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RESEARCH ARTICLE

Potential for Developing Access to Safe Drinking Water in the Highlands Area (Case Study: Bogor City, Indonesia)

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ABSTRACT

The need for water in Indonesia is not directly proportional to its availability. This challenge is not limited to rural areas but also affects urban areas like Bogor City. Since 2004, Regional drinking water company of Bogor City has been classified as healthy and is a pilot city for the prime drinking water zone program alongside two other Indonesian cities. This research aims to assess Bogor City's potential for safe drinking water development, considering the physical environment, readiness of the drinking water system, social conditions, and economic conditions of the community. The methodology used is mixed with a quantitative approach via spatial analysis. The physical environment variable yielded 4 classifications: high potential, potential, moderate potential, and low potential. The very potential classification was dominant in 45 sub-districts. The drinking water system readiness had 4 classifications: potential, moderate potential, low potential, and no potential, with the moderate potential dominating in 51 sub-districts. The community social condition had 4 classifications: potential, moderate potential, low potential, and no potential, with the low potential dominating in 36 sub-districts. The community economic condition variable resulted in 4 classifications. Moderate potential dominates in 29 sub-districts. Bogor City has moderate potential for developing access to safe drinking water. The key factors for this classification are the community's social and economic conditions, as well as the drinking water system's readiness.

Introduction

Water is an important and valuable resource for living organisms, and its existence has a complex and dynamic relationship from various aspects [1–3]. The global need for fresh water in the last 100 years has increased by at least six times, while the availability of fresh water is only 2.5% of the global figure, with two billion people still lacking safe drinking water [4–7]. The increase in demand and needs has led to an increase in water crisis areas in various countries, including Indonesia [8–10]. The depreciation of the availability of water resources has caused at least a 36% reduction in clean water from 17,000 m^3/capita/year in 1990 to 10,759 m^3/capita/year in 2016 [5,11–14]. This reduction occurs due to the exploitation of water resources, one of which is used for 16% of bottled drinking water, which requires 2,000 times more energy than piped water [15–17]. Referring to the quality of bottled water, which can have chemical and plastic contamination, the provision and management of water resources should be carried out in an integrated and sustainable manner through pipelines, which have a relatively low pollution risk [15,18–22].

The provision of clean water in Indonesia as a basic service is targeted at 100% by 2030, with 53.94% in the form of pipes, of which 43.15% are safe drinking water. By 2020, only 93% had access to clean water, with 20% originating from pipes, whereas 8.1% could not be safe [15,23–25]. This occurs not only in rural areas but also in urban areas, such as Bogor City, where the availability of clean water from safe pipes has only reached 4.33% [26]. This problem is quite interesting, referring to one of the regional agencies responsible

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for providing these utilities, namely the Regional Drinking Water Company (*Perusahaan Daerah Air Minum*/ PDAM)). Bogor City has had a healthy PDAM since 2004, which is one of the pilot project cities for the drinking water supply system through the Prime Drinking Water Zone (*Zona Air Minum Prima/*ZAMP) program along with two other cities in Indonesia [26,27].

The provision of drinking water in Bogor City has various obstacles that cannot be separated from environmental problems, as can be seen from the decline in river quality in Bogor City [28]. In addition, technical and non-technical problems, which include water leakage of 35.33% of the tolerance limit of 20%, hilly topography, lack of intervention from the policy side, and lack of PDAM communication, can also hinder the development of safe piped drinking water [26,29–31]. The city minimum wage, which does not reach \$4,000 per year [32], is a problem for communities to consider using safe drinking water through piped networks. This encourages research related to the potential for developing access to safe drinking water in Bogor City to be studied from the aspects of the physical environment, readiness of the drinking water system, social conditions of the community, and economic conditions of the community.

Materials and Methods

Research Location and Time

The research was conducted in all sub-districts of Bogor City, West Java Province, Indonesia, which has a total of 68 sub-districts (Figure 1). Bogor City is located between $6^0 30'0''$–$6^0 42'0''$ South Latitude and $106^0 44'0''$ – $106^0 52'0''$ East Longitude, which is administratively in the center of Bogor Regency. Primary and secondary data were collected for three months, from January to March 2024, including questionnaires distributed online because the general election in 2024 coincided with this period.

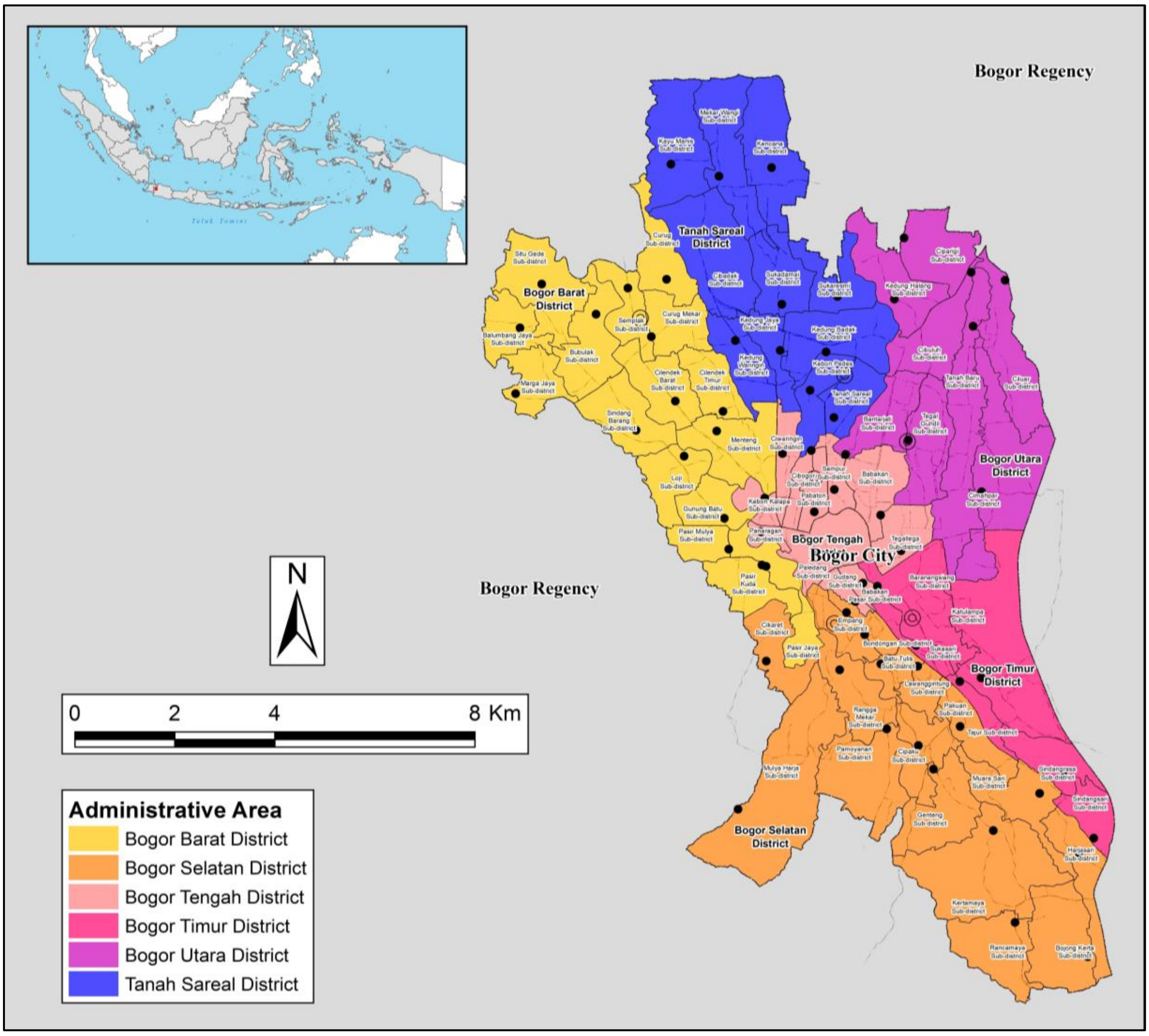

Figure 1. Research location.

Data Collection

This study used a mixed method with a quantitative approach using spatial analysis. The spatial unit in this study was based on regional functions with a spatial analysis scale at the sub-district level. The data collected for this research consists of four variables and 12 sub-variables, with data ranging from 2000 to 2024. The data collected in this study are listed in Table 1.

Table 1. Operational definition of research variables.

No	Variables/sub-variables	Operational definition
1	Physical environment	
a	Residential density patterns	The form of distribution of buildings and population density in a residential area.
b	Topography	The shape of the earth's surface, which includes the height and slope of an area.
2	Readiness of the drinking water system	
a	Drinking water distribution systems	The ratio between the length of the drinking water network and the area of the residential area.
b	Maintenance of drinking water systems	Based on the year of installation of the main distribution and transmission pipeline networks.
c	Type of drinking water material	Types of materials used in main distribution and transmission pipeline networks.
d	Distance from water supply	Distance from water supply to each service zone.
e	Infrastructure supporting the drinking water system	Areas that have supporting infrastructure to reduce drinking water network leaks, such as district metered areas (DMAs).
3	Social conditions of society	
a	Education	The level of population who have not or are not in school and the level of population who are in school is high.
b	Behavior	Community attitudes in managing safe drinking water and waste.
c	Knowledge	Awareness and/or understanding of safe criteria for maintaining drinking water sources so that they are not contaminated by feces and household liquid waste.
4	Economic conditions of society	
a	Regional poverty level	Anthropogenic activity identified through nighttime light visible on the VIIRS-DNB satellite.
b	Household income	Total income earned by the household in a month (Rp/Month).

The minimum number of samples was 384. The target sample was obtained from calculations using the Isaac and Michael Formula by considering the population of Bogor City as 1,114,018, with the assumption that one household has four people [33,34]. The calculation formula can be seen more clearly as follows:

$$S = \frac{\lambda^2 . N . P . Q}{d^2(N-1) + \lambda^2 . P . Q} \tag{1}$$

Where: S = Number of samples; λ^2 = degrees of freedom and error rate; N = Total population; d = the difference between the population means and the sample means; P = chances are right (0.5); Q = chances are wrong (0.5).

The error value used in this study was 5%. Sampling was conducted using stratified random sampling, with the number of households per sub-district being proportional to the number of households in Bogor City. The inclusion criteria used in this study were people domiciled in Bogor City spread across all sub-districts, both customers and non-customers of PDAM, with a minimum age of 15. The determination of the respondent age limit of 15 is based on the minimum working age and workforce in Indonesia.

Data Analysis

Residential Density Patterns

The residential density pattern has two parameters: the distribution pattern of residential buildings, and the level of residential population density. The residential density data used came from land parcel data, updated based on image appearance. The parcel data are then converted using the centroid and processed to determine the building distribution pattern using the Average Nearest Neighbor (ANN) Method with the Manhattan distance calculation method [35]. The formula used was as follows:

$$\overline{D}_0 = \frac{\sum_{i=1}^{n} d_i}{n} \tag{2}$$

$$\overline{D}_E = \frac{0.5}{\sqrt{n/A}} \quad (3)$$

$$ANN = \frac{\overline{D}_0}{\overline{D}_E} \quad (4)$$

Where: $\overline{D}_0$ = the average distance of observations between each feature and its nearest neighbors; $\overline{D}_E$ = the expected average distance for a given feature in a random pattern; d_i = the distance between feature i and its nearest neighbors; n = number of fiture; A = user-defined area value.

If the ANN index shows a value less than 1, it shows a clustered pattern; if the ANN index shows a value equal to 1, it shows a random pattern; and if the ANN index shows a value greater than 1, it indicates a dispersed pattern. This is shown in Figure 2 [36]. ANN measurements can use the ArcGIS tool with the concept of Manhattan or Euclidean distance. This study uses the Manhattan concept, namely the distance between points measured along the perpendicular axis by considering city blocks calculated by adding the (absolute) differences between the x and y coordinates.

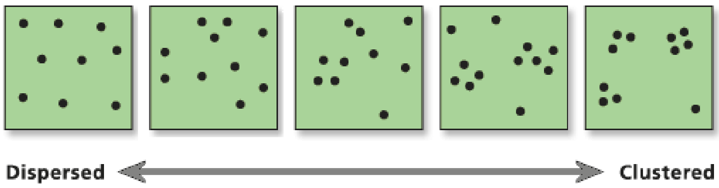

Figure 2. Illustration of ANN Index Results.

The level of residential density refers to SNI 03-1733-1989 regarding procedures for planning urban housing areas, which is divided into three classes: high, medium, and low. This study uses the residential density nomenclature so that the numerator is the population and the divisor is the area of the settlement. The aim is to see the amount of use or need for drinking water per unit area of settlement on each sub-district. The formula used is as follows:

$$Residential\ density = \frac{total\ population}{total\ residental\ area} \quad (5)$$

Topographic Shape of The Area

The topographic shape has two parameters: the slope shape and height level. Slope shape parameters were created and analyzed using RBI (*Rupa Bumi Indonesia*) contour data from BIG (*Badan Informasi Geospasial*) at 2.5 m intervals, and then classified into five classes, which can be seen more clearly in Table 2 [37], while the height level classification is divided into three classes, which are based on the relativity of residential height to the height of water sources in Bogor City, where the average height of water sources is 331 m above sea level.

Table 2. Slope form.

No	Slope (%)	Description
1	< 8	Flat
2	8–15	Sloping
3	15–25	Wavy
4	25–40	Steep
5	> 40	Very steep

Poverty

To determine regional poverty levels using the visible infrared imaging radiometer suite day night band (VIIRS-DNB) satellite imagery approach. This approach is used to determine the intensity of night lights or nighttime lights (NTL), which can be interpreted to mean that the brighter an area is, the higher the income of the people in that area, while the darker the area, the lower the income of the people [38,39]. The formula used can be seen more clearly as follows:

$$A = \frac{T}{N} \quad (6)$$

where A is the Average Light Index (ALI) value, T = total night light intensity measured by the sum of the values of all pixels in the relevant administrative area, and N = the number of all pixels with a positive emission value.

Data Codification

Data coding is carried out to assign values to objects to extract data, so that each object has equality and can be compared with one another in the scientific process [40,41]. The value is given according to the criteria for potential access to safe drinking water from each parameter. The higher the total value of all parameters indicates the higher the potential of an area for access to safe drinking water. The coded parameters are listed in Table 3.

Table 3. Data codification.

No.	Variables/sub-variables/parameters	Value 1	Value 2	Value 3	Value 4	Value 5
1.	Physical environment					
a	Residential density patterns					
	Distribution patterns of residential buildings	Dispersed	-	Random	-	Clustered
	Residential population density levels	Low	-	Moderate	-	High
b	Topography					
	Elevation	Minimum height ≥ 331 m above sea level	-	Minimum height < 331 m above sea level and maximum height ≥ 331 m above sea level	-	Maximum height < 331 m above sea level
	Slope form	Very steep	Steep	Wavy	Sloping	Flat
2.	Readiness of the drinking water system					
a	Drinking water distribution systems	0–100 m/ha	100.01–200 m/ha	200.01–300 m/ha	300.01–400 m/ha	> 400 m/ha
b	Maintenance of drinking water systems	Pipe installation period < 2013	-	Pipe installation period 2013–2016	-	Pipe installation period 2017–2021
c	Type of drinking water material	Others	-	PVC	-	HDPE
d	Distance from water supply	> 12 km	10–12 km	7–9 km	4–6 km	1–3 km
e	Infrastructure supporting the drinking water system	Areas that do not have a pipe network	-	Pipeline network areas without DMAs implementation	Pipeline network area with DMAs implementation	Pipeline network area with ZAMP implementation
3.	Social conditions of society					
a	Education					
	Out-of-school rate	> 30% of the total population per sub-district	24.1–30% of the total population per sub-district	18.1–24% of the total population per sub-district	12.1–18% of the total population per sub-district	≤ 12% of the total population per sub-district
	Higher education degree	0–5% of the total population per sub-district	5.1–10% of the total population per sub-district	10.1–15% of the total population per sub-district	15.1–20% of the total population per sub-district	> 20% of the total population per sub-district
b	Behavior					
	Management of Drinking Water and Household Food or (*Pengelolaan Air Minum dan Makanan Rumah Tangga/* PAMMRT)	0–20% of the total population per sub-district	20.1–40% of the total population per sub-district	40.1–60% of the total population per sub-district	60.1–80% of the total population per sub-district	80.1–100% of the total population per sub-district
	Household Waste Management (*Pengelolaan Sampah Rumah Tangga/*PSRT)	0–20% of the total population per sub-district	20.1–40% of the total population per sub-district	40.1–60% of the total population per sub-district	60.1–80% of the total population per sub-district	80.1–100% of the total population per sub-district
c	Knowledge					
	Stop Open Defecation (*Stop Buang Air Besar*	≤ 80% of the total	80.1–85% of the total	85.1–90% of the total	90.1–95% of the total	95.1–100 of the total

No.	Variables/sub-variables/parameters	Value 1	Value 2	Value 3	Value 4	Value 5
	Sembarangan/SBS)	population per sub-district	population per sub-district	population per sub-district	population per sub-district	population per sub-district
	Household Domestic Wastewater Management (*Pengelolaan Air Limbah Domestik Rumah Tangga/*PALDRT)	0–20% of the total population per sub-district	20.1–40% of the total population per sub-district	40.1–60% of the total population per sub-district	60.1–80% of the total population per sub-district	80.1–100% of the total population per sub-district
4.	Economic conditions of society					
a	Regional poverty level	Very high	High	Moderate	Low	Very low
b	Household income (Rp)	≤ 3,000,000	3,000,001–6,000,000	6,000,001–9,000,000	9,000,001–12,000,000	≥ 12,000,001

Data Classification

Each sub-variable and parameter are calculated using the addition method, which is then normalized to the largest value that can be produced. Each data point was then divided into five classes: no potential (1), low potential (2), moderate potential (3), potential (4), and high potential (5). Class division uses the following formula [42]:

$$K = \frac{a-b}{u} \quad (7)$$

Where: K = Classification, a = highest value, b = lowest value, and u = number of classes.

Results and Discussion

Respondent Profile

The total number of respondents obtained from this study was 635, which exceeded the 384 target respondents. The respondents comprised 534 women and 101 men of various ages. For more detailed information regarding the sociodemographic characteristics of respondents, looking at the respondent's age, the respondent's last education, and the last education of the family head (Table 4). Respondents aged 41 to 50 years had the largest percentage compared to other age groups, at 34.39%. The most recent education of respondents, which dominated, was SMA/K (*Sekolah Menengah Atas/Kejuruan*), amounting to 56.85%, while the final education of the head of the family was also dominated by SMA/K, amounting to 57.64%, and respondents' occupations were dominated by stay-at-home spouses at 70.71%.

Table 4. Respondent profile.

Characteristics	Number of respondents	Percentage (%)
Age (Years)		
< 21	7	1.10
21–30	54	8.50
31–40	132	20.79
41–50	219	34.49
51–60	186	29.29
> 60	37	5.82
Last education		
Elementary school	34	5.35
Junior high school	80	12.60
Senior high/vocational school (SMA/K)	361	56.85
Diploma	43	6.77
Bachelor’s degree	91	14.33
Master’s degree	25	3.94
Doctor degree	1	0.16
Occupation		
Government employee	35	5.51
Labor	19	2.99
Housewife	449	70.71
Employee	66	10.39
Student	8	1.26
Teacher	14	2.20
Retired	20	3.15

Results

Based on the data processing, four maps representing each research variable were obtained, as shown in Figure 3. The physical environmental variable produced four classifications, namely high potential, potential, moderate potential, and low potential, where the high potential classification dominates in Bogor City in 45 sub-districts with an area of 6,791.68 ha (60.98%), while the smallest in the form of the low potential classification is in three sub-districts with an area of 73.53 ha (0.66%). The average values of each sub-variable and parameter in the physical environment variable are listed in Table 5.

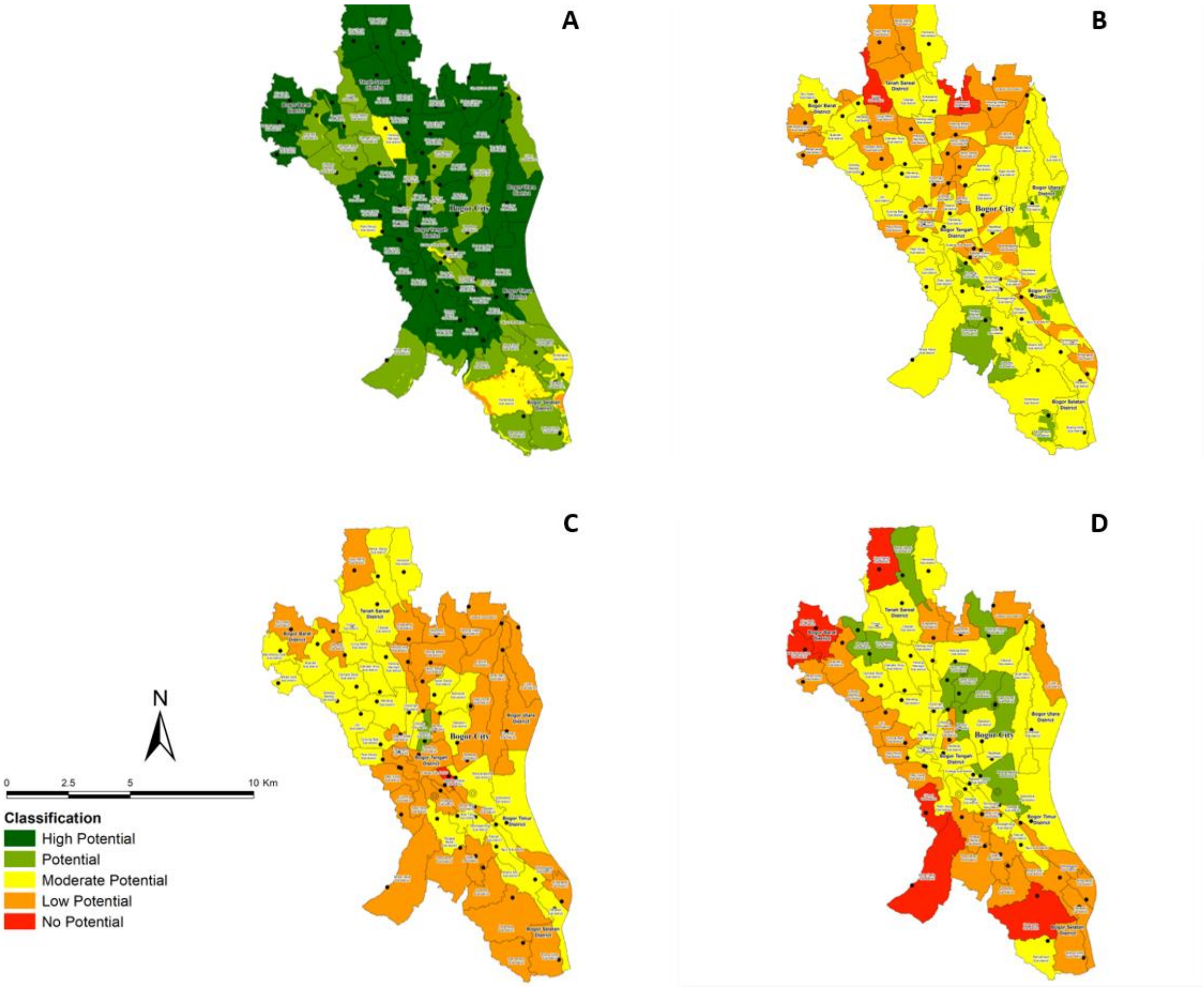

Figure 3. (A) Physical Environmental Variable Map; (B) Readiness of the Drinking Water System Variable Map; (C) Social Conditions of Society Variable Map; (D) Economic Conditions of Society Variable Map.

Table 5. Distribution of class values for physical environmental variable.

Classification of physical environmental variable	Residential density patterns		Topography		Total value
	Distribution patterns of residential buildings	Residential population density levels	Elevation	Slope form	
High potential	4.95	4.48	5.00	4.88	19.30
Potential	3.72	4.06	3.18	4.71	15.67
Moderate potential	3.82	1.31	2.20	4.55	11.88
Low potential	5.00	1.47	1.00	2.35	9.81
Average value	4.48	4.10	4.20	4.79	17.58

Readiness of the drinking water system variable resulted in four classifications: potential, moderate potential, low potential, and no potential, where the moderate potential classification dominates in Bogor City in 51 sub-districts, with an area of 7,053.17 ha (63.32%), while the smallest in the form of a non-potential classification is in two sub-districts with an area of 275.71 ha (2.48%). The average value of each sub-variable in the readiness of the drinking water system is presented in Table 6.

Table 6. Distribution of class values for readiness of the drinking water system variable.

Classification of readiness of the drinking water system variable	Drinking water distribution systems	Maintenance of drinking water systems	Type of drinking water material	Distance from water supply	Infrastructure supporting the drinking water system	Total value
Potential	4.08	1.09	4.28	4.75	3.47	17.67
Moderate potential	3.17	1.13	3.84	3.52	3.14	14.79
Low potential	2.35	1.08	3.59	2.18	3.05	12.26
No potential	3.00	1.00	1.00	1.77	1.00	7.77
Average value	3.00	1.11	3.73	3.19	3.09	14.12

The social conditions of the society variable resulted in four classifications: potential, moderate potential, low potential, and no potential, where the low potential classification dominates in Bogor City with the number of sub-districts being in 36 sub-districts, with an area of 6,330.17 ha (56.83%), while the smallest in the form of a non-potential classification is in one sub-district with an area of 36.04 ha (0.32%). The average values of each sub-variable and parameter in the community social condition variable are listed in Table 7.

Table 7. Distribution of class values for social conditions of society variable.

Classification of social conditions of society variable	Education		Behavior		Knowledge		Total value
	Out-of-school rate	Higher education degree	PAMMRT	PSRT	SBS	PALDRT	
Potential	3.00	5.00	5.00	2.00	5.00	3.00	23.00
Moderate potential	2.17	3.62	4.19	1.76	3.99	1.56	17.29
Low potential	1.56	2.33	4.02	1.31	3.09	1.37	13.68
No potential	3.00	2.00	2.00	1.00	1.00	1.00	10.00
Average value	1.83	2.89	4.09	1.50	3.48	1.46	15.25

The economic conditions of the society variable resulted in four classifications, namely potential, moderate potential, low potential, and no potential, where the moderate potential classification dominates in Bogor City with the number of sub-districts in 29 sub-districts, with an area of 4,472.54 ha (40.15%), while the smallest in the form of non-potential classification is in six sub-districts with an area of 1,733.02 ha (15.56%). The average value of each sub-variable in the community economic condition variables is presented in Table 8. The recapitulation of area per classification for each variable is presented in Table 9.

Table 8. Distribution of class values for economic conditions of society.

Classification of economic conditions of society variable	Regional poverty level	Household income	Total value
Potential	4.07	3.14	7.21
Moderate potential	3.63	2.40	6.03
Low potential	2.58	1.83	4.41
No potential	1.61	1.55	3.16
Average value	3.06	2.20	5.26

Table 9. Recapitulation of classification area for each variable in hectares (ha).

Variable classification	Physical environment	Readiness of the drinking water system	Social conditions of society	Economic conditions of society
High potential	6,791.68	-	-	-
Potential	3,478.99	752.40	63.40	1,558.28
Moderate potential	794.21	7,053.17	4,708.82	4,472.54
Low potential	73.53	3,057.15	6,330.17	3,374.58
No potential	-	275.71	36.04	1,733.02

Each variable value was normalized for spatial analysis to produce a potential map for developing safe drinking water access. This map was then cut based on delineating the placement of DMAs and ZAMP, where PDAM conducts these two programs to maintain the quality, quantity, continuity, and affordability of drinking water. The map can be seen more clearly in Figure 4.

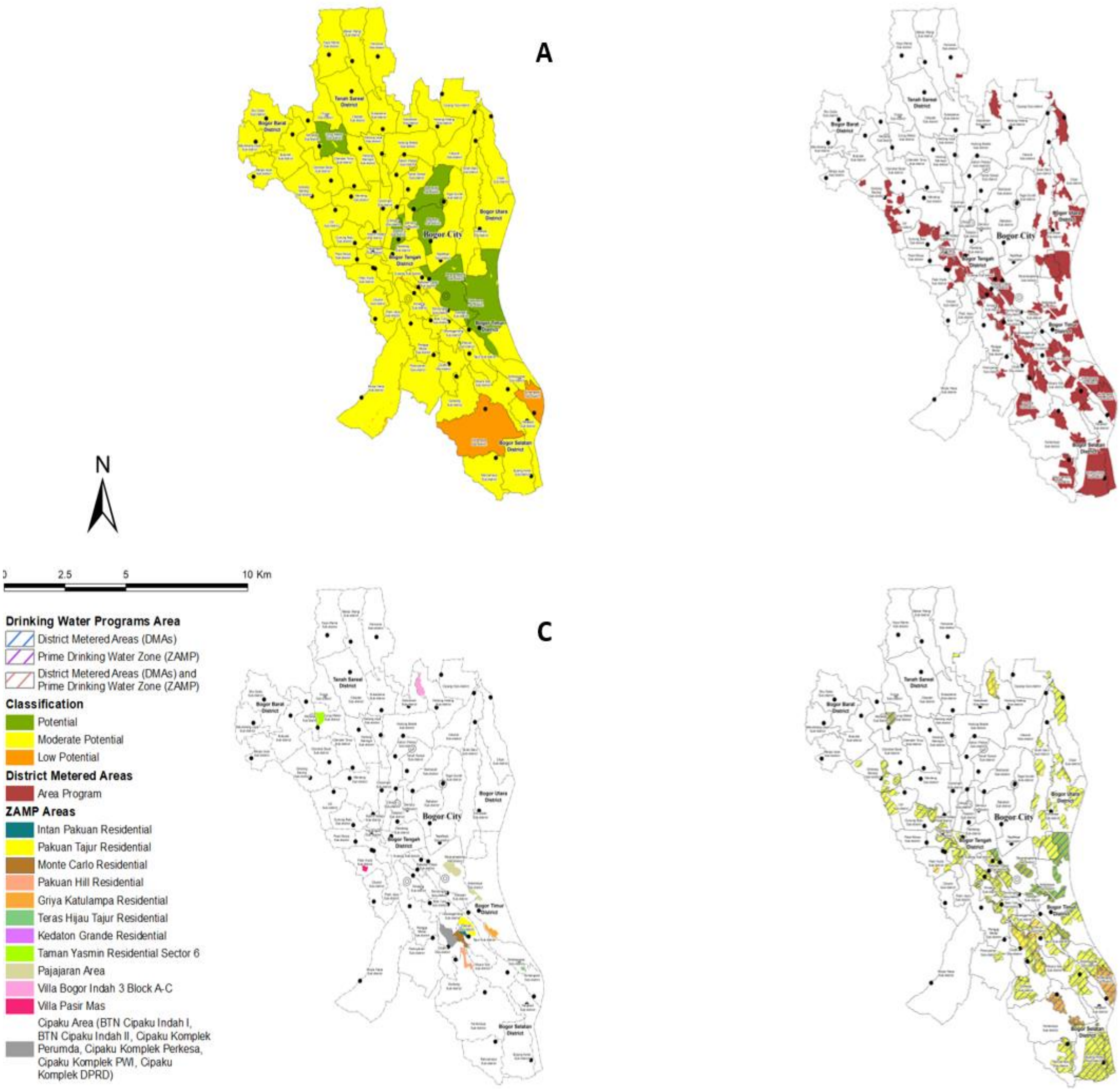

Figure 4. (A) Potential Map for Development of Safe Drinking Water Access; (B) DMAs Delineation Map; (C) ZAMP Delineation Map; (D) Map of Potential Development of Safe Drinking Water Access in DMAs and ZAMP Delineation.

The potential for developing access to safe drinking water produces three classifications, namely, potential, moderate potential, and low potential, where the classification of moderate potential dominates in Bogor City in 65 sub-districts, with an area of 9,499.57 ha (85.29%), followed by potential. In eight sub-districts, with an area of 1,090.22 ha (9.79%), the smallest in the form of low potential classification are in six sub-districts with an area of 548.20 ha (4.92%). The average value of each variable for the potential for developing access to safe drinking water is shown in Table 10. The recapitulation of classification areas in the delineation of DMAs and ZAMP is shown in Table 11.

Table 10. Distribution of class values for potential development of access to safe drinking water.

Classification of potential for development of access to safe drinking water	Physical environment	Readiness of the drinking water system	Social conditions of society	Economic conditions of society	Total value
Potential	4.86	2.84	2.95	3.34	13.99
Moderate potential	4.43	2.82	2.52	2.60	12.36
Low potential	2.87	2.91	2.17	1.71	9.65
Average value	4.39	2.82	2.54	2.63	12.39

Table 11. Recapitulation of classification areas in DMAs and ZAMP delineation in hectares (ha).

Variable classification	DMAs	ZAMP	DMAs and ZAMP
High potential	-	-	-
Potential	146.19	46.94	17.70
Moderate potential	1,193.37	58.55	60.47
Low potential	113.46	-	-
No potential	-	-	-

Discussions

The physical environment in this study showed the highest variable value for each classification of the potential for developing access to safe drinking water. This indicates that the physical environment is not a major obstacle to accessing safe drinking water, even though the topography of Bogor City has a height ranging from 137 m above sea level to 706 m above sea level, which is included in the highlands. The parameter with the lowest value for the physical environment variable was residential population density. In fact, the higher the population density of an area, the more access is needed to clean water [43] including drinking water. This is in line with previous research, which shows that the availability of basic infrastructure for settlements being built is still not in line with the needs of the local population [44].

In addition, the readiness of the drinking water system in Bogor City has a third low variable value that can influence the level of potential for developing access to safe drinking water, especially for maintaining drinking water. This refers to research results that show that the average age of the main piped drinking water in Bogor City is more than a decade. Similar research also shows that the main problem in the pipe network is the old technical age of the pipes; therefore, it is necessary to replace pipes that are stronger and more durable with pipe-type materials, such as high-density polyethylene (HDPE) [45,46]. This is because it affects the quantity, quality, and continuity of drinking water that is distributed, as previous research shows that the older the pipe, the higher the roughness of the pipe, thus affecting residual chlorine levels and flow speed [45,47]. The environment can also cause corrosion in pipes, thereby shortening the life of the pipe if maintenance is not performed [48,49].

On the other hand, the economic condition of the community in this study also showed low values for the second variable, which influences the potential for developing access to safe drinking water, especially those related to total household income. Low-income communities have the potential to experience changes in access to water services, which are influenced by policy [50]. Therefore, affordability is an important aspect of the drinking water supply system, which determines drinking water tariffs in accordance with the mandate from Regulation of the Minister of Home Affairs No. 21 of 2020 concerning Amendments to the Ministerial Regulation No. 71 of 2016 concerning Calculation and Determination of Drinking Water Tariffs, where expenditures by households to meet the basic needs for drinking water do not exceed 4% of the income of the consumer community [51]. The policy of providing more affordable access to safe drinking water is a key factor in alleviating poverty [52].

The social conditions in this research use education, behavior, and community knowledge for analysis of behavior and knowledge using data from the four pillars of the Community Based Total Sanitation (*Sanitasi Total Berbasis Masyarakat/*STBM) program, including PAMMRT, PSRT, PALDRT, and SBS. The results show that the social conditions of the community have the lowest variable value, which can influence the level of potential for developing access to safe drinking water, especially regarding the management of household waste and domestic wastewater. These results are in line with the problem of waste and wastewater in Indonesia, which still needs to be handled seriously so that it does not pollute the environment, and the food chain is contaminated by dangerous and toxic substances [53,54]. Moreover, access to water and sanitation is influenced by spatial, social, economic, and institutional factors [55]. Therefore, the community, together with the government, must ensure that handling access to drinking water, hygiene sanitation, and waste management is effective in maintaining human health and the environment in sustainable development [56].

Providing drinking water cannot rely on individual efforts as water needs continue to increase owing to population growth and settlement development [57,58]. Therefore, centralized efforts through pipe systems are needed in developing areas, especially urban settlements. The data processing results showed that the potential for developing access to safe drinking water in Bogor City was dominated by a moderate potential classification of 85.29%. Although the City of Bogor has made several efforts to improve the water supply system, such as ZAMP and DMAs, most development potential results in these areas are also classified as moderate potential at 64.80% in ZAMP and 81.89% in DMAs.

This shows that the efforts made are still not optimal. Water loss control should not stop at determining DMAs, but requires a technological infrastructure through smart water that includes the Internet of Things (IoT), cloud-based information storage, and big data analysis to obtain real-time data from every measured parameter, such as height, flow, pressure, temperature, and water quality, which are presented online [59]. Inventory and visualization of all infrastructure in spatial form with the help of a geographic information system (GIS) that can be connected online is very important in supporting the implementation of IoT-based water loss control [60].

However, this remains an obstacle for PDAM, where all infrastructure assets have not yet been inventoried spatially. On the other hand, although Bogor City once had a ZAMP area with concepts to be achieved such as smart water in the form of isolated areas having data loggers to control aspects of quantity, quality, continuity, and affordability of water according to ZAMP criteria, but currently the program ZAMP is no longer active. The biggest obstacle to developing ZAMP is the readiness of facilities and infrastructure at PDAM and the capacity of the regional government to implement ZAMP on a large scale [61]. The results of this research prove that the ZAMP and DMAs programs in Bogor City have not been implemented optimally in areas that have the potential to develop access to safe drinking water. This can be seen from three main factors: the social condition of the community, economic condition of the community, and readiness of the drinking water system.

Conclusions

The potential for developing access to safe drinking water in Bogor City can be classified into three categories, with the moderate potential classification representing the majority at 85.29%, followed by potential at 9.79%, and low potential at 4.92%. The highest value observed in the analysis of the potential to develop access to safe drinking water was 14.44 out of 20, and the lowest was 8.84 out of 4. It can be concluded that the physical environment does not represent a significant obstacle in developing access to safe drinking water. Rather, the social conditions of the community, the economic conditions of the community, and the readiness of the drinking water system appear to be the primary factors influencing this outcome. The central government and regional drinking water companies must develop a smart water infrastructure and technology to ensure and maintain optimal drinking water quality. On the other hand, the regional government conducts periodic evaluations and supervises the provision of clean drinking water and sanitation involving community participation.

Author Contributions

RFM: Conceptualization, Methodology, Analysis, Writing – Review & Editing; **DNM**: Conceptualization, Writing – Review; and **NG**: Conceptualization, Methodology, Writing – Review.

Conflicts of interest

There are no conflicts to declare.

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