Drinking Water Demand Analysis and Master Pipe Network Size Planning in Ungasan Village, South Kuta Subdistrict, Badung Regency

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ABSTRACT

Ungasan Village, located in the South Kuta District of Badung Regency, is experiencing increasing water demand due to population growth and the rise of tourism accommodations. This study is a hydraulic planning analysis aimed at designing an optimal main pipe network for clean water distribution. Currently, Perumda Tirta Mangutama, the regional water utility provider, supplies water to Ungasan Village; however, the area's topography and geological conditions—dominated by limestone rock formations—hinder the presence of alternative water sources. Based on data from Perumda Tirta Mangutama (2023), approximately 25% of households (±1,000 residents) still rely on tanker water due to an uneven and suboptimal existing pipe network, leading to service disruptions such as intermittent supply or dead water zones. This study projects the population of Ungasan Village using the Least Square Method, estimating 19,799 residents by 2033 with a maximum daily water demand of 49.50 liters/second. The pipe network is designed in three main segments with pipe diameters of 10 inches and 8 inches, selected based on hydraulic capacity and road availability. The design process used EPANET 2.2 software to simulate flow and pressure conditions, ensuring optimal network performance. The final design achieves a minimum service pressure of 15 meters, coverage rate of 100% of the target population, and improved operational efficiency. This study offers a novel integration of topography-based routing with public infrastructure planning, providing a model for water distribution in karst regions with growing urbanization.

Keywords: Drinking Water, Water Demand, Population Projection, Main Pipe

1. INTRODUCTION

Water is an essential need to support human life and other living things. Along with population growth, the need for water will also continue to increase. Therefore, water supply has become a national strategic issue that must be addressed by the government [1]. Indonesia is one of the countries experiencing a clean water crisis; around 33.4 million people lack access to clean water and 99.7 million lack adequate sanitation facilities [2]. This crisis is mainly caused by the uneven affordability and accessibility of clean water services across the country [3].

In the Badung area, including South Kuta, water services are managed by Perumda Tirta Mangutama. The water treatment plant serving the South Kuta sub-district is located at the Estuary DAM in the Suwung area. However, the water discharge currently flowing to South Kuta Sub-district has not met the growing demand, which is driven not only by population growth but also by the expansion of tourism facilities [4]. Additionally, the intensity and diversity of water needs continue to increase in line with economic development.

Observations in Ungasan village—a part of South Kuta—indicate that a clean water crisis persists. This is primarily due to an underdeveloped and uneven distribution of the main pipe network. As a result, frequent water outages are reported by residents. Furthermore, the region's topography, dominated by limestone hills, complicates the availability of alternative water sources [5]. Consequently, many residents are forced to purchase clean water, with prices ranging from IDR 250,000 to 300,000 per 5,000-liter water tank [6]. Several previous studies have explored water distribution in areas with complex topography using hydraulic modeling and GIS-based network optimization [7]. However, limited research has focused specifically on South Kuta or Ungasan village, where karst terrain poses distinct infrastructure challenges.

This study addresses two main problems: (1) the practical issue of insufficient water distribution in Ungasan village, and (2) the research gap concerning optimal pipe network design in limestone-dominated regions. Thus, the objective of this study is to analyze the clean water demand in Ungasan village and determine the optimal pipe network configuration that ensures reliable water service coverage. The scientific contribution of this study lies in the original application of hydraulic modeling and network optimization methods tailored to karst (limestone) topography, supporting infrastructure planning in such challenging terrains. Moreover, the findings offer transferable insights for other regions facing similar topographical or infrastructural constraints, particularly in areas where water distribution is hampered by geological complexity.

2. THEORY AND METHODS

2.1.1 Drinking Water Supply System (SPAM) & Pipe Planning

The Drinking Water Supply System consists of several units, namely the raw water unit, production unit, distribution unit, service unit, and management unit.Raw water units may include water storage structures, intake/tapping facilities, measurement devices and monitoring tools, pumping systems, and/or conveyance infrastructure and equipment. Raw water can be obtained from various sources, such as surface water (such as rivers, swamps, lakes, and reservoirs), rainwater, and groundwater [8]. Production Unit tis the infrastructure and facilities that can be used to undergo the process of processing raw water into drinking water through physical, chemical, and/or biological methods. This production unit may include treatment structures and equipment, operational devices, measurement and monitoring equipment, and drinking water storage buildings. The production unit may consist of coagulation, flocculation, sedimentation, filtration, neutralization, and disinfection units [9]. Distribution unit is part of the system that is responsible for delivering processed products from the production unit to all service units, where the distributed water has met the 4K criteria, namely quality, quantity, continuity, and affordability. Continuous flow is expected to provide guaranteed water flow for 24 hours every day. This distribution unit involves pumping systems, distribution networks, storage buildings, and measuring and monitoring equipment [8]. The service unit is a unit that functions to receive clean water supplied by the distribution unit. It consists of house connections (SR), public hydrants (HU), and fire hydrants [8]. The Management Unit is divided into two main aspects, namely technical and non-technical management. Technical management includes operational, maintenance, and monitoring activities of the raw water unit, production unit, and distribution unit. Meanwhile, non-technical management involves administrative and service aspects [8]. Clean water distribution pipelines can be classified as follows [10].

1. Distribution Pipe (Feeder System)
   Conduit pipes in distribution pipes usually provide the basic framework of the distribution system. No house connections are allowed in this distribution delivery pipe system, which can be classified into two types, namely. Main Pipe, which is a distribution pipe that has the widest coverage area and has the largest sdiameter, this pipe has a tapping point connected to the secondary Pipe which s the second type of channel in a network system. This pipe plays a role in flowing services from the main main pipe to each service block.
2. Distribution Service Pipe
   Is a pipe that directly serves consumers and taps the secondary main pipe. The diameter used is relatively in accordance with the service discharge to consumers, can be divided into two, namely Branch pipes (Small Distribution Main), can serve directly to the house or can be channeled into smaller pipes. Service pipe, is a pipe used for house connections.

2.2.1 Data Collection

The following is the research location in Ungasan village presented in Figure 1.

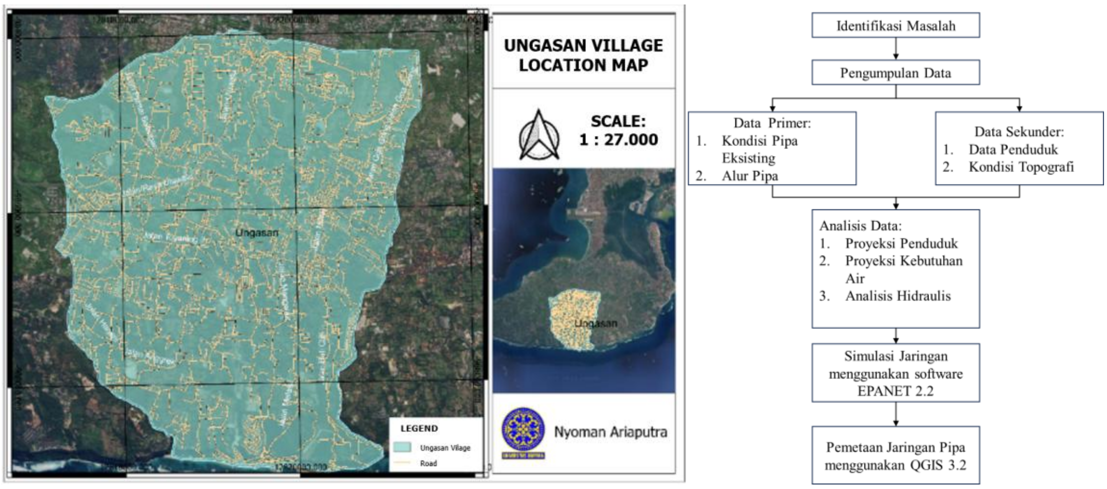

Figure 1 . Ungasan Village Location Map

In this study, primary data collection was conducted to assess the condition of the existing pipeline network in Ungasan Village. The components observed included the physical condition of the pipes as well as the layout of the primary and secondary pipelines. In addition, a site survey was carried out to identify a suitable location for the reservoir, taking into account land area and elevation. This was necessary because existing pipeline conditions serve as a critical foundation for planning and developing an effective water distribution system. Secondary data such as population statistics and topographical characteristics of Ungasan Village were collected to provide supporting information for the analysis.

2.2.2 Drinking water demand analysis

In analyzing drinking water demand, it is necessary to carry out population projections to determine the number of residents in the planned drinking water demand projection.

1. **Population Projection**

Population projections are needed to estimate the fulfillment of clean water needs in the service area. Population projection calculations are carried out using three methods, including arithmetic, geometric, and least square methods [11]. Among these, the least square method was selected as the basis for the final design because it considers long-term population trends and minimizes the impact of short-term fluctuations by fitting a regression line to historical data. This method provides a more stable and statistically reliable estimate for future population growth, which is crucial for designing sustainable water supply infrastructure that can accommodate projected demand over the planning horizon. The method is divided to three, arithmetic method, geometric method, least square method as shown in the equation below

Arithmetic Method

$$P_n = P_0 + Ka(n) \tag{1}$$

Geometric Method

$$P_n = P_0\,(1+r)^n \qquad \text{with} \qquad r = \left(\frac{P_n}{P_0}\right)^{\frac{1}{n}} - 1 \tag{2}$$

Where:

Least Square Method

$$P_n = a + b(n) \tag{3}$$

$$a = \frac{(\Sigma P).(\Sigma t^2) - (\Sigma t).(\Sigma Pt)}{n.(\Sigma t^2) - (\Sigma t)^2} \tag{4}$$

$$b = \frac{n.(\Sigma Pt) - (\Sigma t).(\Sigma P)}{n.(\Sigma t^2) - (\Sigma t)^2} \tag{5}$$

Where:

$P_{(n)}$ = total population in year n
$P_{(0)}$ = total population in the base year
t = year
n = time period between base year and year n (in years)
r = population growth rate
n in a and b = number of years of data available

2. **Water Demand Analysis**

Water demand is the amount of water required for basic needs / a unit of water consumption, where water loss and water requirements for firefighting are also taken into account. The calculation of clean water needs is listed as follows [12]

House Connection Water Demand (SR)

The value of SR water demand is influenced by the number of people served and household water consumption in each village, where in this projection household water consumption is assumed to be 120 L/person/day, referring to the Indonesian National Standard on Drinking Water Supply System Planning (SNI 7831:2012) for domestic water needs.

$$Q_{SR} = SR\ x\ Underserved\ Population \tag{8}$$

Description:
Q(SR = SR Water Demand (L/day)
SR = Household water consumption (L/life/day)
Population = Total population served (people)

Domestic Needs

$$Q_{Domestik} = Q_{SR} + Q_{KU} \tag{9}$$

Description:
Q(DOMESTIC = Domestic water demand (L/day)
Q(SR = SR Water Demand (L/day)
QKU = Public tap water demand (L/day)

Non-Domestic Needs

$$Q_{Non\ Domestic} = 20\%\ x\ Q_{Domestic} \tag{10}$$

Description:
QNON DOMESTIC = Non-domestic water demand (L/day)
Q(DOMESTIC = Domestic water demand (L/day)

Total Requirement

$$Q_{Total\ (L/day)} = Q_{Domestic} + Q_{Non\ Domestic} \tag{11}$$

Description:
QTotal = Total water demand (L/day) or (L/second)
QNON DOMESTIC = Non-domestic water demand (L/day)
Q(DOMESTIC = Domestic water demand (L/day)

Total Water Loss

According to Indonesian Ministry of Public Works and Housing Regulation No. 18/PRT/M/2007, a standard allowance of 20% is commonly applied to account for water losses (Non-Revenue Water) and non-domestic uses in water demand projections. This percentage reflects typical losses due to leakage, unauthorized consumption, and operational inefficiencies in distribution systems, and serves as a planning benchmark in the design of water supply infrastructure.

$$Amount\ of\ Water\ Loss = 20\%\ x\ Q_{Total} \tag{12}$$

Description:

Q(NON DOMESTIC = Non-domestic water demand (L/day)

Q(DOMESTIC = Domestic water demand (L/day)

Average Day Requirement (Qhr)

$$Q_{hr} = Total\ Needs\ (L/s) + Amount\ of\ Water\ Loss \tag{13}$$

Description:

Q(hr = Average daily water demand (m3 /day)

Total Demand = Total water demand

Maximum Day Demand (Qhm)

$$Q_{hm} = F_{hm}\ x\ Q_{hr} \tag{14}$$

Description:

Q(hm = Maximum day demand (m^3/day)

F(hm = day factor

Q(hr = Average daily demand (m^3/day)

Peak Hour Demand (Qjp)

$$Q_{jp} = F_{jp}\ x\ Q_{hm} \tag{15}$$

Description:

Qj = Peak hour demand (m3 /h)

Fj = hour factor

Qh = Maximum day demand (m3 /day)

2.2.1 Hydraulic Analysis of Piping Networks

1. Pipe Dimension Calculation

The calculation of pipe dimensions is carried out using the *Hazen-William* equation as follows.

$$\mathbf{Q = 0.2785\ x\ C\ x\ D^{2.63}\ x\ S^{(0.54)}} \tag{16}$$

Where:

Q = flow discharge (m3/sec)

C = Roughness coefficient

D = Pipe diameter (m)

S = Pipe slope = difference in height/pipe length (m/m)

2. Loss of Pressure

- **Major Loss**

The major loss can be calculated using the equation from *Hazen William* as follows [14], which is chosen due to its simplicity and suitability for analyzing water flow in pressurized pipes, especially in systems where the fluid is water and the flow is turbulent.

$$hf = \left(\frac{Q}{0.2785\ \times C_H \times D^{2.63}}\right) \times L \tag{17}$$

Description:
hf = Major energy or pressure loss
Q = Water discharge in the pipe (m3 /det)
f = Coefficient of friction
L = Pipe length (m)
D = Pipe diameter (m)
g = Earth's gravitational acceleration (m/s2)

- **Minor Loss**

Minor energy loss can be calculated based on the *Darcy - Weisbach* equation as follows [14], as it provides a more universally applicable and theoretically rigorous method suitable for calculating localized losses due to fittings, valves, and changes in flow direction.

$$hf = k\frac{V^2}{2g} \textbf{ or } hf = k\frac{Q^2}{2A^2 g} \tag{18}$$

Description:

k = Minor loss coefficient

V = velocity

g = Earth's gravitational acceleration

3. Reservoir Capacity Calculation

$$\mathbf{V}= \frac{20\%\times 24\times 3.600\times K}{1.000(\frac{m3}{liter})} \tag{19}$$

Where:
V = reservoir volume (m^3)
K = maximum day demand (Liter/second)

Reservoir Dimension Calculation

$$\mathbf{V}= \frac{A}{t} \tag{20}$$

$$\mathbf{P}= \sqrt{A} \tag{21}$$

$$\mathbf{L}= \frac{A}{P} \tag{22}$$

Where:
V = reservoir volume (m^3)
t = reservoir height (m)
A = reservoir base area (m^2)
P = reservoir length (m)
L = reservoir width (m)

2.2.1 Pipe Accessories Needs

In the transmission pipeline network, there are pipe accessories consisting of *air valves*, *gate valves*, and *wash outs*.

1. *Air Valve*

   Air valve is an air valve that relieves pressure in the pipe so that it does not burst. [16]
2. *Gate Valve*

Gate valve is a valve used to control the opening and closing of flow (stop valve) which is not too high. The gate valve also functions as a flow discharge controller when there is a change in flow direction. In the distribution of clean water, the gate valve is placed at the fork of the pipe.

3. *Wash Out*
   Wash out or drain pipe serves to drain sediment or sediment in the distribution pipe [16]. *Wash outs* are installed in places with relatively low elevations along the pipeline.

2.2.2 Simulasi dan Pemetaan Jaringan Perpipaan

The pipe network simulation was conducted using EPANET 2.2 software. This software was selected due to its capability to model the hydraulic and water quality behavior of pressurized pipe networks accurately, allowing for detailed analysis of flow rates, pressure distribution, and system performance under various demand scenarios. For the pipeline network mapping, QGIS 3.2 was utilized because of its open-source nature, user-friendly interface, and robust functionality in handling spatial data, which enables precise geospatial representation and integration with other GIS-based datasets relevant to infrastructure planning.

3. RESULTS AND DISCUSSION

3.1.1 Drinking Water Demand Analysis

Population projections are used as material to analyze water demand in Ungasan Village, without population projections, the analysis of water demand in the population cannot be carried out because population projections are one of the main data in analyzing water demand. Population projections are carried out for 10 years with a starting year of 2023 to 2033. The following calculation results are presented in

table 1.

Table1 . Calculation Results of Three-Method Projection

Ungasan Village						
Total Population	**Year**	**Growth**	**Population Growth (%)**	**Arithmetic**	**Geometrics**	**Least Square**
13488	2017			13488	13452	12750
13488	2018	0	0,0%	13948	13898	13164
13708	2019	220	1,6%	14408	14359	13579
13957	2020	249	1,8%	14867	14835	13994
15327	2021	1370	9,8%	15327	15327	14408
		459,8	3,32%			
		(Ka)	**Average**			
		Standard Deviation		7712	762	718

From the calculation of the standard deviation and correlation coefficient obtained by the three methods, it is found that the

Standard Deviation is close to 0, namely the calculation with the Least Square method. On. Therefore, considering this, the most accurate method to use in population projections in Ungasan village is the *least square* method. The following are the results of population projections using the *least square* method in figure 2

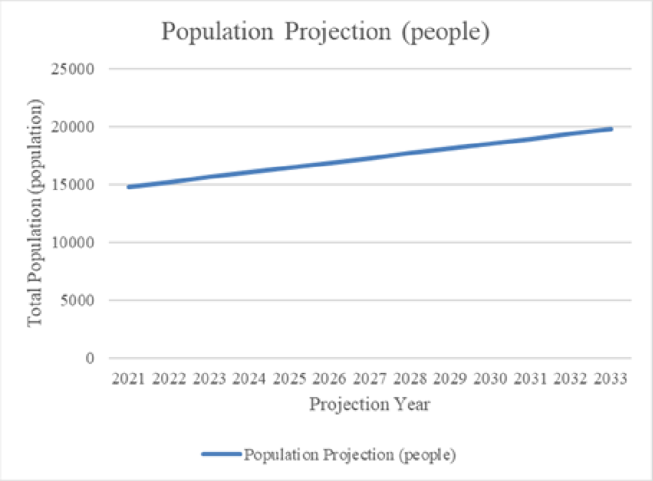

Figure 2 . Ungasan Village Population Projection Chart

Based on the projection results, it was found that in the 10th year, 2033, there was an increase of 4,976 people and was used as a reference to determine the projected water demand.

2. Projected Drinking Water Demand

In this calculation, a projection of drinking water demand was carried out in Ungasan village with a household water consumption of 120 liters/person/day [12]. Projections were made until 2033. Can be seen in table 3.

Table3 . Projected Drinking Water Needs of Ungasan Village

UNGASAN VILLAGE DRINKING WATER DEMAND PROJECTION		
Description	Unit	2033 Projection Year Data
A. Population		
Total Population		19799
Service Level		100%
Population Served		19799
B. Domestic Needs		
SR	L/day	2375880
KU		
SR Water Demand		
KU Water Requirement		
Domestic Needs	L/day	2375880
C. Non-Domestic Needs		
20% Domestic Demand	L/day	475176

UNGASAN VILLAGE DRINKING WATER DEMAND PROJECTION		
Description	Unit	2033 Projection Year Data
D. Total Water Requirement		
	L/day	2851056
	L/sec	32.99833333
E. Water Loss		
% Water Loss		20%
Total Water Loss	L/sec	6.599666667
F. Average Water Requirement		
Total Water Requirement	L/sec	39.598
G. Maximum Day Requirement		
Coefficient Factor		(1,2-2)
Water Requirements	L/sec	49.4975
H. Peak Hour Requirement		
Coefficient Factor		2
Water Requirements	L/sec	98.995

Based on the results of the analysis of drinking water demand, the maximum day demand is estimated at 49.4975 liters per second. This figure is essential in determining the design capacity of the distribution pipe network and the reservoir dimensions. However, to ensure the long-term reliability and adequacy of the water supply system, it is important to consider contextual factors that can influence future demand. For instance, the growth of the tourism sector in the region is expected to increase the number of temporary residents and visitors, leading to higher water consumption during peak travel seasons. Additionally, patterns of seasonal migration—such as the influx of workers or students—may cause periodic fluctuations in demand. Climatic factors, especially during the dry season, can also intensify water usage due to reduced availability from natural sources and increased household consumption. Therefore, these variables must be integrated into the demand projection model to ensure that the planned infrastructure can accommodate not only current needs but also future surges in water usage driven by socio-economic and environmental dynamics.

3.1.2 Hydraulic Analysis of Piping Networks

1. Hydraulic Profile of Pipe Plan

In planning the installation of the main pipe in Pecatu Village, the hydraulic profile of the elevation of the main pipe plan in Pecatu Village is made into 4 segments. The main pipe line is placed based on the grouping of public roads based on its function. The public roads according to their function [16], namely Arterial Roads, Collector Roads, Local Roads and Neighborhood Roads

- Segment A: Elevation of the main pipeline from the reservoir to Jl. Uluwatu. Segment A belongs to the Collector Road group

- Segment B: Elevation of the main pipeline Jl. Uluwatu- Jl. Uluwatu Pecatu. Segment B is included in the Collector Road group
- Segment C: Elevation of the main pipeline Jl. Uluwatu- Jl. Pura Batu Pageh. Segment C belongs to the Collector Road group

2. Calculation of Plan Pipe Diameter

Based on the calculation results with the Hazen William equation, the size of the plan is as follows in table 4

Table4 . Pipe Segment

Pipe Segment	**Diameter (inch)**
Reservoir - Uluwatu Road□ SEGMENT	
Jalan Uluwatu - Jl. Pura Batu Pageh□ SEGMENT	
Jalan Uluwatu - Jalan Uluwatu Pecatu□ SEGMENT	8

The planned main pipe diameter obtained above is the result of calculations with consideration of the location elevation factor, pipe length, pressure difference, discharge, and conveyance speed. Another major factor in obtaining the above pipe diameter data is the result of projected drinking water demand in Ungasan Village until 2033.

3.1.1 Reservoir Capacity Analysis

The results of the reservoir volume calculation are as follows:

Transmission Reservoir Volume = 1000 m^3

With the results of the calculation of the reservoir dimensions obtained as follows

a. Reservoir Length (p) = 10 m
b. Reservoir Width (l) = 10 m
c. Reservoir Height = 10 m

This volume was determined based on projected water demand patterns, taking into account peak hour usage and maximum day consumption. The reservoir is designed to ensure sufficient storage capacity to buffer fluctuations during daily peak hours, as well as to provide operational flexibility and reliability during periods of highest demand. Additionally, it includes a contingency margin to accommodate potential supply interruptions and ensure consistent service delivery.

3.1.1 Pipe Accessories Needs

The needs of pipe accessories are as follows

1. Pipe Plan from the reservoir to Jl. Raya Uluwatu
   - Air Valve: 3 pieces
   - Bend 45: 5 pieces
2. Pipeline Plan from Jl Raya Uluwatu - Jl Pura Batu Pageh
   - Air Valve: 3 pieces
   - Bend 45: 11 pieces
   - Gate Valve: 1 piece

3. Pipeline Plan from Jl Raya Uluwatu- Jl Uluwatu Pecatu
    - Air Valve: 2 pieces
    - Bend 45: 4 pieces
    - Gate Valve: 1 piece

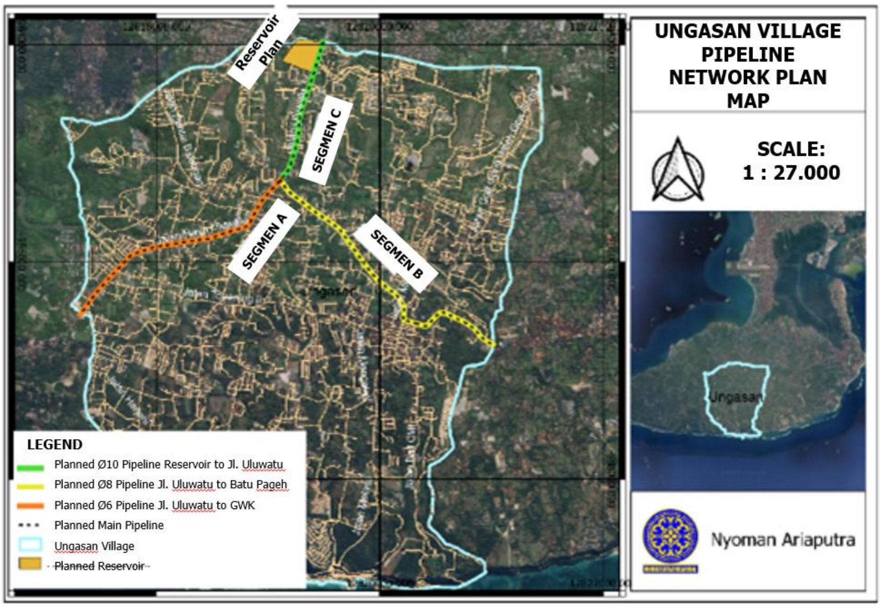

Image3 . Map of Ungasan Village Pipeline Network Plan

The pipeline network plan map for Ungasan Village illustrates a proposed water distribution system consisting of three main segments: a Ø10 pipe from the reservoir to Jalan Uluwatu, a Ø8 pipe connecting Jalan Uluwatu to Batu Pageh, and a Ø6 pipe extending from Jalan Uluwatu to the GWK area (Garuda Wisnu Kencana). The map also outlines the location of the planned reservoir and the administrative boundary of Ungasan Village. This infrastructure layout can be analyzed within the framework of Integrated Urban Water Management (IUWM), which emphasizes a holistic approach to urban water systems—integrating water supply, sanitation, stormwater management, and environmental sustainability.

In the context of IUWM, the planned pipeline network reflects an effort to align water infrastructure with the spatial layout and development patterns of the village. The alignment of the pipeline with main roads suggests attention to accessibility, ease of maintenance, and minimal disruption to the built environment. The use of varying pipe diameters indicates a strategic distribution design tailored to local demand, water pressure considerations, and future population growth. Moreover, the presence of a designated reservoir aligns with IUWM principles that encourage the development of resilient infrastructure capable of accommodating peak demands and buffering against supply interruptions. By considering peak hour and maximum day consumption in the reservoir design, the system supports reliability and service continuity, which are central to sustainable water management in urbanizing areas like Ungasan. Overall, this planning approach demonstrates an understanding of IUWM as a guiding framework for delivering efficient, adaptive, and integrated urban water services.

One of the primary concerns is climate change, which may alter rainfall patterns, reduce groundwater recharge, and increase the frequency of extreme weather events. These factors could challenge the reliability of current water sources and increase the vulnerability of the system, especially in dry seasons or during periods of drought. In addition to environmental uncertainty, changes in water-related policies at the regional or national level could shift priorities in water allocation, pricing, or environmental protection. Such policy changes may require infrastructure adaptation or operational restructuring. Furthermore, Ungasan, as part of Bali, is closely tied to the tourism sector, which is subject to fluctuations in both local development and international travel trends. Rapid growth in tourism can significantly increase water demand and strain the existing infrastructure, especially if it outpaces the planned capacity. Conversely, a decline in tourism may affect the economic justification or funding available for infrastructure expansion or maintenance.

4. CONCLUSIONS

The purpose of this research is to analyze the drinking water needs of Ungasan Village and determine the appropriate size for the distribution pipe network design. Based on calculations using the least square population projection method, the projected population in 2033 is estimated at 19,799 people. The maximum day water demand is calculated to be 49.4975 liters per second. The optimal main pipe size is an Ø8-inch diameter pipe along Jl. Uluwatu-Pecatu and Jl. Pura Batu Pageh, while an Ø10-inch diameter pipe is designated for the connection between the reservoir and Jl. Raya Uluwatu. The reservoir volume required, based on projected demand, is approximately 855.3168 m^3.

This design is expected to offer efficiency in water delivery and cost-effectiveness due to appropriate sizing, while also allowing for flexibility to accommodate future demand increases. When compared to similar studies conducted in regions with comparable topographical characteristics, such as in other coastal Balinese villages, the findings align with typical patterns of water consumption and infrastructure needs, thereby supporting external validity. A key novelty of this study lies in the adaptation of the distribution network design to the specific geographic and demographic conditions of Ungasan, which differ from other inland or densely populated urban areas. However, the study has certain limitations, including potential uncertainties in population projection and the exclusion of seasonal variations in water consumption, which may affect the accuracy of demand estimation and system performance under peak or off-peak conditions.

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