

Population Growth Forecasting and Clean Water Demand Analysis for Denpasar City Toward 2030

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DOI: <https://doi.org/10.51583/IJLTEMAS.2026.15020000076>

Received: 24 February 2026; Accepted: 02 March 2026; Published: 17 March 2026

ABSTRACT

Water is poised to become the most critical natural resource of the third millennium, influencing both economic stability and human survival, particularly as developing nations face rapid population growth. This surge in population and industrial activity is driving up water demand while simultaneously depleting available resources. The resulting gap between high demand and dwindling supply poses significant challenges for water distribution. This study outlines a methodology for forecasting population growth and water demand in the Denpasar area over a ten-year period.

Three projection models—linear, quadratic, and exponential—were evaluated to identify the most accurate solution. The findings indicate that the quadratic method provides the most reliable forecast for Denpasar's future water needs. Current projections reveal that existing water infrastructure can only meet 41.63% of total demand. Consequently, it is imperative for the Denpasar municipal government to implement more robust strategies to address this substantial supply deficit.

Keywords: Population trends, sustainability, freshwater reserves, demand, forecasting

INTRODUCTION

In the third millennium, water has emerged as a paramount natural resource. Its significance spans both economic stability and the fundamental sustenance of human life. Projections suggest that within the next two generations, developing nations will face acute water crises as the global population is expected to surge toward three billion.

In Indonesia, rapid demographic growth and expanding industrialization have driven a steady rise in clean water demand. Paradoxically, this escalating need coincides with the depletion of existing water sources, including both groundwater and surface water. These multifaceted challenges regarding water availability directly impact current supply levels.

Rapid population growth presents a critical challenge for major urban centers, including Denpasar. An expanding population necessitates a corresponding increase in clean water provision. A key indicator of success in meeting these needs is the robustness of long-term planning systems. In this context, this study examines the operational planning at the Regional Water Utility (RWU) Denpasar Water Treatment Plant, specifically focusing on the production and distribution infrastructure required to meet the community's water demands over a ten-year projection period.

Production

To serve its customer base across Denpasar, RWU Denpasar manages a total water resource capacity of 815 liters per second (lps), which is derived from the following sources:

- Tukad Ayung III Water Treatment Plant: 385 lps capacity.
- Deep Wells (8 units): 180 lps capacity.
- Water Purchase from RWU Badung: 150 lps.
- Water Purchase from RWU Gianyar: 25 lps.
- Water Purchase from PTTB: 75 lps.

Distribution System

To ensure a continuous 24-hour supply with consistent pressure, RWU Denpasar utilizes three strategically located reservoirs across the service area. The transmission and distribution network spans 1,050,019 meters of piping to deliver water from sources to consumers.

This infrastructure is categorized into main pipes and service pipes. The main pipes—comprising primary, secondary, and tertiary lines—are responsible for transporting water throughout the distribution zones, while service pipes manage the final delivery to individual customers. These pipes are integrated into a network system designed to provide equitable and reliable water supply.

THEORETICAL FRAMEWORK

Curvilinear trend analysis—encompassing linear, quadratic, and exponential models—is employed to forecast population growth and clean water requirements.

Linear Trend

To simplify the calculation of trend equations, a coded year (X) is utilized in place of the actual year (t). The fundamental formula is $X = t - t'$, where t' represents the mean of the initial and final years of the study period. The linear trend equation is defined as follows:

$$Y_t = a + bx \quad (1)$$

Variable Definitions:

Y_t : The calculated trend value for a specific timeframe.

a : The intercept value of Y_t when the time variable $x=0$,
representing the baseline value at t

b : The gradient or slope of the trend line, indicating the
rate of change per unit of time.

x : The coded time interval, defined as $x = t - t'$

The Method of Least Squares

The Least Squares method is employed to determine the most accurate line of best fit for a given time series. This mathematical approach (often associated with the Chi-square principle) functions by minimizing the sum of the squared differences between the actual observed values (Y) and the predicted trend values (Y_t). By applying this principle, the Least Squares technique ensures that the value of $\Sigma (Y - Y_t)$ is kept at its absolute minimum, resulting in the most precise estimation possible.

$$\text{With } a = \frac{\sum Y}{n} \text{ and } b = \frac{\sum XY}{\sum X^2} \quad (2)$$

where **n** represents the total number of data pairs within the observed set.

Quadratic Trend Analysis

The mathematical expression for the quadratic trend is defined as follows:

$$Y_t = a + bx + cx^2 \quad (3)$$

where:

$X = t - t' =$ defined as the temporal distance between the
specific year of interest and the
calculated average year.

The least squares approach produces the following results:

$$a = \frac{(\sum Y)(\sum X^4) - (\sum X^2 Y)(\sum X^2)}{n(\sum X^4) - (\sum X^2)^2} \quad (3.a)$$

$$b = \frac{\sum XY}{\sum X^2} \quad (3.b)$$

$$c = \frac{n(\sum X^2 Y) - (\sum X^2)(\sum Y)}{n(\sum X^4) - (\sum X^2)^2} \quad (3.c)$$

Exponential Trend Analysis

The general mathematical expression for the exponential trend model is defined as follows:

$$Y_t = a e^{b(t-t')} \quad (4)$$

$$Y_t = a e^{bX}$$

where $e \approx 2,71828$

The coefficients of the equation, denoted as **a** and **b**, are determined using the following formulas:

$$\ln Y_t = \ln a + bX$$

$$\text{Then: } a = \text{anti ln } \frac{\sum \ln Y}{n}$$

(4.a)

$$b = \frac{\sum (X \ln Y)}{\sum (X)^2} \quad (4.b)$$

To determine the most accurate projection among the three methods previously discussed, the model that yields the minimum sum of squared residuals or the smallest deviation value $\sum(Y-Y_i)^2$ will be selected.

METHODOLOGY

To further investigate the aforementioned issues, statistical methods are employed as analytical tools, given the quantitative (numerical) nature of data regarding population figures and clean water requirements. These methods facilitate the processing of numerical data, rigorous analysis, and the formulation of objective conclusions.

A scientific approach consisting of the following stages is utilized to resolve the research problems statistically:

- **Problem Identification:** Precisely defining and understanding the core issues, where quantitative information proves most beneficial.
- **Fact-Finding:** Gathering relevant and detailed facts that directly correspond to the subject of the study.
- **Primary Data Collection:** Acquiring the most recent original data, as essential information is often unavailable in existing secondary sources.
- **Data Classification:** Categorizing data based on specific characteristics and organizing them into systematic groups.
- **Data Presentation:** Summarizing information through tables, diagrams, and descriptive measures, following these analytical steps:
 - a. Analyzing population data collected from the field.
 - b. Evaluating clean water demand.
 - c. Comparing population trends with water production trends.
 - d. Strategic planning for raw water requirements.
 - e. Planning production equipment for intake units.

Given that this research focuses on long-term projections, time series analysis was selected as the primary analytical framework. This method provides precise metrics for informed decision-making, future forecasting, and strategic planning.

RESULTS

Population Forecasting

Table 1. Population of Denpasar City

Year	Population
2022	1,031,000
2023	1,053,000
2024	1,075,000
2025	1,097,000

Projections for the Year of 2030

Linear Trend Analysis

Table 2. Calculation of the Linear Trend Equation

(t)	(X)	Population (Y)	XY	X ²
2022	- 1,5	1,031,000	-557,136	2.25
2023	- 0,5	1,053,000	-186,636	0.25
2024	0,5	1,075,000	191,277,6	0.25
2025	1,5	1,097,000	585,345	2.25
	$\sum X = 0$	$\sum Y = 4,256,000$	$\sum XY = 110,000$	$\sum X^2 = 5$

then
$$a = \frac{\sum Y}{n} = \frac{4.256.000}{4} = 1,064,000$$

$$b = \frac{\sum XY}{\sum X^2} = \frac{110.000}{5} = 22,000$$

Quadratic Trend Analysis

Table 3. Calculation of the Quadratic Trend Equation

(t)	(X)	Population (Y)	XY	X ²	X ² Y	X ⁴
2022	-1,5	1,031,000	-1,546,500	2.25	2,319,750	5.0625
2023	-0,5	1,053,000	-526,500	0.25	263,250	0.0625
2024	0,5	1,075,000	537,500	0.25	268,750	0.0625
2025	1,5	1,097,000	1,645,500	2.25	2,468,250	5.0625
	$\sum X = 0$	$\sum Y = 4,256,000$	$\sum XY = 110,000$	$\sum X^2 = 5$	$\sum X^2 Y = 5,320,000$	$\sum X^4 = 10.25$

then
$$a = \frac{(\sum Y)(\sum X^4) - (\sum X^2 Y)(\sum X^2)}{n(\sum X^4) - (\sum X^2)^2}$$

$$= \frac{(4.526.000)(10,25) - (5320000)(5)}{4(10,25) - 25} = 1,064,000$$

$$b = \frac{\sum XY}{\sum X^2} = \frac{110000}{5} = 22,000$$

$$c = \frac{n(\sum X^2 Y) - (\sum X^2)(\sum Y)}{n(\sum X^4) - (\sum X^2)^2}$$

$$= \frac{4(5320000) - (5)(4256000)}{4(10,25) - 25} = 0$$

Consequently, the quadratic trend equation is formulated as follows:

$$Y_t = 1,064,000 + 22,000 X$$

$$Y_t = 1,064,000 + 22,000 (t-t')$$

for $t = 2030$

$$Y_{2030} = 1,064,000 + 22,000 (2030-2023.5)$$

$$Y_{2030} = 1,207,000$$

Exponential Trend Analysis

Quadratic Trend Analysis

Table 3. Calculation of the Quadratic Trend Equation

(t)	(X)	Population (Y)	XY	X ²	X ² Y	X ⁴
2022	-1,5	1,031,000	-1,546,500	2.25	2,319,750	5.0625
2023	-0,5	1,053,000	-526,500	0.25	263,250	0.0625
2024	0,5	1,075,000	537,500	0.25	268,750	0.0625
2025	1,5	1,097,000	1,645,500	2.25	2,468,250	5.0625
	$\sum X = 0$	$\sum Y = 4,256,000$	$\sum XY = 110,000$	$\sum X^2 = 5$	$\sum X^2 Y = 5,320,000$	$\sum X^4 = 10.25$

$$\text{then } a = \frac{(\sum Y)(\sum X^4) - (\sum X^2 Y)(\sum X^2)}{n(\sum X^4) - (\sum X^2)^2}$$

$$= \frac{(4.526.000)(10,25) - (5320000)(5)}{4(10,25) - 25} = 1,064,000$$

$$b = \frac{\sum XY}{\sum X^2} = \frac{110000}{5} = 22,000$$

$$c = \frac{n(\sum X^2 Y) - (\sum X^2)(\sum Y)}{n(\sum X^4) - (\sum X^2)^2}$$

$$= \frac{4(5320000) - (5)(4256000)}{4(10,25) - 25} = 0$$

Consequently, the quadratic trend equation is formulated as follows:

$$Y_t = 1,064,000 + 22,000 X$$

$$Y_t = 1,064,000 + 22,000 (t-t')$$

for $t = 2030$

$$Y_{2030} = 1,064,000 + 22,000 (2030-2023.5)$$

$$Y_{2030} = 1,207,000$$

Exponential Trend Analysis

Table 4. Estimating the Exponential Trend Model

(t)	(X)	Population (Y)	Ln Y	X ln Y	X ²
2022	-1.5	1,031,000	13.8460398	-20.7690596	2.25
2023	-0.5	1,053,000	13.8671538	-6.9335769	0.25
2024	0.5	1,075,000	13.8878312	6.94391561	0.25
2025	1.5	1,097,000	13.9080897	20.86213461	2.25
	$\sum X = 0$	$\sum Y = 4,256,000$	$\sum \ln Y = 55.51$	$\sum X \ln Y = 0.103$	$\sum X^2 = 5$

$$\text{then } a = \text{anti ln } \frac{\sum \ln Y}{n}$$

$$= \text{anti ln } \frac{\sum 55.51}{4} = 1,063,716$$

$$b = \frac{\sum (X \ln Y)}{\sum (X)^2} = \frac{0.103}{5} = 0.021$$

$$e \approx 2.71828$$

Consequently, the exponential trend equation is formulated as follows:

$$Y_t = 1,063,716 e^{bX}$$

$$Y_t = 1,063,716 e^{b(t-t')}$$

for $t = 2030$

$$\begin{aligned} Y_{2030} &= 1,063,716 * 2.71828^{0.021(2030-2023.5)} \\ &= 1,219,290 \end{aligned}$$

The Sum of Squared Residuals $\sum (Y - Y_t)^2$ for Each Trend Model shown in Table 5.

Table 5. Calculated Values Across Different Trend Models

(t)	Linear Trend	Quadratic Trend	Exponential Trend
2022	0	0	72,250
2023	0	0	155,692
2024	0	0	3,152
2025	0	0	572,068
Sum	0	0	803,163

Based on the calculated values above, the model with the lowest value of $\sum (Y - Y_t)^2$ among all utilized trends was selected. A minimum value of 0 was achieved through the quadratic trend, indicating it as the most accurate model for this dataset. Consequently, the population projections for Denpasar will be estimated using the quadratic trend approach, as detailed in Table 6.

Table 6. Population Projection Results

Year	Linear Trend	Quadratic Trend	Exponential Trend
2026	1,119,000	1,119,000	1,121,053
2027	1,141,000	1,141,000	1,144,844
2028	1,163,000	1,163,000	1,169,140
2029	1,185,000	1,185,000	1,193,951
2030	1,207,000	1,207,000	1,219,290
2031	1,229,000	1,229,000	1,245,165
2032	1,251,000	1,251,000	1,271,590
2033	1,273,000	1,273,000	1,298,576
2034	1,295,000	1,295,000	1,326,134
2035	1,317,000	1,317,000	1,354,278

Clean Water Production Forecasting

Table 7. Water Production Levels in Denpasar City

Year	Volume (m3)
2022	29,839,429
2023	31,500,000
2024	32,800,000
2025	34,000,000

Linear Trend Analysis

Table 8. Estimating the Linear Trend Equation for Water Production

(t)	(X)	Volume (m ³) (Y)	XY	X ²
2022	-1.5	29,839,429	-44,759,143.5	2.25
2023	-0.5	31,500,000	-15,750,000	0.25
2024	0.5	32,800,000	16,400,000	0.25
2025	1.5	34,000,000	51,000,000	2.25
		$\sum Y = 128,139,429$	$\sum XY = 6,890,857$	$\sum X^2 = 5$

$$\text{Then } a = \frac{\sum Y}{n} = \frac{128.139.429}{4}$$

$$= 32,034,857.25$$

$$b = \frac{\sum XY}{\sum X^2} = \frac{6890857}{5}$$

$$= 1,378,171.3$$

Consequently, the resulting linear trend equation is expressed as follows:

$$Y_t = 32,034,857.25 + 1,378,171.3 (X)$$

$$= 32,034,857.25 + 1,378,171.3 (t-t')$$

for $t = 2030$

$$Y_t = 32,034,857.25 + 1,378,171.3 (2030-2023.5)$$

$$= 40,992,970.7$$

Quadratic Trend Formulation

Table 9. Calculation of the Quadratic Trend Model Parameters

Year (t)	(X)	Volume (m ³) (Y)	XY	X ²	X ⁴	X ² Y
2022	-1.5	29,839,429	-44,759,143.5	2.25	5.0625	67,138,715
2023	-0.5	31,500,000	-15,750,000	0.25	0.0625	7,875,000
2024	0.5	32,800,000	16,400,000	0.25	0.0625	8,200,000
2025	1.5	34,000,000	51,000,000	2.25	5.0625	76,500,000
	0	$\sum Y = 128,139,429$	$\sum XY = 6,890,857$	$\sum X^2 = 5$	$\sum X^4 = 10.25$	$\sum X^2 Y = 159,713,715$

therefore
$$a = \frac{(\sum Y)(\sum X^4) - (\sum X^2 Y)(\sum X^2)}{n(\sum X^4) - (\sum X^2)^2}$$

$$= \frac{(128139429)(10.25) - (159713715)(5)}{4(10.25) - 25}$$

$$= 32,178,785.69$$

$$b = \frac{\sum XY}{\sum X^2} = 1,378,171$$

$$c = \frac{n(\sum X^2 Y) - (\sum X^2)(\sum Y)}{n(\sum X^4) - (\sum X^2)^2}$$

$$= 115,143$$

Consequently, the quadratic trend equation is formulated as follows:

$$Y_t = 32,178,785.69 + 1,378,171 (X) - 115,143 (X)^2$$

$$Y_t = 32,178,785.69 + 1,378,171 (t-t') - 115,143 (t-t')^2$$

for $t = 2030$

$$Y_{2030} = 32,178,785.69 + 1,378,171 (2030-2023.5) -$$

$$115,143 (2030-2023.5)^2$$

$$= 36,272,105.4$$

Exponential Trend Analysis

Table 10. Calculations for the Exponential Trend Line Equation

Year (t)	(X)	Volume (m ³) (Y)	Ln Y	X Ln Y	X ²
2022	-1.5	29,839,429	17.21	-25.8170118	2.25
2023	-0.5	31,500,000	17.27	-8.63274905	0.25
2024	0.5	32,800,000	17.31	8.652969537	0.25
2025	1.5	34,000,000	17.34	26.01280662	2.25
	0	ΣY= 128,139,429	Σln Y =69.12	ΣX ln Y =0.216	ΣX ² =5

therefore $a = \text{anti ln } \frac{\sum \ln Y}{n} = 31,997,309$

$$b = \frac{\sum (X \ln Y)}{\sum (X^2)} = 0.043$$

$$e \approx 2.72$$

Consequently, the exponential trend equation is formulated as follows:

$$Y_t = 31,997,309e^{0.043(X)}$$

$$= 31,997,309e^{0.043(t-t')}$$

for t = 2030

$$Y_{2030} = 31,997,309 * 2.72^{0.043(2030-2023,5)}$$

$$= 42,371,311.73$$

Following the same methodology used for population forecasting, the quadratic trend was selected for projecting water demand based on the calculated values of $\sum(Y-Y_t)^2$.

Tabel 11. Calculated Values Across Different Trend Models

Year	Linear Trend	Quadratic Trend	Exponential Trend
	$(Y-Y_t)^2$	$(Y-Y_t)^2$	$(Y-Y_t)^2$
2022	16,427,882,144	169,740,249	155,650,413,596,621
2023	23,786,399,367	1,527,681,001	116,973,363,666,758
2024	5,784,682,460	1,527,671,620	90,543,265,189,205
2025	10,427,309,842	169,769,434	69,146,251,209,925
Sum	$\Sigma(Y-Y_t)^2 = 56,426,273,812$	$\Sigma(Y-Y_t)^2 = 3,394,862,303$	$\Sigma(Y-Y_t)^2 = 432,313,293,662,508$

Table 12. Predicted Output for Clean Water Production

Year	Linear Trend	Quadratic Trend	Exponential Trend
2026	35,480,286	34,904,569.44	42,315,422
2027	36,858,457	35,591,882.44	42,315,422
2028	38,236,628	36,048,909.44	42,315,422
2029	39,614,799	36,275,650.44	42,315,422
2030	40,992,971	36,272,105.44	42,315,422
2031	42,371,142	36,038,274.44	42,315,422
2032	43,749,313	35,574,157.44	42,315,422
2033	45,127,485	34,879,754.44	42,315,422
2034	46,505,656	33,955,065.44	42,315,422
2035	47,883,827	32,800,090.44	42,315,422

DISCUSSION

Clean Water Production Relative to Residential Demand in Denpasar City

To determine the water requirements for the community, a standard urban consumption rate of (160 liter/capita/day) is utilized. The projected production and service levels are planned according to the

following parameters:

- Domestic Service: Targeted to cover 80% of the total population, encompassing residential households and public hydrants.
- Non-domestic Service: Established at 23% of the domestic service volume, which includes government and social institutions, industrial and commercial sectors, ports, and other facilities.
- Water Loss: Accounted for at 20% of the combined domestic and non-domestic consumption.

Based on the aforementioned criteria, the following table illustrates the projected water requirements for Denpasar City for the year of 2030.

Table 13. Clean Water Demand Projections for Denpasar City in 2030

Description	Unit	Total water demand	Remarks
Total Population Projection 1,207,000 capita	m ³ /h	193,120	Demand = 0,160 m ³ /h
Domestic Service Requirements	m ³ /h	154,496	Domestic Service: Targeted to cover 80% of the total population
Non-Domestic Service Requirements	m ³ /h	44,417.6	Non-domestic Service: Established at 23% of the domestic service volume
Estimated Water Loss	m ³ /h	39,782.7	Accounted for at 20% of the combined domestic and non-domestic consumption
Aggregate Water Demand	m ³ /h	238,696.32	

Based on the data presented above, the total production requirement for the Denpasar Municipal Water Utility (RWU) is estimated at 238,696.32 m³/day for the 2030 projection. In contrast, the projected clean water production for the same year is calculated at 36,272,105.44 m³/year (approximately 99,375.63 m³/day).

Consequently, the capacity of Denpasar's water production to meet the total community demand is calculated as follows:

$$\text{Service Coverage Percentage} = \frac{99375,63}{238696,32} \times 100\% = 41,63\%$$

This indicates that the city of Denpasar can only fulfill 41.63% of its aggregate clean water requirements. This calculation highlights a significant gap between current water treatment capacity and future urban demand.

To address the escalating demand driven by population growth, shifting consumption patterns, and limited water sources, the Denpasar Water Utility (RWU) is considering the development of new deep wells (boreholes) alongside continued water purchases from neighboring utilities.

Currently, the primary water sources utilized by the Denpasar Municipal Water Utility to serve its customers include:

- The Ayung III Belusung Water Treatment Plant.
- Deep boreholes (groundwater wells).
- Water purchases from the Badung and Gianyar Regional Water Utilities, as well as PT. TB.

However, long-term reliance on deep wells poses a severe environmental risk. Extensive groundwater extraction can lead to gradual land subsidence, which threatens the safety of the ecosystem and future human generations. While these impacts may not be immediately apparent, they represent a significant legacy burden.

To mitigate this, dependency on external water purchases and groundwater can be reduced by constructing new surface water treatment plants or optimizing the production capacity of existing facilities.

Table 14. Clean Water Production Projections

Year	Clean Water Production Forecast		
	m ³ /year	m ³ /s	l/s
2026	34,904,569.44	1.10681664	1,106.82
2027	35,591,882.44	1.12861119	1,128.61
2028	36,048,909.44	1.14310342	1,143.10
2029	36,275,650.44	1.15029333	1,150.29
2030	36,272,105.44	1.15018092	1,150.18
2031	36,038,274.44	1.14276619	1,142.77
2032	35,574,157.44	1.12804913	1,128.05
2033	34,879,754.44	1.10602976	1,106.03
2034	33,955,065.44	1.07670806	1,076.71
2035	32,800,090.44	1.04008404	1,040.08

By incorporating a multiplication factor ranging from 1.0 to 1.15, a value of 1.11 was selected as the initial planning baseline.

This factor is intended to compensate for potential pipe leakages and operational water usage within the treatment facilities. Consequently, the peak raw water requirements are presented in Table 15.

Table 15. Clean Water Demand Projections for Denpasar City

Year	Raw Water Requirement (l/s)	Peak Demand (l/s)
2026	61,470.4	68,232.14
2027	62,678.93	69,573.62
2028	63,887.47	70,915.09
2029	65,096	72,256.56
2030	66,304.53	73,598.03
2031	67,513.07	74,939.5
2032	68,721.6	76,280.98
2033	69,930.13	77,622.45
2034	71,138.67	78,963.92
2035	72,347.2	80,305.39

CONCLUSION

Based on the analysis presented above, the following conclusions can be drawn:

1. Demographic and Demand Modeling: Population growth and clean water requirements in Denpasar are most accurately represented and projected using a quadratic trend equation.
2. Supply-Demand Deficit: Current projections indicate that Denpasar's Water Treatment Plants will only be capable of fulfilling 41.63% of the total estimated clean water demand.
3. Strategic Resource Management: To meet future water requirements, the Regional Water Utility (RWU) must prioritize the optimization of existing facilities and negotiate new raw water source agreements. These measures are essential to reduce dependency on deep-well extraction and external water purchases.
4. Capacity Expansion: In response to rapid population growth in the Denpasar area, it is imperative to expand production capacity to ensure the long-term fulfillment of public water needs.

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