Development of Linear Programming Models of Water Price Compliant to The Regulation of Ministry of Home Affairs, Indonesia

by

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LIST OF ABBREVIATIONS

BI	Bank Indonesia
BLMOP	Bi Level Multi Objective Linear Program
BPS	Badan Pusat Statistik
B_r	Basic Rate
CCP	Chance Constrained Programming
CGE	Computable General Equilibrium
COD	Chemical Oxygen Demand
C_t	Total cost
CVaR	Conditional Value at Risk
DEA	Data Envelopment Analysis
DEYAs	Municipal Water Supply Sewerage Companies
EAPP	Eastern African Power Pool
Fr	Full rate
Ga	Government agencies
GARG	Greater Accra Region of Ghana
GWCL	Ghana Water Company Limited
H	Household
HWDP	Household Water Demand Prediction
i	Interest
ICR	Independent Component Analysis
IDR	Indonesia Rupiah
I_{jp}	Long term investments
I_{nf}	Inflasi
IPA	Instalasi Pengolahan Air (Water Treatment Plant)
L_c	Large Comercial
LFP	Linear Fraction Programming
L_i	Large Industry
L_r	Low rate
L_{rap}	Profit to assets ratio
MWB	Municipal Water Board

NRW	Non Revenue Water
PDAM	Perusahaan Daerah Air Minum (Regional Water Company)
Q_3	Quantity supply
R	Revenue
RO	Research Objective
R_{Lag}	Prior period income
R_{WHS}	Rain Water Harvesting Systems
S_c	Small Commercial
S_i	Small Industry
S_a	Special social
S_r	Special rate
Sub	Subsidy
W_{FD}	Water Framework Directive
W_{MP}	Minimum Wage Province
W_{PI}	Water Price Index

Pembangunan Model Pengaturcaraan Linear bagi Harga Air Mematuhi Peraturan Kementerian Dalam Negeri, Indonesia

ABSTRAK

Tarif dan harga air di Medan, Sumatera Utara kali terakhir disemak pada 2017. Tarif yang merupakan mekanisme struktur penentuan harga air itu perlu dikaji semula setiap lima tahun sekali sebagaimana termaktub dalam Peraturan Kementerian Dalam Negeri, Indonesia, No. 23, 2006. Pada masa ini, tarif dan harga air berdasarkan peraturan tersebut tanpa sebarang penegasan sekunder. Tambahan pula, tarif dan harga air yang tidak tepat digunakan membawa kepada hasil dan keuntungan yang tidak optimum sekaligus menjejaskan kewangan perniagaan. Di Medan, Perusahaan Daerah Air Minum (PDAM) Tirtanadi, adalah pengendali air yang bertanggungjawab mengurus, membekal dan mengagihkan air bersih dan terawat, justeru ia berkewajipan untuk mengenakan harga kepada pelanggan mengikut peraturan air yang ditetapkan. Oleh itu, tujuan penyelidikan ini adalah untuk membangunkan model pengaturcaraan linear (LP) komprehensif untuk mengoptimumkan harga air di Medan dalam rangka kerja kawal selia Kementerian Dalam Negeri, Indonesia. Kajian ini didorong oleh keperluan mendesak untuk menangani interaksi kompleks antara kecekapan ekonomi dan kesaksamaan sosial dalam pengurusan sumber air. Dengan landskap geografi dan sosio-ekonomi Medan yang pelbagai, mencapai model penetapan harga air seimbang yang memenuhi pematuhan kawal selia sambil memastikan akses yang saksama, daya maju ekonomi dan penggunaan sumber yang mampan mewakili cabaran yang ketara. Penyelidikan ini menggunakan pendekatan LP yang mantap untuk memodelkan strategi penetapan harga air, menggabungkan pelbagai kekangan seperti kos pengeluaran, kos sosial, subsidi, hasil dan keuntungan yang mematuhi garis panduan kawal selia air. Dengan menganalisis harga air yang berbeza berdasarkan kumpulan pelanggan dan blok, kajian ini bertujuan untuk mengenal pasti harga air yang optimum dengan mengenal pasti ralat semasa dalam struktur tarif dan memastikan potensi harga air baharu di Medan. Sumbangan utama penyelidikan ini termasuk pembangunan rangka kerja LP novel yang menyepadukan pertimbangan alam sekitar, ekonomi dan sosial ke dalam keputusan penetapan harga air. Kajian ini juga memberikan pandangan empirikal tentang keberkesanan mekanisme penetapan harga air yang berbeza, menawarkan cadangan dasar yang berharga untuk pengurusan sumber air di Medan dan konteks yang serupa. Melalui analisis strategi penetapan harga air yang rapi, penyelidikan ini menyumbang kepada bidang pengurusan sumber air yang lebih luas dengan memajukan pemahaman tentang cara pengaturcaraan linear boleh digunakan secara berkesan untuk menyelesaikan masalah membuat keputusan yang kompleks dalam konteks pematuhan peraturan dan matlamat pembangunan mampan. Penyelidikan ini bukan sahaja menangani jurang kritikal dalam literatur mengenai harga dan pengurusan air tetapi juga menawarkan alat praktikal untuk penggubal dasar, utiliti air dan pihak berkepentingan yang terlibat dalam tadbir urus sumber air. Dengan mencadangkan model LP berskala dan boleh disesuaikan, kajian itu menggariskan potensi pendekatan analisis untuk memaklumkan dan menambah baik dasar penetapan harga air, akhirnya menyumbang kepada pengurusan sumber air penting yang mampan di Medan.

Development of Linear Programming Models of Water Price Compliant to The Regulation of Ministry of Home Affairs, Indonesia

ABSTRACT

The water tariff and price in Medan, North Sumatera was last reviewed in 2017. The tariff, which is the structure mechanism for determining the water price, must be reviewed once every five years as stipulated in the Regulation of the Ministry of Home Affairs, Indonesia, No. 23, 2006. Currently, the water tariff and price based on the that regulation without any secondary affirmation. Futhermore, the inaccurate water tariff and price that currently being implemented may lead to suboptimal revenue and profit thus affected the business financially. In Medan, the Perusahaan Daerah Air Minum (PDAM) Tirtanadi, is the water operator responsibles for treatment, supplies and distributes the clean and treated water thus it has obligation to charge the customers the price based on the stipulated water regulation. Therefore, the aim of this research is to develop a comprehensive linear programming (LP) model for optimizing the water pricing in Medan within the regulatory framework of the Ministry of Home Affairs, Indonesia. This study is motivated by the pressing need to address the complex interplay between economic efficiency and social equity in water resource management. With Medan's diverse geographical and socio-economic landscape, achieving a balanced water pricing model that meets regulatory compliance while ensuring equitable access, economic viability, and sustainable resource use represents a significant challenge. The research employs a robust LP approach to model water pricing strategies, incorporating various constraints such as production cost, social cost, subsidy, revenue and profit that complied to the water regulatory guidelines. By analysing different water pricing based on customers group and block, this study aims to identify optimal water pricing by recognising the current error in tariff structure and ensure the potential of new water price in Medan. Key contributions of this research include the development of a novel LP framework that integrates environmental, economic, and social considerations into water pricing decisions. The study also provides empirical insights into the effectiveness of different water pricing mechanisms, offering valuable policy recommendations for water resource management in Medan and similar contexts. Through a rigorous analysis of water pricing strategies, this research contributes to the broader field of water resource management by advancing understanding of how LP can be effectively applied to resolve complex decision-making problems in the context of regulatory compliance and sustainable development goals. This research not only addresses a critical gap in the literature on water pricing and management but also offers practical tools for policymakers, water utilities, and stakeholders involved in the governance of water resources. By proposing a scalable and adaptable LP model, the study underscores the potential for analytical approaches to inform and improve water pricing policies, ultimately contributing to the sustainable management of vital water resources in Medan.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Water is a vital necessity for humans in daily life as well as for physical and biological needs. Water is also used for various purposes to fulfil the needs of health care, sanitation, irrigation, industry, power generation, navigation, tourism, and others. According to Young (2014), water is a precious and economic commodity, so it has an economic value in supporting daily human life. Therefore, water demand growth is faster than the supply growth, which causes the price of water to be expensive.

The expensive cost of water is caused by limited water resources to produce water for human life. Water is no longer a free item provided by nature. Instead, it has become a valuable commodity, so water must be preserved, protected and managed properly. Costs are needed to invest in water resources so that they can be beneficial and sustainable (Jalali, 2019). Therefore, water must be managed by an institution that can serve the community adequately and responsibly (Yekti *et al*., 2020).

In Medan, *Perusahaan Daerah Air Minum* (PDAM) manages water for community needs. PDAM is a monopoly company; thus, it has the right to determine the selling price of water for seven customer groups, namely low tariff (L_r), basic tariff (B_r) group I block II, basic tariff (B_r) group II block I, full tariff (F_r) group II block II, full tariff (F_r) group III block I, full tariff (F_r) group III block II and special tariff (S_r). The water price set for the F_r and S_r groups is very burdensome because all the F_r and S_r groups are subjected to progressive rates, which is the rate for groups that consume water above the standard of basic needs for drinking water (The Regulation of the Ministry of Home Affairs No. 23, 2006, Chapter II, article 6, paragraph 3). The application of progressive tariff is aimed at protecting raw water (Chapter II, article 8, paragraph 2) and providing subsidies to groups of underprivileged customers (Chapter VI, article 21, paragraph 2e). The F_r and S_r are groups pay a higher price than the basic tariff because it provides a level of profit for PDAM and counters cross-subsidies (Chapter I, article 1, paragraph 14).

Table 1.1 shows the percentage of households obtaining drinking water from various sources across districts or cities in 2014. This situation arises the limited water supply capacity provided by the PDAM, which fails to meet all the water needs of Medan's residents. PDAM frequently interrupts the water distribution to homes for reasons such as network maintenance, drought, or other technical issues. Furthermore, the water quality supplied by the PDAM often does not meet health standards or suffers from issues like odor, taste, or contaminants. This situation prompts people to seek alternative water sources they deem cleaner or safer. Consequently, in addition to domestic usage, a significant portion of the PDAM's water supply is designated for industrial and fishery purposes. As a result, the community turns to various alternative water sources, such as wells, rainwater, rivers, and springs, to fulfill their water requirements. The diverse use of water sources illustrates the community's efforts to ensure adequate, available, and high-quality water for their daily needs, as perceived by Medan's residents

Table 1.1 The percentage of households that consume drinking water from several sources according to district or city in 2014.

No	District (City)	Piped	Pump	Well	Springs	Others (river, rain)
1	Karo	24.57	24.26	0.84	33.97	36.86
2	Deli Serdang	9.69	20.27	19.33	3.03	0.00
3	Serdang Bedagai	2.59	57.01	13.15	0.20	1.28
4	Langkat	4.20	27.80	34.33	2.10	7.11
5	Medan	31.73	4.23	3.16	0.00	0.00
6	Binjai	5.60	11.13	26.95	0.00	0.13
7	Sibolga	59.11	0.36	0.44	10.60	0.00
8	Tanjung Balai	50.25	1.16	0.00	10.60	0.00
9	Pematang Siantar	74.47	8.73	0.31	1.35	0.30
10	Tebing Tinggi	10.16	42.22	3.92	0.18	0.00

Source: The Central Bureau of Statistics National Socio-economic Survey (2014).

Besides that, the people of Medan often litter in random places, even in rivers. According to The Indonesia Ministry of Environment (2012), wastewater from households contains large amounts of COD (Chemical Oxygen Demand), nutrients and faecal coli which so far represent the primary sources of pollution to the surface water or rivers, so that rivers are polluted by many pollutants such as domestic waste, industrial waste, mining waste, agricultural waste, fishery waste, solid waste, to metal waste, and poor sanitation. Meanwhile, rivers are surface water that is managed by PDAM to produce water that is suitable for use and as a result, PDAM has to pay expensive fees to buy chemicals for processing the contaminated water in order to reach standards suitable for community consumption (Riyanto, 2017).

1.2 Perusahaan Daerah Air Minum (PDAM) Tirtanadi

Figure 1.1 displays the map of Medan, North Sumatera. It is known that the population of Medan City is around 2,279,894 people out of 569,974 households (*Badan Pusat Statistik* [BPS], 2019). A large population causes many problems; one of them includes the crisis of proper water supply, such as low level of clean water services and poor quality of raw water in the treatment process, cause discomfort to the welfare of people in Medan.

Figure 1.1 Map of Medan, North Sumatera.
Source: PDAM *Tirtanadi* Zone-1.

This PDAM company is a monopoly company in providing clean water for the Medan population. This matter is stated under Government Regulation Number 14, 1987. It indicated that the clean water infrastructure was handed over to the level one local government (province). Moreover, the management is managed by PDAM *Tirtanadi* and controlled by the level two government (Medan City).

The water PDAM Tirtanadi supplies comes from six water treatment plants (*Instalasi Pengolahan Air* or IPA). Table 1.2 shows the water treatment plants (IPA) PDAM located in Medan, North Sumatera, Indonesia.

Table 1.2 Water treatment plant (IPA) PDAM.

Name of IPA	**Location**	**A lot of water is produced**	**Water resources**
Sunggal	*Jl. Sunggal Pekan No.1A, Kota Medan, Sumatera Utara 20135*	1,800 l/s	*Belawan river*
Limau Manis	*Jalan Limau Manis Tanjung Morawa Deli Serdang*	500 l/s	*Belumai river*
Sibolangit	*Jalan Limau Manis Tanjung Morawa Deli Serdang*	644 l/s	*Sibolangit spring*
Hamparan Perak	*Jalan Hamparan Perak Desa Klambir Deli Serdang*	200 l/s	*Belawan river*
Belumai	*Jalan Limau Manis Tanjung Morawa Deli Serdang*	500 l/s	*Belumai river*
Delitua	*Jalan Pamah Delitua Medan 20355*	1,450 l/s	*Deli river*

Source: PDAM *Tirtanadi* Zone-1.

The six IPAs are insufficient to fulfil the water needs of Medan's people, which causes water shortages. Furthermore, the current PDAM tariff is still a problem for PDAM management because the tariff is set much lower than the cost of water production. In such conditions, it is difficult for PDAM management to maintain or develop services for the customer community, causing losses for PDAM due to tariffs that are too low. For this reason, a reasonable tariff increase is needed so that it can improve the PDAM's finances to improve its services to the community on an ongoing basis. PDAM is burdened with the obligation to maintain good service and water quality in accordance with the regulation stipulated by the Ministry of Health, 24-hour non-stop flow and sufficient water pressure (Hariani *et al*., 2020).

The water tariff is a water service fee policy set by the Regional Head for the use of each cubic meter or other volume unit provided by PDAM that the customer must pay. PDAM sets the tariff structure and variations based on the provisions of consumption blocks, customer groups and tariff types.

According to The Regulation of ministry of Home Affair No. 23, 2006, PDAM gives attention to the purchasing power of the community. Therefore, it is necessary to develop an appropriate tariff structure by considering the following:

a. Affordability of tariffs for low-income communities in meeting their basic daily drinking water needs.
b. To determine the production costs incurred by PDAM.
c. To determine the progressive tariff.
d. To implement cross-subsidies between customer groups and strive to conserve water consumption.

Determining tariffs is very important for consumers in deciding to purchase services or goods in determining tariffs. PDAM is influenced by two factors, namely seeking profits so that it can be sustainable and providing low tariffs to low-income people. Sometimes, the tariff set is irrational (too low) according to the principles of business entities in seeking profit. Since PDAM is socially oriented, the revenue from the sale of water obtained is unable to meet the operation and maintenance costs. Accordingly, the local government must provide subsidies in an effort to improve the implementation of the water supply system carried out by PDAM. This effort is made to achieve a balance between revenue and operation and maintenance costs in accordance with the provisions of laws and regulations.

The Regulation of ministry of Home Affair No. 23, 2006 applies the principle of full cost recovery. This principle implies that PDAM is expected to generate tariff revenues with a minimum value that can cover all operational costs. Therefore, PDAM is expected to be able to maintain and improve the quantity, quality and continuity of its services to the community.

PDAM must strive to increase tariffs to achieve full cost recovery. Full cost recovery is one of the critical variables in financial management that can improve services in various aspects, such as affordability and fairness, service quality, water usage efficiency, infrastructure rehabilitation, and others.

In determining the selling price of water, PDAM does not have an accurate mathematical model. Instead, it complies with the Regulation of Ministry of Home Affair No. 23, 2006. Mathematically, the price of water determined by PDAM has not been able to prove its accuracy. Therefore, this study uses a LP model to determine the minimum selling price of water. This model is compliant with the Regulation of Ministry of Home Affair No. 23, 2006 and is obtained by translating verse by verse from the regulation into structured mathematical equations.

1.3 Problem Background

The Regulation of Ministry of Home Affairs No. 23, 2006 is a government regulation used by PDAM to ascertain the selling price of water. The water company does not have a mathematical model for determining the selling price of water; thus, its mathematical formulation and model have never been established. The regulation is very binding and stiff. Suppose there is a change or economic turmoil, the regulation cannot be changed, and the water selling price cannot be adjusted before five years because it depends on government policy (The Regulation of the Ministry of Home Affairs No. 23, 2006, Chapter VI, Article-23 paragraph-1, 2). Difficulty in water management by PDAM is the consequence of the devolution of many governmental powers to Indonesian provinces and districts (the Asian Development Bank, 2016). Based on this regulation, the water supply and sanitation sub-sectors are under a fragile organisational and management state as well as underdeveloped implementing regulations (Saban *et al.*, 2021). The water tariff for Medan, North Sumatera was last reviewed in 2017. Therefore, it is time to review them again since the tariff must be reviewed every five years. Current tariff mechanism by PDAM in 2017 can be seen in Table 1.3.

Table 1.3 Current water price in 2017 by PDAM

No.	Customer	(Price/m^3)
1	Low tariff	1,623.8
2	Basic tariff group I block II	2,405.4
3	Basic tariff group II block I	12,045.6
4	Full tariff group II block II	5,634.0
5	Full tariff group III block I	6,915.1
6	Full tariff group III block II	12,572.9
7	Special tariff	53,821.9

The tariff set by the PDAM is lower than the cost of production, as a result, PDAM cannot cover all operational costs and is not incurred as a part of operational costs. Furthermore, it does not even meet the principle of full cost recovery, in which the tariff revenue should have a minimum value to cover all operational costs. According to the Ministry of Public Works and Public Housing (2022), due to the low tariffs set by PDAM, the coverage of its services in urban areas is only 40%, while the unserved area is 60%.

Water customers are still vulnerable to tariff increases, which prevent PDAM from covering its operational costs. Reasonable tariff adjustments are considered to improve PDAM’s services to the community in a sustainable manner and improve its efficiency.

PDAM is a business entity that carries out two functions: "social oriented" (non-profit service to the community in providing clean water) and "Profit oriented" (aims to generate profits so that the company can be sustainable). Since PDAM is socially-oriented, the revenue earned is unable to meet the operation and maintenance costs. PDAM provides cheap tariffs to low-income communities, and the tariffs set are irrational (too low). Besides, according to *Badan Pusat Statistik* (BPS, 2022), the poor people of Medan were approximately 12.36%. Therefore, as an extension of the regency/city government, PDAM is obliged to provide cheap, clean water services to low-income or poor communities.

The application of LP for water pricing has been explored in various countries, reflecting a global interest in optimizing water resources management to achieve economic efficiency, environmental sustainability, and social equity. Each country's approach to using LP for water pricing is shaped by its unique water resource challenges, regulatory frameworks, and socio-economic contexts. Here's an overview of how LP has been used for water pricing in different countries, highlighting the diverse applications and objectives:

a) Australia

Australia has utilized LP models to manage its scarce water resources, especially in the Murray-Darling Basin. The country focuses on maximizing water use efficiency in agriculture while ensuring environmental flows are maintained. LP models have been employed to optimize irrigation water distribution and pricing, taking into account the trade-offs between agricultural water use and environmental conservation (*Connor et al*., 2004).

b) China

In China, LP has been applied to address the complex water allocation and pricing challenges posed by rapid urbanization and industrialization. Studies have focused on optimizing water supply systems in cities like Beijing, where LP models help determine water tariffs that encourage conservation and ensure the financial viability of water utilities, while also considering the social impact of pricing policies (li *et al*., 2018).

c) Egypt

Egypt faces significant water management challenges due to the limited water supply from the Nile River and increasing demand from agriculture. LP models have been used to optimize the allocation of Nile water for different uses, with water pricing serving as a mechanism to promote efficient use and distribution of water resources among agricultural, industrial, and domestic sectors (Wahba *et al*., 2017).

d) Spain

Spain employs LP models to manage water resources and pricing in its semi-arid regions, where water scarcity poses a significant challenge. The models have been used to assess the economic value of water in agriculture, inform water pricing policies, and optimize the allocation of water resources among users to balance economic, environmental, and social objectives (Berbel *et al*., 2006).

The LP model is used to solve optimisation problems with an objective function that minimises the price of water with various constraints faced so as to provide accurate water selling prices. The nature of "linear" here means that all mathematical functions in this model are linear functions, while programming means planning. Therefore, LP is a way to solve problems using linear equations or inequalities to achieve the best objective among all feasible alternatives to obtain an optimum result equation.

These examples underscore the versatility of LP in addressing water pricing and management challenges across different countries. By incorporating economic, environmental, and social factors into the decision-making process, LP provides a powerful tool for developing sustainable and equitable water pricing policies. Based on research studies conducted in numerous countries utilising LP models, this research will also investigate water pricing employing the LP model. This model has two functions; the objective function and the constraint function. The objective function contains the objectives to be achieved, namely, to maximise profits and minimise production costs. In