Water Demand Estimation Based On Land Use In Urban City

Nur Diyana Mohamad, Zulfa Hanan Ash'aari, Nurfatin Izzati Ahmad Kamal

Abstract: Putrajaya city has transformed from rubber plantation in the late 1920s into federal administrative centre due to overcrowding and congestion in the former. Since the relocation of the administrative capital, many government servants had been encourage to move to the city and sudden increased of the population grow to more than 100,000 in recent year. This situation boosted a strong economic appeal, which expand urban activities and population growth, especially urbanization process. Thus, the city government should contemplate the allotment of land use effectively based on sustainable water resources. As the corresponding pressure on water resources keep on increasing, it is vital to identify the water demand future in Putrajaya City related to domestic and non-domestic activities as the first step to optimize land use allocation. Domestic sectors is define as household and public hydrant, while non-domestic sectors include offices, industrial areas, public amenities and utilities. Result shown that the total city population forecast in 2030 amounted to 150,124 people, increasing by more than 40,000 people from 2019. From the estimation, the domestic water consumption in 2019 multiplied from 614,150 litre/day to 888,231 litre/day in 2030. Thus, the water needs of the population of Putrajaya from 2019-2030 year increased by 44.63%.

Index Terms: land use, population forecast, urban, water demand

1. INTRODUCTION

WATER demand estimation and forecasting has become an important component in planning and managing effective water resources. Forecasting or predicting the amount of water to be supplied is a very crucial element for design and operational demand. In order to guarantee a high reliability of water supplies, a strenuous investment to increase flow and operational programme is needed. In this case, water demand stipulates both current and/or expected water consumption in any given area over a specific time period [1]. In fact, forecasting water demand is intrinsically challenging, as the factors that most directly affect water demand are hard to predict. In addition, the accuracy of water demand projections depends on the availability of reliable population and water consumption data as well as an understanding of the distribution of different type of users, land uses, social and economic factors particularly within the community [2]. Growth in population means mounting demand and competition for water usage involving domestic, industrial, and municipal uses [3], [4], [5]. In line with the statement, Bhatta [6] also agreed that the population growth triggers the expansion of new building construction for numerous activities. Each urban activity has different characteristics related to water consumption such as economic activities, agriculture, industry and settlements [7], thus the condition of the space pattern evoke the necessity of water. The provision of clean water is very crucial for the social and economic city development as it becomes more scare due to urban development, which increase water use and subsequently creates a realistic threat to global water crisis [8]. As in Putrajaya City, the federal administrative centre of the Malaysian capital, which has rapid development, it may or may not, encountered the problem of water supply in future if no proper planning and mitigation measures is considered. In fact, the recent water crisis in Selangor including Putrajaya [9, 10] should provide valuable lesson and guidance on the need and importance of promoting water demand management as part in Economic Scarce Water Management. Since land use has their own diverse activity characteristics, this allow the estimation of water needs in every type of activity in Putrajaya city become the key component in water supply management [11]. In addition, the population increase signifies that additional space is required for housing, public amenities and infrastructure [12]. Therefore, this research tries to estimate the availability of existing clean water source with city development requirement planning according to Putrajaya land use categories.

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2 METHODOLOGY

2.1 Study Area

Putrajaya, officially known as Federal Territory of Putrajaya was chosen as the study area because of its well-planned city where most of the main government offices and buildings are located and operated with a total land area of 49 km^2 (twenty precincts) and eleven precincts covered with residential area. The seat of government was relocated in 1999 from Kuala Lumpur to Putrajaya due to overcrowding and congestion in the previous city. The development of Putrajaya started in the early 1990s. Today, major landmarks have been completed and the population is expected to grow in the near future. As of 2012 almost all of Malaysia's governmental ministries had relocated to Putrajaya and by 2019, the population had increased to 103,800 people [13]. This study was conducted in Putrajaya city by analyzing the basis unit of water need using the projection from the number of people up to year 2030. The need for clean water was performed based on domestic and non-domestic sectors. The intention for the Malaysian Government administrative centre establishment off from Kuala Lumpur was originated as early as 1993. Among the main rationales for relocation of administrative centre away from Kuala Lumpur were; not only to secure a quality urban living and environment for the new administrative centre and to lessen the pressure on Kuala Lumpur's over-stretched infrastructure, but also to resolve the significant shortage of government land to cater for risen demand for office space [14]. Supposedly, it was easier and cost effective to have a

new site development [15] and since the demand for clean water will increase with the city development [16, 17], thus analysis on the availability of existing clean water source in a city is highly needed to ensure secured and ample water supply. The Putrajaya land use map and detail description of the study area was visualized and recorded in Fig. 1 and Table 1 accordingly.

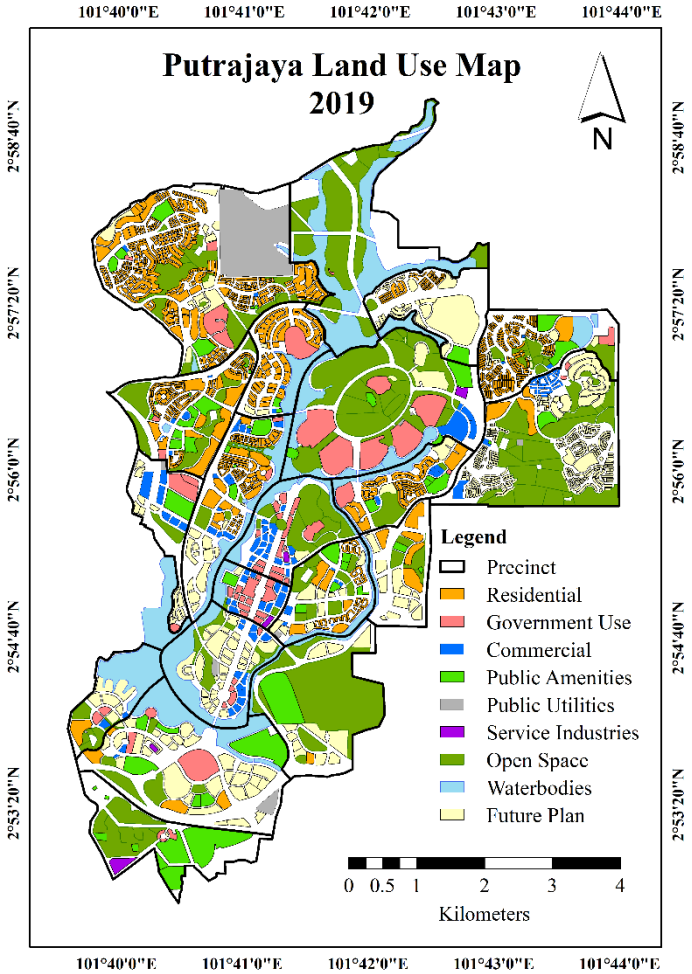


***Fig. 1**. Putrajaya land use map*

TABLE 1

DESCRIPTION OF THE STUDY AREA

Precinct	Area (km^2)	Type of premises/buildings
Residential area		
Precinct 5	3.17	Apartment
Precinct 6	1.40	Apartment
Precinct 8	3.42	Apartment, bungalow, 2-storey house, 3-storey house
Precinct 9	2.58	Apartment, 2-storey house
Precinct 10	1.27	Bungalow
Precinct 11	5.78	Apartment, bungalow, condominium, 2-storey house, 3-storey house
Precinct 14	1.64	Apartment, bungalow, 2-storey house, 3-storey house
Precinct 15	4.70	Apartment, condominium, 2-storey house
Precinct 16	1.23	Apartment, bungalow, 2-storey house, 3-storey house
Precinct 17	1.54	Apartment
Precinct 18	1.45	Apartment
Non-residential area		
Precinct 1	4.38	Government office (main), restaurant, hall, complex
Precinct 2	1.87	Government office, restaurant, hall, complex
Precinct 3	0.76	Government office, hall, complex
Precinct 4	1.68	Government office, restaurant, park
Precinct 7	0.63	Hospital, office, market
Precinct 12	1.75	Construction site
Precinct 13	4.08	Wetland, office
Precinct 19	3.30	Water treatment plant, corporate office
Precinct 20	2.55	Place of worship, cemetery, corporate office

2.2 Population Forecasting

The design of water supply network for water demand purposes is based on the population projection of a particular city or town, which is estimated for the design period. Any underestimated value will make the system incompetent for the purpose intended; likewise, overestimated value will make it costly. Population change in the city over the years will take place; hence, the system should be designed considering the population at the end of the design period [18]. Factors affecting changes in population include increase due to births, decrease due to deaths, migration increase/decrease, and increase due to annexation [19]. The present and past population record for the city was acquired from the census population records. After collecting these population figures, the population at the end of the design period was predicted using various methods that is suitable considering the growth pattern of the city. Population forecasting can be estimated using the following methods:

1. Arithmetical Increase Method
2. Geometrical Increase Method
3. Incremental Increase Method
4. Graphical Method
5. Comparative Graphical Method
6. Master Plan Method
7. Logistic Curve Method

However, only the first two methods were used to forecast the population [20] as following:

Arithmetical Increase Method

$$Pn = P + nx \qquad (1)$$

Where:
P population at present
n number of decades
x average of increase of n decades

Geometrical Increase Method

$$Pn = P\left(1 + \frac{IG}{100}\right)n \qquad (2)$$

Where:
P population at present
n number of decades
IG geometric mean (%)

2.3 Estimation of Water Demand

According to the uniform technical guidelines by National Water Service Commissions, Malaysia [21], information on the water supply needs of the development are to be provided in

terms of total daily demands. The total daily demands were estimated based on the submitted Layout Plans, proposed types of physical developments envisaged, and unit rates of demand by various types of premises as listed in Table 2. The estimation of water demand performed in this study was calculated based on the list provided below.

TABLE 2
TABULATION OF ESTIMATED WATER DEMAND RATE FOR PLANNING OF EXTERNAL WATER RETICULATION SYSTEM [21]

Type of premises/Buildings	Average daily water demand (l/day)
Low cost terrace house / low cost flat	1100 / unit
Single storey terrace house / low cost house (less than RM25,000) / low medium & medium cost flats	1300 / unit
Double storey terrace house / high cost flat / apartment / town house	1500 / unit
Semi detached house / cluster	2000 / unit
Bungalow / condominium	2000 / unit
Wet market	1500 / stall
Dry market	450 / stall
Shop house (single storey) / low cost shop	2000 / unit
Shop house (double storey)	3000 / unit
Shop house (three storey)	4100 / unit
Shop house (four storey)	4550 / unit
Building for heavy industry*	65,000 / hectare
Building for medium industry*	50,000 / hectare
Building for light industry*	33,000 / hectare
Office / complex / commercial (domestic usage)	1000 / 100 square metre
Community centres or halls	1000 / 100 square metre
Hotel	1500 / room
Education institutions (other than school and kindergarten)	100 / student
Day school / kindergarten	50 / student
Fully residential school/ institution of higher learning with hostels facilities	250 / student
Hospital	1500 / bed
Mosque or other place of worship	50 / person
Bus terminal	900 / service bay
Petrol kiosk (with car washing bay)	50,000 / unit
Petrol kiosk (without car washing bay)	10,000 / unit
Stadium	55 / person
Restaurant	25 / square metre

* As classified under the Piawaian Perancangan Kawasan Perindustrian issued by the Jabatan Perancangan Bandar dan Desa or its successor

3 RESULTS AND DISCUSSION

3.1 Population Growth Trend

The projection towards clean water was analysed by considering the number of people. The number of the population was projected up to nine years ahead in 2020 to be precise. Therefore, the analysis result of the population number was projected toward the clean water need in 2030. The projected number of total population in Putrajaya city was based on demography data during 2010-2019, which is based on the availability of geometric data by the Department of Statistics, Malaysia [13]. Arithmetic method was applied to find out the growth index of the population every year. The number of population growth was calculated using percentage applying the methods mentioned previously. Table 3 shows the average percentage of population growth of Putrajaya city comprising 3378 people/year or 3.97 percent per year.

TABLE 3
THE POPULATION GROWTH OF PUTRAJAYA CITY DURING 2010-2019

Year*	Population	Increment	Growth
	(people)	(people)	(%)
2010	73400		
2011	77500	4100	5.59
2012	78300	800	1.03
2013	79700	1400	1.79
2014	80900	1200	1.51
2015	83000	2100	2.60
2016	84400	1400	1.69
2017	87500	3100	3.67
2018	97200	9700	11.09
2019	103800	6600	6.79
Total		30400	35.74
Average		3378	3.97

* As reported by Department of Statistics Malaysia [13]

3.2 Population Forecasting Results

The population projection of Putrajaya city considered in this study was performed using two different equations as mentioned previously; Arithmetical Increase Method (1) and Geometrical Increase Method (2). The data used in the analysis of population number was Putrajaya's population data from 2010 to 2019 in order to predict the number of population in 2030. Based on the population number of Putrajaya city, the projected number of population in 2020 until 2030 was estimated using both methods as following:

- P_{2019} = 103,800 person
- r = 3.97%
- P_{2010} = 73,400 person
- t = 9 years

According to Table 4, it was estimated that the average projection of population number in Putrajaya City in 2030 is 150,124 person and that shows an increase of 44.63% of people for the next decade, which is almost 50% of the current total population.

TABLE 4
POPULATION FORECAST IN 2019-2030

Year	n	Geometric	Arithmetic	Projection Average
		(people)	(people)	(people)
2019*	0	103800	103800	103800
2020	1	107921	107178	107549
2021	2	112205	110556	111381
2022	3	116660	113934	115297
2023	4	121291	117312	119302
2024	5	126107	120690	123398
2025	6	131113	124068	127590
2026	7	136318	127446	131882
2027	8	141730	130824	136277
2028	9	147357	134202	140779
2029	10	153207	137580	145393
2030	11	159289	140958	150124

* Current population estimated by Department of Statistics Malaysia (official website) [13]

3.3 Water Demand Analysis

The water demand in this research referred to raw water demand that has to be processed into clean water. Raw water demand standard divided into two types namely domestic and non-domestic water demand. The analysis of raw water

demand in Putrajaya city was referred to standardized criteria of estimated water demand rate for planning of external water reticulation system by National Water Service Commissions, Malaysia [21]. The number of people in Putrajaya city in 2030 was projected at 150,124 individuals. Considering the number of population, Putrajaya is classified into a metropolitan city category as referred to the Department of Statistics Malaysia [22] in Table 5. Commonly, the demand from big cities has criteria as follow:

- Consumption of household network litre/person/day
- Consumption of public hydrant network litre/person/day
- The comparison between household (HS) and public hydrant (PH) networks: HS:PS = 80:20

TABLE 5
THE CLASSIFICATION OF CITIES BY STRATA [22]

Strata	Population
Metropolitan	75,000 and more
Big city	10,000 – 74,999
Small city	1,000 – 9,999
Rural	Less than 1,000

3.4 Water Demand Analysis on Household Sector

Household (HS) Network

Domestic water demand is the annual water demand influenced by physical activities and prosperity level. Domestic water use includes indoor and outdoor uses at residences. The future water demand for Putrajaya city for domestic (residential) area was estimated in Table 6.

TABLE 6
AVERAGE WATER DEMAND FOR HOUSEHOLD (HS) NETWORK

Year	Population	Service Rate	Number of people served	Average water demand
	(people)	(%)	(people)	(l/d)
[a]	[b]	[c]	[d]	[e]
2019	103800	80	83040	588200
2020	107549	80	86040	609447
2021	111381	80	89105	631157
2022	115297	80	92238	653349
2023	119302	80	95441	676043
2024	123398	80	98719	699257
2025	127590	80	102072	723013
2026	131882	80	105506	747332
2027	136277	80	109022	772236
2028	140779	80	112623	797750
2029	145393	80	116315	823896
2030	150124	80	120099	850700

Where:
[a] projected years
[b] calculation result of the projected number of population
[c] service ratio between HS:PH
[d] [b] x [c]

Public Hydrant (PH) Network

Usually, public hydrant demand is allocated around 20% of the total water demand in a city [23]. This public hydrant is specifically designed to provide adequate water to firefighters, of which the design of the public hydrant system is focused on maintaining a sufficient pressure to assure water flow. The future water demand for hydrant consumption in Putrajaya city is shown in Table 7. In 2030, the average water consumption for public hydrant service has risen up to 37,531 litre/day.

TABLE 7
AVERAGE WATER DEMAND FOR PUBLIC HYDRANT (PH) NETWORK

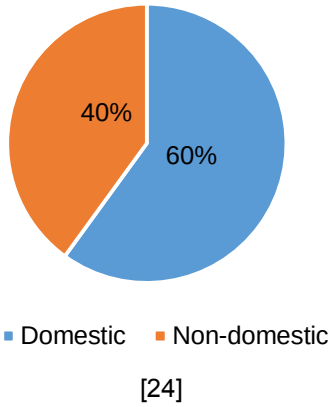
Year	Population	Service Rate	Number of people served	Average water demand
	(people)	(%)	(people)	(l/d)
[a]	[b]	[c]	[d]	[e]
2019	103800	20	20760	25950
2020	107549	20	21510	26887
2021	111381	20	22276	27845
2022	115297	20	23059	28824
2023	119302	20	23860	29825
2024	123398	20	24680	30850
2025	127590	20	25518	31898
2026	131882	20	26376	32971
2027	136277	20	27255	34069
2028	140779	20	28156	35195
2029	145393	20	29079	36348
2030	150124	20	30025	37531

Where:
[a] projected years
[b] calculation result of the projected number of population
[c] service ratio between HS:PH
[d] [b] x [c]

3.5 Water Demand Analysis of Domestic and Non-Domestic Sector

The water demand analysis in this study was differentiated into two major different sectors, which is domestic and non-domestic sector. Referring to the Malaysia Water Industry Guide [24], the common amount of water demand for each sector was illustrated in Fig. 2.

Fig. 2. Proportion of domestic and non-domestic consumption



[24]

The percentage between domestic and non-domestic area: DA:NDA = 60:40 [24], which is in the ratio of 3:2. Based on the results shown in Table 8, the current estimation of average total water demand used for domestic and non-domestic sector was 55,702,500 (60.73%) litre/day and 36,022,515 (39.27%) litre/day, respectively (percentage; 60:40), which is almost in line with the reported values by Malaysia Water Industry Guide [24].

3.6 Raw Water Demand in Putrajaya City

Based on the results shown for clean water demand analysis in Putrajaya (refer Table 8), the current estimation of total water demand reached 91,725,015 litre/day in 2019 with domestic sector of total water demand comprised of 55,702,500 litre/day while non-domestic sector encompassed for 36,022,515 litre/day. Surely, by looking at the values, this demand will be definitely kept rising in line with the growing

number of population. In addition, by taking into account the total water demand for future land use planned for the city, there would be an additional increase of another 21,997,176 litre/day, which summed up to 113,722,191 litre/day. Based on the criteria provided by National Water Service Commissions [21], the average of clean water in each year obtained from reservoir should be in the range of 0.0024 m^3/sec to 0.0162 m^3/sec. If the capacity of Putrajaya reservoir were compared to the water demand, the result would be negative. Besides, by the additional future land use planned in their city master plan with the existing water demand, it is contemplated that they would be an immense demand of clean water demand in upcoming years. Therefore, optimization analysis is a necessity to be conducted in order to overcome the limited amount of raw water supply in Putrajaya especially for future demand.

TABLE 8
ESTIMATION OF TOTAL AVERAGE WATER DEMAND BY LAND USE CATEGORY

Sector	Land use	Type	Total water demand (l/day)	Total water demand (l/s)	Total water demand (m^3/s)
Domestic	Residential	Double storey terrace	7003500	81.06	0.0811
		Triple storey terrace	357000	4.13	0.0041
		Semi-detached	4222000	48.87	0.0489
		Apartment	41256000	477.50	0.4775
		Bungalow	652000	7.55	0.0075
		Condominium	2212000	25.60	0.0256
Total			55,702,500	644.70	0.6447
Percentage (%)			60.73		
Non-Domestic	Government Use	Office	22133920	256.18	0.2562
	Commercial	Business centre	2090404	24.19	0.0242
		Restaurant	1370891	15.87	0.0159
		Hotel	747000	8.65	0.0086
		Petrol station	100000	1.16	0.0012
	Public Amenities	School	1787100	20.68	0.0207
		Hospital/Clinic	889500	10.30	0.0103
		Mall/Hall/Complex	4963942	57.45	0.0575
		Mosque	1750000	20.25	0.0203
	Service Industries	Cooling plant	189757	2.20	0.0022
Total			36,022,515	416.93	0.4169
Percentage (%)			39.27		
Comparison between existing and future land use water demand					
Current		80.66%	91,725,015	1061.63	1.06
Future plan		19.34%	21,997,176	254.60	0.25

4 CONCLUSION

Based on the previous points of analysis, this study conclude that:

- The average projected number of population in Putrajaya during 2030 was 150,124 people.
- Based on domestic and non-domestic water demand, the clean water consumption used in Putrajaya reached 55,702,500 litre/day to 36,022,515 litre/day, respectively with a total of 60.73% for domestic sector and 39.27% for non-domestic sector.
- It is anticipated that almost 20% of future land use has yet to be developed in the city, which projected to be an increase of total water demand of 21,997,176 litre/day together with the increase of 44.63% of total population in the next decade.
- The average amount of clean water in each year obtained from Putrajaya reservoir comprised of 0.64 m^3/sec for domestic and 0.42 m^3/sec for non-domestic, which resulted in negative correlation if it was compared with the water demand. Therefore, optimization analysis was needed to be performed for future needs of water demand in the city.

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REFERENCES

[1] Nigam, A. K., Rahi, D. C. (2016b). Estimating Water Demand and Forecasting Water Demand for Year 2041 Jabalpur City. International Journal of Innovations in Engineering and Technology (IJIET); 7(2): 14-21.

[2] Nigam, A. K., Rahi, D. C. (2016a). Analysis of Water Demand and Forecasting Water Demand for Year 2048 Jabalpur City. SSRG International Journal of Civil Engineering (SSRG–IJCE); 3(7): 37-42.

[3] United Nations (UN). (2007). Water and Food and Agriculture Organization of the United Nations (FAO). 2007. Coping with Water Scarcity: Challenge of the Twenty-First Century. New York, NY: UN-Water and FAO.

[4] Manzardo, A., Ren, J., Piantella, A., Mazzi, A., Fedele, A., Scipioni, A. (2014). Integration of water footprint accounting and costs for optimal chemical pulp supply mix in paper industry. Journal of Cleaner Production, 72, 167-173.

[5] Boretti, A., & Rosa, L. (2019). Reassessing the projections of the World Water Development Report. npj Clean Water; 2(1): 1-6.

[6] Bhatta, B. (2010). Analysis of urban growth and sprawl from remote sensing data. Springer Science & Business Media.

[7] Jefferies, D., Muñoz, I., Hodges, J., King, V. J., Aldaya, M., Ercin, A. E., Hoekstra, A. Y. (2012). Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine. Journal of Cleaner Production; 33: 155-166.

[8] Van der Bruggen, B., Borghgraef, K., Vinckier, C. (2010). Causes of water supply problems in urbanised regions in developing countries. Water resources management; 24(9): 1885-1902.

[9] Lim, I. (2019, August 6). Klang Valley water disruption: Why does it happen so often? Retrieved from https://www.malaymail.com/news/malaysia/2019/08/06/klang-valley-water-disruption-why-does-it-happen-so-often/1777926

[10] Yusof, T. A. (2019, December 23). It's time to get serious about water contamination. Retrieved from https://www.nst.com.my/news/nation/2019/12/550237/its-time-get-serious-about-water-contamination

[11] McKinsey & Company (2009). The global corporate footprint – Risks, opportunities and management options. CCSI Water & Adaptation Service Line; 3-9.
[12] JPBD (2016). Jabatan Perancangan Bandar dan Desa. Malaysia National Report for the 3rd United Nations Conference on Housing and Sustainable Urban Development (Habitat III). 1-97.
[13] DOSM (2020, January 14). Department of Statistics, Malaysia. Population Quick Info website. Retrieved from http://pqi.stats.gov.my/searchBI.php
[14] Siong, H. C. (2006b). Putrajaya–administrative Centre of Malaysia-planning concept and implementation. In Sustainable urban development and Governance conference; 1-20.
[15] Siong, H. C. (2006a). Lessons learned from planning of Putrajaya city–Administrative Centre of Malaysia. In Seminar UTMSIT Workshop, Shibaura Institute, Japan; 1-19.
[16] Abughlelesha, S. M., & Lateh, H. B. (2013). A review and analysis of the impact of population growth on water resources in Libya. World Applied Sciences Journal; 23(7): 965-971.
[17] Anang, Z., Padli, J., Rashid, N. K. A., Alipiah, R. M., & Musa, H. (2019). Factors Affecting Water Demand: Macro Evidence in Malaysia. Jurnal Ekonomi Malaysia; 53(1): 17-25.
[18] Anisha, G., Kumar, A., Kumar, J. A., & Raju, P. S. (2016). Analysis and design of water distribution network using EPANET for Chirala Municipality in Prakasam District of Andhra Pradesh. International Journal of Engineering and Applied Sciences; 3(4): 53-60.
[19] Mekonnen, Y. A. (2018). Population Forecasting for Design of Water Supply System in Injibara Town, Amhara Region, Ethiopia. Population, 10(10): 54-65.
[20] Newbold, K. B. Population geography: tools and issues. Rowman & Littlefield; 2017.
[21] National Water Service Commissions (SPAN). (2018). Uniform Technical Guidelines: Water Reticulation and Plumbing: Suruhanjaya Perkhidmatan Air Negara, Selangor, Malaysia; 2018.
[22] DOSM (2010). Department of Statistics, Malaysia. Buletin Perangkaan KKLW 2011. Retrieved from https://www.rurallink.gov.my/wp-content/uploads/2015/05/23.pdf
[23] Ghozali, A., Yanti, R. M. K. (2017). The analysis of clean water demand for land use optimization based on water resource balance in Balikpapan city. Proceedings of the 3rd International Conference on Construction and Building Engineering (ICONBUILD); 1903(100013): 1-13.
[24] MWIG. (2018). Malaysia Water Industry Guide. The Malaysian Water Association (MWA); 2018.