IJERMS

International Journal of Engineering Researches and Management Studies

MAPPING OF WATER STRESS AREAS IN CENTRAL JAKARTA BASED ON WATER STRESS INDEX

Firdaus Ali*[1,2,3], Dwi Lintang Lestari[2], Marsya Dyasthi Putri[2] & Khalidah Nurul Azmi[2]

[*1]Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia

[2]Indonesia Water Institute, Tanjung Barat Indah, South Jakarta, 12530, Indonesia

[3]Ministry of Public Works and Housing, Jl. PattimuraNo.20 KebayoranBaru, South Jakarta, 12110, Indonesia

ABSTRACT

Water stress in Central Jakarta is mainly caused by population growth and increased development, which is not related by increased public awareness to the environmental condition. This study aims to determine water stress level in Central Jakartaand provide strategic directions and policies. This study discusses water stress conditions using index related to SDG Indicator 6.4.2-Water Stress. The index consisting of indicators selected: availability of water, piped water service coverage, continuity of water resources, groundwater quality, quality of piped water, flood, land use, availability of sanitation facilities, water demand, level of education, purchasing ability of water, level of public trust. This study uses descriptive statistic to obtain the results. Calculation of indicator is weighted based on justification adjusted to the existing condition. Results of index weighting is water stress index (WSI) which can be mapped for each sub-district. WSI for Central Jakarta is 0,18-0,52, describing no water stress to very high of water stress. Kartini, Kebon Kelapa, Kemayoran are sub-districts in high index; Karang Anyar needs special attention related to its very high index. Through mapping, strategic directions and policies can be provided which are revitalize water body, increase flow of piped water, and improve quality of water resources.

KEYWORDS: Indicators of Water Stress, Water Resources, Water Stress Index

1. INTRODUCTION

As the capital city of Indonesia, Jakarta must be able to meet the needs of clean water for the people. However, with the increasing population and the growth of development which are uncontrolled including water usage to meet the needs, more people in Jakarta will experience the water scarcity. Water provided by local water company in Jakarta has not been able to meet the needs of clean water for residents and commercials. Therefore, many residents and commercials in Jakarta use groundwater as a source of clean water.

Central Jakarta has the highest population density which is 18.745 people/km^2 (Central Jakarta Statistics Agency, 2009). High population density will increase the percentage of open land-use into settlements that reduce the amount of water infiltration and green open area. With reduction in the amount of water infiltration and the lack of water resources in Central Jakarta (there are only five lakes) (Regional Environmental Management Agency of Jakarta, 2009), it is possible that water stress conditions will occur in this region. Allotments in this region are offices, trade centers, and public facilities, so that the use of ground water becomes dominant. However, groundwater in Central Jakarta has the highest contents of coliform, iron, and manganese than groundwater in other regions of Jakarta (Regional Environmental Management Agency of Jakarta, 2009) so that the groundwater is not feasible to be used directly. Likewise, with the surface water quality, number of inundation points in this region is quite large (nine inundation points) so that it can pollute surface water (Regional Environmental Management Agency of Jakarta, 2009). The high value of BOD, COD, and turbidity in lakes, reservoirs, and rivers in Central Jakarta (Regional Environmental Management Agency of Jakarta, 2009) is indicators of surface water pollution occur in this region.

Following Sustainable Development Goals (SDGs), by 2030, it is targeted to ensure sustainable withdrawals and supply of freshwater to address water scarcity. In this case, mapping water stress areas of Central Jakarta is needed to be done. Water Stress Index (WSI) is applied for mapping the areas of Central Jakarta, as this related to the SDG Indicator 6.4.2-Water Stress. From this study, it can be known the level of water stress in Central Jakarta, and some strategic directions and policies can be provided to address the water stress problem in this region.

IJERMS
International Journal of Engineering Researches and Management Studies

2. METHODS

Data used in this study is qualitative data needs to be transformed into quantitative data by obtaining an index that becomes a value in a given space and time. The independent variable is each component that affects water stress, while the dependent variable is the water stress. The independent variable used in this study is the water stress index indicator. The independent variables consist of twelve indicators selected as the details from the five components. Population boundaries are vary depending on indicator to be calculated. In this study, questionnaire distribution is carried out to each sub-district based on sample calculation. WSI criteria can be obtained by formulating some affected components and indicators in the field. Calculation of indicators is done with the method based on Ismail (2010). By weighting the value and WSI obtained, mapping of water stress areas can be done. In this study, each indicator has a maximum value of 20, and will be given a scoring with a weighting value. The method is to provide a quantitative scale on each indicator that describes the level of influence of water stress. After the weight values are obtained, then the value is averaged.

- Indicator of Water Availability

$$KA = \frac{AT + AP + PAM}{P} \qquad (1)$$

Where: KA = water availability (m^3/year/person); AT = groundwater debit (m^3/year); AP = surface water debit (m^3/year); PAM = piped water debit/PAM (m^3/year); P = population (person). The classification of this indicator are: If KA > 1700 m^3/year, then $I_1 = 20$; If $1000 < KA \leq 1700$ m^3/year, then $I_1 = 15$; If $500 < KA \leq 1000$ m^3/year, then $I_1 = 10$; If $KA \leq 500$ m^3/year, then $I_1 = 5$.

- Indicator of Availability of Piped Water Service

$$T = \frac{\text{Population of PAM customers}}{\text{Total Population}} \times 100 \qquad (2)$$

Where: T = percentage of pipeline service coverage/PAM (%). To determine the value of this indicator (I_2), the value of T is multiplied by 20.

- Indicator of Water Sources Continuity

The term continuity in this study is continuity of piped water for PAM customers and aside from piping for residents who are not PAM customers. Determination of the score is as follows: Duration of water flow < 6 hours, will be given a score of 5; Duration of water flow 6-12 hours, will be given a score of 10; Duration of water flow 12-24 hours, will be given a score of 15; Duration of water flow 24 hours, will be given a score of 20.

$$I_3 = \frac{(\%NPAM \times KAT) + KAS + (\%PAM \times KPAM)}{3} \qquad (3)$$

Where: I_3 = Indicator value of continuity of clean water; %NPAM: Percentage of population who are not PAM customers; KAT: Score continuity in groundwater sources; KAS: Continuity score on river water sources; %PAM: Percentage of population who are PAM customers; KPAM: Continuity score on piped water sources/PAM.

- Indicator of Groundwater Quality

Parameters of groundwater quality are referring to the Decree of Minister of Health No. 907/MENKES/SK/VII/2002 about Drinking Water Quality and Requirements. Parameters were calculated using pollutant index to obtain groundwater quality status in accordance with Attachment II of the Decree of Minister of State No. 155 of 2003 about Use of Environmental Indexes on Water Pollutants. Four groups of pollutant index based on the level are: $0 \leq PIj \leq 1.0$: Meet the quality standard; $1,0 < PIj \leq 5.0$: Lightly polluted; $5.0 < PIj \leq 10$: Moderately polluted; $PIj > 10$: Severely polluted.

PIj value is the basis for determining the groundwater quality indicator, which are: If $PIj \geq 20$, then I4 = 0; If $PIj < 20$, then I4 = 20 - PIj.

- Indicator of Piped Water Quality

Determination of this indicator scores distributed evenly across 3 parameter classifications. The parameters are odor, taste, and clarity. Each parameter is classified and scored as follows: good 20,

ISSN: 2394-7659
IMPACT FACTOR- 3.775

IJERMS

International Journal of Engineering Researches and Management Studies

ordinary 15, and bad 5. Then, the piped water quality indicator value can be calculated by looking for an average such as the equation below:

$$I_5 = \frac{SB+SR+SK}{3} \quad (4)$$

Where: SB = Odor score; SR = Taste score; SK = Clarity score; I_5 = Piped water quality indicator value.

- Indicator of Flood

$$I_6 = \left(1 - \frac{b}{w}\right) \times 20 \quad (5)$$

Where: I_6 = Flood indicator value; b = area prone to flooding (ha); w = sub-district area (ha).

- Indicator of Land Use

Scores for determining the indicator of land use are as follows: Open land score = 2; Settlement = 7; General facility = 10, and Industry = 2.

$$I_7 = (L \times 20) + (P \times 7) + (F \times 10) + (I \times 2) \quad (6)$$

Where: I_7 = Land use indicator value; L: Percentage of open land allotment area; P: Percentage of settlement allocation area; F: Percentage of area allocated for public facilities; I: Percentage of industrial allotment area.

- Indicator of Availability of Domestic Wastewater Sanitation Facilities

Scores for determining this indicator are as follows: Communal system = 20; Semi-communal/modular system = 15; Individual System = 10; and River = 5.

$$I_8 = (20 \times K) + (15 \times SK) + (10 \times V) + (5 \times S) \quad (7)$$

Where: I_8 = Indicator value for availability of liquid waste sanitation facilities; K = Percentage of regions using communal systems; SK = Percentage of regions using semi-communal/modular systems; V = Percentage of regions using individual systems; S = Percentage of regions that dispose of liquid waste directly into rivers.

- Indicator of Clean Water Consumption Level

$$A = \frac{(P \times A1) + (Np \times A2)}{P + Np} \quad (8)$$

Where: A = Clean Water Consumption Level in sub-district (l/person/day); P = Piped water customers (person); Np: Non piped water customers (person); A1 = Level of clean water consumption by customer (l/person/day); A2 = Level of clean water consumption by non-customer (l/person/day). Based on the level of clean water needs is 50 liters/person/day for human in primary needs, the determination of this indicator value is as follows: If A ≥ l/person/day, then I_9 = 20; If A < 90 l/person/day, then the indicator value is calculated using the following equation:

$$I_9 = \frac{A}{90} \times 20 \quad (9)$$

Where: I_9 = The value of indicator of clean water consumption level; A = Clean water requirement level (l/person/day).

- Indicator of Education

$$I_{10} = P \times 20 \quad (10)$$

Where: I_{10}: Educational indicator values; P: Percentage of high school graduates.

- Indicator of Public Water Purchasing Ability

ISSN: 2394-7659
IMPACT FACTOR- 3.775

IJERMS

International Journal of Engineering Researches and Management Studies

Water purchasing ability in this study is divided into the purchasing ability by customers and non-customers. The value of water purchasing ability can be found for each sub-district with the approach taken is weighted as in the equation below:

$$F = \frac{(P \times AP) + (NP \times ANP)}{P + NP} \quad (11)$$

Where: F = Value of water purchasing ability in sub-district (%); P = Average income for piped water customers (persons); NP = The average income of residents not piped water customers (people); AP = Value of water purchasing ability for piped water customers (%); ANP = Value of water purchasing ability for non-piped water customer (%).

Then, the value of water purchasing ability in sub-district is divided into 3 groups based on the Regulation of Minister of Home Affairs No. 26 of 2006, which is less than 4%, between 4% to 4,5%, and more than 4,5%. The determination of the value of the indicator which distributed evenly is: If $F \geq 4{,}5\%$, then the value of I11 is 5; If $4\% < F < 4{,}5\%$, then the value of I11 is 10; If $F \leq 4\%$, then the value of I11 is 20.

- Indicator of Public Trust Level

  The public trust level in this study is the public perception of the quality of clean water used as drinking water. The equation below is used to find the percentage value of the public trust level in each sub-district.

$$T = \frac{(P \times T1) + (NP \times T2)}{P + NP} \quad (12)$$

Where: T = Percentage of population using bottled water (%); P = Number of PAM customers (persons); NP = Number of non-PAM customers (persons); T1 = Percentage of customers consuming bottled water (%); T2 = Percentage of non-costumers consuming bottled drinking water (%). Then, the determination of this indicator value is using the equation:

$$I_{12} = (1 - T) \times 20 \quad (13)$$

Where: I_{12} = Indicator value of public trust level; Q = Percentage of population consuming bottled water (%).

In this study, WSI will has a range 0 to 1. If the WSI value approaching 1, it describes the area approaching water stress conditions. Otherwise, if the WSI value approaching 0, it indicates the area does not experience water stress conditions. The WSI values can be obtained by:

$$WSI = \frac{20 - \left(\frac{\sum_{i}^{1} Ii . Wi}{Wt}\right)}{20} \quad (14)$$

Where: WSI = Water Stress Index; Ii = Indicator value of i; Wi = Indicator weight of i; Wt = Total weighting. A Wi value is the weight of each indicator. Weight value is the result of an assessment by team of experts in clean water sector who know the condition of research location. Weight value is the average value of assessment's results.

By knowing WSI value from each sub-district, the level of water stress from the area can be known. Water stress level classification is divided into 5 levels. The five WSI classifications are as follows: The area which the water stress level is very high: $WSI > 0{,}5$; water stress level is high: $0{,}4 < WSI \leq 0{,}5$; water stress level is moderate: $0{,}3 < WSI \leq 0{,}4$; water stress level is low: $0{,}2 < WSI \leq 0{,}3$; not in water stress condition: $WSI \leq 0{,}2$.

3. RESULTS AND DISCUSSION

Based on the WSI calculations, mapping of water stress areas can be done for each sub-district in Central Jakarta (see Figure 1). The WSI range for Central Jakarta is from 0,18 until 0,52. This result is based on the weight of each indicator, thus composing the WSI.

ISSN: 2394-7659
IMPACT FACTOR- 3.775

IJERMS
International Journal of Engineering Researches and Management Studies

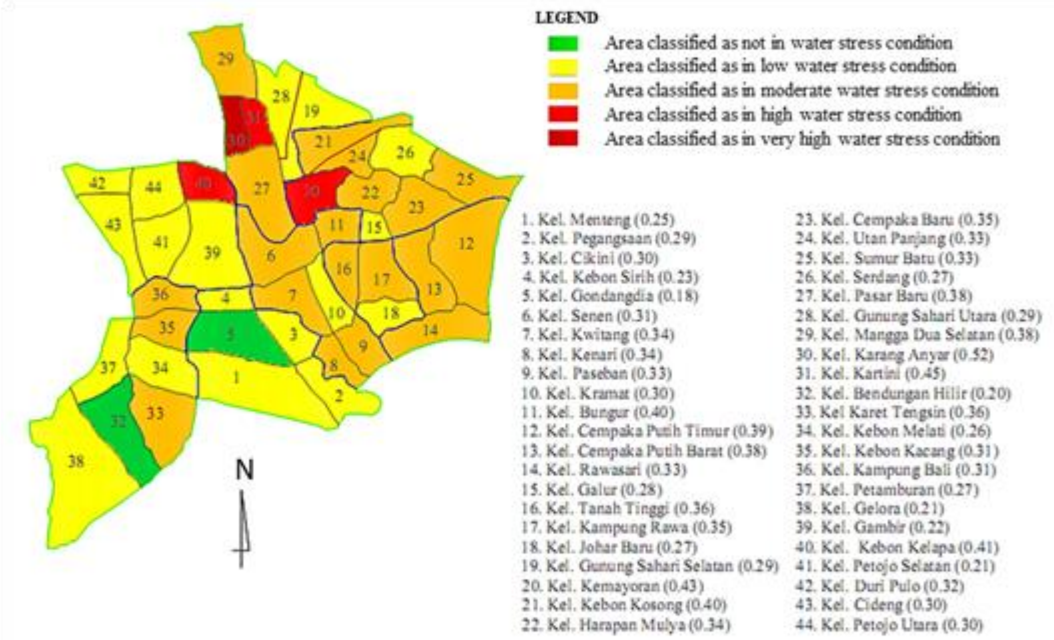

Fig 1: Mapping of Water Stress Areas in Central Jakarta

Strategic direction and policies that can be given to overcome water stress must be based on indicators that affect water stress condition. From the study and the obtained results, condition of water stress in Central Jakarta is affected by indicators of piped water service coverage, continuity of water resources, land use, availability of domestic wastewater sanitation facilities, education, public water purchasing ability, and level of public trust. However, other indicators such as water availability, groundwater quality, piped water quality, flood, and level of clean water consumption showed high values. In some sub-districts, availability and continuity of water resources greatly determine the condition of water stress. Hence, some steps must be taken as the top priority in determining the policies that will be taken to address the water stress problems in Central Jakarta. To make it easier and to prioritize policies in each area, Figure 2 depicts a mapping of strategic directions and policies in each sub-district of Central Jakarta which generally are to revitalize water body, increase piped water discharge, and improve quality of water resources.

IJERMS
International Journal of Engineering Researches and Management Studies

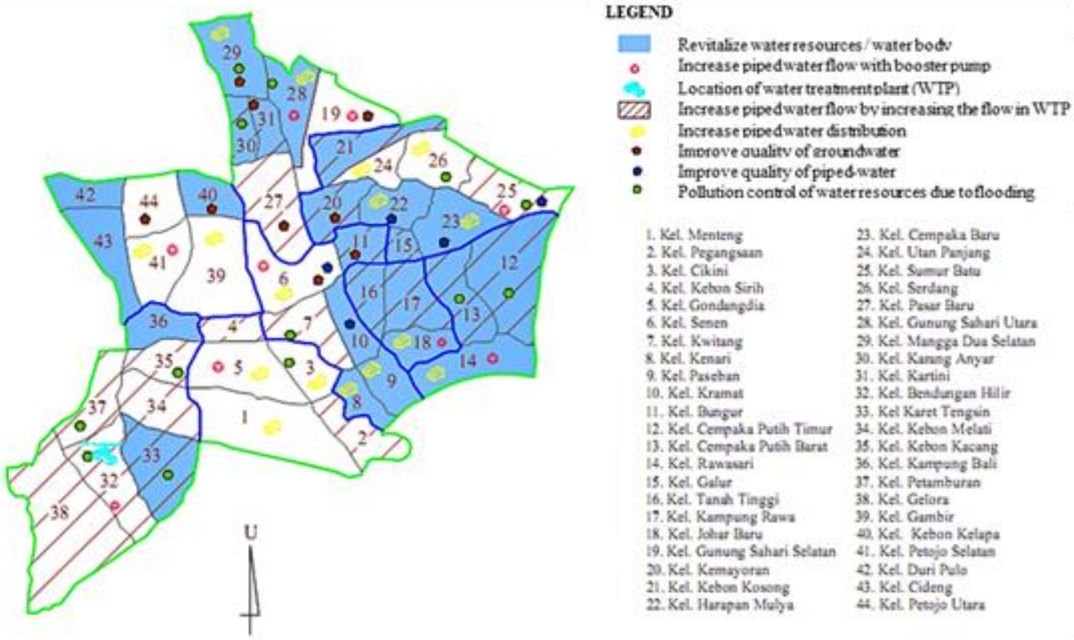

Fig 2: Strategic Directions and Policies Map to address Water Stress in Central Jakarta

Following Sustainable Development Goals (SDGs), by 2030, it is targeted to ensure sustainable withdrawals and supply of freshwater to address water scarcity. Form this study, it is expected that the WSI contribute to achieve the SDG Target 6.4 with correlating it to the SDG Indicator 6.4.2-Water Stress. It can be said that WSI will improve the sustainability of water usage as the SDG Indicator 6.4.2-Water Stress.

4. CONCLUSION

Water stress level in Central Jakarta using WSI are in condition not in water stress, low water stress, moderate water stress, high water stress, and very high of water stress. Strategic direction and policies to deal with are revitalize water body, increase piped water discharge, and improve quality of water resources. Further research including more specific weighting needed for each sub-district so that each sub-district has different weight values according to the existing conditions, and it is needed to be able to include education indicators and purchasing ability of drinking water in the calculation of WSI.

References

1. *Araújo, J.C.d., Döll, P., Güntner, A., Krol, M., Abreu, C.B.R., Hauschild, M., and Mendiondi, E.M. 2004. "Water Scarcity Under Scenarios for Global Climate Change and Regional Development in Semiarid Northeastern Brazil". Water International, Vol. 29, No. 2 (June), 209-220.*
2. *Badan Pengelolaan Lingkungan Hidup Daerah Provinsi DKI Jakarta (Regional Environmental Management Agency of Jakarta). 2009. Status LingkunganHidup Daerah Provinsi DKI Jakarta (Regional Environmental Status of Jakarta). Author, Jakarta.*
3. *Badan Pusat Statistik Kota Administrasi Jakarta Pusat (Central Jakarta Statistics Agency). 2009. Kecamatan Dalam Angka (Sub-district in Figures). Author, Jakarta.*
4. *California Water Sustainability: Sustainability indicator framework to support water decisions [online]. "Indicators by Goal". Davis: University of California. Available from: https://indicators.ucdavis.edu/water/indicators/water-stress-index*
5. *Food and Agriculture Organization of the United Nations. 2018. "Sustainable Development Goals: SDG Indicator 6.4.2-Water Stress". Author (March).*
6. *Ismail, T.A. 2010. "Perumusan Indeks Rawan Air di Daerah Perkotaan (StudiKasus: Jakarta Utara) (Formulation of Water Stress Index in Urban Area (Case Study: North Jakarta)". Thesis (Bachelor's Degree), Depok, Universitas Indonesia.*

IJERMS
International Journal of Engineering Researches and Management Studies

7. *Mlote, S.D.M., Sullivan, C., and Meigh, J. 2002. Water Poverty Index: a Tool for Integrated Water Management. In 3rd WaterNet/Warfsa Symposium 'Water Demand Management for Sustainable Development' (Dar es Salaam, Oct. 30-31).*
8. *Molle, F., and Mollinga, P. 2003. "Water poverty indicators: conceptual problems and policy issues". Water Policy, 5, 529-544.*
9. *Nepomilueva, Daria. 2017. "Water scarcity indexes: Water availability to satisfy human needs". Thesis (Bachelor's Degree), Helsinki Metropolia University of Applied Sciences.*
10. *Ruess, Paul. 2015. "Mapping of Water Stress Indicators". CE 394K Term Paper.*
11. *Sullivan, C., Meigh, J., and Lawrence, P. 2005. "Application of The Water Poverty Index at Different Scales: A Cautionary Tale". Water International, Vol. 31, No. 3 (Sep), 412-426.*