Level of Approaching Stress
$0 < WSI_{e,1} \leq 0.12$	$0 < WSI_{e,2} \leq 0.06$	No stress
$0.12 < WSI_{e,1} \leq 0.40$	$0.06 < WSI_{e,2} \leq 0.20$	Watch
$0.40 < WSI_{e,1} \leq 1$	$0.20 < WSI_{e,2} \leq 0.5$	Warning
$1 < WSI_{e,1} \leq 1.72$	$0. < WSI_{e,2} \leq 0.86$	Moderate
$1.72 < WSI_{e,1} \leq 1.88$	$0.86 < WSI_{e,2} \leq 0.94$	Severe
$1.88 < WSI_{e,1} \leq 2$	$0.94 < WSI_{e,2} \leq 1$	Extreme

The monthly WSI_{e1} result of the Bang Pakong watershed was directly obtained from Nilsalab and Gheewala [7] and the obtained data from this study were further used for calculating the annual WSI_{e1} and both the annual and monthly WSI_{e2}. The two approaches proposed by Nilsalab et al. [8] were adjusted specifically for the case of Thailand by using the country data. The annual equation of the WSI_{e1} is expressed in Equation (1) [6,7]. Equations (2) and (3) are the annual and monthly equations of the WSI_{e2} [6,8,16].

$$\text{annual } WSI_{e1(THA)} = \frac{2}{1 + \left(e^{-1.82(DTA^{*}_{e1})}\right)\left(\frac{1}{0.01} - 1\right)} \tag{1}$$

where

annual $WSI_{e1(THA)}$ means water stress index with reference to environmental water requirement where the water demand explicitly includes EWR;

DTA^{*}_{e1} means the DTA_{e1} in relation to precipitation variation and flow regulation. If flow is regulated by dam, strong regulation flow (SRF) is defined and the DTA^{*}_{e1} is calculated as $DTA^{*}_{e1} = \sqrt{VF} \times DTA_{e1}$. If flow is not regulated by dam, non-strong regulation flow (non-SRF) is defined and the DTA^{*}_{e1} is calculated as $DTA^{*}_{e1} = VF \times DTA_{e1}$;

VF (variation factor) means precipitation variation quantifying from the arithmetic standard deviations of the log-transformed values of monthly (S^{*}_{month}) and annual rainfall (S^{*}_{year}) as $VF = e^{\sqrt{\ln(S^{*}_{month})^2 + \ln(S^{*}_{year})^2}}$;

DTA_{e1} means the demand to availability where the water demand explicitly includes EWR as one of the components;

$DTA_{e1} = \frac{WD+EWR}{WA}$

WD is water demands for agriculture, industry, household, and livestock;

EWR is environmental water requirement;

WA is water availability

$$\text{annual } WSI_{e2(THA)} = \frac{1}{1 + \left(e^{-1.82(DTA^{*}_{e2})}\right)\left(\frac{1}{0.01} - 1\right)} \tag{2}$$

where

annual $WSI_{e2(THA)}$ means water stress index with reference to environmental water requirement where the water availability explicitly excludes EWR;

DTA^{*}_{e2} means the DTA_{e2} in relation to precipitation variation and flow regulation. If flow is regulated by dam, strong regulation flow (SRF) is defined and the DTA^{*}_{e2} is calculated as $DTA^{*}_{e2} = \sqrt{VF} \times DTA_{e2}$. If flow is not regulated by dam, non-strong regulation flow (non-SRF) is defined and the DTA^{*}_{e2} is calculated as $DTA^{*}_{e2} = VF \times DTA_{e2}$;

VF (variation factor) means precipitation variation quantifying from the arithmetic standard deviations of the log-transformed values of monthly (S^*_{month}) and annual rainfall (S^*_{year}) as $VF = e^{\sqrt{\ln(S^*_{month})^2 + \ln(S^*_{year})^2}}$;
DTA_{e2} means the demand to availability where EWR is explicitly reserved by subtracting it from the water availability;
$DTA_{e2} = \frac{WD}{WA - EWR}$
WD is water demands for agriculture, industry, household, and livestock;
EWR is environmental water requirement;
WA is water availability

$$\text{monthly } WSI_{e2(THA)} = \frac{1}{1 + \left(e^{-3.84(DTA^*_{e2,month})}\right)\left(\frac{1}{0.01} - 1\right)} \quad (3)$$

where

monthly $WSI_{e2(THA)}$ means water stress index with reference to environmental water requirement where the water availability explicitly excludes EWR;

$DTA^*_{e2,month}$ means the $DTA_{e2,month}$ in relation to variability of annual rainfall which is calculated as $DTA^*_{e2,month} = S^*_{year} \times DTA_{e2,month}$;

S^*_{year} means the geometric standard deviation of annual rainfall;
$DTA_{e2,month}$ means the demand to availability where EWR is explicitly reserved by subtracting it from the water availability;
$DTA_{e2,month} = \frac{\text{monthly WD}}{\text{monthly WA} - \text{monthly EWR}}$
monthly WD is water demands for agriculture, industry, household, and livestock on a monthly basis;
monthly EWR is environmental water requirement on a monthly basis;
monthly WA is water availability on a monthly basis.

The two approaches proposed by Nilsalab et al. [8] were adjusted basically from the annual and monthly WSI of Pfister et al. [6] and Pfister and Bayer [16]. Hence, the term DTA^*_e is also associated with a variation of rainfall (VF) and a river flow regulation [6]. Accordingly, the term DTA^*_e is equal to the product of VF and DTA_e. The *VF* is calculated by means of the arithmetic standard deviations of the log-transformed values of monthly and annual rainfall. Then, the river flow regulation linked to obtain the values of DTA^*_e is used to account for flow regulations by water reservoirs or dams. If a watershed has a substantial alteration of flow regimes by dams, the value of *VF* will be reduced by applying square root. In the case of the monthly DTA^*_e, the river flow regulation is not taken into account and the *VF* is replaced by the variability of annual rainfall (s^*_{year}), a geometric standard deviation of the log-transformed values of annual rainfall [16].

Other than the adjustment of WSI_e for the case of Thailand, the calculation of EWR for all 25 watersheds including the Bang Pakong watershed in this study was based on the VMF method of Pastor et al. [14] similar to Nilsalab and Gheewala [7]. The methodology described above is illustrated through a flowchart in Figure 2.

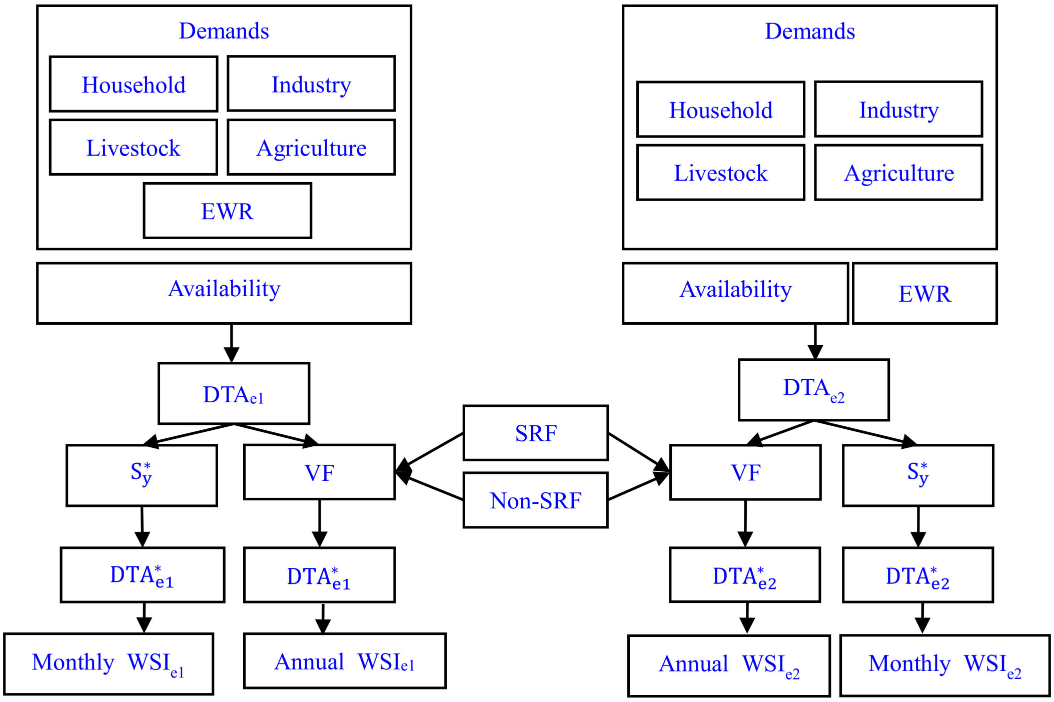

Figure 2. Flowchart of methodology.

3. Results and Discussion

The WSI_e values of the Bang Pakong watershed using the two approaches are presented in Table 2. The annual water stress results revealed the same level of classification for both the approaches as the Bang Pakong watershed needs attention to monitor the stress situation; therefore, these annual results cannot be used to evaluate the implications of applying the different approaches. Explicit incorporation of EWR in the two approaches can be seen from the monthly results.

Table 2. WSI_e values based on the two approaches for explicitly including environmental water requirement (EWR).

Bang Pakong	Annual	Monthly											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(1) WSI_{e1}	0.39 Watch	1.83 Severe	1.15 Medium	0.76 Warning	0.47 Warning	0.14 Watch	0.26 Watch	0.39 Watch	0.48 Warning	0.22 Watch	0.17 Watch	0.78 Warning	1.37 Medium
(2) WSI_{e2}	0.09 Watch	0.99 Extreme	0.64 Medium	0.22 Warning	0.05 No stress	0.02 No stress	0.06 Watch	0.11 Watch	0.16 Watch	0.05 No stress	0.03 No stress	0.28 Warning	0.79 Medium
(3) Seawater intrusion		Event occurred										Event occurred	
(4) Reduce water pollution												Event occurred	

(1) Based on human perspective; (2) based on environmental perspective; (3) record water events [10]; (4) literature [17]. The grey background color means no data records found.

The stress situation was revealed in January for both approaches; however, the levels of stress were different as a severe level of stress situation is indicated by the WSI_{e1} whereas an extreme level of impending stress situation is predicted using the WSI_{e2}. Based on the water events recorded by the Hydro and Agro Informatics Institute (HAII) [10], the stress situation and seawater intrusion occur in the Bang Pakong watershed mainly in the dry season. Less rainfall and water allocation based on limited available freshwater in the dry season can lead to the impossibility to satisfy all human and environmental demands for water. Although the environmental water is regulated at the minimum flow, this minimum EWR is not enough for alleviating the effect of seawater intrusion and the problem of water quality. The Royal Irrigation Department (RID) reported that 26.5 and

97.8 million m^3 of freshwater were recorded for pushing down the seawater at the Kgt. 3 station and the station at Tambon Paknum, Chachoengsao province during November to February [18]. During December 2007 to February 2008, the stored water in the Klong Si Yad, Khun Dan Prakan Chon and Phra Prong reservoirs located in the upstream of the Bang Pakong watershed released around 71, 29 and 10 million m^3 to increase the environmental water for slowing down the seawater intrusion in the downstream [12]. Moreover, different EWRs of the Bang Pakong watershed have been estimated by three different organizations at 19.8 million m^3/month [19], 147.44 million m^3/year [20] and 42 million m^3/year [11]; all claiming to be based on the minimum flow of historical monthly runoff. However, the impact of seawater intrusion still gets worse in the dry season due to the lack of water for pushing down the seawater as mentioned in the studies of the Royal Irrigation Department [19] and HAII [20]. Additionally, the strategic plan on Thailand's water resources management recommends increasing EWR during the dry season through constructing small to medium scale water reservoirs in the sub-watersheds, especially in the watersheds affected by the estuary tide [11]. Accordingly, this somehow matches with the results from both the WSI_{e1} and WSI_{e2}.

The EWR of Bang Pakong watershed accounted for in these two approaches is calculated by using the VMF method of Pastor et al. [14] which is developed to deal with improper allocation of environmental flow during the high and low flow periods. As a result, the EWR in the dry season particularly during November, December and January is higher than the requirement in the wet season. Although there is more water available for human demand in the wet season, a more stressful situation is revealed by using the WSI_{e1}. On the other hand, as the WSI_{e2} approach gives the first priority to the EWR, the results may provide useful new insights regarding the importance of EWR on policy and future plan for water resource management.

Currently, RID explicitly takes EWR into account as one of the water demand sectors as human and environment are both important. Thus, the WSI_{e1} approach corresponds to the consideration of RID and should be preferred for the case of the Bang Pakong watershed and the water allocation priorities could be rearranged accordingly [7]. However, as this study would like to highlight and emphasize the importance of EWR in the case of Thailand, applying the WSI_{e2} approach would be recommended rather than the WSI_{e1} approach. Then, water allocation priorities can be rearranged only for human demands for water while the EWR is already safeguarded by setting it aside (cannot be allocated to any human demand).

Consequently, maintaining river functions and ecosystem services is given as the most important responsibility and the highest priority is given to the environmental sector. The WSI_{e2} where the available water associated with the EWR, especially following the monthly basis is recommended. Thus, the monthly WSI_{e2} (Equation (3)) was further applied for calculating the results for 25 watersheds. The results are illustrated in Figure 3 and the values of WSI_{e2} are presented in Table 3. Although the stress situation does not yet exist based on the interpretation of the WSI_{e2} approach, we still need to pay attention to the critical areas which are seen in two regions (Figure 3); the central part during the dry season (from November to April) and the northeastern region during the wet season (from May to October). This is because there is intensive crop cultivation in the central region especially in irrigated areas, and of course the agricultural sector is the most water intensive sector of the country. The amount of rainfall in the northeastern region is lower than other regions because of the geography.

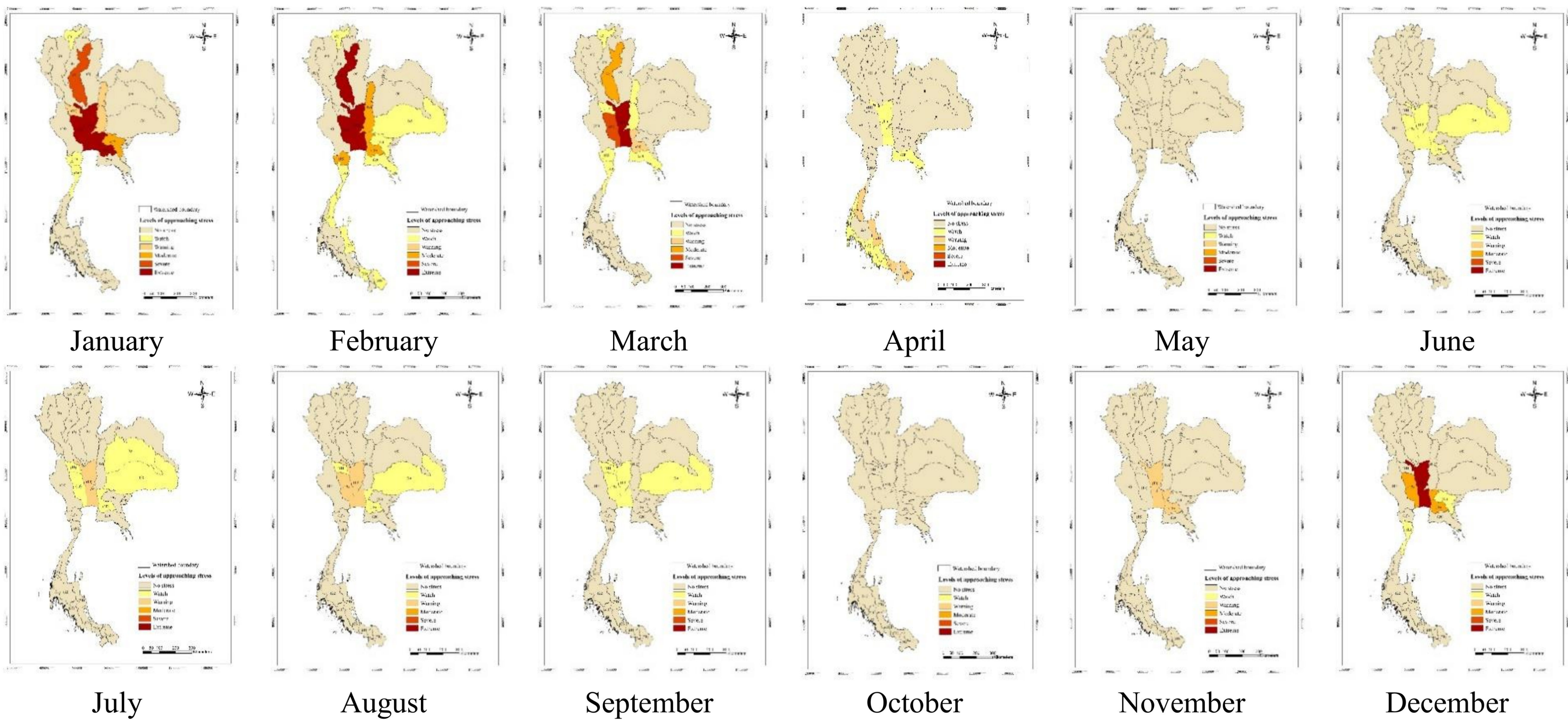

Figure 3. Maps of monthly water stress index with reference to environmental water.

Table 3. Results of Thailand's monthly water stress index with reference to environmental water requirements.

Month Watershed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Salawin	0.02	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Kok	0.14	0.09	0.08	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.02
Ping	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Wang	0.03	0.03	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.02
Yom	0.92	0.96	0.50	0.02	0.01	0.04	0.05	0.04	0.03	0.02	0.02	0.04
Nan	0.03	0.04	0.05	0.01	0.01	0.02	0.03	0.02	0.02	0.01	0.01	0.01
Khong	0.05	0.06	0.04	0.03	0.01	0.04	0.03	0.03	0.03	0.02	0.02	0.02
Chi	0.05	0.04	0.02	0.02	0.01	0.06	0.08	0.05	0.06	0.02	0.01	0.02
Mun	0.05	0.06	0.02	0.02	0.01	0.09	0.08	0.08	0.07	0.02	0.01	0.02
Chao Phraya	1.00	1.00	0.99	0.08	0.02	0.12	0.31	0.27	0.07	0.03	0.32	0.98
Sakae Krang	0.24	0.05	0.08	0.03	0.02	0.04	0.10	0.17	0.08	0.02	0.04	0.03
Pasak	0.47	0.20	0.06	0.02	0.02	0.03	0.06	0.05	0.04	0.03	0.04	0.05
Thachin	1.00	1.00	0.90	0.04	0.02	0.10	0.20	0.23	0.07	0.02	0.05	0.53
Mae Klong	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Phetchaburi	0.09	0.49	0.07	0.02	0.01	0.02	0.03	0.03	0.02	0.01	0.01	0.02
West Coast Gulf	0.15	0.19	0.19	0.05	0.02	0.04	0.05	0.04	0.02	0.02	0.02	0.09
Prachin Buri	0.61	0.15	0.06	0.02	0.01	0.03	0.03	0.03	0.02	0.02	0.02	0.08
Bang Pakong	0.99	0.64	0.22	0.05	0.02	0.06	0.11	0.16	0.05	0.03	0.28	0.79
Tonle Sap	0.02	0.03	0.03	0.03	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
East Coast Gulf	0.04	0.14	0.12	0.09	0.02	0.02	0.01	0.02	0.01	0.02	0.05	0.05
Peninsula East Coast	0.05	0.06	0.04	0.20	0.03	0.04	0.03	0.05	0.03	0.02	0.01	0.01
Tapi	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.01	0.01
Thale sap Songkhla	0.02	0.02	0.01	0.08	0.03	0.03	0.02	0.04	0.03	0.02	0.01	0.01
Pattani	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Peninsula West Coast	0.03	0.04	0.01	0.11	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01

The availability of water depends on rainfall; therefore, climate change can bring about a change in rainfall pattern which will affect the water availability (in both spatial and temporal dimensions). Rainfall patterns change to more intense rainfall on rainy days and more dry days in a year. Additionally, increased temperature can lead to the increase in crop water requirement in order to compensate the increased evaporative loss. All these effects will lead to potential changes in the results of water stress levels. In this study, we used the forecasted rainfall in Thailand during 2020–2025 under the RCP 4.5 scenario for investigating its influence and contribution on the results of water stress level using the proposed index. The RCP 4.5 was selected because it represents an intermediate pathway considering the implementation of a climate policy with aims at stabilizing CO_2 concentrations. The forecasted rainfall data is supported by another project on water footprinting of food, feed and fuel for effective water resource management [21]. The monthly WSI_{e2} results under climate change condition are presented in Figure 4 and Table 4.

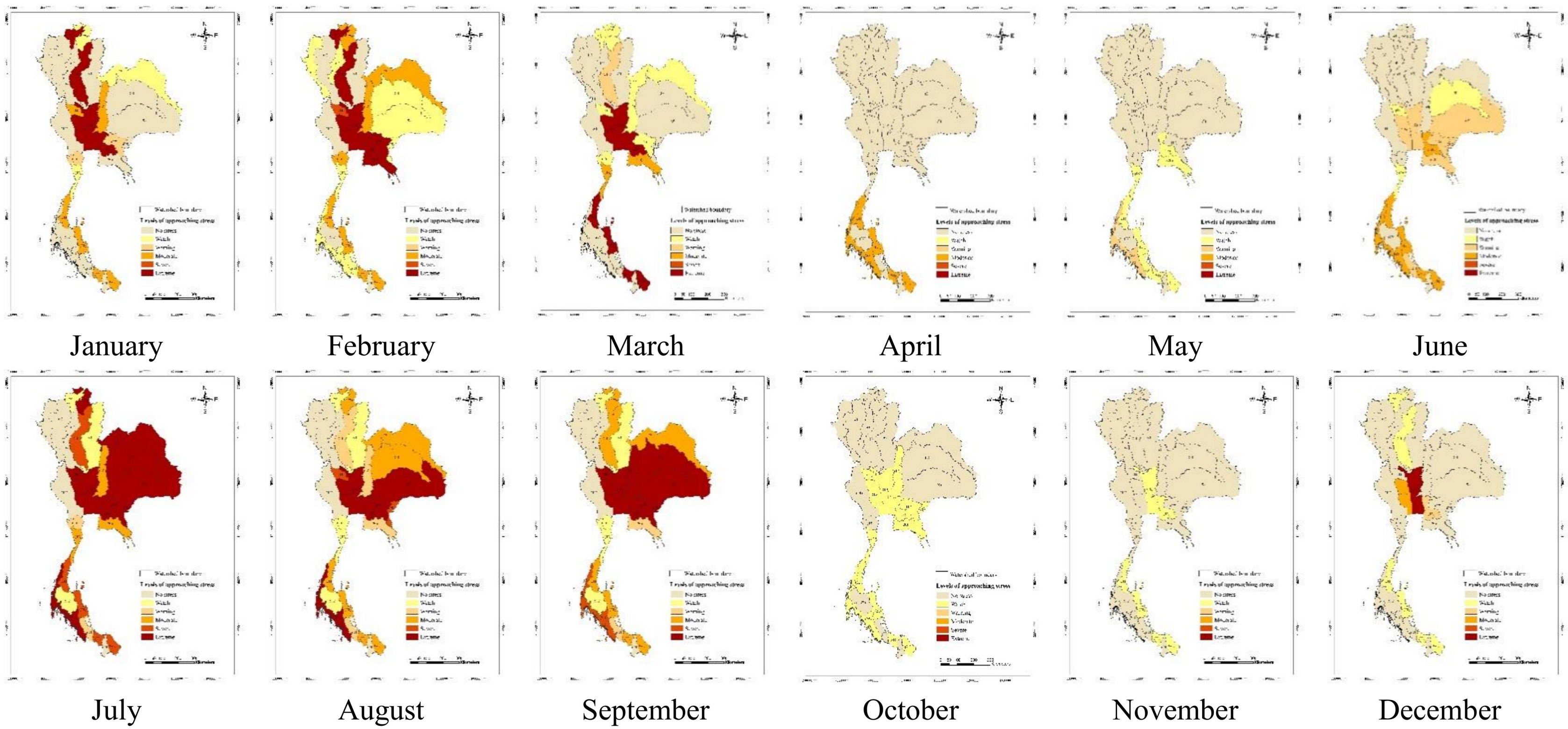

Figure 4. Maps of monthly water stress index with reference to environmental water under climate change.

Table 4. Results of Thailand's monthly water stress index with reference to environmental water requirements under climate change.

Month / Watershed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Salawin	0.05	0.11	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02
Kok	0.99	1.00	0.19	0.01	0.01	0.02	0.18	0.14	0.10	0.02	0.01	0.06
Ping	0.02	0.02	0.02	0.01	0.01	0.01	0.03	0.02	0.03	0.01	0.01	0.01
Wang	0.06	0.06	0.02	0.01	0.01	0.01	0.05	0.03	0.03	0.01	0.01	0.02
Yom	1.00	1.00	0.47	0.02	0.01	0.04	0.88	0.41	0.63	0.03	0.02	0.08
Nan	0.04	0.04	0.05	0.01	0.01	0.03	0.19	0.12	0.18	0.02	0.01	0.01
Khong	0.06	0.52	0.07	0.02	0.01	0.05	0.97	0.69	0.78	0.04	0.02	0.02
Chi	0.06	0.09	0.03	0.02	0.01	0.09	0.98	0.81	0.98	0.03	0.01	0.02
Mun	0.04	0.10	0.02	0.02	0.01	0.27	1.00	0.99	1.00	0.04	0.01	0.02
Chao Phraya	1.00	1.00	1.00	0.08	0.02	0.34	1.00	1.00	1.00	0.11	0.10	0.97
Sakae Krang	0.71	0.88	0.18	0.04	0.02	0.09	0.99	0.87	0.98	0.07	0.02	0.04
Pasak	0.61	0.84	0.08	0.02	0.01	0.04	0.86	0.47	0.95	0.06	0.02	0.05
Thachin	1.00	1.00	0.98	0.03	0.02	0.34	1.00	0.99	1.00	0.08	0.03	0.50
Mae Klong	0.02	0.02	0.02	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.01	0.01
Phetchaburi	0.44	0.67	0.13	0.02	0.01	0.03	0.36	0.13	0.13	0.02	0.01	0.02
West Coast Gulf	0.12	0.19	0.66	0.05	0.06	0.13	0.69	0.17	0.09	0.10	0.02	0.04
Prachin Buri	0.21	0.96	0.09	0.06	0.02	0.34	1.00	0.95	0.99	0.07	0.01	0.02
Bang Pakong	1.00	1.00	0.96	0.24	0.07	0.66	1.00	0.99	0.99	0.14	0.06	0.32
Tonle Sap	0.02	0.17	0.05	0.08	0.03	0.37	1.00	0.87	0.99	0.09	0.01	0.01
East Coast Gulf	0.04	0.97	0.77	0.47	0.07	0.23	0.72	0.34	0.40	0.10	0.03	0.03
Peninsula East Coast	0.67	0.77	0.95	0.63	0.18	0.53	0.92	0.76	0.73	0.17	0.12	0.09
Tapi	0.01	0.01	0.01	0.03	0.04	0.05	0.10	0.09	0.07	0.03	0.02	0.02
Thale sap Songkhla	0.03	0.07	0.05	0.36	0.13	0.24	0.30	0.28	0.24	0.05	0.03	0.02
Pattani	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.01
Peninsula West Coast	0.04	0.13	0.04	0.76	0.43	0.83	1.00	0.94	0.91	0.15	0.06	0.03

The comparison of the monthly water stress map under climate change condition and the current water stress map revealed a significant increase in water stress during January to March in the dry season and during July to September in the wet season. This is because the forecasted rainfall in 2025 decreased in every watershed leading to changes in the level of water stress in several watersheds based on the existing demands for water. The potential effect of climate change on the availability of water in the future, especially in the wet season which could potentially have less rainfall, should be considered in the long-term plans on water resource management and agriculture. This is the same as other studies on the impact of climate change on water availability which revealed that the impact of climate change becomes a significant factor influencing changes in precipitation and temperature [9,22,23]. Although the levels of water stress in some watersheds increase due to less rainfall, their environmental water is already safeguarded as the first priority is given to the environmental water in the WSI_{e2} approach.

4. Conclusions

Two approaches were considered for explicitly incorporating EWR into the WSI for the purpose of prioritizing EWR in water scarcity calculations. Both the approaches for incorporating EWR into the WSI were seen to work well for assessing the stress situation in Thailand during the dry months as confirmed by comparison of the predicted results with the actual situation. The WSI_{e1} based on human perspective puts lower emphasis on environment (water resources) than the WSI_{e2}. Therefore, the selection of the approach will depend on the priority level of water for the country. Based on the national agenda, higher priority for the environment implies the use of WSI_{e2} for policy making whereas a lower priority favors the use of WSI_{e1}. EWR estimated by the variable monthly flow method showed a good correlation with the actual situation in Thailand. Moreover, the WSI_{e2} approach would be highly recommended in order to maintain the EWR as the first priority. Additionally, climate change and its variability cause significant impacts on water resources especially in the wet season which could potentially have less rainfall. Although the levels of water stress in some watersheds increased due to less rainfall, their environmental water is already safeguarded as the first priority is given to the environmental water. However, there would potentially be high risk of water scarcity for agriculture which mainly relies on rainfall in Thailand. The results of applying the WSI_{e2} approach could help to select the areas that have less water scarcity, and to shift crop cultivation for alleviating the impact of water scarcity. The proposed approach could easily be adopted by other countries using their specific precipitation data.

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