Optimization modeling of Cipancuh reservoir operational by Sugeno's fuzzy inference system method

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Abstract. Cipancuh reservoir is the only one reservoir for irrigation in Cipancuh. Volume of Cipancuh reservoir is depending on the rain fall. In previous research, mentioned that the potential of Cikandung river water source, can increase the volume of Cipancuh reservoir so as to irrigate the rain-fed rice fields around it. But in fact, the Cipancuh reservoir water release arrangement is still very manual, depending on weather and conditions. So, in this research proposed a new rule for operational Cipancuh reservoir. This rule is expected for optimum water using and can be accounted, so as water reservoir release can meet the demand according to its target. Reservoir operation is made by fuzzy logic method. This method is built on fuzzy logic which is a way to map an input space into the output space. Between input and output there is one black box that must map the input to the appropriate output. In the calculation use Sugeno's fuzzy inference system method. The results show that the release by Sugeno's fuzzy inference system method is almost the same as the required release of water in the field. The results of this research is expected to give contribution either be a new method in the optimization of reservoir operational.

Keywords:Cipancuh reservoir, reservoir operation, optimization, fuzzy logic, Sugeno method

1. Introduction

Cipancuh reservoirs located at Situraja, Gantar district, Indramayu regency, West Java, is the only reservoir to irrigate the fields in Cipancuh. In a previous study, "Study of Potential Optimization of Water Resources for Cipancuh Irrigation Area Development" (Suprapti, 2014,[1]) stated that the potential of water source around Cipancuh reservoir, Cikandung River, can increase the Cipancuh reservoir discharge so it can irrigate the rain-fed rice fields around it. But the reality in the field, the water release arrangement Cipancuh reservoir is still very manual, depending on conditions and weather. There are no rules in writing, so there is illegal take of water either directly from the reservoir or the water from the canal.

On the basis of this condition, then in this research proposed a new rule for Cipancuh reservoir operation. The new reservoir operation regulation is intended to make the water reservoir optimum and accountable, in the hope that the water release of the reservoir can meet the water needs as targeted. Reservoir operation is made by Sugeno's fuzzy inference system method modeling.

Sugeno's fuzzy inference system method is built based on fuzzy logic which is a way to map an input space into an output space. Between input and output there is one black box that must map the input to the appropriate output. There are several reasons fuzzy logic is used, among others, fuzzy logic is very flexible, has a tolerance to the data is not appropriate, and able to model the functions of nonlinear very complex. On the basis of several of these reasons, the researcher believes that the Sugeno's fuzzy inference system method is suitable to be applied as one of the operational methods of Cipancuh reservoir with the fact that the inputs are not clear because they come from rain-fed rivers.

This research aims to prove that the Sugeno's fuzzy inference system method can be used as one method for reservoir operations so that the amount of release Cipancuh reservoir as needed. The results shows that the release by Sugeno's fuzzy inference system method is almost the same as the required release of water in the field. So, this research is expected to give contribution as a new method in the optimization of reservoir operations so that it can be utilized for the management of the reservoir.

2. Literature Review

2.1. The concept of fuzzy logic
The concept of fuzzy logic is already present to us for a long time. As an example:

a. The warehouse manager asks how much inventory there is, then the production manager determines the quantity of goods to be produced tomorrow.
b. The restaurant waiter serves the guest well, then the guest will give a tip.
c. Taxi passengers want how fast the speed of the vehicle, then the taxi driver set the taxi gas footing.

From some examples above shows that fuzzy logic is a proper way to map an input space into an output space. Between input and output there is one black box that must map the input to the appropriate output.

2.2. The reason for using fuzzy logic
Some reasons why people choose to use fuzzy logic, namely: the concept of fuzzy logic is easy to understand because the mathematical concepts underlying fuzzy reasoning are very simple and easy to understand, it is very flexible, it has a tolerance to incorrect data, it is capable of modeling very complex nonlinear functions, it can build and apply the experiences of experts directly without having to go through the training process, it can work with conventional control techniques, it is based on natural language, etc.

Fuzzy basics modeling and application by applying fuzzy logic techniques can be found in Cao et al. (1992), Lin (1994) and Wang (1994), while for the application of fuzzy techniques in the operation of reservoirs found in Ikebuchi et al. (1994), Russell and Campbell (1996) and Shresta et al. (1996), (Suharyanto, 2005, [2] in Nina Pebriana, 2014, [3]).

2.3. Fuzzy logic method
Professor Zadeh (California University) was recognized as the initiator of the concept of the fuzzy set in 1965. He describes the mathematical calculations to give a picture of vagueness or blur into the form of linguistic variables. The idea can be interpreted as a generalization of the classical set theory that combines qualitative and quantitative approaches. The fuzzy principle is built on uncertainty, saying that if the complexity of a system increases, one's ability to make precise and significant statements about the behavior of the system will diminish to some extent (Imam Robandi, 2006 in Nina Pebriana, 2014, [3]).

Sri Kusumadewi (2003, [4]), states that the fuzzy set has two attributes namely linguistic (naming the group representing a particular state or condition with natural language) and numerical (a value / number indicating size in a variable). In fuzzy logic, membership of an element in a set is not expressed explicitly (crips), but the fuzziness of the linguistic variables by using membership values lies between values 0 to 1.

2.4. Membership functions
The membership function is a curve showing the mapping of data input points into their membership values (often referred to as membership degrees) that have intervals between 0 and 1. One way that can be used to obtain membership value is through approach function.

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2.5. Fuzzy inference system
The inference process is the process of changing from an input in a fuzzy domain to an output in the fuzzy domain. There are several inference systems in the fuzzy method of Tsukamoto, Mamdani and Sugeno. In this research used Sugeno method.

2.6. Sugeno method
Reasoning with Sugeno method is similar to Mamdani's method of reasoning, only the (consequent) output of the system is not a fuzzy set, but rather a constant or a linear equation. This method was first introduced by Takagi-Sugeno Kang in 1985.

a. Sugeno fuzzy model of zero order
   In general the form of fuzzy model Sugeno zero order is:
   $$IF\,(x_1 \ \ is \ \ A_1) \bullet (x_2 \ \ is \ \ A_2) \bullet ... \bullet (x_N \ \ is \ \ A_N) \ \ THEN \ \ \ z = k$$
   with Ai is the set of i-fuzzy as antecedents, and k is a constant (crisp) as consequent.
b. Sugeno's first order fuzzy model
   In general the shape of the first order Sugeno fuzzy model is:
   $$IF\,(x_1 \ \ is \ \ A_1) \bullet ... \bullet (x_N \ \ is \ \ A_N) \ \ THEN \ \ \ z = p_1 * x_1 + ... + p_N * x_N + q$$
   with Ai is the set of i-fuzzy as antecedents, and pi is a constant (crisp) as the consequence to-i and q is also a constituent in consequence.

3. Methodology
The methodology of this research is illustrated by diagram flow as follows:

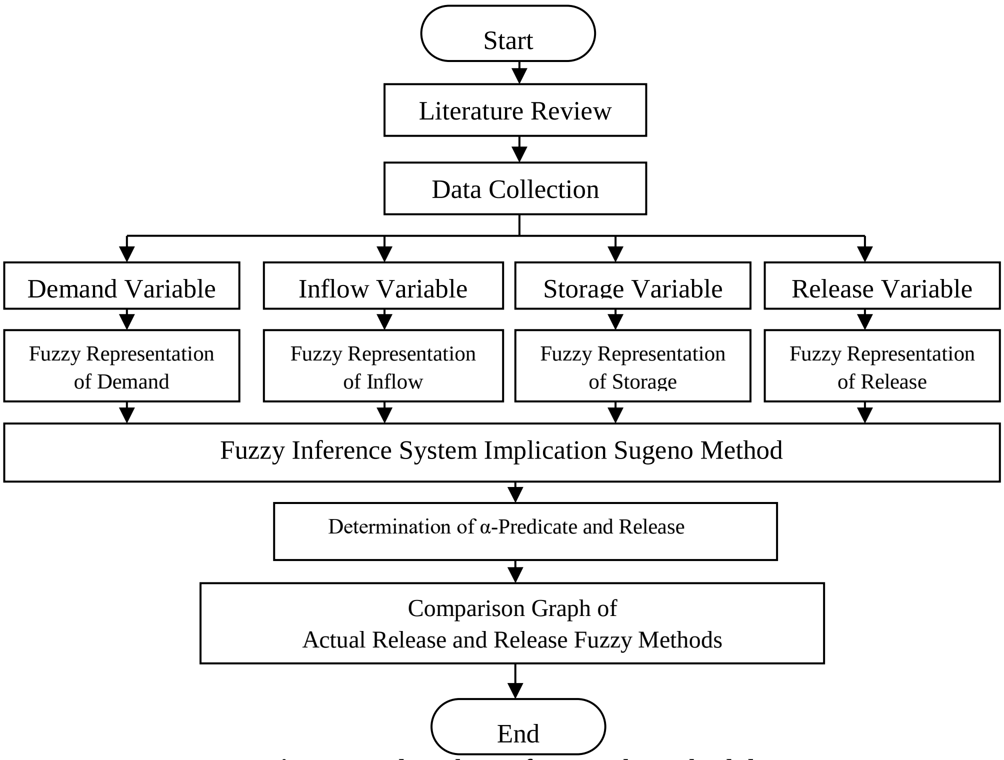

Figure 1. Flowchart of research methodology.

The calculation process of fuzzy logic method (Panigrahi and Mujumdar, 2000, [5]), includes:

1) The formation of fuzzy functions of variable demand, inflow, storage, and release
2) The establishment of a fuzzy representation membership function for all four variables

3) Use of application implication function with fuzzy inference system of Sugeno method
4) The determination of α- predicate and release is based on the result of implication function point no 3 for each month for one year
5) Draw a graph of the release result at point 4 and the actual release graph, then compare it.

4. Discussion and Analysis

4.1. The establishment of fuzzy functions and membership functions

The formation of fuzzy functions and membership functions for each variable are based on the following table:

Table 1. Storage, actual release, total inflow and demand of Cipancuh reservoir.

Month	Storage (x10^6 m3)	Actual Release (x10^6 m3)	(P-E)*A (x10^6 m3)	Seepage (x10^6 m3)	Inflow (x10^6 m3)	Suplesion (x10^6 m3)	Total Inflow (x10^6 m3)	Demand (x10^6 m3)
January	6,18	13,54	0,625	0,0042	12,32	0,00	12,32	12,514
February	5,58	13,63	0,330	0,0036	12,52	0,00	12,52	11,456
March	4,80	7,02	0,173	0,0029	7,41	2,73	10,15	10,316
April	5,36	11,71	0,277	0,0036	10,63	5,30	15,93	16,202
May	4,56	7,27	0,187	0,0027	5,15	12,26	17,40	17,588
June	2,62	3,26	-0,022	0,0019	1,38	18,29	19,66	19,639
July	0,71	2,11	-0,028	0,0009	1,44	24,13	25,57	25,536
Agust	0,01	0,01	-0,016	0,0008	0,11	17,49	17,60	17,588
September	0,09	0,00	-0,003	0,0008	1,14	10,98	12,11	12,111
October	1,22	0,00	-0,035	0,0012	0,64	3,46	4,09	4,059
November	1,82	5,04	0,176	0,0016	6,87	10,31	17,17	17,348
December	3,82	10,33	0,348	0,0025	12,32	4,25	16,57	16,911

Fuzzy set in this research consists of four variables, namely demand, inflow, storage and release. Each variable is subdivided into several conditions. The determination for each set condition is made based on the probability of occurrence by using Weibull formula. The membership value of the fuzzy representation for each variable is as follows:

Table 2. The membership value of the fuzzy representation of demand variable.

No.	Condition	Probability (%)	Demand (x10^6 m3)	μ SB	μ B	μ S	μ Sdk	μ SSdk
1		7,692	25,536	1,000	0,000	0,000	0,000	0,000
2	Very many	15,385	19,639	1,000	0,000	0,000	0,000	0,000
3		23,077	17,588	0,000	1,000	0,000	0,000	0,000
4	Many	30,769	17,588	0,000	1,000	0,000	0,000	0,000
5		38,462	17,348	0,000	0,767	0,233	0,000	0,000
6		46,154	16,911	0,000	0,344	0,656	0,000	0,000
	Medium	50,000	16,557	0,000	0,000	1,000	0,000	0,000
7		53,846	16,202	0,000	0,000	0,920	0,080	0,000
8		61,538	12,514	0,000	0,000	0,091	0,909	0,000
9	Few	69,231	12,111	0,000	0,000	0,000	1,000	0,000
10		76,923	11,456	0,000	0,000	0,000	0,635	0,365
11	Very few	84,615	10,316	0,000	0,000	0,000	0,000	1,000
12		92,308	4,059	0,000	0,000	0,000	0,000	1,000

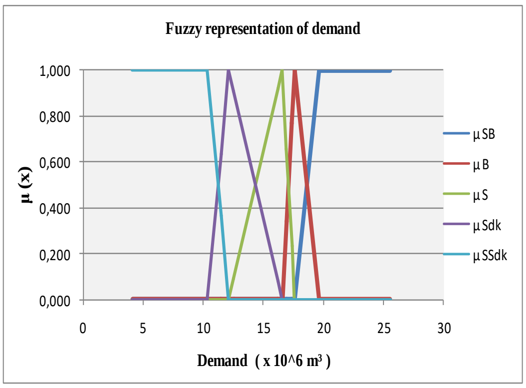

Figure 2. Fuzzy representation of demand.

Table 3. The membership value of the fuzzy representation of inflow variable.

No.	Condition	Probability (%)	Inflow (x10^6 m3)	μ SB	μ B	μ S	μ K	μ SK
1		7,69	25,565	1,000	0,000	0,000	0,000	0,000
2	Very wet	15,38	19,663	1,000	0,000	0,000	0,000	0,000
3		23,08	17,605	0,089	0,911	0,000	0,000	0,000
4	Wet	30,77	17,404	0,000	1,000	0,000	0,000	0,000
5		38,46	17,174	0,000	0,801	0,199	0,000	0,000
6		46,15	16,566	0,000	0,276	0,724	0,000	0,000
	Medium	50,00	16,247	0,000	0,000	1,000	0,000	0,000
7		53,85	15,929	0,000	0,000	0,919	0,081	0,000
8		61,54	12,516	0,000	0,000	0,049	0,951	0,000
9	Dry	69,23	12,324	0,000	0,000	0,000	1,000	0,000
10		76,92	12,115	0,000	0,000	0,000	0,904	0,096
11	Very dry	84,62	10,145	0,000	0,000	0,000	0,000	1,000
12		92,31	4,095	0,000	0,000	0,000	0,000	1,000

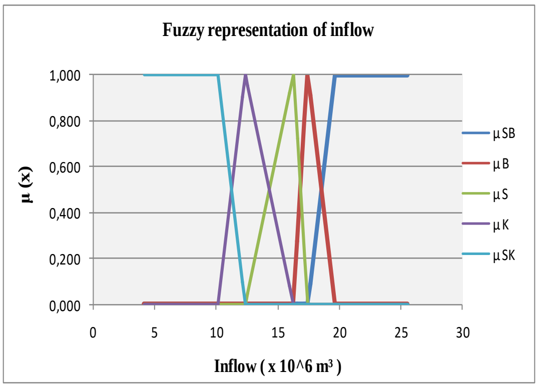

Figure 3. Fuzzy representation of inflow.

Table 4. The membership value of the fuzzy representation of storage variable

No.	Condition	Probability (%)	Storage (x10^6 m3)	μ ST	μ T	μ S	μ R	μ SR
1		7,69	6,18	1,000	0,000	0,000	0,000	0,000
2	Very high	15,38	5,58	1,000	0,000	0,000	0,000	0,000
3		23,08	5,36	0,719	0,281	0,000	0,000	0,000
4	High	30,77	4,80	0,000	1,000	0,000	0,000	0,000
5		38,46	4,56	0,000	0,852	0,148	0,000	0,000
6		46,15	3,82	0,000	0,380	0,620	0,000	0,000
	Medium	50,00	3,22	0,000	0,000	1,000	0,000	0,000
7		53,85	2,62	0,000	0,000	0,702	0,298	0,000
8		61,54	1,82	0,000	0,000	0,300	0,700	0,000
9	Low	69,23	1,22	0,000	0,000	0,000	1,000	0,000
10		76,92	0,71	0,000	0,000	0,000	0,552	0,448
11	Very low	84,62	0,09	0,000	0,000	0,000	0,000	1,000
12		92,31	0,01	0,000	0,000	0,000	0,000	1,000

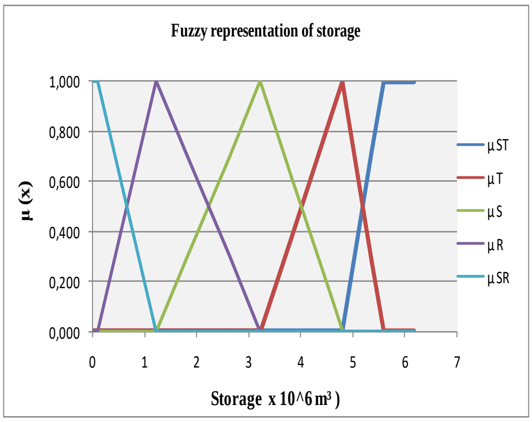

Figure 4. Fuzzy representation of storage.

Table 5. The membership value of the fuzzy representation of release variable.

No.	Condition	Probability (%)	Actual Release (x10^6 m3)	μ SB	μ B	μ S	μ Sdk	μ SSdk
1		7,69	13,63	1,000	0,000	0,000	0,000	0,000
2	Very many	15,38	13,54	1,000	0,000	0,000	0,000	0,000
3		23,08	11,71	0,428	0,572	0,000	0,000	0,000
4	Many	30,77	10,33	0,000	1,000	0,000	0,000	0,000
5		38,46	7,27	0,000	0,288	0,712	0,000	0,000
6		46,15	7,02	0,000	0,229	0,771	0,000	0,000
	Medium	50,00	6,03	0,000	0,000	1,000	0,000	0,000
7		53,85	5,04	0,000	0,000	0,748	0,252	0,000
8		61,54	3,26	0,000	0,000	0,293	0,707	0,000
9	Few	69,23	2,11	0,000	0,000	0,000	1,000	0,000
10		76,92	0,01	0,000	0,000	0,000	0,006	1,000
11	Very few	84,62	0,00	0,000	0,000	0,000	0,000	1,000
12		92,31	0,00	0,000	0,000	0,000	0,000	1,000

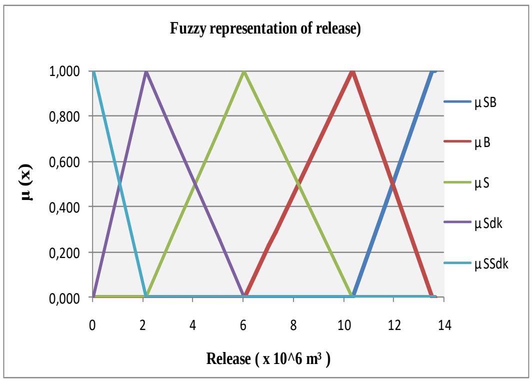

Figure 5. Fuzzy representation of release.

4.2. Sugeno's fuzzy inference system method

The fuzzy inference system used in this researh is the Sugeno method. The output (consequent) in the Sugeno method is a constant or linear equation that is flexible depending on the objectives to be achieved. Each rule (proposition) is made following the IF as antecedents and THEN as a consequence. Expansion of proposition by using fuzzy operator AND . The following is an application of the implication function according to Sugeno's fuzzy inference system:

(R1) IF demand is medium And water in reservoir is medium And inflow is medium
THEN Release = 2.92*demand
(R2) IF demand is very few And water in reservoir is low And inflow is very dry
THEN Release = 1.05* demand
(R3) IF demand is medium And water in reservoir is high And Inflow is dry
THEN Release = 1.02*inflow - demand
(R4) IF demand is medium And water in reservoir is very high And inflow is wet
THEN Release = 1.33*inflow - demand

(R5) IF demand is medium And water in reservoir is very high And inflow is medium
THEN Release = 0.7*demand
(R6) IF demand is medium And water in reservoir is very high And inflow is wet
THEN Release = 1.68*demand
(R7) IF demand is very many And water in reservoir is low And inflow is very wet
THEN Release = 1.83*demand
(R8) IF demand is very many And water in reservoir is high And inflow is very wet
THEN Release = 1.51*demand
(R9) IF demand is many And water in reservoir is low And inflow is wet
THEN Release = 0.4*demand
(R10) IF demand is many And water in reservoir is low And inflow is very dry
THEN Release = 0.8*demand
(R11) IF demand is few And water in reservoir is very high And inflow is dry
THEN Release = 1.1* demand
(R12) IF demand is few And water in reservoir is low And inflow is dry
THEN Release = 1.12*demand

Based on the implication function of the Sugeno's fuzzy inference system method, the determination of α-predicate and release (Z) is performed on each rule for each month.

January :

(R1) IF demand is medium And water in reservoir is medium And inflow is medium
THEN Release = 2.92*demand
α-predicate = μ demand is medium ∩ μ volume is medium ∩ μ inflow is medium
= MIN (μ (12.514) ∩ μ (6.18) ∩ μ (12.32))
= MIN (0.909 ∩ 0 ∩ 0) = 0
THEN Release (Z) = 2.92*demand

Z = 36.541	α.Z = 0

(R2) IF demand is very few And water in reservoir is low And inflow is very dry
THEN Release = 1.05* demand
α-predicate = μ demand is very few ∩ μ volume is low ∩ μ inflow is very dry
= MIN (μ (12.514) ∩ μ (6.18) ∩ μ (12.32))

= MIN (0 ∩ 0 ∩ 0.002) = 0

THEN Release (Z) = 1.05* demand

Z = 13.140	α.Z = 0

...
...
...

(R12) IF demand is few And water in reservoir is low And inflow is dry
THEN Release = 1.12*demand
α-predicate = μ demand is few ∩ μ volume is low ∩ μ inflow is dry
= MIN (μ (12.514) ∩ μ (6.18) ∩ μ (12.32))
= MIN (0.909 ∩ 0 ∩ 0.998) = 0
THEN Release (Z) = 1.12*demand

Z = 14.016	α.Z = 0

The determination of α-predicate is continued for the other months for one year.

Table 6. Recapitulation of the Sugeno's fuzzy inference system method in January.

Recapitulation in January						
Rule	μ Demand 12,514	μ Volume of Water 6,18	μ Inflow 12,32	α	Z	α*Z
R1	0,909	0	0	0	36,541	0
R2	0,000	0	0,002	0	13,140	0
R3	0,091	0	0,998	0	0,052	0
R4	0,091	1	0	0	3,872	0
R5	0,091	1	0	0	8,760	0
R6	0,091	0	0	0	21,024	0
R7	0,000	0	0	0	22,901	0
R8	0,000	0	0	0	18,896	0
R9	0,000	0	0	0	5,006	0
R10	0,000	0	0	0	10,011	0
R11	0,909	1	0,998	0,909	13,765	12,518
R12	0,909	0	0,998	0	14,016	0
					Total	12,518

The calculation is continued for the other months of the year.

4.3 Comparison Fuzzy release method and water requirement

The following is the calculation result for Cipancuh reservoir operation arrangement with modeling of Sugeno's fuzzy inference system method and water requirement in field

Table 7. Comparison of fuzzy volume release method and water requirements in the field.

Month	Storage (x10^6 m3)	Actual Release (x10^6 m3)	Total Inflow (x10^6 m3)	Demand (x10^6 m3)	Fuzzy Release (x10^6 m3)
January	6,18	13,54	12,32	12,514	12,518
February	5,58	13,63	12,52	11,456	11,459
March	4,80	7,02	10,15	10,316	10,807
April	5,36	11,71	15,93	16,202	17,230
May	4,56	7,27	17,40	17,588	17,982
June	2,62	3,26	19,66	19,639	19,678
July	0,71	2,11	25,57	25,536	25,640
Agust	0,01	0,01	17,60	17,588	18,340
September	0,09	0,00	12,11	12,111	12,232
October	1,22	0,00	4,09	4,059	4,262
November	1,82	5,04	17,17	17,348	17,379
December	3,82	10,33	16,57	16,911	16,955
			Total :	**181,269**	**184,482**

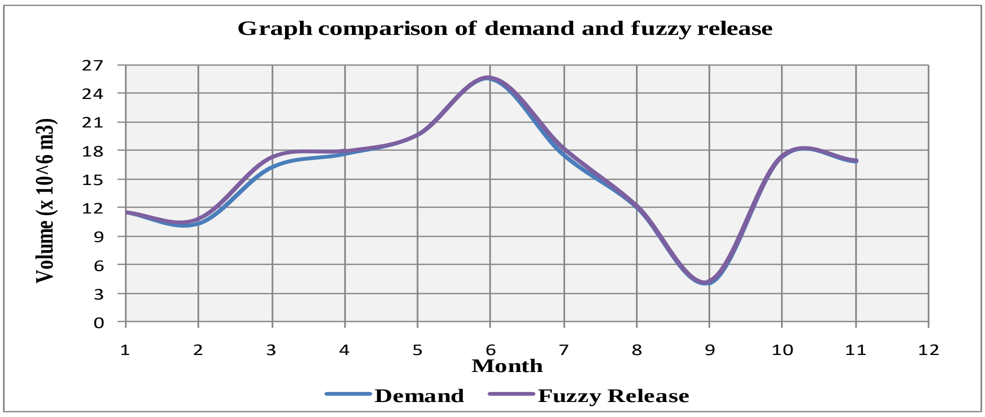

Figure 6. Graph comparison of fuzzy release and demand.

5. Conclusion
Sugeno's fuzzy inference system method can be used as rule of operation pattern of Cipancuh reservoir, because the method can produce releases as needed. Data processing by Sugeno's fuzzy inference system method is expected to be able to made in a special computer programme (application software) to facilitate and speed up the calculation. With this application software, water reservoir calculation can be done easily in the field and can be tested applied to the operating system of reservoir.

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