

Development of Water Stress Index for Water Resources under Changing Climate in Klang Valley

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Abstract

Malaysia has been facing water scarcity with insufficient water resources to meet the increasing water demand, especially in urbanised and developed areas. Water scarcity is mainly affected by climate condition which has controlled the availability of renewable freshwater resources and the seasonality of water supply. It is also affected by water demand which is based on population trends and socio-economic developments. The severe El Nino phenomenon occurred in 1997-1998 and 2015-2016 where precipitation decreased significantly and caused a prolonged drought. Water resources shortage due to the inability of the water supply dam to provide a sufficient amount of water has affected water supply disruption to the entire population especially in Selangor and Klang Valley. This research focused on the development of water stress index on water resources assessment under global climate change impacts in Klang Valley (Selangor, Wilayah Persekutuan Kuala Lumpur and Wilayah Persekutuan Putrajaya). Water stress is becoming more localised and should include relevant geographical and temporal dimensions in its representation. The water stress index (WSI) is used to obtain a comprehensive understanding of the current and future status of water resource conditions related to the sustainability of water resources. The research will carry out WSI analysis which indicates the ratio of water resources availability/water yield value to the water demand/water use which will gradually be increasing for 2015, 2020, 2030, 2040 and 2050 with selected 4 climate change scenarios with 15 realisations as reported in Special Report on Emission Scenarios by the Intergovernmental Panel on Climate Change, Assessment Report No. 4 (SRES IPCC AR4). Development WSI for Klang Valley is assessed to identify the potential districts that will be facing water stress in existing and future conditions due to climate change impacts. Water Stress Index (WSI) shown that Klang Valley has been experiencing extremely high and high water stress under climate change scenario (SRES A1B). The analysis indicated that the water resources availability and water yield are gradually increasing at 7% while at the same time the water demand is rapidly increasing at 16% from 2030 to 2050. Assessment of water surplus and deficit was calculated to determine the ratio of water availability against water demand. The WSI maps produced will able to assist the required adaptation measures such as the identification of alternative water resources as the supplementary water supply is necessary to ensure water security in the future. Water stress projections in relation to climate change need to be developed as a predecessor to policies and infrastructural intervention for long-term water security and sustainability.

Keywords: Water Scarcity, Water Stress Index, Climate Change Projection, Water Resources Sustainability

Introduction

Malaysia has been facing water scarcity with insufficient water resources to meet the increasing water demand, especially in urbanised and developed areas. Water scarcity is affected by climate conditions which had impacted on the availability of renewable freshwater resources and the seasonality of water supply. It is also affected by water demand which was based on population trends and socio-economic developments. The severe El Nino phenomenon occurred in 1997-1998 and 2015-2016 where precipitation decreased significantly and caused a prolonged drought. Water resources shortage due to the inability of the water supply dam to provide a sufficient amount of water has affected water supply disruption to the entire population especially in Selangor and Klang Valley.

Water Stress Index (WSI) is a useful tool to obtain a comprehensive understanding of the current and future status of water resource conditions related to the sustainability of water resources. WSI is one of the improvements on the original Falkenmark water stress index which compares per capita renewable water resources in a region with regional demand data (Falkenmark, 1989). A Water Stress Indicator (WSI) that assessing water resource supplies and recognising environmental water requirements as an important parameter of available freshwater was developed by Smakhtin, et al (2005). Total water availability is based on the Mean Annual Runoff (MAR) and estimated Environmental Water Requirements (EWR) which are expressed as long term mean annual river runoff that should be reserved for environmental purposes. Advanced water stress indicator (WSI) was developed by Pfister et al. (2009) in life cycle assessment (LCA) water impact assessment that accounts for water use based on human health, ecosystem quality and damage to resources.

The study main objective is to calculate water stress indices that are generated from existing and water projection in the context of climate change impacts on water resource, availability and demand (use) for water risk management. This research focused on the development of WSI on water resources assessment under global climate change impacts in Klang Valley (Selangor, Wilayah Persekutuan Kuala Lumpur and Wilayah Persekutuan Putrajaya). Water stress is becoming more localised and should include relevant geographical and temporal dimensions in its representation. Water stress projections concerning climate change need to be developed as a predecessor to policies and infrastructural intervention for long-term water security and sustainability. WSI was carried out to produce water scarcity assessment to identify high water use sectors and water stress by districts level.

Study Area

This research has selected Klang Valley as the study area which consisted of Selangor, Wilayah Persekutuan Kuala Lumpur (WPKL) and Wilayah Persekutuan Putrajaya (WPP) with a total area of 8,326 km². **Table 1** indicates the study area breakdown by state and district for Klang Valley. The study location map is as shown in **Figure 1**.

Table 1. Study Area Breakdown by State and Districts

State	Districts	Area (km ²)	
Wilayah Persekutuan Kuala Lumpur (WPKL)	-	243	
	Sub Total		243
Wilayah Persekutuan Putrajaya (WPP)	-	49	
	Sub Total		49
Selangor	Gombak	840	
	Petaling	885	
	Klang	573	
	Hulu Langat	1,194	
	Sepang	1,740	
	Kuala Langat	1,056	
	Hulu Selangor	484	
	Kuala Selangor	612	
	Sabak Bernam	650	
	Sub Total		8,034
TOTAL AREA			8,326

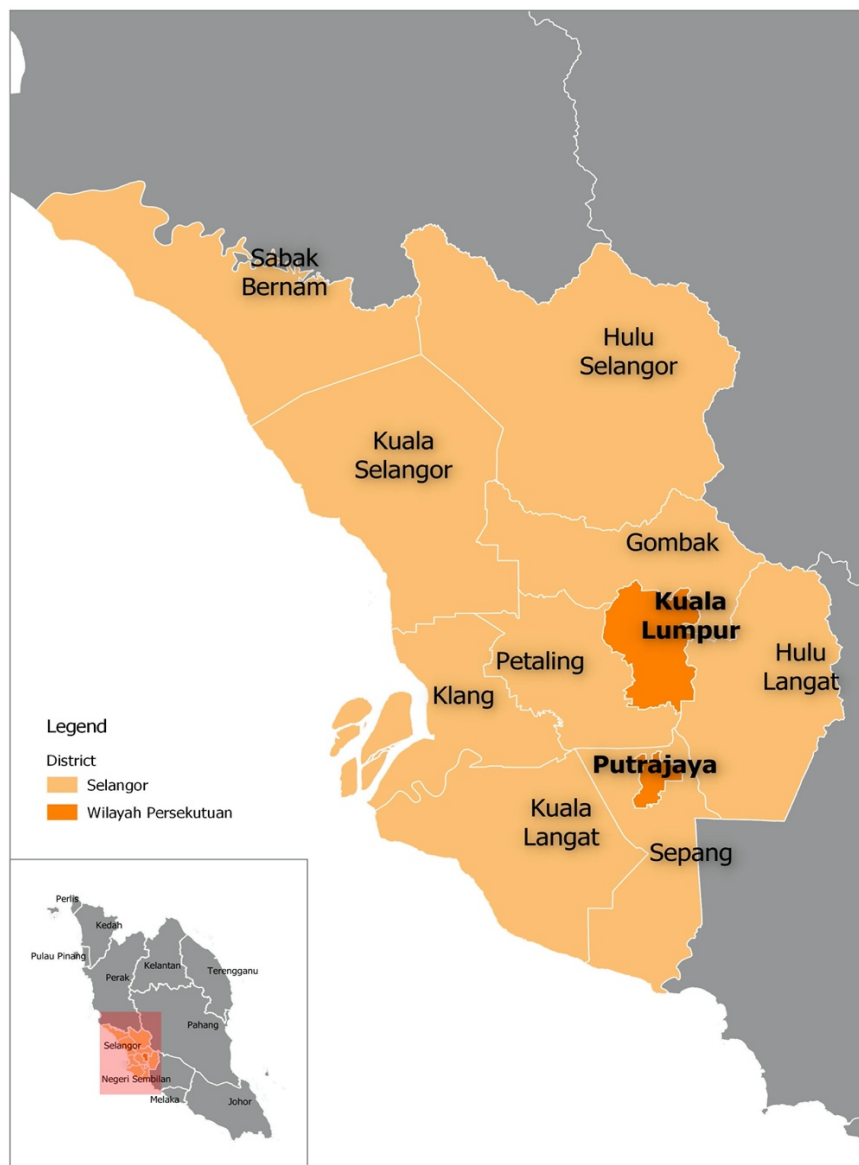


Figure 1. Study Area

Methodology

Research methodology focussed on WSI calculation for water resources and water supply, WSI calculation and assumption and lastly WSI method of assessment for water scarcity. Second, data collection and input will be focussing on the collection and review of hydrology, hydro-climate, GIS, water demand, water supply dam and water supply (water treatment plant). Third, climate change data input will be taken from NAHRIM's previous study, Regional Hydroclimate Model (REG-HCM) and Watershed Environmental Hydrology – Hydroclimate Model (WEHY-HCM). Fourth, WSI analysis that using data input from the model simulations for WSI under 3 climate change scenarios (A2, A1B, B1) for periods of 2015 – 2050. WSI results were translated into maps visualisation. Fifth and the last, assessment of WSI will concentrate on the identification of water stress areas by district and state level, water surplus deficit and main factor caused the water stress.

Water resources assessment is fundamentally a data/information collection exercise followed by the presentation of these data/information to provide value-added products on the spatial and temporal characteristics of the available water supplies and their usage. WSI assessment involves data collection and review which will provide value added products on the spatial and temporal characteristics of the available water supplies and water demand/use based on three data types which are biophysical, hydrometeorological and water use data.

The Regional Hydroclimate Model of Peninsular Malaysia (RegHCM-PM) is a mesoscale atmospheric model component and a regional land hydrology model component that was utilized in the earlier Peninsular Malaysia climate change study. Two studies have been conducted in Peninsular Malaysia by NAHRIM entitled “Study of the Impact of Climate Change on Hydrology Regimes and Water Resources (2006)” and “Extension Study of the Impact of Climate Change on Hydrology Regimes and Water Resource (2014)” to determine the expected changes in the hydrologic regime and water resources consequent to global CC and local land use changes. The extension study conducted in 2014 was based on 15 climate projections for the 21st century by 3 different coupled land-atmosphere-ocean Global Climate Models (GCMs) that are ECHAM5 of the Max Planck Institute of Meteorology of Germany, CCSM3 of the National Centre for Atmospheric Research (NCAR) of the USA, and MRI-CGCM2.3.2 of the Meteorological Research Institute of Japan under four different greenhouse gas emission scenarios (A1Fi, A2, A1B, B1). The atmospheric model component of the RegHCM-PM is a 5th generation mesoscale model (MM5) which is a non-hydrostatic model downscaled to 6km x 6km spatial resolution.

WEHY-HCM (Kavvas et al. 2012; Kure et al. 2012) is a coupled model of atmospheric and hydrologic processes at the watershed scale, based on the WEHY watershed hydrology model (Kavvas et al. 2004; Chen et al. 2004 a, b) that is coupled with the MM5 atmospheric model through the atmospheric boundary layer. The WEHY-HCM-PM consists of three components which are an atmospheric model component, a land-surface model component that includes the atmospheric boundary layer and a watershed hydrology module that includes a hill slope process model component with coupled groundwater flow-river channel flow routing model component. These processes are mutually interacting within the WEHY-HCM-PM. The MM5 atmospheric component of the WEHY-HCM is also the atmospheric component of RegHCM-PM. In order to assess the impact of climate change on the water balances and flooding conditions for Klang Valley, the physically-based, spatially-distributed WEHY watershed hydrology model was first calibrated and validated using the historical rainfall-runoff data.

WSI analysis is simulated for water availability and water demand based on hydro-climate data and projected water demand for all districts in Klang Valley. Watershed atmospheric (hydro-climate) simulation that run and assemble hydro-climate data for Klang Valley.

Simulation hydrology modelling of water availability which runs and assembles land surface hydrology data and information based on gridded data for district based WSI. Calculation of WSI with climate change scenarios (2015, 2020, 2030, 2040 and 2050) embedded for each gridded to represent each district in Klang Valley derived from projected monthly and annual rainfall/streamflow data input. Identification of Strongly Regulated Flow (SRF) for specific WSI calculation with future water demand taken from the National Water Resources Study (NWRS), 2011.

Calculation

The water stress index (WSI) is used to indicate the ratio of water consumed that deprives other users in the same watershed of water. Water stress is commonly defined by the ratio of total annual freshwater withdrawals to hydrological availability. Average Characterisation Factor (CF) is the selected method used to assess total impacts of water consumption within a region/district level and to characterize the impact of an activity proportionally to the impact of total water consumption. The effects of consumptive water demand as a function of total water availability as shown in **Equation 1**. Water to availability ratio (WTA) is initially calculated for each gridded in district i , which is a fraction of available water (WA) used (WU) by each sector j . Critical ratio is known as moderate and severe water stress within threshold ranging between 20% to 40% (Alcamo et. al. 2000). Expert judgements and thresholds for severe water stress might vary from 20% to 60% (Alcamo et al. 2000) if local conditions are accounted for. Calculation of WSI is based on a ratio of WTA with more than 10,000 individual watersheds described in WaterGAP2 global model (Alcamo et al. 2003) was used. This data is based on annual averages but both monthly and annual variability of precipitation may lead to water stress changes during specific periods.

$$WTA_i = \frac{\sum_j WU_{ij}}{WA_i} \quad \text{Equation 1}$$

WTA calculated for each districts in order to account for variation in monthly and annual flows by applying a weighting factor. The weighted WTA is marked as WTA* and the WSI is calculated as in **Equation 2**.

$$WSI = \frac{1}{1 + e^{-6.4WTA^*} \left(\frac{1}{0.01} - 1 \right)} \quad \text{Equation 2}$$

WTA* is defined by flow regulation by dams (strong regulation flow, SRF) and without dams (non-SRF); $WTA^* = \sqrt{VF} \times WTA$ (for SRF) and $WTA^* = VF \times WTA$ (for non-SRF). The WTA* is established in order to address the variation of water availability affecting water stress level. Thus, precipitation variation (Variation Factor, VF) and flow regulation are taken into account in Pfister's method. WSI indicated that the minimal water stress as 0.01. the distribution curve is adjusted to result in WSI 0.5 for WTA of 0.4 in order to show the threshold between moderate and severe water stress as the median value. Any WSI value with greater 0.5 is considered as a severely stressed area.

Results

In the context of the Water Stress Index (WSI), the approach developed by Stephen Pfister was used to construct the district-based water stress indices utilising projected water yield and water demand that is possibly impacted by climate change conditions. WSI is defined as an index calculated based on Stephen Pfister's model to represent the level of water stress in a specific area using a ratio of total water demand or consumption against water yield or availability (Brown et.al, 2011). The future water yields based on simulated future runoff as produced from the WEHY model have been analysed for four different gas emissions scenarios (B1, A1B, A2 and A1FI) by means of an average of 14 projections (A1B, A2 and B1), average A1B, average A2 and average B1 for period 2010 – 2100.

This study calculated WSI that covers the complete spectrum of future greenhouse emissions scenarios based from the best possible scenario of Special Report on Emissions Scenarios (SRES) B1 to the worst-case scenario SRES A1FI, while also including the scenarios SRES A1B (most likely), and SRES A2 (second worst) in order to account for the uncertainty in the future greenhouse emissions. The results selected to be presented in this paper is under the SRES A1B as it showed moderate impact which is most likely to be experienced in Malaysia under future climate change condition.

The water yields for climate change condition of average A1B of 2030 and 2050 for Klang Valley was shown in **Figures 2**. It can be observed that these maps shown similar water yield maps as the difference value is considered small. The water yield assessment result is tabulated in **Table 2**. Future water yields under climate scenario of average A1B for 2030 and 2050 is projected for all the districts in Klang Valley with total of 25,670 MLD and 27,377 MLD respectively. In 2050, water yield for A1B scenario is projected to increase for 7% amounted 1,707 MLD compared to 2030. Generally, the projected water yield for all districts in Wilayah Persekutuan and Selangor showed an increasing trend (more water) for all districts ranging from 11% to 4% of future water availability.

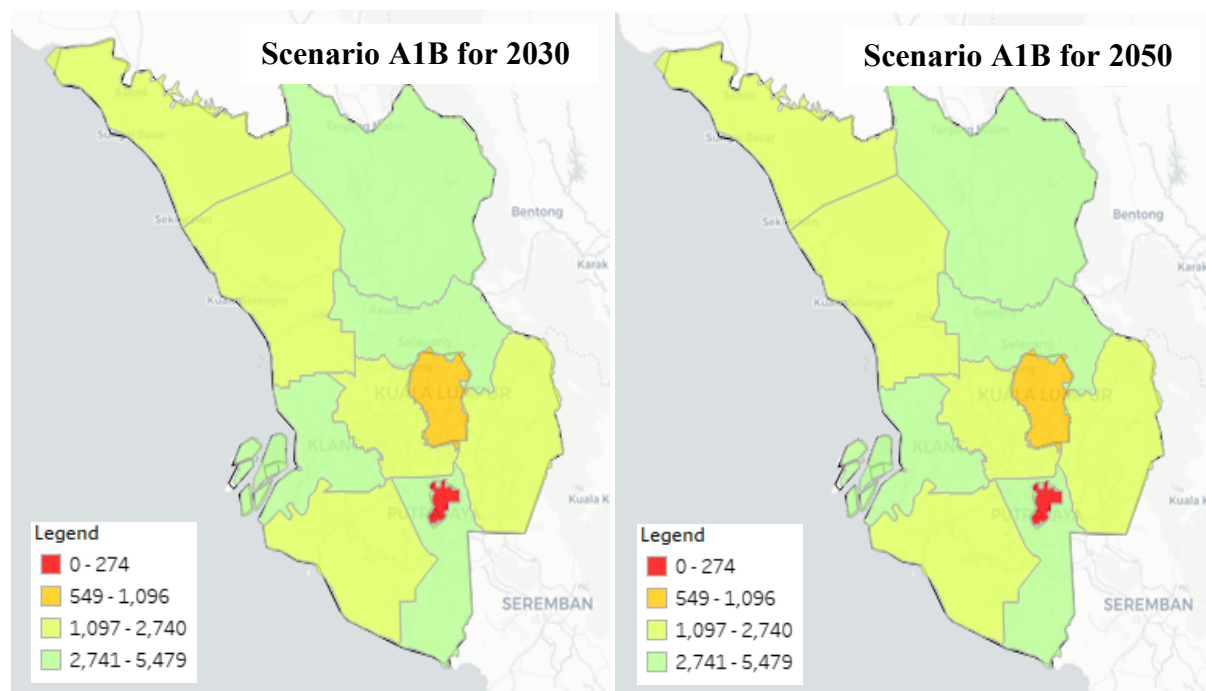


Figure 2. Water yield map produced under climate change scenario A1B for 2020 and 2050.

Table 2. Water yield assessment under future scenario of A1B for 2030 and 2050

State	District	Water Yield (MLD)			
		A1B			
		2030	2050	Diff	Diff (%)
Selangor	Sabak Bernam	1,667	1,850	183	11%
	Petaling	2,223	2,307	84	4%
	Kuala Selangor	2,345	2,553	208	9%
	Klang	3,672	3,859	187	5%
	Hulu Langat	2,255	2,416	161	7%
	Gombak	2,886	3,024	138	5%
	Kuala Langat	1,320	1,417	97	7%
	Hulu Selangor	3,466	3,705	239	7%
	Sepang	4,762	5,118	356	7%
SUB TOTAL		24,596	26,249	1,653	7%
Wilayah Persekutuan	Putrajaya	112	121	9	8%
	Kuala Lumpur	962	1,007	45	5%
SUB TOTAL		1,074	1,128	54	5%
TOTAL		25,670	27,377	1,707	7%

Figure 3 and Table 3 indicated water use/water demand projection maps for future scenario (average A1B) for 2030 and 2050 with total demand amounted 8,003 MLD and 9,251 MLD consists of domestic, industrial, irrigation, livestock and non-revenue water (NRW) with an increment of 16% that is equal to 1,247 MLD. Most of the districts showed increased in the total water demand consists of domestic, industrial, irrigation, livestock and non-revenue water (NRW) ranging from 11% to 29%. Two districts, Hulu Langat and Putrajaya were assessed to experience highest water demand (29%) due to development of Putrajaya as government administration centre which increased residential rate as Hulu Langat and Sepang is the adjacent districts closest to Putrajaya. It is also obvious to find that Hulu Selangor and Petaling district will be experiencing a rise of demand under industry and domestic sector in 2050 with 26% and 255 increments respectively. It was detected that 2 districts (Sabak Bernam and Kuala Selangor) that experiencing decreased for 10% and 2% respectively in comparison from the year 2030 to 2050 due to reduction in water demand projection for irrigation scheme of paddy plantation under Integrated Agricultural Development Authority - Barat Laut Selangor (IADA-BLS).

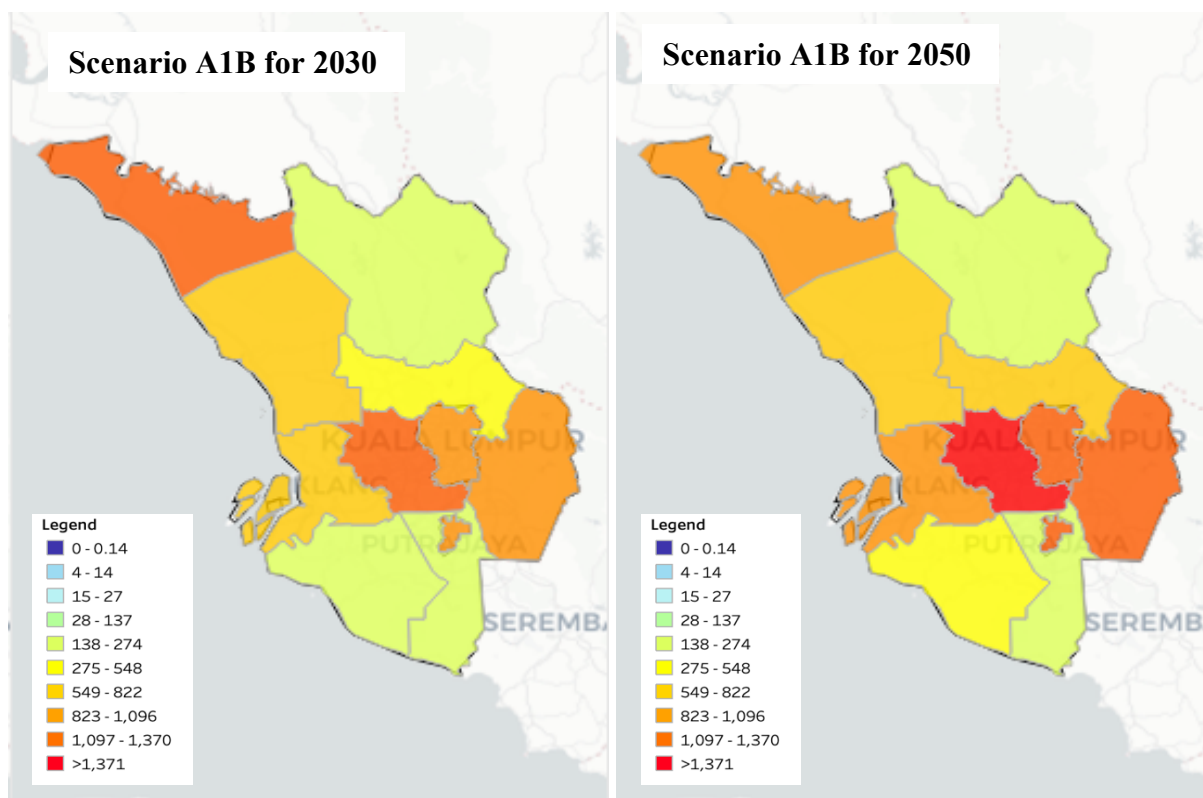


Figure 3. Projected water demand map produced for climate change scenario A1B for 2020 and 2050.

Table 3. Water demand assessment under future scenario of A1B for 2030 and 2050

State	District	Water Demand			
		MLD			
		2030	2050	Diff	Diff (%)
Selangor	Sabak Bernam	1,166	1,045	-121	-10%
	Petaling	1,296	1,619	323	25%
	Kuala Selangor	622	609	-13	-2%
	Klang	774	904	130	17%
	Hulu Langat	980	1,267	288	29%
	Gombak	527	623	96	18%
	Kuala Langat	241	289	48	20%
	Hulu Selangor	206	259	53	26%
	Sepang	193	240	47	24%
SUB TOTAL		6,005	6,855	850	14%
Wilayah Persekutuan	Putrajaya	963	1,245	282	29%
	Kuala Lumpur	1,036	1,152	116	11%
SUB TOTAL		1,999	2,396	397	20%
TOTAL		8,003	9,251	1,247	16%

The constructed district-based WSI for the respective districts and time horizons are divided into five stress categories namely, low (< 0.1) presented in green; medium-low (0.1 - 0.2); moderate (0.2 - 0.5); high (0.5 – 0.8) and extremely high (> 0.8). Most of the high and extremely high WSI are located in the districts particularly in urban and high populated and also industrial/irrigation areas.

The produced WSI maps for 2030 and 2050 under climate change scenarios (A1B) is shown in **Figure 4**. Most of the high and extremely high WSI are located in the districts particularly in urban and high populated and also industrial/irrigation areas. **Table 4** showed that there is a slight increase in WSI value for all the districts. In 2030, Kuala Lumpur, Putrajaya and 7 districts in Selangor (Sabak Bernam, Petaling, Kuala Selangor, Klang, Hulu Langat, Gombak and Kuala Langat) fall under extremely high category with Kuala Langat and Hulu Selangor placed under the high category. Sepang is the only district that fall under moderate. In 2050, Wilayah Persekutuan (Kuala Lumpur and Putrajaya) and 6 districts in Selangor (Sabak Bernam, Petaling, Kuala Selangor, Klang, Hulu Langat and Gombak) identified under extremely high category with 3 districts (Kuala Langat, Hulu Selangor and Sepang) grouped under high category. In 2030 and 2050, the average WSI value is 0.92 with all districts fall under extremely high category except for Kuala Langat, Hulu Selangor and Sepang. This can be considered that Klang Valley is experiencing extremely high WSI in the context of water availability to water demand under district-based level.

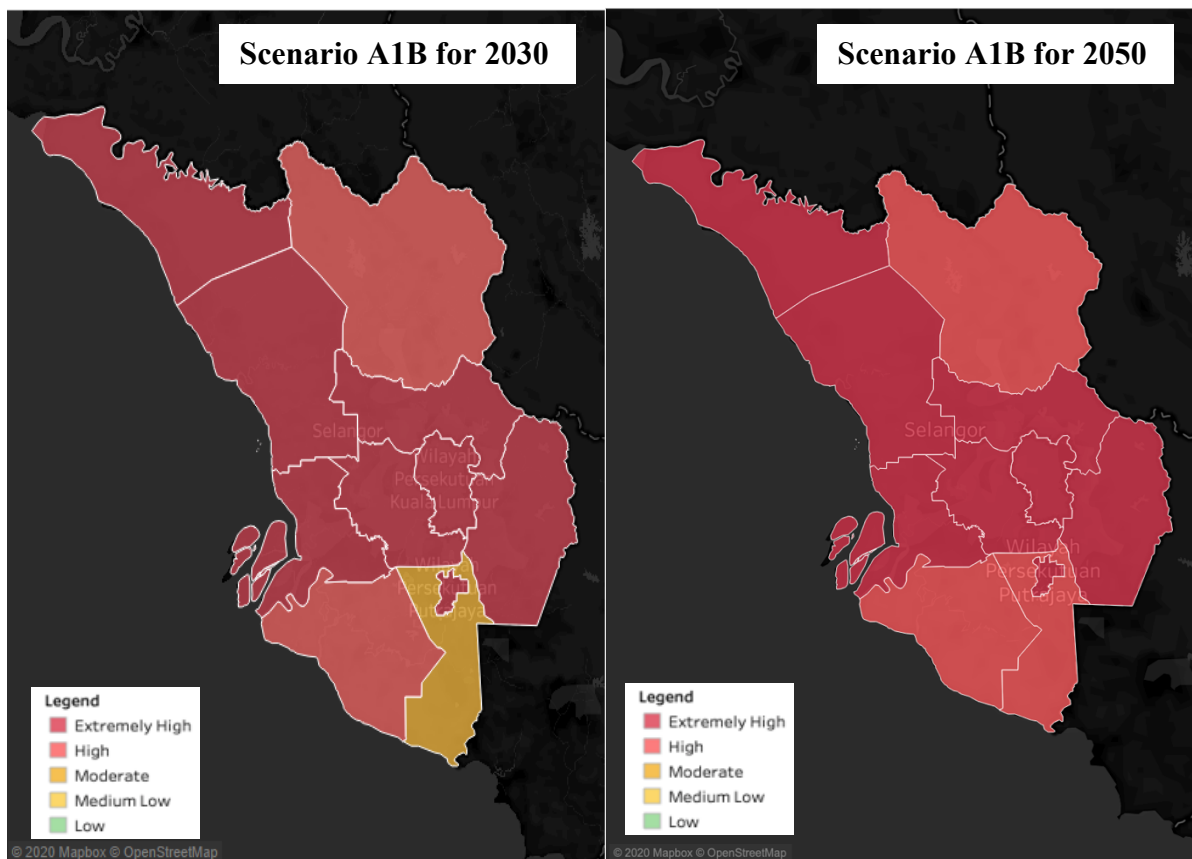


Figure 4. WSI map produced under climate change scenario A1B for 2020 and 2050.

Table 4. WSI assessment under future scenario of A1B for 2030 and 2050

State	District	WSI	
		A1B	
		2030	2050
Selangor	Sabak Bernam	1.00	1.00
	Petaling	1.00	1.00
	Kuala Selangor	1.00	1.00
	Klang	0.96	0.97
	Hulu Langat	1.00	1.00
	Gombak	0.93	0.93
	Kuala Langat	0.63	0.70
	Hulu Selangor	0.53	0.53
	Sepang	0.49	0.50
SUB TOTAL		0.84	0.85
Wilayah Persekutuan	Putrajaya	1.00	1.00
	Kuala Lumpur	1.00	1.00
SUB TOTAL		1.00	1.00
TOTAL		0.92	0.92

Conclusions

Sustainable Development Goals (SDGs) Target 6.4 addresses water scarcity by measuring water use efficiency (Indicator 6.4.1) and measuring the level of water stress (Indicator 6.4.2) This research study was carried out to produce water scarcity detailed analysis to identify high water use sectors and water stress by districts and watershed level. Water scarcity in Klang Valley can be identified by assessment of WSI developed under district level.

Assessment of WSI in Klang Valley with 8 out 11 districts fall under extremely high stress indicated that the study area is facing serious water scarcity by districts level. It showed that projected water availability increased just small increment of 7% under A1B climate change scenario compare to the increment of water demand which is doubled bringing up the value to 16% from 2030 to 2050. The remaining 3 districts (Kuala Langat, Hulu Selangor and Sepang) fall under high stress category under the same time horizons and climate change scenario. It is identified that high WSI in Sabak Bernam would affect the irrigation water availability for Integrated Agricultural Development Authority - Barat Laut Selangor (IADA-BLS) irrigation scheme. As for Hulu Langat and Putrajaya with the highest increase in water demand with 29% from 2030 to 2050 due to escalation of projected domestic and industrial sectors water demand.

It was concluded that WSI has shown that Klang Valley has been experiencing water stress and will be more significant in the future. Assessment of water surplus and deficit was calculated to determine the ratio of water availability against water demand. The analysis indicated that the water resources availability and water yield are gradually increasing while at the same time the water demand is rapidly increasing aligning with urban development. Therefore, the needs to identify alternative water resources as the supplementary water supply for non-potable use is necessary to ensure the water security in future.

Development of WSI can be improved by updating the gridded hydrological model with temporal and spatial aggregation; including both surface and groundwater resources for water availability; aggregating to different geographic scales such as district/country scale, aquifer scale and watershed / hydrological sub basins scale.

The WSI maps produced will be able to assist the required adaptation measures such as the identification of alternative water resources as the supplementary water supply is necessary to ensure water security in the future. Integrating CC impacts into risk management and other strategic planning activities in the public and private sector organisations are essential to adapt CC in the water and related sectors. It could be realised through early planning, best use of available information and modify existing planning mechanisms towards climate resilience as well as the strong political will to adapt CC factors in socio-economic development.

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