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ASSESSMENT OF WATER SUPPLY AND DEMAND IN PENINSULAR MALAYSIA

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Abstract: In 2020, there have been a lot of water shortages in the state of Selangor mainly because of pollution from surrounding tributaries, there was increase in destruction and degradation of water catchments. All these factors have resulted in the increase in water shortages in the catchment and the demand remain higher. This study serves to look into the water demand and supply issues by analyzing the trend and relationship between demand and supply of water in Langat catchment of Peninsular Malaysia, evaluating the current water availability and water demand for different sectors, such as agriculture, industry, and domestic. Using and analyzing the status of future scenarios of the water supply system and then evaluate them to make recommendations for these different future scenarios using an Integrated Water Resource Modelling tool called Water Evaluation and Planning (WEAP) by obtaining meteorological, population and climate data from relevant authorities and entering the data into WEAP which will simulate results based on the data input and scenarios suggested by the users. The results obtained from the simulation has shown that an increase in population growth rate will result in increased demand for water as shown where in 2009 the demand for water is 364 million cubic meters (MCM) and in 2040 it is 582 MCM. Low population growth rate however shows that as population growth rate decreases demand and unmet demand for water decreases. For the current account year (2009), the unmet demand for both scenarios is 198 MCM and for the last year of scenarios of 2040, the unmet water demand for the reference scenario is 229 MCM and that of the low population growth rate scenario is 137 MCM. On other hand, the change in climate scenario with reduced precipitation will result in less water input received by the Langat catchment hence leading to rise in unmet water demands and rise in water demands as well. Hence this study will help water management authorities to plan and allocate available resources accordingly so that it does not affect water availability for future generations.

Keywords: WEAP; Water demand; Langat; Hydrological data

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INTRODUCTION

Fogden (2009) states that water use has increased over the years, water use increase is twice population growth, hence as a result there is increased demand for water for domestic use, agriculture, and industrial use overall. The rapid rising demand in fresh water and decrease in supplies of fresh water will cause more countries to experience intense water shortages. According to predictions more than 1.5 billion people are believed to be experiencing severe water scarcity and about 67% of the world population will be experiencing stressed water sources by 2025.

As mentioned by Khan et. al (2018) that the number of people on the planet has grown exponentially; in just the past century, the population has tripled, and water use has grown six fold. Malaysia is a country located in South-East Asia and has been experiencing extensive economic development since 1980. This has caused an upscale of water demand in the residential, industrial, and commercial aspects of the country. It was predicted that by 2020 if it had not been for the COVID-19 pandemic, Malaysia could have fully industrialized hence the government had to conserve, manage, utilize, and develop water sources through sustainable and environmentally conscious schemes (Anang *et al*., 2019).

Malaysian Water Sector noted that there was a decrease in water resources in *Selangor* and *Negeri Sembilan* states. The government of Malaysia has great concern about provision of adequate water in the Selangor state. In 2020 *New Strait Time* wrote in an article, 'Selangor water crisis: Less talk, more action', showed great concern on the issues of water shortages in the state of Selangor mainly caused by the pollution of tributaries in the area, the article elaborated on how there was increase in destruction and degradation of water catchments due to lack of Environmental Assessment Impact (EIA) reports done on construction and development companies; there is also lack of a structure that properly manages water resources.

Another major issue highlighted in the article was the need to increase tariffs of offenders who cause pollution in areas where water for domestic use is acquired. An article on *The Edge Malaysia Weekly* noted that Suruhanjaya Perkhidmatan Air Negara or the National Water Services Commission's (SPAN) publication, Water and Sewerage Statistics 2019, indicated that Selangor had a water treatment capacity of 4,706 million liters a day however the demand in Selangor was 4,856 million liters a day in 2018.

Another major concern for Suruhanjaya Perkhidmatan Air Negara or the National Water Services Commission is that in 2019 its publication showed that Selangor's water services operating expenditure was RM2.78 billion and the revenue received was RM2.11 billion bringing a large deficit of RM 668.23 million. According to the ministry's data, an average of 5.93 trillion liters of treated water, which is more than enough to sustain the water demand in Selangor and Johor, were lost nationwide daily in 2017. The issues stated above have sparked interest in whether the state and federal government will be able to provide adequate water for the regions in and around the Selangor state, taking into account the Langat river basin which is longest and lies within the state. The major issue of concern is whether the available water resources in the catchment will be able to sustain the people, industries and agricultural sectors that lie within the catchment.

After taking note of all the problems mentioned above, this research serves to use the Water Evaluation And Planning (WEAP) software to analyze the trend of water supply and demand and the water resources at hand in the Langat catchment. Hence the objectives of this study set are to: 1. To analyze the trend and relationship between demand and supply of water in Langat catchment, evaluate the current water availability and water demand for different sectors, such as agriculture, industry, and domestic using WEAP. 2 To analyze the status of future scenarios of the water supply system and then evaluate them to make recommendations for these different future scenarios.

METHODOLOGY

Study Location

The Langat River catchment is in the south-eastern parts of the Selangor state of Malaysia. **Fig. 1** indicates the boundaries of Langat River catchment and its major tributaries which are Langat River, Semenyih River and Labu River.

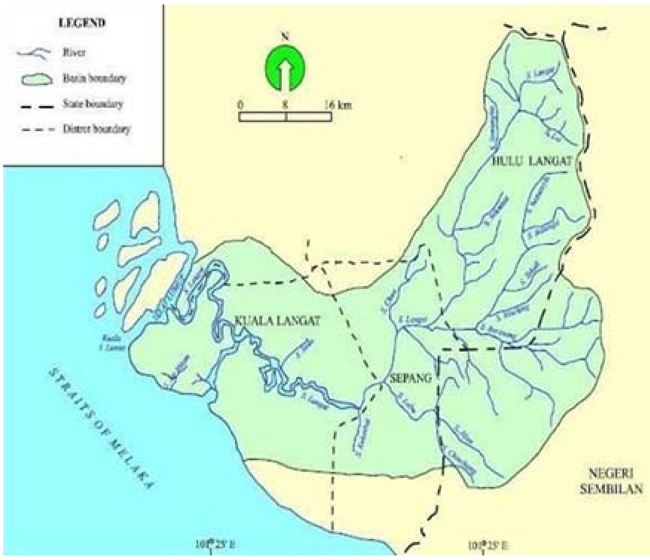

Fig. 1 Langat basin (DID, 2009)

The catchment has an estimated area of 2350 km^2, Langat River, the main tributary, having a length of 182 km. This catchment has a tropical climate, having annual rainfall of 2145mm and annual evapotranspiration of 1500mm. The catchment has been chosen as the study area due to its importance to the country. The catchment has an important role of providing water for both domestic use and commercial use to approximately 2.5 million people that live inside and outside of the basin, comprising of Kuala Lumpur, which is the capital city of Malaysia and it contains highest population density in Malaysia and Federal Territories of Putrajaya and Cyberjaya.

Data collection and Utilization

The data used in this research (from 2009 to 2019) was attained from different government ministries by emailing them and filling out application forms to confirm the exact information required and for which years. The following are data needed for the study and from where it was obtained:

- Catchment map in shapefile format from the Drainage and Irrigation Department (DID) and Lembanga Urus Air Selangor (LUAS)
- Land use map in shapefile format and land use data (catchment area) from Federal Department of Town and Country Planning Malaysia and from Department of Statistics Malaysia as well.
- Hydrological data such as rainfall station data, evaporation, streamflow data and data about dams and reservoirs in the catchment from the Drainage and Irrigation Department (DID)
- Meteorological and population data from Department of Statistics Malaysia
- Water demand data including water consumption in the industry sector, domestic and water use rates from Lembanga Urus Air Selangor (LUAS).

WEAP modelling tool

WEAP has a module to model hydrologic processes. The hydrological model is partially theoretical, continuous in time, partially distributed, and deterministic. Since the model is partially theoretical, it needs calibration and verification. **Fig. 2** shows the overall hydrologic modeling framework. To develop the model structure, the whole Langat area was observed as a single catchment in WEAP, according to available hydrological data from respective government departments and ministries, and three sub-districts which were domestic, industrial and agricultural demands. The next model structure to be developed considered elements which were River (stream), Demand site (service area), Reservoir, Transmission link, Return flow, Runoff, infiltration, Catchment, Streamflow gauge, for monthly time steps between 2009 to 2040. From the period which flow data are available, data sets for year 2009-2019 were used for model calibration and validation. The modeling of a catchment using the WEAP comprised of these main steps Levite *et al.* (2003): (1). Definition of the study area and time frame- this is for setting up of the time frame that included the last year of scenario creation which actually is the last year of analysis, the initial year of application. This includes the spatial boundary, time frame, system components, and the configuration of the problem. (2). Thereafter the creation of the current account takes place- this is more or less the existing water resources situation of the study area. Under the current account available water resources and a variety of existing demand nodes are stipulated. This is very crucial since it forms the core of the whole modeling process. This can be used for calibration of the model to adapt it to the existing situation of the study area. A current account provides an outline of the actual situation of the system with regards to water demand, supply resources and pollution loads. It can also be considered as a calibration step in the enhancement of an application. Establishing key assumptions in the current accounts, is necessary to characterize policies, costs and factors that affect demand, pollution, supply, and hydrology. (3). Establishment of scenarios based on future and expected increases in the various indicators. This forms the core of the WEAP model since this allows for possible water resources management processes to be adopted from results generated by running the model. The scenarios are mainly used to tackle "what if situations", for example what if reservoirs functioning rules are altered, what if groundwater supplies are fully utilized, what if population growth occurs. Scenarios creation can take into consideration factors that change with time. Establishing these scenarios on the current accounts can be used to explore the impacts of alternatives on the future water supply and demand.

In developing a WEAP model, the study boundary, the study period, and components of the study system were required to be defined as an independent set of data and assumptions. The study area was defined as a particular water supply system, such as a river basin or a groundwater aquifer, or political or geographic boundaries SEI (2011). The spatial boundary of the study area for Langat catchment was created in WEAP (**Fig. 3**) by making use of built-in GIS-based layers of ocean, country, states, cities, and major rivers. In this step, the area boundary of Selangor was chosen from the world map given in WEAP.

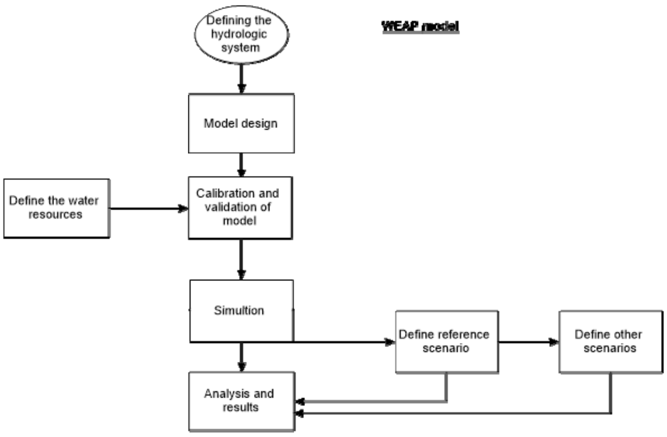

Fig. 2 Modelling framework of WEAP

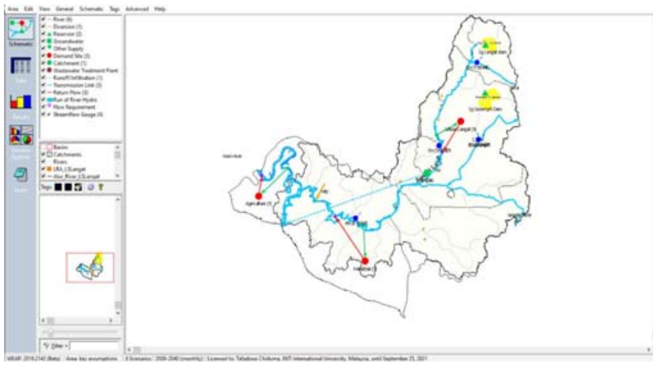

Fig. 3 Schematic representation of Langat basin in WEAP.

To notify WEAP on how the demand is met, the user needs to connect the supply system which has been identified previously to each demand site. This was completed in the schematic view where transmission link is added from the water supply source. The link was first positioned on the river, then pointing to the demand node. This was done for the three demand sites represented in this study (industrial, urban and agricultural). After transmission links were added the return flow links, were then incorporated into the model to inform WEAP on how the demand is satisfied, this was done by connecting the return flows from the demand sites.

The return flow links were connected back to the rivers. After the schematic map components of the system had been executed, the required data for each component of the system was incorporated in the current accounts (2009) to stand for the actual situation of the system in current condition WEAP, the data can be entered by putting numbers directly or using WEAP data entry wizards like Expression Builder, Time Series Wizard, Read From File Wizard or Lookup Function Wizard SEI (2011).

The information for demand sites and catchments, supply and resources, hydrology, key assumptions and other assumptions were needed to input under the current accounts to represent the current state of the water supply demand system. During scenarios analysis, the alternatives data were necessary to modify under the respective scenarios and to analyze impacts of alternatives in the future water supply demand.

RESULTS AND DISCUSSIONS

Calibration and Validation

The WEAP model was calibrated and validated according to observed stream flow data from 2009 to 2014 was used for calibration, while data from 2015-2019 was used for validation. The calibration was done with the Parameter Estimation (PEST) in WEAP based on monthly time-steps. SEI (2011) describes PEST as 'a free software package for Model-Independent Parameter Estimation and Uncertainty Analysis'. By comparing simulated streamflow to historically observed streamflow and automatically modifying some parameters, it helped to improve the accuracy of simulations. The six years of observed discharge data, from 2009 to 2014 were selected for the model parameters adjustment.

After the calibration, the quality of the model was evaluated according to the study by Moriasi *et al.* (2007) who recommend three quantitative approaches to quantify how well the WEAP model fits the observed data in watershed simulations. These methods are: (1) Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance, it indicates how well the plot of observed versus simulated data fits the 1:1 line.

The NSE ranges between $-\infty$ and 1.0 with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. (2) Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counter parts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. (3) Ratio of the root mean square error to the standard deviation of measured data (RSR).

RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR varies from the optimal value of 0, which indicates zero RMSE (root mean square error) or residual variation and therefore perfect model simulation, to a large positive value. The lower RSR, the lower the RMSE, and the better the model simulation performance. The calibrated model presented the simulated streamflow that were closely comparable to the observed data. The streamflow data from the Department of Drainage and Irrigation (DID) was calibrated and as shown in **Fig. 4** According to the results obtained and observed the simulated streamflow is similar to the observed streamflow. For the first two years, 2009 and 2010 the simulated and observed streamflow are very similar, however for the following years of both calibration and validation the simulated streamflow is lower than the observed data. In the calibration period (2009-2014), the average observed discharge is 35 m^3/s while the simulated discharge is 23 m^3/s. For the validation period (2015-2019), the average observed, and simulated discharge values are 33 m^3/s and 25 m^3/s respectively.

The calibrated model gives rational values of NSE, PBIAS, and RSR as shown in **Table 1**. The NSE for the calibration period is 0.95 and validation period is 0.89, RSR values are 0.21 for calibration and 0.34 for validation whereas PBIAS are 9.82% and 11.09% for the calibration and validation period, respectively. According to the rating classified by Moriasi *et al.* (2007) as shown in **Table 2** below, the NSE, PBIAS, and RSR of the calibrated validated period are categorized as Very good, whereas only the PBIAS for the validation period is characterized as Good, showing that the model was capable of simulating scenarios of future changes such as climate change and population growth. These ratings show how well the model performs; hence they can also be termed as performance ratings. Hence if the value given is 0.95 for calibration of NSE, this means the rating is very good and this shows that the performance of the model is also very good. Additionally a lower value of RSR (less than one) shows better model performance.

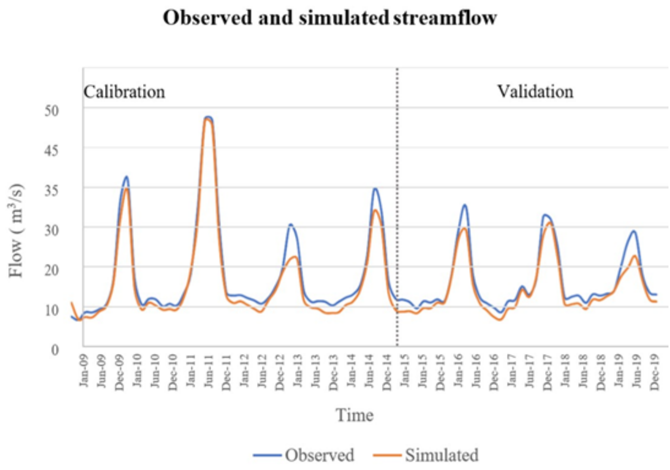

Fig. 4 Simulated streamflow

Table 1. Performance ratings for PBIAS, NSE and RSR

Rating	NSE	PBIAS%	RSR
Very good	0.75-1.00	< ±10	< 0.50
Good	0.65 - 0.75	±10 - ±30	0.50 - 0.60
Satisfactory	0.50 - 0.65	±30 - ±50	0.60 - 0.70
Unsatisfactory	≤ 0.5	≥ ±50	> 0.70

Table 2. Accuracy of model through quantitative analysis by calibration and validation

Simulations	NSE	PBIAS	RSR
Calibration (2009-2014)	0.95	9.82	0.21
Validation (2015-2019)	0.89	11.09	0.34

Reference scenario

The reference scenario for this study was set using information from current accounts as well as census information from the Department of statistics Malaysia. To set the reference scenario the date, population and growth rate of population were entered in WEAP as key assumptions. The growth from function in WEAP was used to process the data. The last census before current account year was done in 2000, yielding a population growth rate of 1.3% and the population in the Langat catchment was 6,63,293 people. According to the graphical results simulated by WEAP in **Fig. 5** in the reference scenario the water demand decreases steadily from 2009 to 2014 where the demand is 364 MCM in 2009 to 359 MCM in 2014, thereafter there is a steep rise in the water demand for all demand sites in the catchment, that is urban, industrial and agriculture. In 2040 the demand for water in the reference scenario for all demand sites is 441 MCM as shown in **Fig. 5**. Similarly, the unmet water demand for all demand sites in the Langat catchment decreased between 2009 to 2014, thereafter having a steep rise until the year 2040, the unmet demand increases from 40 MCM to 110MCM.

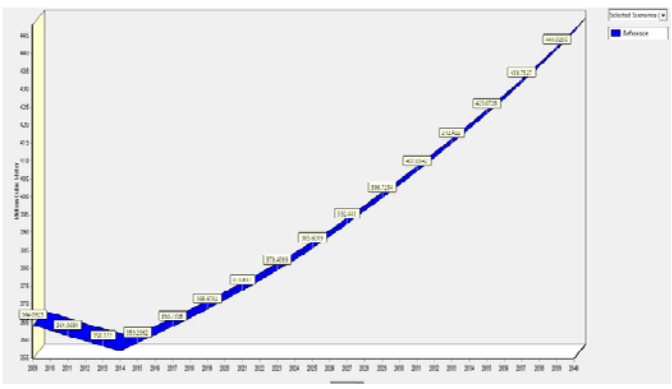

Fig. 5 Graphic representation of reference scenario water demand in WEAP

High population growth rate

In this scenario WEAP is used to project results for a rise in population growth at a rate of 3% instead of the 1.3% in the current account within the Langat catchment. This scenario is based on the data that is provided by Department of statistics annually, the data shows a gradual rise in the population of people in the catchment annually. The results in WEAP were simulated by assuming this scenario and results are analyzed accordingly.

Langat is a largely urbanized area in Malaysia because of being in the capital state of Selangor. This area is close to the capital Kuala Lumpur, where most people work. The population in the area is increasing annually as shown by the population data and people migrate from other areas to Selangor to ensure ease of mobility when travelling to work. Also, students both international and local flock into Selangor especially for tertiary education; this also results in increase of population gradually. **Fig. 6** shows the water demand in this scenario increases from 364 MCM in 2009 to 582 MCM in 2040, this shows that the demand for water doubles over the 31 years, however in the reference scenario the demand for water in 2040 is 441 MCM.

This means that increase in population is directly proportional to increase in demand for water for all demand sites (urban, agricultural, and industrial). **Fig. 7** outlines the comparison between unmet water demand for the reference scenario and the high population growth rate scenario, in the reference scenario the population growth rate is 1.3% and in the high population growth rate scenario is 3%, this means that there is a higher population in the high population growth rate scenario and a lower population in the reference scenario.

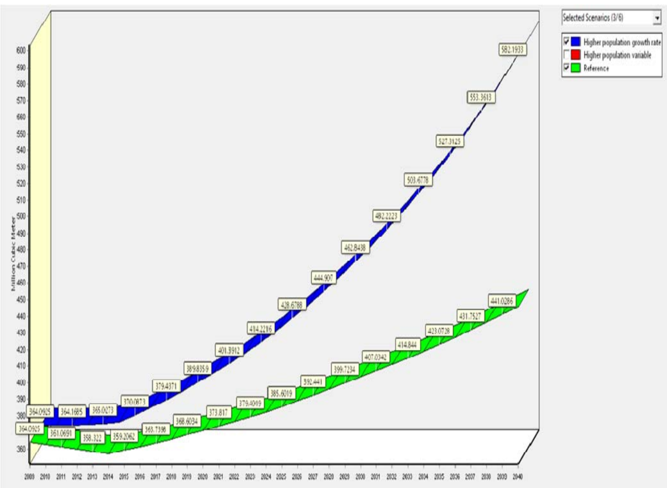

Fig. 6 Analysis for high population growth rate in Langat

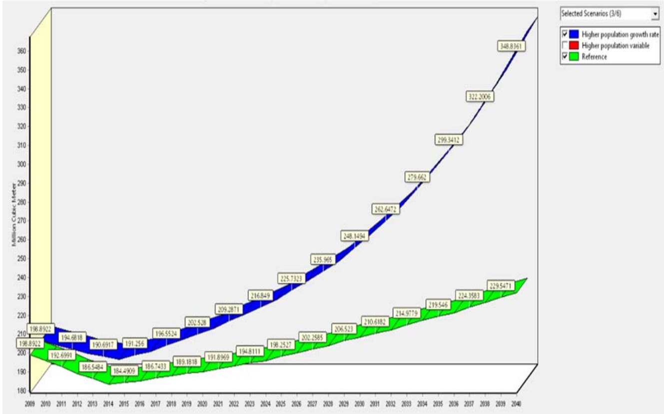

Fig. 7 Unmet water demand comparison between reference scenario and high population growth rate scenario

The unmet demand for water in 2040, according to the high growth rate scenario, is 348MCM and that of the reference scenario is 229MCM. This factor shows that meeting the demands of water in the catchment is highly dependent on the population increase because increase in population means increase in water demand for both domestic and industries due to increased industrialization. Previous research Azlinda (2009) was carried out on water demand in the catchment of Langat, for the scenario of high population of 2.2% this scenario gave the Unmet Demand value of 230.5MCM in 2010. This is less than the 348 MCM observed in this study.

Climate Change

Due to the increased effects in global warming, there has been a shift in climatic seasons worldwide. In some regions there is more rain than expected in other regions there is less rain than expected. Both these scenarios can be investigated in WEAP; however, for this study by observing the rainfall data from the Department of Drainage and Irrigation (DID), the most suitable scenario is the decrease in rainfall as shown by rainfall data collected. The data from the DID assisted in concluding which result best suites the Langat catchment.

Climate change is essential for the water supply system because it can change the existing water management situations and increase the requirement for new management options Mounir *et al*. (2011). This is primarily a result of the effects of global warming, hence this scenario was simulated and observed in WEAP.

For the analysis of climate change effect in Langat catchment the climate change scenario was constructed by using the climate data acquired from climate change model and the water year method that is in-built in WEAP.

This scenario looks at the impact of climate change in the Langat catchment using the WEAP built in NetCDF files climatic data sets for temperature, wind and humidity from Princeton university, that are found in WEAP. These data sets were used to simulate climate changes in WEAP, together with the precipitation data from the seven-gauge stations in Langat, for example at rain gauge *station 2817003* precipitation in 2009 was 2432.5mm and in 2019 it was 1766mm giving a 666.5mm difference in rainfall received. By observing the rainfall data provided by the DID, it is concluded that from 2009 to 2019 there has been a decrease in rainfall received in the catchment.

Figs. 8 and **9** illustrate that the change in climate scenario with reduced precipitation will result in less water input received by the Langat catchment hence leading to rise in unmet water demands and rise in water demands as well.

Low population growth rate

This scenario looks at the impact of decreasing the population growth rate for Langat catchment from normal population growth rate of 1.3% to -3% which can be a result of decrease in fertility rate and increase in mortality rate. For WEAP analysis under this scenario, the annual population growth rate in key assumption is changed as -3%, and the annual activity level of Langat is projected applying this low rate. The water demand for all demand sites is shown **Fig. 10**, the graph depicts that when there is a low population growth rate (blue) the demand of water decreases sub-sequentially, when Langat catchment has a lower population growth rate the demand for water also decreases over the years because there will be less pressure on natural and water resources. The unmet demand also decreases for this scenario.

Fig. 11 shows the comparison for unmet demand for all demand sites between the reference scenario with a population growth rate of 1.3% and the low population growth rate of 3%. From the current account year (2009) unmet demand for both scenarios is 198 MCM and for the last year of scenarios review 2040 the unmet water demand for the reference scenario is 229 MCM and that of the low population growth rate scenario is 137 MCM. this means that with low population growth it means that there will be lower demand for water.

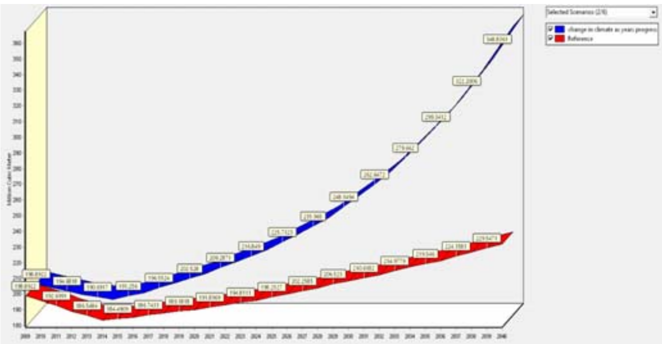

Fig. 8 Water demand for all demand sites between reference scenario and climate change scenario

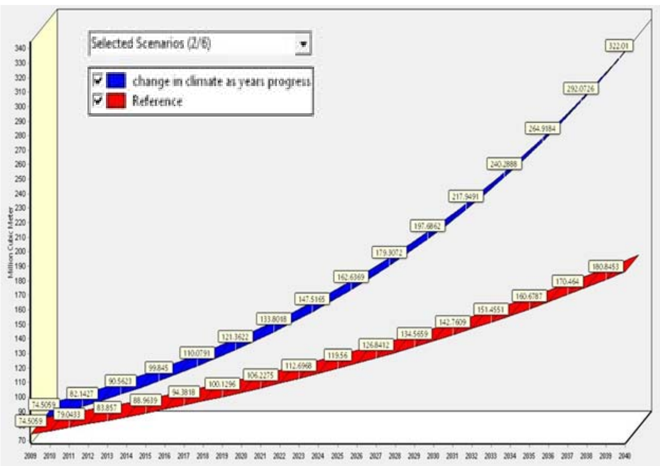

Fig. 9 Unmet demand for all demand sites

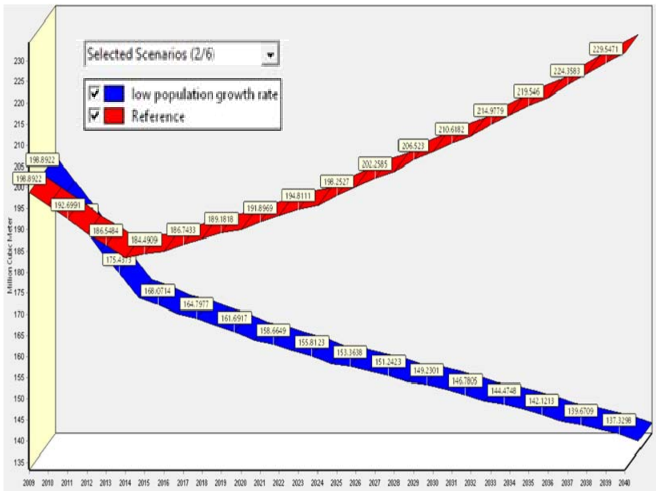

Fig. 10 Water demand of Langat catchment with low population growth rate

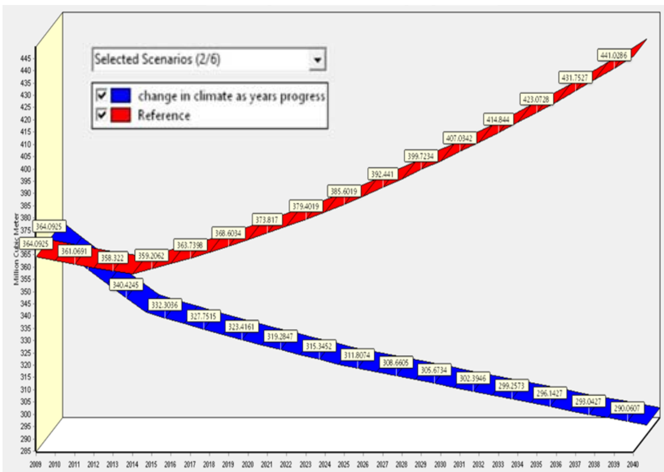

Fig. 11 Unmet demand comparison between low population growth rate and reference scenarios

This might become evident because the world is adapting fast to technology and most of the jobs no longer require physical attendance, that is people can work virtually this means that if the rate of people working virtually increases it means that there will no longer be any need for people to travel from other states to the Selangor state for jibs hence there will be a decrease in population in the area resulting in decrease in water demand and unmet water demand in Langat.

CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to apply WEAP to Langat catchment by performing scenario analysis of the water management and development in the catchment. For simulation of an analysis in WEAP, accurate data is required to model the hydrology and water management more precisely. The model was able to simulate the catchment water management scenario.

The calibration and validation results from the stream flow data showed that the results modelled in WEAP were good and very good, therefore the model was well adapted to the Langat catchment. The model would have worked much better if there had been availability of additional data. This study was also aimed at predicting the future demand and supply of water by simulating different scenarios in the software.

The results obtained will assist water resource management authorities to plan and distribute water resources for the current generation and also plan for the future generations. Scenarios in Langat were modelled according to the data that was available and the results were analyzed in the form of graphs for demand sites and the three scenarios that were implemented in WEAP, these were: High population growth rate, Low population growth rate and Climate change. These scenarios were used to draw a conclusion about the future supply and demand of water in the" Langat catchment, for scenario 1, High population growth rate, the results showed that an increase in population growth rate will mean an increase in the demand for water and the supply requirement. Scenario 2, Low population growth rate, showed that if the population growth rate decreases in the Langat catchment there will be a decrease in supply requirement and water demand. Lastly scenario 3, Climate change, shows that with global warming and global seasonal changes which result in less water input in the catchment, this will also result in reduced water availability in the catchment for human use hence there will be a strain on water resources leading to increased demand and supply requirement. The model would have worked much better if there had been availability of additional data.

Scenarios in Langat were modelled according to the data that was available and the results were analyzed in the form of graphs for demand sites and the scenario that were implemented in WEAP, was: High population growth rate, climate change and low population growth which used to draw a conclusion about the future supply and demand of water in the Langat catchment. The other hydrological models, should be run to compare results simultaneously for example MODFLOW, should be used to simulate groundwater and surface water interactions, which should then be compared and connected to WEAP.

To improve the accuracy of water balance, groundwater inflow to and outflow from the region, especially seepage from the Langat and Semenyih dams, should be investigated. Future projections should be applied over a longer time frame, such as more than 100 years, in order to project progress in the far future and to prepare for the long run.

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