Intl. J. River Basin Management Vol. 14, No. 1 (March 2016), pp. 65–73

Research paper

Assessment of future water availability under the changing climate: case study of Klang River Basin, Malaysia

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ABSTRACT

This study aims to assess future water deficit and availability in Klang valley in the context of climate change. A surface water budget model for Klang river basin was developed using MIKE BASIN. The parameters for the Nedbør-Afstrømnings (NAM) model were determined and examined by trial-and-error approach and evaluated based on correlation coefficient (R), Nash–Sutcliffe efficiency (R_{NS}), and overall water balance error (WB_{er}). The climate change scenario assessment used downscaled projected future rainfall data from 18 Global Circulation Models for the period 2046–2065. The assessment of water availability was carried out for Klang Gates Dam. The calibration and validation results for NAM model were satisfactory. The reservoir model verification result showed that the observed and simulated dam level were slightly dissimilar, which may be due to insufficient input data, particularly rainfall data as rainfall stations were very sparse upstream of the dam. The water deficit analysis for 2046–2065 showed that there will be water shortage in most of the months. The results of this assessment will help decision-makers evaluate the water availability and existing water infrastructure capacity in the vicinity of Klang river basin, particularly with respect to future raw and treated water yield.

Keywords: Water availability; reservoir modelling; climate change; Global Circulation Model (GCM)

1 Introduction

The changing climate poses an enormous challenge globally. According to Intergovernmental Panel on Climate Change (Stocker *et al.* 2013), climate change will impact global water cycle, with greater disparity between wet and dry regions and also wet and dry seasons. In the year 1998, Klang valley region, the most urbanized region in Malaysia, was hit by an unprecedented (at that time) drought despite being situated in tropical rainforest climatic region with abundant rainfall. Most recently, from the month of February–April 2014, another extreme drought event has caused water shortage throughout the states of Selangor and Negeri Sembilan. Reservoirs in the two states were drying up and the water levels dipped to critical levels, forcing the water supply operators to impose water rationing exercise starting from February and ending in April 2014. The impact of these extreme drought events on the most densely populated region in Malaysia necessitates study on water resources availability in this region, particularly in the context of climate change.

According to the National Water Resources Study 2000–2050 (EPU 2000), the state of Selangor is expected to experience increasing water deficit. Dams and interstate water transfer scheme were proposed to meet the rising demand. In the following report, the Review of the National Water Resources Study 2000–2050 (DID 2011), a few of these projects were completed – such as the Selangor Dam – while some were and currently are still under construction, such as the Pahang–Selangor water transfer scheme. Climate change will also impact on the availability of water resources in the region (NAHRIM 2006, 2014, Kabiri *et al.* 2015). Various studies used hydrologic models and GCM data to assess the impact of climate change on water resources (Conway and Hulme 1996, Wurbs *et al.* 2005, Christensen and Lettenmaier 2007, Shaaban *et al.* 2011, Cox *et al.* 2012, Milano *et al.* 2013). For impact studies, coarse-resolution GCMs are required to be downscaled to fine-

Received 21 November 2014. Accepted 28 June 2015.

ISSN 1571-5124 print/ISSN 1814-2060 online
http://dx.doi.org/10.1080/15715124.2015.1068178
http://www.tandfonline.com

resolution or catchment scale (Wilby and Wigley 1997). Fundamentally, there are two methods of downscaling – statistical and dynamical. The selection of the method depends upon a variety of factors, such as the objective of the study, the parameter of interest, available computation power, data requirement, and the location of study area (Murphy 1999). For Klang valley region, based on climate projections, annual rainfall in this region is expected to decrease up to 5% (MNRE 2011). Simulation of future river flows, based on various GCM data, indicates a lower baseflow for dry seasons during most of twenty-first century (NAHRIM 2006, 2014, Shaaban *et al.* 2011).

For the simulation of water supply and assessment of water availability, water balance models such as Water Evaluation and Planning System (Raskin *et al.* 1992) and Mike Basin (DHI 2006a) were utilized. Mike Basin, developed by Danish Hydraulic Institute (DHI), was used as a decision-support tool for integrated water resources management and planning (Jha and Gupta 2003, ProGea 2003, DHI 2006b). The rainfall–runoff model within Mike Basin, known as the Nedbør-Afrstrømnings (NAM) model, is a lumped conceptual model (Nielsen and Hansen 1973), which were used by a number of studies for runoff simulation (Lørup *et al.* 1998, Madsen 2000, Vaitiekuniene 2005, Smith and Rodgers 2010, Doulgeris *et al.* 2011). DHI (2008) developed a surface water budget model for McKenzie River Basin in western Oregon using Mike Basin. This model provided a quantitative assessment of water distribution and allocation within the basin. Smith and Rodgers (2010) developed an Ord River Mike Basin water balance model for Western Australia's Department of Water to prepare operating strategy for current conditions and future scenarios.

This study aims to assess the potential impact of climate change on water availability for Klang Valley region and the adequacy of current water supply infrastructures to meet future water demand. This study is conducted in two phases. In the first phase, the assessment is focused solely on Klang Gates Dam as pilot study. The second phase of the study will be more comprehensive, including assessment of all seven water supply dams (Selangor, Tinggi, Batu, Klang Gates, Semenyih, Langat, and Tasik Subang) serving the entire population of Klang metropolitan region. These assessments will be able to assist in the future planning for development and adaptation measures in the context of climate change impact.

2 Background

Klang valley metropolitan area comprises the capital city of Kuala Lumpur, the administrative capital of Putrajaya, and the districts of Petaling, Hulu Langat, Gombak, and Klang of the state of Selangor. The current population in this region is 7.2 million and is projected to reach 10 million by year 2020. The rapid development is expected to put immense pressure on water supply in this region. In DID (2011), water demand was projected to increase 1194 MLD from 2015 up to year 2050 for Gombak, Klang, Petaling, and Kuala Lumpur.

Klang valley experiences equatorial climate, with an average annual rainfall of 2300 mm. Despite the abundant rainfall, Klang valley is vulnerable to extreme drought events, as seen in the 1998 and the most recent early 2014 water crisis. There are a total of seven dams serving the population in Klang Valley. The two dams operating within Klang river basin, which are Klang Gates Dam and Batu Dam, supply water for Gombak, Klang, and Petaling districts, and the Federal Territory of Kuala Lumpur.

2.1 *Description of study site*

Klang Gates Dam is situated in the north-eastern part, as shown in Figure 1. The catchment area for Klang Gates Dam is covered by forest, namely the Ulu Gombak Forest Reserve. The terrain in this area is mostly hilly, with altitude of up to 1200 m ASL. Tributaries of Klang river, such as Sungai Seleh, Sungai Pemulas, and Sungai Songlai, flow into Klang Gates reservoir. Total area of the catchment is about 76 km^2. Water from the reservoir is channelled by gravity to Bukit Nanas and Wangsa Maju Water Treatment Plant (WTP). The Bukit Nanas WTP has a design capacity of 145 MLD, while Wangsa Maju WTP's design capacity is 45 MLD. In the case of water shortage in Klang Gates Dam, Wangsa Maju WTP will draw water from Sungai Gombak. The dam has two functions. The main purpose is for water supply, operated by Puncak Niaga Sdn. Bhd.; the secondary purpose is for flood control by Drainage and Irrigation Department (DID). The total reservoir capacity is 32 MCM.

3 Methodology

3.1 *Mike Basin*

To simulate water yield for Klang Gates reservoir, this study used Mike Basin. In general, it can be used to simulate and assess the allocation and abstractions of water for irrigation, domestic and industrial water supply, and also for energy production, flooding, navigation, and environmental constraints at any location of interest. For rainfall–runoff modelling, embedded NAM model was utilized.

Daily observed rainfall, evaporation, and streamflow data were acquired from DID. Rainfall stations with more than one decade of complete observed data were selected. The locations of the selected stations are shown in Figure 1. Boundary of Klang river catchment was delineated to outlet point at the DID streamflow station located at Jambatan Sulaiman at Klang River (station number 3116430). It has been chosen for the purpose of rainfall–runoff model calibration and validation. The total catchment area up to the station is approximately 466 km^2. The subcatchments within were delineated according to locations of reservoir outlet points and other points of interest. The mean areal rainfall for each subcatchment was estimated by using arithmetic average for stations within and nearest to the subcatchments.

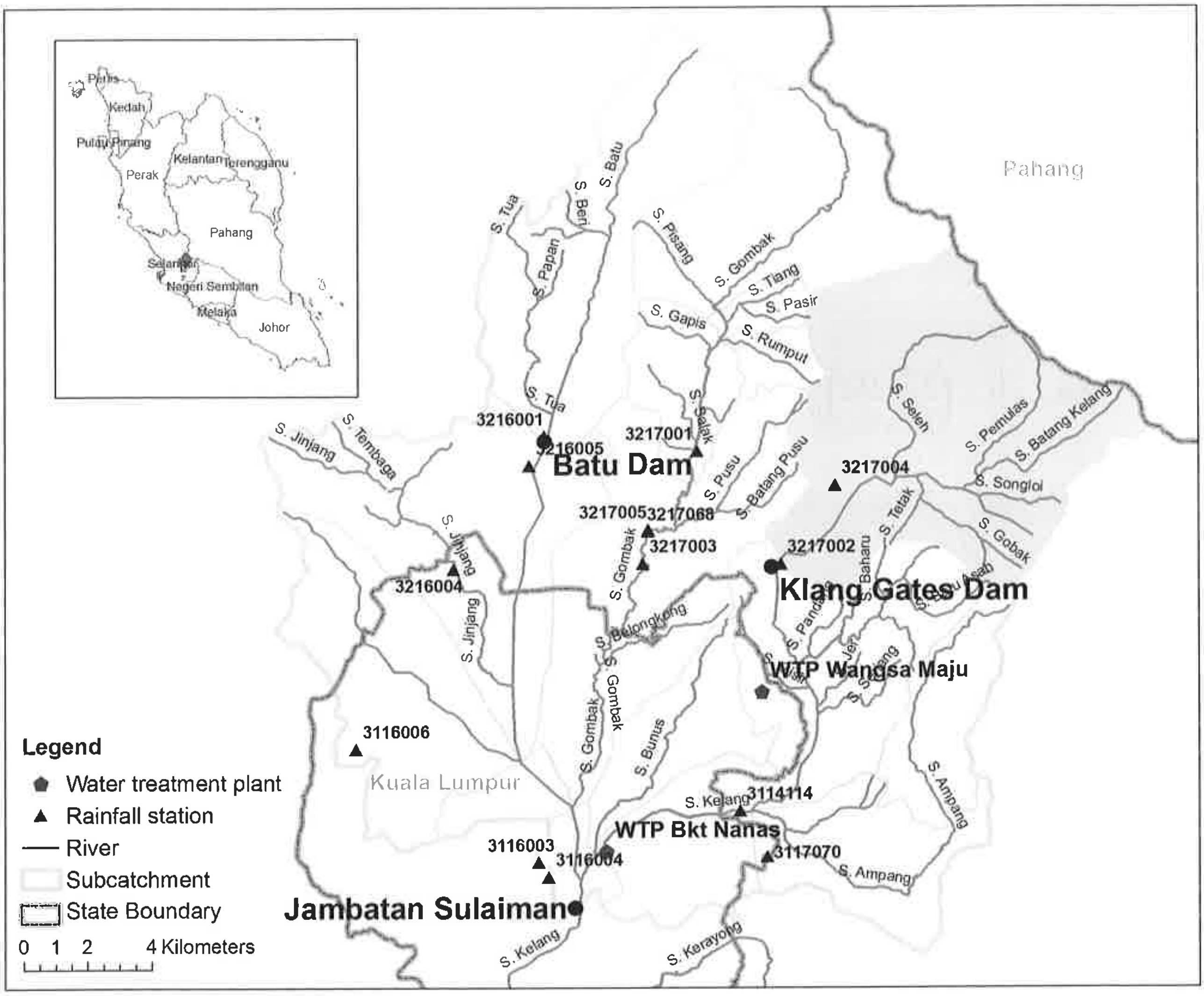

Figure 1 Location of study area, with Klang Gates Dam catchment in grey shade. Several points of interest and the rainfall stations used in this study are shown here.
Source: Department of Survey and Mapping Malaysia, 2007.

Klang Gates Dam's operational data, dam characteristics, and water demand data were obtained from Puncak Niaga Sdn. Bhd. for use in reservoir modelling. To focus on the effects of climate change on water supply, we assumed the water demand to be constant.

The Mike Basin model for the studied catchment was schematized based on geospatial data of the subcatchment, river network, streamflow station, and dam location. Hydro-meteorological data and physical catchment characteristics data or parameters are main inputs for the rainfall–runoff model. The model output, coupled with reservoir and water demand data, was used for reservoir modelling.

3.2 *Rainfall–runoff model*

For NAM hydrological model calibration, observed streamflow data for the period of 1 September 1996 to 31 January 1998 was chosen, while model was validated using data from 1 February 1998 to 31 December 2000. These periods were chosen based on the availability of the most complete observed streamflow data. A total of 22 parameters in the NAM model were calibrated based on each subcatchment's characteristics. Parameters which were found to be more sensitive were further adjusted manually by trial and error (Madsen 2000). The initial test runs showed that the simulated hydrograph shape was sensitive towards changes in the overland flow runoff coefficient (CQOF), maximum water content in root zone storage ($L_{\max}$), time constant for routeing baseflow (CKBF), and baseflow (BF). CQOF was determined based on the land use in each subcatchment, and BF was determined from historical flow records. These four parameters were further fine-tuned for optimal results.

The performance of the NAM model was evaluated by three criteria (Doulgeris *et al.* 2011): overall water balance error (WB_{er}), correlation coefficient (R), and the Nash–Sutcliffe efficiency (R_{NS}) (Nash and Sutcliffe 1970). The formulas are

Table 1 Mike Basin reservoir model input data

Data	Value	Operational data	Value
Water demand (m^3/s)	2.2 (190 MLD)	Minimum operational level (m)	84
Dam characteristics		Flood control level (m)	95.16
Dam crest level (m)	97.87	Minimum release requirement (m^3/s)	0.32
Top of dead storage level (m)	80	Maximum spillway discharge (m^3/s)	376.6
Bottom level (m)	70.5	Initial water level (m)	94.2

listed in Eqs 1–3:

$$\mathrm{WB}_{\mathrm{er}} = \left|1 - \left(\frac{\sum_{i=1}^{N} Q_{\mathrm{s},i}}{\sum_{i=1}^{N} Q_{\mathrm{o},i}}\right)\right|, \tag{1}$$

$$R = \left(\frac{\sum_{i=1}^{N}(Q_{\mathrm{o},i} - \overline{Q_{\mathrm{o}}})(Q_{\mathrm{s},i} - \overline{Q_{\mathrm{s}}})}{\sum_{i=1}^{N}(Q_{\mathrm{o},i} - \overline{Q_{\mathrm{o}}})^2 \sum_{i=1}^{N}(Q_{\mathrm{s},i} - \overline{Q_{\mathrm{s}}})^2}\right), \tag{2}$$

$$R_{\mathrm{NS}} = 1 - \left(\frac{\sum_{i=1}^{N}(Q_{\mathrm{o},i} - Q_{\mathrm{s},i})^2}{\sum_{i=1}^{N}(Q_{\mathrm{o},i} - \overline{Q_{\mathrm{o}}})^2}\right), \tag{3}$$

where $Q_{o,i}$ is the observed discharge at time i, $Q_{s,i}$ is the simulated discharge at time i, $\bar{Q}_o$ is the mean observed discharge, $\bar{Q}_s$ is the mean simulated discharge, and N is the total number of time steps. The nearer WB_{er} value is to zero, and the values of R and R_{NS} to unity, the better is the performance of the model.

3.3 *Reservoir model*

The Mike Basin reservoir storage model operates by the principles best described by Eq. 4 (Jensen and Marker 2010):

$$\text{Storage}(S_t) = \text{Initial storage}(S_{t-1}) + \text{inflow}(I_t) - \text{releases}(R_t) - \text{spill}(s_t) - \text{losses}(L_t). \tag{4}$$

Klang Gates Dam operates by operational rule curve. The magnitude of water supplied to WTPs differ according to different times or seasons in a year and the level of water in the dam at that particular time. Flood control rule curve indicates the amount of water to be released according to the rate of the rise of water level at the reservoir or the inflow rate (Wurbs 1991). Unfortunately, flood control rule curve for Klang Gates Dam was not available. The reservoir model was verified by comparing observed dam level from year 1997 to 2011 to simulated dam level. Table 1 listed the input data required for Mike Basin reservoir model. All dam data available is sourced from Puncak Niaga

Table 2 Total future monthly rainfall for Klang Gates subcatchment

	Total monthly rainfall (mm)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual
2046	74.8	127.4	160.9	192.9	206.1	163.8	210.4	223.2	282.9	305.8	321.9	212.7	**2482.8**
2047	63.9	130.0	165.0	193.2	259.7	138.3	160.8	266.4	314.0	317.2	331.9	178.6	**2518.9**
2048	89.4	125.4	142.5	219.2	196.6	170.2	195.3	243.0	282.5	354.5	305.1	268.1	**2591.7**
2049	64.9	101.1	215.7	237.5	257.5	166.9	257.9	270.5	259.2	303.5	298.6	222.2	**2655.6**
2050	45.8	97.6	141.9	237.2	263.3	139.2	226.5	239.3	315.5	275.9	311.9	184.8	**2478.9**
2051	84.8	109.2	191.8	223.9	247.8	181.3	218.1	265.1	245.9	370.9	369.6	281.2	**2789.5**
2052	91.5	235.6	211.9	193.9	279.9	184.8	195.7	237.8	253.3	290.6	365.2	181.2	**2721.4**
2053	36.6	119.3	113.2	179.0	277.6	160.6	248.3	296.7	261.7	306.9	315.8	184.0	**2499.6**
2054	70.1	139.5	169.2	221.7	275.5	159.0	182.2	368.4	334.2	331.4	367.2	248.4	**2866.7**
2055	91.7	183.4	190.4	235.7	213.5	124.0	195.3	244.6	337.9	281.3	303.5	196.8	**2598.0**
2056	108.0	145.8	209.3	198.2	282.7	165.9	167.0	243.0	290.6	237.5	398.4	226.3	**2672.6**
2057	64.7	99.5	280.6	235.1	257.1	183.2	202.7	288.4	354.9	331.2	303.0	243.4	**2843.9**
2058	133.1	127.5	177.0	219.0	249.7	165.1	182.5	280.7	365.0	332.7	432.3	227.2	**2891.7**
2059	86.6	171.1	194.2	217.5	224.2	203.2	216.8	262.5	346.5	366.2	340.3	169.7	**2798.7**
2060	109.9	162.9	237.3	231.1	287.9	128.0	226.4	288.4	314.0	320.1	365.2	252.0	**2923.1**
2061	60.1	134.5	162.4	199.6	252.7	159.2	196.8	230.9	281.8	290.8	321.5	214.3	**2504.7**
2062	67.4	105.4	182.4	198.4	270.7	160.4	206.6	251.6	374.8	315.0	346.1	216.9	**2695.6**
2063	79.4	89.0	146.9	233.4	243.2	153.0	192.1	275.6	330.4	338.5	280.2	253.4	**2615.1**
2064	114.5	220.3	155.0	207.0	270.5	199.9	180.7	249.9	351.5	320.8	330.3	180.8	**2781.1**
2065	72.8	199.8	166.4	169.2	278.2	150.7	218.8	331.3	278.6	295.3	318.6	214.7	**2694.4**
Mean	**80.5**	**141.2**	**180.7**	**212.1**	**254.7**	**162.8**	**204.0**	**267.9**	**308.7**	**314.3**	**336.3**	**217.8**	**2681.2**

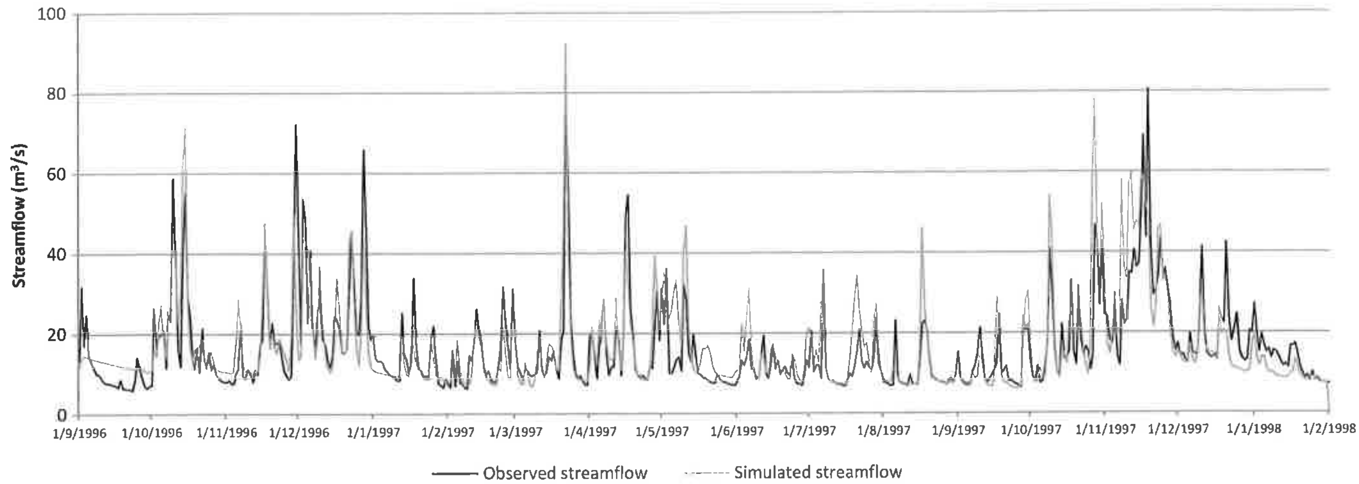

Figure 2 Comparison of observed and simulated streamflow at DID station 3116430 for calibration period.

Sdn. Bhd. and Gibson and Dodge (1983). In this study, an initial water level of 94.2m is assumed. This value was derived from the average of the observed dam level from 1997 to 2011.

3.4 *Future rainfall*

This study used projected rainfall data derived from 18 GCM output of Coupled Model Inter-comparison Project 3 (CMIP3) (Meehl *et al.* 2007) from Data Integration and Analysis System developed by University of Tokyo. The projection was based on SRES (Special Report on Emissions Scenarios) (Nakićenović *et al.* 2000) A1B, which placed balanced emphasis on all energy sources. A statistical bias-correction and downscaling technique (Nyunt *et al.* 2012) was used to transform large-scaled GCMs of climate parameters to regional-scaled projection for this study. An ensemble average of the 18 GCMs for the future daily rainfall data projected from year 2046 to 2065 (20 years) was used as input to the MIKE Basin reservoir model. The future monthly rainfall data for Klang Gates subcatchment is shown in Table 2.

4 Results and discussion

4.1 *Rainfall–runoff modelling*

Figures 2 and 3 show the hydrograph comparisons of observed and simulated streamflow at DID station at Jambatan Sulaiman (station number 3116430) for calibration and validation periods, respectively. For calibration, the low flows match well with the observation. However, generally the high flows follow the observed streamflow pattern which is found to be reasonable. Similar trend was present for the validation period.

Table 3 shows the results of statistical evaluation of NAM calibration and validation, carried out for both daily and monthly time step. By evaluating for different temporal scales, we are able to assess the short- and long-term water balance. The WB_{er} for calibration and validation is both well below 10%, which suggests that the long-term water balance is well represented. The R and R_{NS} values vary for different temporal scales, with improved result for monthly time step for both calibration and validation periods. All the R and R_{NS} values are

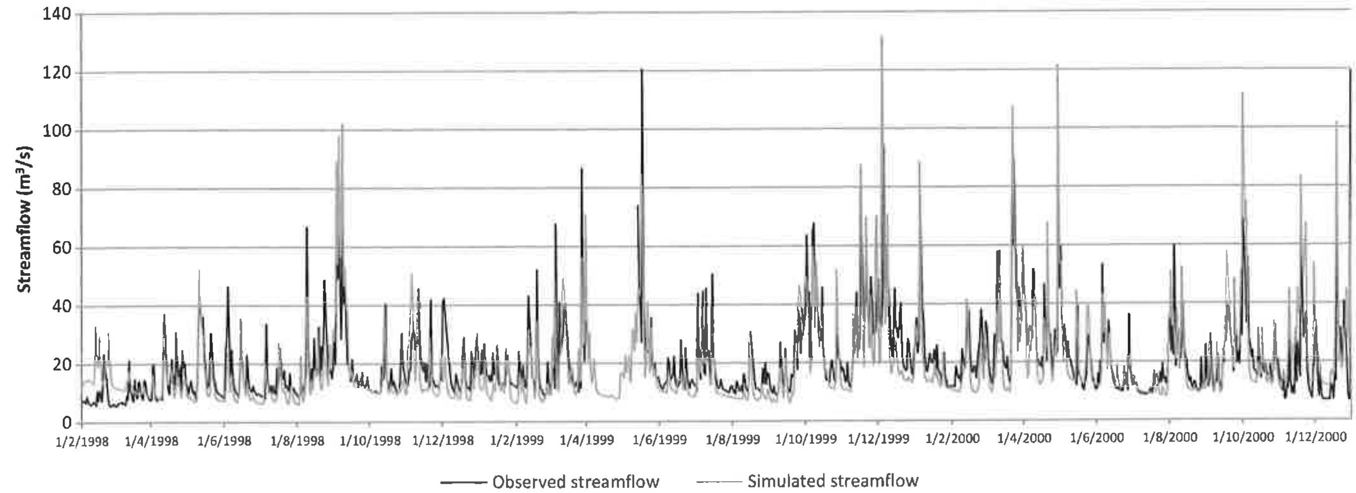

Figure 3 Comparison of observed and simulated streamflow at DID station 3116430 for validation period.

Table 3 Summary of model evaluation results for daily and monthly time steps

			Daily		Monthly	
Simulation	Time range	WB_{er} (%)	R	R_{NS}	R	R_{NS}
Calibration	1/9/1996–1/2/1998	3.91	0.79	0.56	0.91	0.79
Validation	1/2/1998–31/12/2000	5.13	0.73	0.36	0.83	0.60

within acceptable range except for R_{NS} during validation period for daily time step.

The projected average future inflow into Klang Gates Dam is presented in Table 4.

4.2 *Reservoir modelling*

Figure 4 compares the observed and simulated dam level for Klang Gates Dam from year 1997 to 2011. In general, the overall trend is similar for the observed and simulated dam level, except from 2007 to the middle of 2009, and then starting again from 2010 to 2011. At certain periods, such as the 1998 drought event, the trend or shape of the simulated dam level corresponds quite well with the observed dam level from the beginning of the year 1998 to near the end of that same year, with overestimation of the magnitude. It is observed that during the period of reservoir evaluation analysis (15 years), the simulated dam level never exceeded the flood control level of 95.16 m while the recorded dam level exceeds the level, especially after 2001. It is possible that the flood control level changed after 2001. It could also be due to the lack of flood control operational rule curve in the model, which was not provided by the dam operator, as flood control in Klang Gates Dam is under the jurisdiction of DID. However, flood storage was supposed to be empty most of the time to provide space for sudden huge inflow of water and minimize flood risk downstream. Another possibility is that human intervention caused the observed dam level to exceed the flood control level. Nevertheless, for the period of mid-2004 to the end of 2005, and also the whole of 2010, the simulation result showed overestimation. Between 2007 and the end of 2008, there are a few periods of underestimation. The reasons for the discrepancies could possibly be due to disparity between actual and modelled dam operation and also insufficient rainfall data, as only two rainfall stations are established in the upper Klang Gates Dam catchment. Overall, the shape of the simulated reservoir level follows the observed trend during certain periods.

Table 5 shows the statistical evaluation results for the reservoir simulation. The WB_{er} is found to be about 0.05%, which approached perfect ($WB_{er} \approx 0\%$). The R and R_{NS} resulted from daily time step showed that both are less than satisfactory (0.70 and 0.49, respectively), but the results for monthly time step, 0.82 and 0.84, are acceptable. This could mean that for

Table 4 Average future inflow into Klang Gates Dam

	Average inflow into dam (m^3/s)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
2046	0.849	0.661	0.542	0.848	1.131	0.931	1.265	1.715	2.859	3.484	4.305	2.919	**1.792**
2047	1.525	1.145	1.045	1.210	2.104	1.288	0.896	2.128	3.347	3.909	4.610	2.655	**2.155**
2048	1.605	1.123	0.840	1.466	1.521	1.082	1.309	2.025	2.990	4.332	4.361	3.816	**2.206**
2049	1.897	1.368	1.635	2.000	2.557	1.719	2.422	3.069	3.178	3.892	4.127	3.360	**2.602**
2050	1.602	1.138	0.854	1.416	2.245	1.052	1.811	2.147	3.559	3.448	4.192	2.728	**2.183**
2051	1.457	1.057	1.143	1.650	2.314	1.585	1.935	2.619	2.865	4.587	5.557	4.355	**2.594**
2052	2.248	2.441	2.554	2.185	3.149	2.127	1.969	2.444	2.883	3.483	5.024	2.798	**2.776**
2053	1.534	1.123	0.771	0.798	1.985	1.258	1.931	3.148	3.105	3.880	4.386	2.593	**2.209**
2054	1.590	1.233	1.069	1.572	2.579	1.564	1.325	3.864	4.444	4.694	5.745	4.033	**2.810**
2055	2.110	2.009	1.902	2.303	2.263	1.133	1.427	2.203	3.825	3.568	4.221	2.871	**2.486**
2056	1.522	1.422	1.582	1.697	2.753	1.716	1.362	2.203	3.170	2.709	5.198	3.667	**2.417**
2057	1.773	1.245	2.097	2.388	2.720	1.971	1.937	3.084	4.496	4.636	4.698	3.743	**2.899**
2058	2.535	1.630	1.496	1.924	2.465	1.545	1.453	2.667	4.443	4.606	6.521	4.101	**2.949**
2059	2.209	1.932	1.786	2.237	2.286	1.975	2.130	2.784	4.203	5.070	5.252	3.019	**2.907**
2060	1.831	1.697	2.032	2.522	3.168	1.631	2.008	3.117	3.981	4.308	5.427	4.108	**2.986**
2061	1.984	1.560	1.373	1.619	2.149	1.370	1.451	2.036	2.957	3.541	4.312	3.369	**2.310**
2062	1.590	1.115	1.026	1.346	2.251	1.327	1.617	2.273	4.445	4.399	5.082	3.695	**2.514**
2063	1.891	1.299	1.031	1.688	2.061	1.252	1.410	2.574	3.897	4.355	4.102	3.704	**2.439**
2064	2.054	2.305	1.560	1.872	2.778	2.149	1.610	2.452	4.266	4.345	4.812	2.934	**2.761**
2065	1.640	1.865	1.480	1.357	2.492	1.448	1.816	3.461	3.615	3.898	4.612	3.175	**2.572**
Mean	**1.772**	**1.468**	**1.391**	**1.705**	**2.349**	**1.506**	**1.654**	**2.601**	**3.626**	**4.057**	**4.827**	**3.382**	**2.528**

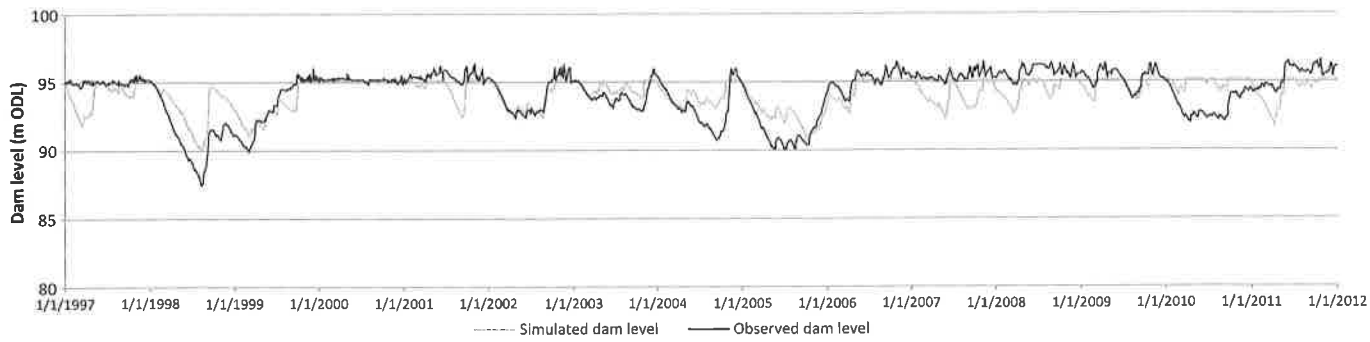

Figure 4 Comparison of observed and simulated dam level at Klang Gates Dam.

Table 5 Evaluation of Mike Basin reservoir model results for daily and monthly time steps

			Daily		Monthly	
Simulation	Time range	WB_{er} (%)	R	R_{NS}	R	R_{NS}
Reservoir model validation	1/1/1997–31/12/2011	0.05	0.70	0.49	0.92	0.84

Table 6 Summary of total monthly water demand deficit for projected period 2046–2065

	Total monthly water demand deficit (MLD)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual
2046	539	1597	1768	1712	1875	2046	2635	2799	2709	2381	1584	0	**21,645**
2047	448	1597	1412	1140	906	999	2019	2210	2138	1824	208	0	**14,901**
2048	0	1452	1357	1140	884	1376	2135	2210	2138	1907	159	0	**14,759**
2049	0	598	1071	719	88	8	994	1178	636	0	0	0	**5293**
2050	0	1376	1299	1140	807	994	1771	2206	1892	1601	0	0	**13,086**
2051	343	1597	1459	1140	455	669	1628	1768	1711	861	0	0	**11,631**
2052	0	23	0	0	0	0	0	18	72	0	0	0	**112**
2053	77	1597	1403	1613	1033	1294	2059	1827	1711	1081	0	0	**13,695**
2054	0	1195	1281	1140	390	361	1625	1767	725	0	0	0	**8485**
2055	0	59	525	484	0	14	1133	1768	1711	381	0	0	**6075**
2056	81	1489	1178	796	238	55	1232	1768	1711	1768	114	0	**10,430**
2057	0	772	1060	409	0	0	465	1178	209	0	0	0	**4094**
2058	0	41	778	713	85	74	1210	1768	1228	0	0	0	**5896**
2059	0	0	579	268	0	0	574	1178	641	0	0	0	**3239**
2060	0	623	1035	166	0	0	279	719	12	0	0	0	**2833**
2061	0	457	1131	717	394	389	1624	1994	1991	1768	52	0	**10,518**
2062	51	1593	1303	1140	722	832	1776	2161	1795	199	0	0	**11,572**
2063	0	627	1178	1066	552	659	1797	2025	1717	853	0	0	**10,473**
2064	0	0	354	686	0	0	568	1312	776	0	0	0	**3697**
2065	0	854	1138	713	353	241	1431	1691	796	0	0	0	**7217**
Mean	**77**	**877**	**1066**	**845**	**439**	**501**	**1348**	**1677**	**1316**	**731**	**106**	**0**	**8983**

monthly time step-based water balance analysis, the reservoir model is capable of producing an adequate water yield.

4.3 *Water deficit analysis*

The reservoir model simulation was run with future rainfall data from 2046 to 2065 to determine water yield adequacy in terms of water deficit. The magnitude of water availability deficit is calculated based on the reduction of water availability against the designated daily water demand, 190 MLD (2.2 m^3/s). Table 6 shows the summary of the result, where water availability deficit occurs every month except December. Mean monthly deficit shows that most of the maximum deficits occurred in the months of July, August, September, and October and minor deficit happened in February, March, and April. The months of December, January, and November have the least amount of deficits. These trends are identified to be corresponding with Malaysia's monsoonal climate. The largest total water availability deficit, or the driest year, is projected to be in the year 2046, followed by 2047. The year with the least deficit is 2052.

5 Conclusion

Projection and assessment of future water quantity or availability is imperative for policy-makers to plan around possible water supply disruptions. This study's findings suggest that in the future, it is very likely that the changing climate will cause prolonged droughts and water shortages. Most of the maximum water deficits occurred in the months of March, July, August, and September. Minimal deficits happened in November, while no water shortage happened at all in December. This suggests that there could be a workaround – for example, optimization of the water supply operational rule curve together with the flood control rule curve – to reduce incidences of water shortage. The overall results imply potential serious water shortages in the future if adaptation measures were not carried out. However, this model could still be improved. It should be noted that this study is based on the assumption that water demand remains the same in the future, and emission scenario A1B was realized. Better water management and awareness of water conservation will be able to lessen the impact of climate change on water supply. Policy-makers and water authorities will have to plan ahead for climate change adaptation and also take other non-climatic changes into account – such as the booming population and the development and expansion of urban areas – to avoid potential water crisis. The public also plays an important role as the reduction of water demand per capita will be able to lessen the stress on water resources, for now or in the future.

6 Way forward

The NAM rainfall–runoff model performance is adequate but the reservoir model in Mike Basin could be improved, particularly in terms of flood operation. To improve the efficiency of water supply and flood control operations in Klang Gates Dam, we need to further study on the optimization of the operational rule curves, by considering whether the rule curves need revision if and when the climate changes. Non-revenue water issue is also a serious concern, as currently the percentage is quite high, which points towards inefficient water management. In the next phase of this study, all dams serving the Klang Valley will be included in the analysis to give a more complete picture of future water availability and water yield in the region in order to fulfil projected water demand particularly from domestic and industrial sector. DID (2011) provides future water demand projection, which could be used for the future study. We will also use newly generated hydro-climate data for the period 2010–2100 from 15 realizations of 3 GCMs under A1B, A2, B1 and A1Fi scenarios (NAHRIM 2014). The Pahang–Selangor water transfer programme and other water supply projects (under construction or in planning) within the state of Selangor will be considered as possible scenarios. In order to inform the decision-makers or stakeholders of the reliability of this study, the uncertainties in this study will also be quantified.

Acknowledgements

We thank the DID and GEOSS/AWCI (University of Tokyo) for making their hydrological and rainfall observed and projected data available free of charge. We gratefully acknowledge Puncak Niaga Sdn. Bhd. for their willingness and cooperation in providing Klang Gates Dam operational data for this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

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