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GROUNDWATER VULNERABILITY OF THAILAND'S LOWER CHAO PHRAYA BASIN

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ABSTRACT: Since global warming effects water resources, especially, surface water sources, groundwater is an essential water source, when facing the critical drought. Groundwater is less sensitive than surface water because groundwater response is delayed. However, groundwater may face critical drought and shortage. Groundwater vulnerability is a tool to identify critical areas for maintaining water quantity and quality. The Fuzzy-Catastrophe-based DRASTIC model, drought persistence and several climate scenarios were combined to estimate the vulnerability on the confined aquifers of Thailand's Lower Chao Phraya (LCP) basin. Thus, critical areas that may face groundwater shortage were identified. Our analysis predicted that most of the basin would have few effects on climate change. However, vulnerability maps showed that 5% of the basin may be critical areas that may show groundwater shortage, especially, drought persistent areas with low rainfall. Generated maps identify 'hotspots' and can help decisions on groundwater development and economic growth and aid planning policy.

Keywords: Drastic, Climate change, Groundwater vulnerability, Groundwater resource, Groundwater resources planning

1. INTRODUCTION

Groundwater is a very important natural resource and can be a second source of water supply when facing critical droughts or limited accessible surface water since surface water is more sensitive than groundwater to a climate fluctuation. So, groundwater is an important water source because groundwater response is delayed relative to climate changes on the surface water [1]. Decreasing in surface water level contributes significantly to the groundwater decline. Although groundwater is a renewable resource, much groundwater cannot be renewed in the human life spans [2]. Then, groundwater will become a limited resource and must be conserved.

Hydrological systems and water resources affect global climate change, such as flood, drought and seawater intrusion. They are very significant in the tropical climate, especially, groundwater vulnerability and sustainability [3–6]. Thailand is in the tropical zone. Then, the groundwater resources in Thailand will face these problems. The linkage between groundwater and climate change is inherently complicated. Therefore, these are the need to study the impact of climate on groundwater quickly, before it becomes exhausted.

The effect of drought on water resources has been studied by Wongsa and Rangsiwanichpong et al. [7,8]. Tanachaichoksirikun et al. [9] reported that groundwater affected climate change: especially, in Thailand's Lower Chao Phraya (LCP) basin, groundwater is still sustainable but shortage may be faced in some aquifers.

The DRASTIC framework consists of seven indices i.e. depth to water table (D), net recharge (R), aquifer media (A), soil media (S), topography or slope (T), the impact of the vadose zone (I) and hydraulic conductivity (C). These factors were assigned by ratings and weighting by Aller et al. [10]. The model succeeded in predicting groundwater quality in unconfined aquifers [11–13]. Seeboonruang [14] modified DRASTIC to show that the groundwater vulnerability affected climate change in the unconfined aquifers. However, the DRASTIC model has disadvantages, because the regional characteristics vary the appropriate weightings and ratings [15]. So, the DRASTIC framework was modified to the Fuzzy-Catastrophe DRASTIC Framework (FCF) for confined aquifers by Nadiri et al. [16,17]. However, the modified DRASTIC has not been used to determine climate change impact on groundwater vulnerability.

Therefore, we investigated the impact of climate change on the groundwater vulnerability, by combining climate change, history of drought persistent and FCF, to investigate critical areas that affect climate change. This is the first time, FCF has been used to evaluate the challenge of confined aquifers: it was applied to the LCP basin because it is a confined aquifer, that was affected by climate change [9].

2. STUDY AREA

Thailand's LCP basin locates in the central plain; it covers ~41,300 km^2, which covers Bangkok, the capital city, and 21 provinces. Groundwater flows from the north to the south. The Tenasserim Hills locate in the west and small hills are in the east, the south connects to the Gulf of Thailand. The north connects to the Upper Chao Phraya basin - see Fig. 1. The hydrogeology is Tertiary-Quaternary formation that the depositions are coastal and fluvial deposits [18,19]. The aquifers consists mainly of sands, gravels and clay lenses, that can be divided into eight confined aquifers - the Bangkok (BK), Phra Pradaeng (PD), Nakorn Luang (NL), Nonthaburi (NB), Sam Khok (SK), Phayathai (PT), Thonburi (TB), and Pak Nam (PN) aquifers [1,9].

3. DATA AND METHOD

3.1 Climate and Rainfall

Climate records from LCP monitoring stations indicated that the average annual temperature has increased from 27.1°C (1983-1998) to 27.4°C (1999-2014) and the maximum temperature is nearly 40.6°C in April, while the minimum temperature is ~12.7°C in December. In addition, the average annual rainfall had increased from 1,191 mm (1983-1998) to 1,208 mm (1999-2014) and the maximum monthly rainfall is ~348 mm in September, the minimum rainfall is ~11 mm in December and the average monthly rainfall is 83 - 139 mm.

Wattanasetpong et al. [20] predicted the future climate in the LCP basin based on 30 years of weather records and several criteria. Future climates were separated into the 'near' future predictions for 2020-2049 and 'far' predictions for 2050-2099. We preferred the IPSL-CM5A-MR climate model, from the Coupled Model International research group (CMIP5) from the Institute Pierre Simon Laplace, which offers the minimum bias and root mean square error on past data for the annual precipitation in the Chao Phraya watershed which closely covers the LCP basin [21].

Representative Concentration Pathway (RCP) is a map of greenhouse gas concentration (not emissions) trajectory in the Fifth Assessment Report (AR5) [22]. We selected three pathways for climate modeling, which could be considered, depending on the number of greenhouse gases emitted in 2100. Three RCPs - RCP2.6, RCP4.5, and RCP8.5, which cover the range of likely future radiative forcing values, were selected.

3.2 Climate Exposure

Climate exposure is an index level for the fluctuation of rainfall between the past and future (Fig. 2a and 4). The south boundary produces the local increase in rainfall. The maximum increase in rainfall occurs near the Gulf of Thailand ~10% (RCP8.5) and the minimum increase in rainfall occurs near the Tenasserim Hills ~6% (RCP2.6). We classified climate exposure into four classes (ΔR^0, ΔR^{1+}, ΔR^{2+}, and ΔR^{3+}) as shown in Table 1. The worrisome factor is rainfall increase because it contributed to flooding. Therefore, the basin may show groundwater vulnerability from future rainfall which will affect climate change.

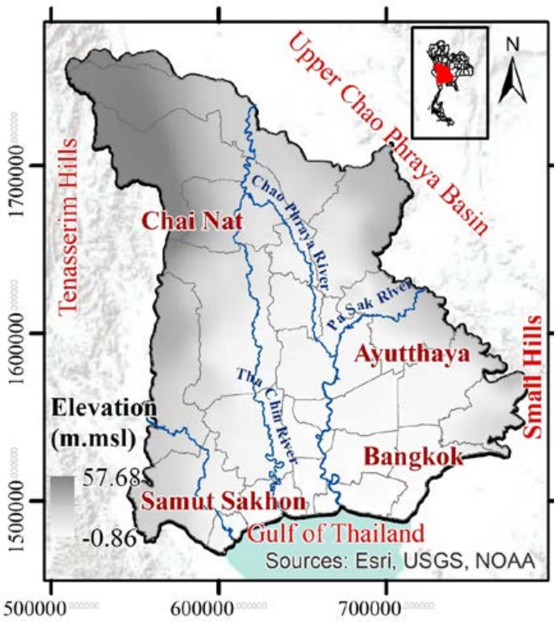


Fig. 1 Location of Thailand's LCP Basin

Table 1 Impact of climate change (ICC) indices

Climate exposure	Drought persistence (times/10years)			
	0	≤ 3	4-5	> 6
$\Delta R^{3+} > 3.36\%$	I^{2+}	I^{+}	I^{0}	I^{-}
$1.68\% < \Delta R^{2+} \leq 3.36\%$	I^{+}	I^{0}	I^{-}	I^{2-}
$0.36\% < \Delta R^{1+} \leq 1.68\%$	I^{0}	I^{-}	I^{2-}	I^{3-}
$-1.68\% < \Delta R^{0} \leq 0.36\%$	I^{-}	I^{2-}	I^{3-}	I^{4-}

Note: I^{2+} = best, I^{+} = good, I^{0} = no impact, I^{-} = low impact, I^{2-} = moderate impact, I^{3-} = high impact, I^{4-} = very high impact

Table 2 Groundwater vulnerability indices (VI)

Drought exposure	DRASTIC index				
	33-41	42-49	50-57	58-65	66-73
I^{2+}	Ex	Vg	B	G	N
I^{+}	Vg	B	G	N	N
I^{0}	B	G	N	N	L
I^{-}	G	N	N	L	M
I^{2-}	N	N	L	M	H
I^{3-}	N	L	M	H	Eh

Note: Ex = excellent, Vg = very good, B = better, G = good, N = none, L = low, M = moderate, H = high, Eh = extremely high vulnerability

3.3 Drought Persistence

Drought persistence is the historical report and frequency of droughts. It was monitored and calculated by several factors of the Thailand Land Development Department (LDD). Drought persistence was divided into four classes, 0, <3, 4-5 and >6 times/10 years [14] as shown in Fig. 2b. Drought persistence highlighted the adaptation of groundwater management. In this basin, droughts occurred near the boundary, but the central area remains fertile.

3.4 Impact of Climate Change

Droughts contributed to the change in climate change index (Fig. 5), that divided into six classes, as shown in Table 1. When an area did not have enough rainfall and a high frequency of droughts, it had a high impact on climate change in that area, but if the area had high rainfall and no drought, the area had no impact on climate change.

3.5 Fuzzy Catastrophe DRASTIC Framework

DRASTIC was designed by the US Environmental Protection Agency [10]: it is a method that describes the allowable pollution potential hydrogeologic setting. The system has two major steps: (a) is the hydrogeologic settings map design, and (b) overlaying the relative rating system. DRASTIC uses seven parameters to classify the pollution potential of an aquifer. The sensitivity index of our study modified weightings and ratings for FCF by Nadiri et al. [16,17] as shown in Table 3.

The DRASTIC index (D_i) was analyzed:

$$D_i = D_rD_w+R_rR_w+A_rA_w+T_rT_w+I_rI_w+C_rC_w \quad (1)$$

where D_i = DRASTIC index for a mapping unit, r = rating, w = weighting factor for D, R, A, S, T, I, C.

Depth to water (D) = depth from the ground surface to the top of the confining layer. If the groundwater aquifer is deep, water is harder to infiltrate.

Net recharge (R) = average monthly infiltration from the ground surface and becomes groundwater.

Aquifer media (A) = the porous media between bedrock and the confining layer. An aquifer, that has larger grain size or more openings, leads to higher permeability and lower attenuation capacity.

Soil media (S) = media between the ground surface and unsaturated zone. The soil has a significant impact on the recharge that infiltrates the aquifer.

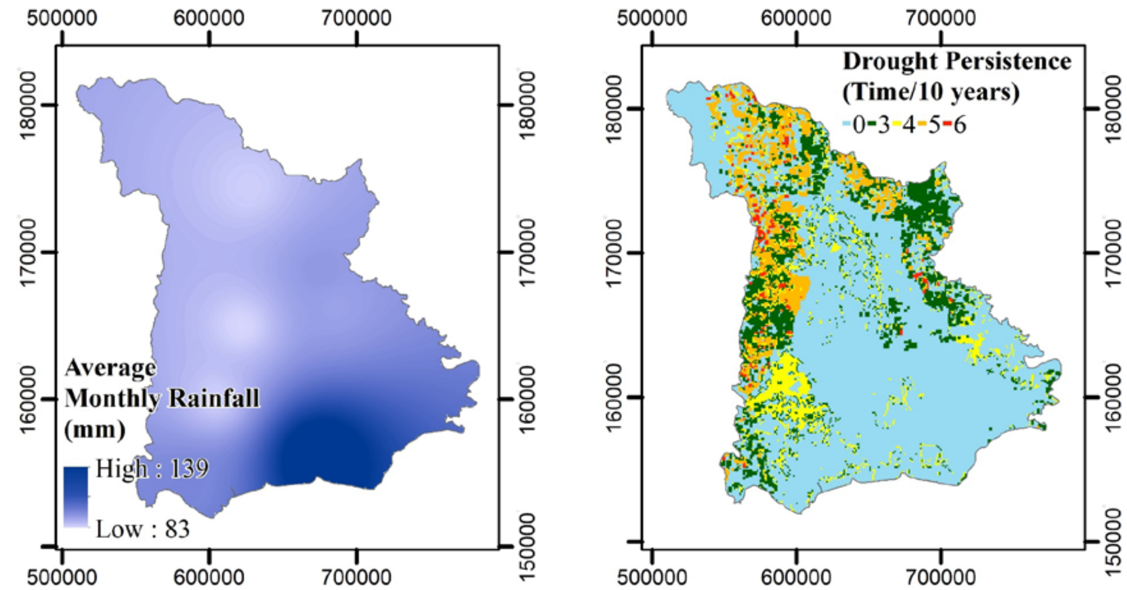
Topography (T) = slope of the land surface. It makes recharge take longer to infiltrate.

Impact of vadose zone (I) = material above the water table below the topsoil, which is clay in the confined aquifer. Hence, the impact of the vadose zone was set to 1 due to the clay lenses.

Hydraulic conductivity (C) = ability of an aquifer to transmit water, controlling the rate at which groundwater will flow under a given hydraulic gradient.

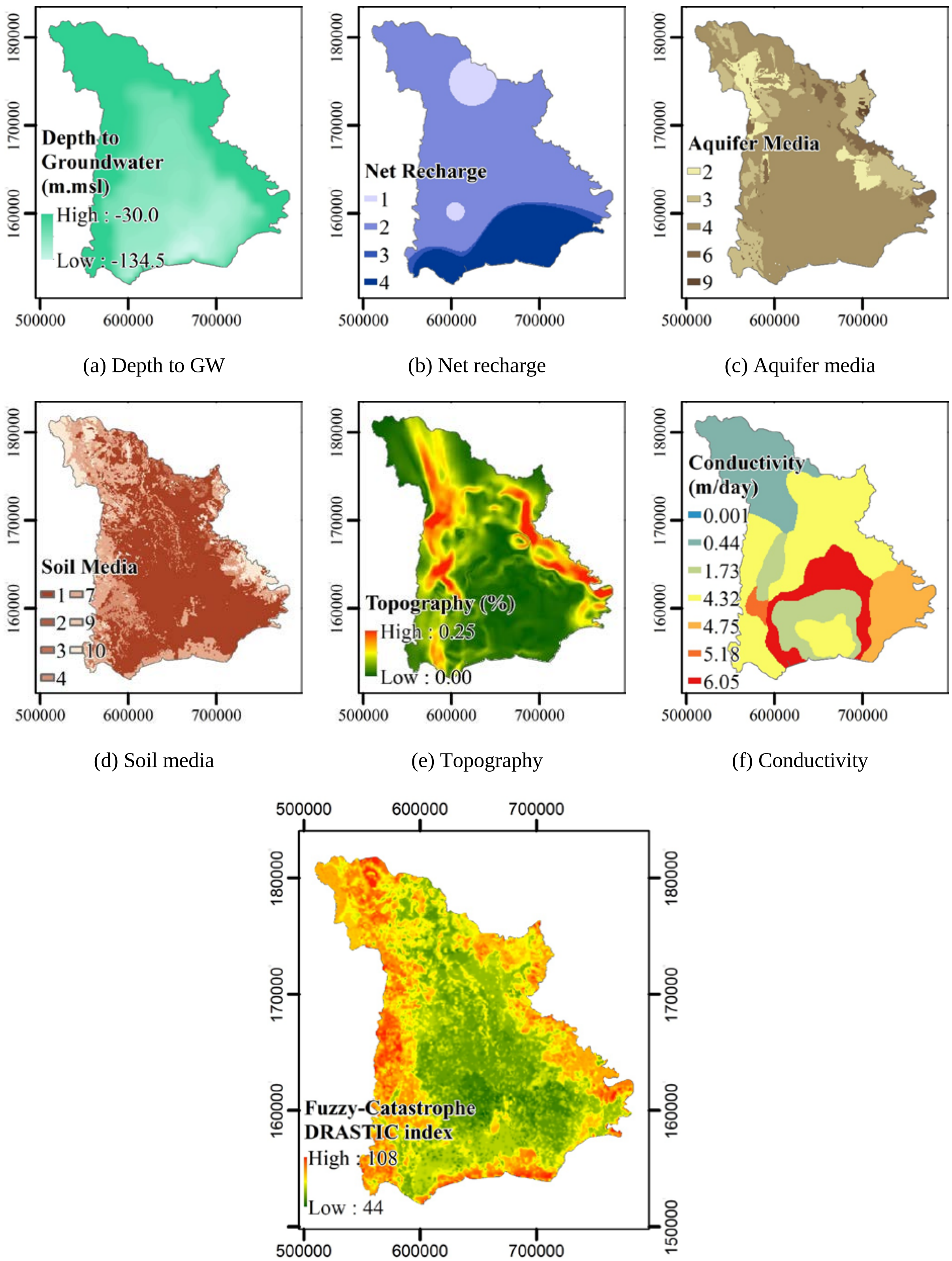
Table 3 Fuzzy Catastrophe DRASTIC index

DRASTIC parameter	Classification range			Mean	Normalized Value of mean	Catastrophe fuzzy membership function	Priority	Catastrophe Drastic Weight
Depth to groundwater (m)	-77.2	class 1	-49.8	-58.5	1.00	1.00	0.67	5
	-49.8	class 2	-37.4	-42.9	0.67	0.87		
	-37.4	class 3	-25.0	-30.9	0.42	0.80		
	-25.0	class 4	-12.6	-18.8	0.16	0.69		
	-12.6	class 5	-10.0	-11.0	0.00	0.00		
Recharge (mm/year)	7.1	class 1	8.2	8.1	0.00	0.00	0.63	4
	8.2	class 2	10.5	9.1	0.22	0.61		
	10.4	class 3	11.6	11.0	0.66	0.90		
	11.6	class 4	13.3	12.4	1.00	1.00		
Aquifer media (rate)	2	class 1	3	2.7	0.00	0.00	0.62	3
	3	class 2	4	3.8	0.31	0.67		
	4	class 3	6	4.1	0.40	0.79		
	6	class 4	9	6.2	1.00	1.00		
Soil media (rate)	1	class 1	2	1.1	0.00	0.00	0.69	6
	2	class 2	3	2.5	0.17	0.55		
	3	class 3	4	3.0	0.30	0.74		
	4	class 4	7	6.0	0.57	0.89		
	7	class 5	9	7.4	0.74	0.95		
	9	class 6	10	9.6	1.00	1.00		
Topography (percent)	0	class 1	2	0.04	-	-	1.00	7
Impact of vadose zone	0	class 1	1	1	-	-	0.00	1
Conductivity (m/day)	0.0	class 1	1.1	0.4	0.00	0.00	0.56	2
	1.1	class 2	4.0	1.7	0.30	0.67		
	4.0	class 3	12.0	4.7	1.00	1.00		



(a) Average monthly rainfall (b) Drought Persistence

Fig. 2 Climate situation of Thailand’s LCP Basin



(a) Depth to GW

(b) Net recharge

(c) Aquifer media

(d) Soil media

(e) Topography

(f) Conductivity

(g) Fuzzy-Catastrophe DRASTIC index

Fig. 3 Combining Fuzzy-Catastrophe DRASTIC index

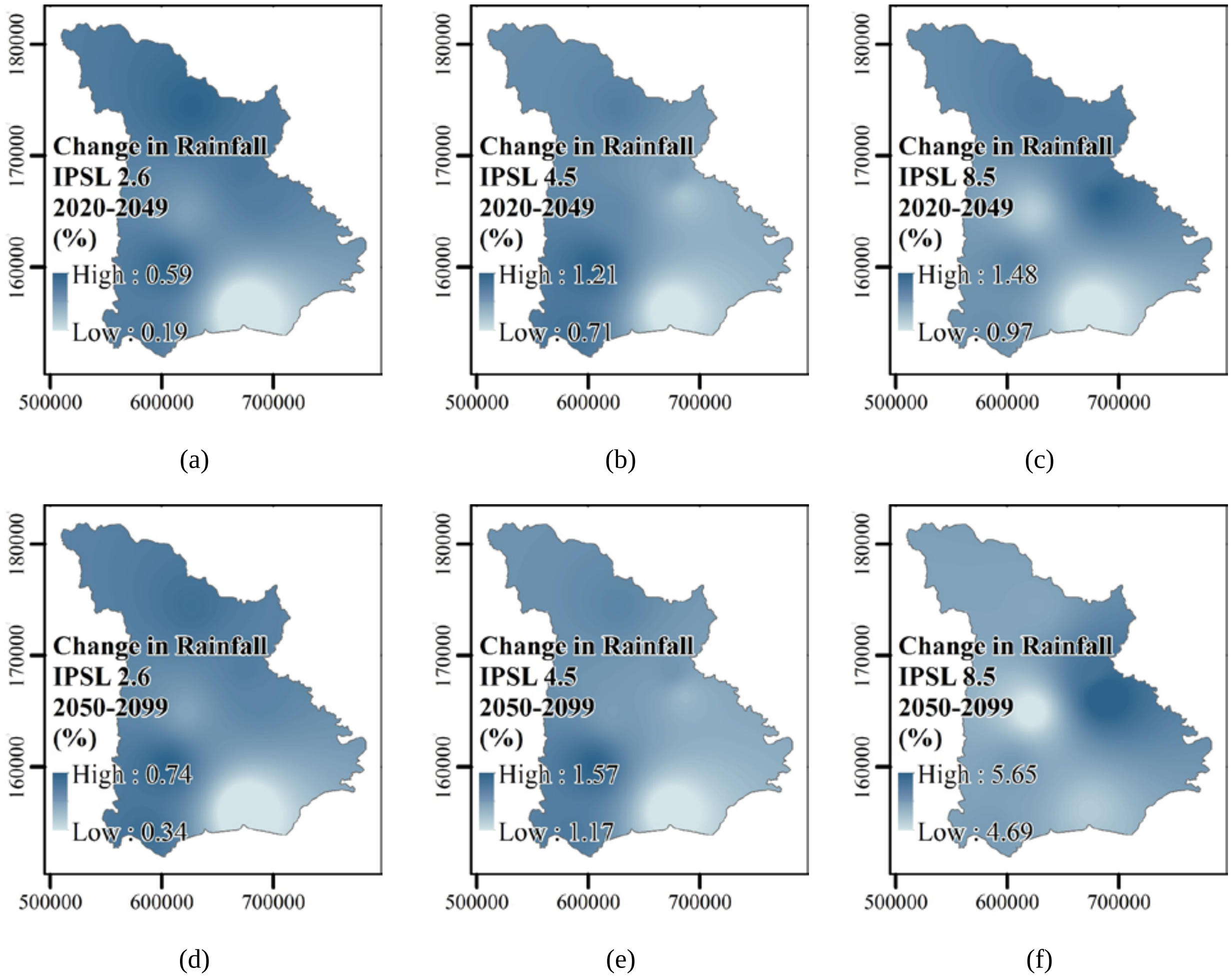


Fig. 4 Future Change in Rainfall under RCP 2.6, 4.5 and 8.5 in 2020 – 2049 and 2050 – 2099

3.6 Groundwater Vulnerability

Groundwater vulnerability is a major problem because it is key to groundwater management. The groundwater vulnerability was derived from the combination of FCF and the impact of climate change. The indicators are shown in Table 2. The groundwater impact is critical when the impact of climate change and the FCF is high, it implies the risk of change is very high. The degree of groundwater and climate change vulnerability can affect groundwater management. In addition, in the red areas, identified as highly sensitive areas – high drought persistence, a slight increase in rainfall and high values of DRASTIC – are causes for concern (Fig. 6).

4. RESULTS AND DISCUSSION

4.1 Future Groundwater Vulnerability

The future groundwater vulnerability map is represented in Fig. 6. The extreme risk values are shown in warms tone and change to better qualities are shown with cold tones. When the RCP2.6 was used for 2020-2049 and 2050-2099, it shows the highest vulnerability indices (5%) of the total area that the area may face future drought. Most of these areas are located near the boundary of the basin, where a lower rainfall rate recharged the groundwater and there was a history of drought. However, the RCP8.5 model, for the same periods, shows the highest groundwater resilience, i.e. the groundwater would cause only small climate change: the high rainfall would recharge and there would be few droughts. However, in RCP4.5, groundwater vulnerability was predicted for 2050-2099, because this period would have relatively high rainfall near the Gulf of Thailand but low rainfall near the Tenasserim hills

The main reason for the greater vulnerability to the impact of climate change in the central area is the area is relatively flat and the soil media is clay lenses. Whereas, near the area with persistent drought, it has slight vulnerability because the rainfall is low.

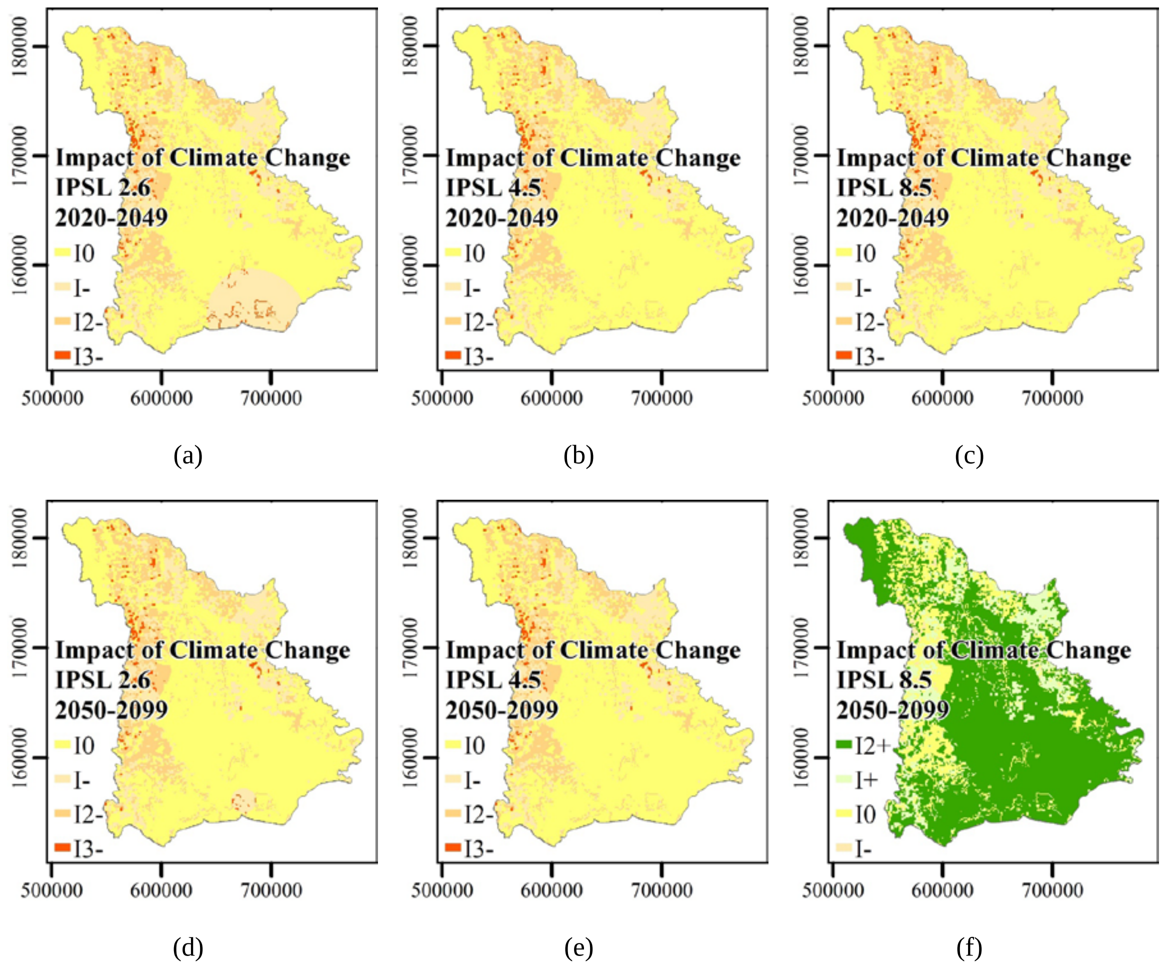


Fig. 5 Impact of climate change indices under RCP 2.6, 4.5 and 8.5 in 2020 – 2049 and 2050 – 2099

5. CONCLUSION

We investigated the groundwater vulnerability under climate change in Thailand's Lower Chao Phraya (LCP) basin to aid decisions in groundwater management. We combined the Fuzzy Catastrophe DRASTIC Framework (FCF), climate change scenarios, and drought persistence to consider groundwater characteristics, climate exposure and history of drought occurrence. The climate scenarios in the Representative Concentration Pathway (RCP) were 2.6, 4.5 and 8.5. The Geographic Information System technique was used to analyze the periods 2020-2049 and 2050-2099.

The critical areas in the LCP basin had 5% because that area has low rainfall, a history of high drought frequency and high values of FCF. However, the groundwater vulnerability continuously decreased in all scenarios because the rainfall increased, especially under the RCP8.5 scenario. Although RCP2.6 was lower rainfall (but higher than the base case (1983-2014)), the groundwater vulnerability still resilient.

The climate change has a lower impact on groundwater vulnerability in a confined aquifer when compared with the unconfined aquifers because the FCF index shows that the low impact of the vadose zone value. However, the topography, soil media, and depth to groundwater are the most important factors in the LCP basin because they show high FCF weight.

The impact of climate change was significantly affected by drought persistence. However, we did not include future land use, which should probably be considered in an extension of this work.

We concluded the groundwater vulnerability in the Lower Chao Phraya basin has a little impact in the RCP2.6 scenario and no impact on the RCP8.5 scenario because it included increased rainfall.

At this stage, we did not consider human activities, e.g. land use and pumping, which can have more impact on the groundwater system. However, these will be considered in future work.

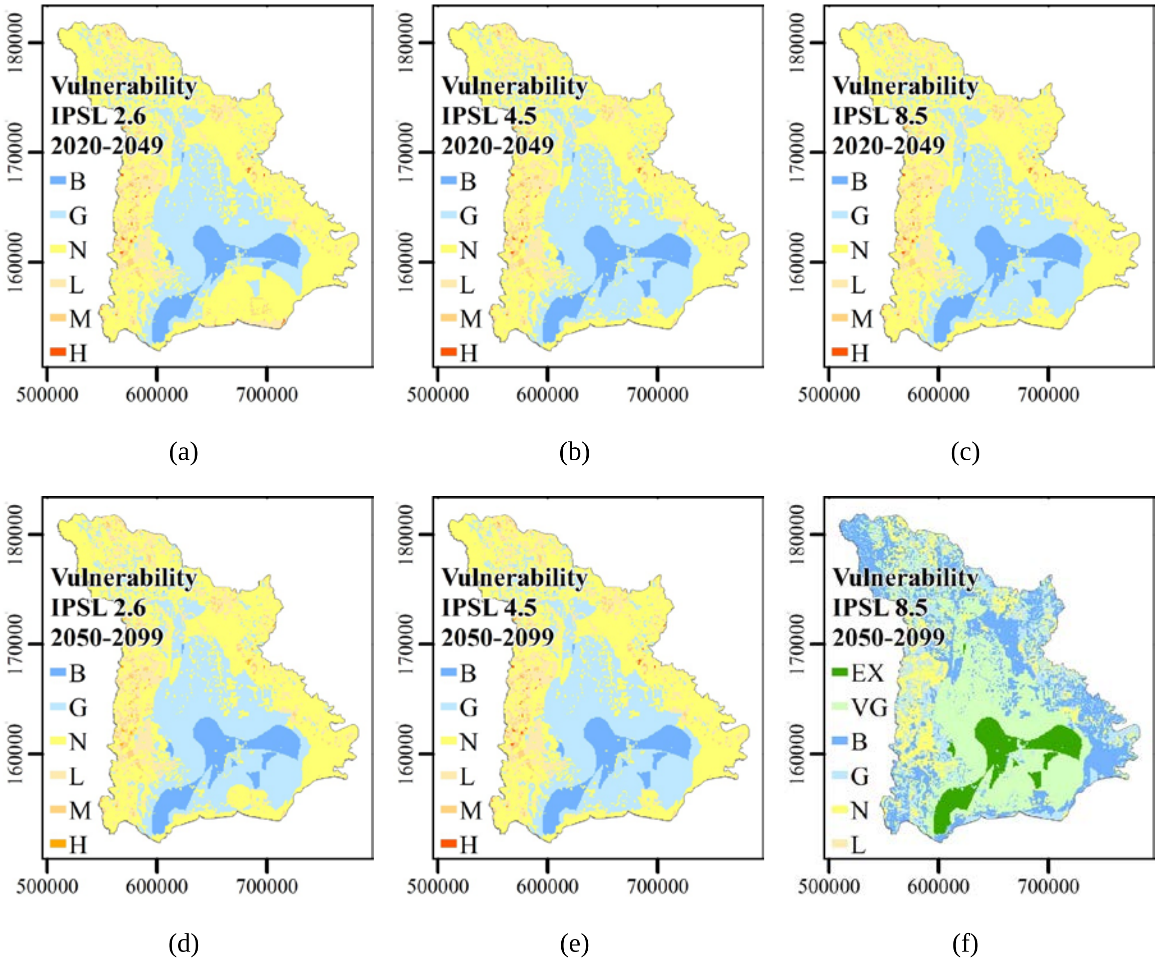


Fig. 6 Groundwater vulnerability indices under RCP 2.6, 4.5 and 8.5 in 2020 – 2049 and 2050 – 2099

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Seeboonruang U., An Empirical Decomposition of Deep Groundwater Time Series and Possible Link to Climate Variability, Global NEST Journal, Vol. 16, Issue 1, 2014, pp. 87–103.

[2] Foster S. S. D., and Chilton P. J., Downstream of Downtown: Urban Wastewater as Groundwater Recharge, Hydrogeology Journal, Vol. 12, Issue 1, 2004, pp. 115–120.

[3] Chris M. H., Harm D., Diana M. A., and Dirk K., Groundwater Recharge and Storage Variability in Southern Mali, Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations, Taylor and Francis Group, London, United Kingdom, 2012, pp. 33–48.

[4] Green T. R., Taniguchi M., Kooi H., Gurdak J. J., Allen D. M., Hiscock K. M., and Aureli A., Beneath the Surface of Global Change: Impacts of Climate Change on Groundwater, Journal of Hydrology, Vol. 405, Issue 3–4, 2011, pp. 532–560.

[5] Taylor R., and Callist T., The Impacts of Climate Change and Rapid Development on Weathered Crystalline Rock Aquifer Systems in the Humid Tropics of Sub-Saharan Africa: Evidence from South-western Uganda, Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations, 2012, pp. 17–32.

[6] White I., and Tony F., Reducing Groundwater Vulnerability in Carbonate Island Countries in the Pacific, Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations, 2012, pp. 75–110.

[7] Wongsa S., Impact of Climate Change on Water Resources Management in the Lower Chao Phraya Basin, Thailand, Journal of Geoscience and Environment Protection, Vol. 3, Issue 3,

2015, pp. 53–58.
[8] Rangsiwanichpong P., Kazama S., and Ekkawatpanit C., Assessment of Flood and Drought Using Ocean Indices in the Chao Phraya River Basin, Thailand, The 7th International Conference on Water Resources Engineering, in Proc. the 7th International Conference on Water Resources Engineering, 2016, pp. 1–6.
[9] Tanachaichoksirikun P., Seeboonruang U., and Saraphirom P., Impact of Climate Change on the Groundwater Sustainability in the Lower Chao Phraya Basin, Thailand, The 4th International Conference on Engineering, Applied Science and Technology, in Proc. the 4th International Conference on Engineering, Applied Science and Technology, 2018, pp. 119–122.
[10] Aller L., Bennett T., Lehr J. H., Petty R. J., and Hackett G., DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Setting, 1987, pp. 1–622.
[11] Huan H., Wang J., Zhai Y., Xi B., Li J., and Li M., Quantitative Evaluation of Specific Vulnerability to Nitrate for Groundwater Resource Protection Based on Process-based Simulation Model, Science of the Total Environment, Vol. 550, 2016, pp. 768–784.
[12] Ouedraogo I., Defourny P., and Vanclooster M., Mapping the Groundwater Vulnerability for Pollution at the Pan African Scale, Science of the Total Environment, Vol. 544, 2016, pp. 939–953.
[13] Shrestha S., Semkuyu D. J., and Pandey V. P., Assessment of Groundwater Vulnerability and Risk to Pollution in Kathmandu Valley, Nepal, Science of the Total Environment, Vol. 556, 2016, pp. 23–35.
[14] Seeboonruang U., Impact Assessment of Climate Change on Groundwater and Vulnerability to Drought of Areas in Eastern Thailand, Environmental Earth Sciences, Vol. 75, Issue 1, 2016, pp. 1–13.
[15] Sadat-Noori M., and Ebrahimi K., Groundwater Vulnerability Assessment in Agricultural Areas Using a Modified DRASTIC Model, Environmental Monitoring and Assessment, Vol. 188, Issue 1, 2016, pp. 1–18.
[16] Nadiri A. A., Sedghi Z., Khatibi R., and Gharekhani M., Mapping Vulnerability of Multiple Aquifers Using Multiple Models and Fuzzy Logic to Objectively Derive Model Structures, Science of the Total Environment, Vol. 593–594, 2017, pp. 75–90.
[17] Nadiri A. A., Sedghi Z., Khatibi R., and Sadeghfam S., Mapping Specific Vulnerability of Multiple Confined and Unconfined Aquifers by Using Artificial Intelligence to Learn from Multiple DRASTIC Frameworks, Journal of Environmental Management, Vol. 227, 2018, pp. 415–428.
[18] Piancharoen C., Groundwater and Land Subsidence in Bangkok, Thailand, IAHS Publication, Issue 121, 1977, pp. 355–364.
[19] Piancharoen C. and Chuamthaisong C., Groundwater of Bangkok Metropolis, Thailand, IAH Memoire, Vol. 11, 1978, pp. 510–528.
[20] Wattanasetpong J., Charoenvaravut P., and Laosinwattana W., Downscaling Climate Models in Thailand by Artificial Neural Network Method, Thesis of Civil Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, 2015, pp. 1–326.
[21] Ruangrassamee P., Khamkong A., and Chuenchum P., Assessment of Precipitation Simulations from CMIP5 Climate Models in Thailand, The 3rd EIT International Conference on Water Resources Engineering, in Proc. the 3rd EIT International Conference on Water Resources Engineering (ICWRE3), 2015, pp. 1–9.
[22] IPCC, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2014, pp. 2–26.