COMPARISON AND CORRELATION AMONG MEASUREMENT RESULTS OF OBSERVATORY, HELLMAN, AND TIPPING BUCKET SENSORS

PERBANDINGAN DAN KORELASI ANTARA HASIL PENGUKURAN SENSOR OBSERVATORIUM, HELLMAN*, DAN* TIPPING BUCKET

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ABSTRACT

Rainfall data analysis from three types of sensors installed on Maritime Meteorology Station owned by Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG's) in Pontianak has been carried out. The three types of sensors were Observatory (OBS), Hellman, and Tipping Bucket (TB). This research used analysis of variance (ANOVA) and correlation tests because although calibrations to the rainfall sensors are performed every year, their measurement results are still different.Comparison results showed that there were no significant differences among them, while correlation tests revealed that there were strong correlations between the measurement results of OBS and Hellman (0.9457), OBS and TB (0.9869), and Hellman and TB (0.9651).

Keywords: rainfall, raingauge, ANOVA, correlation

ABSTRAK

Berbagai analisis data curah hujan dari tiga jenis sensor yang dipasang pada Stasiun Meteorology Maritim milik Badan Meteorologi dan Geofisika (BMKG)telah dilakukan di Pontianak. Ketiga jenis sensor tersebut adalah observatorium (OBS), Hellman*, dan* tipping bucket *(TB). Semua analisis yang menggunakan uji analisis varian (ANOVA) dan uji korelasi tersebut dilakukan karena meskipun kalibrasi terhadap ketiga sensor curah hujan tersebut selalu dilakukan setiap tahun, semua hasil pengukurannya masih berbeda.Semua hasil perbandingan menunjukkan bahwa tidak ada perbedaan yang bermakna di antara ketiganya, sedangkan uji korelasi mengungkapkan bahwa ada hubungan yang kuat antara semua hasil pengukuran OBS dengan Hellman (0,9457), OBS dengan TB (0,9869), dan Hellman dengan TB (0,9651).*

***Kata kunci**: curah hujan, alat ukur curah hujan, ANOVA, korelasi*

INTRODUCTION

Rainfall data or information, especially in a dense populated area, is essential for various sectors. This information is required in the sector of urban plan to examine the water availability in that region.[1,2,3] In addition, the data can be utilized as the early warning system for flood and drought. Rainfall information is also needed to determine the initial time for planting in the agriculture sector.[4] Rainfall information is also very useful in the fields of transportation[5] and tourism.[3]

To obtain this kind of information, the users do not have to install rain gauges by themselves. Some of the information has been provided by a government agency called BMKG that has a special task to conduct weather and climate observations.

It is common that a BMKG's meteorological station, such as Airport Meteorological Station, installs more than one rainfall measurement systems. The rainfall measurement result, from this station is used as one of decision support information for the plane's take off and landing mechanism on an airport. On the other hand, the rainfall measurement system redundancy is also a dilemma. In case all systems are working well, for example, which kind of rainfall measurement data is used? What is the reason for this selection?

The aim of this study was to investigate comparison and correlation among measurement results of observatory, Hellman, and tipping bucket sensors as the most favorite rainfall sensor types in Indonesia. The study results are used to give a scientific reason for the measurement data selection.

BASIC THEORY

Precipitation is defined in some different ways. It is an event of water droplets or ice crystals falling from the cloud down to the ground.[6,7] The precipitation can also in the mixed form of solid and liquid[8], or liquid and air, such as fog[7].

Rainfall is only one type of precipitation. Some variables of rainfall are the amount, time of occurrence, form, character, and intensity.[9] One millimeter rainfall means that the amount of the deposited water on an area of one square meter is 1000 ml or one liter,[6] while the rainfall intensity is the amount of rainfall per unit time interval.[10]

An instrument to measure the amount of rainfall is called a rain gauge(hyetometer, ombrometer, pluviometer, regenmeter, or udometer).[11] Some types of rainfall sensors that are widely used, particularly in Indonesia are OBS, Hellman, and TB.[12] They are different, especially in their working principle (Figure 1).

OBS is a sensor to measure rainfall manually and its result is highly dependent on the reading accuracy of operators on the measuring cup. This kind of sensor only measures the amount of cumulative rainfall within a period of time, for example 24 hours. Hence, this sensor can not measure the rainfall intensity. Measurements are performed once a day, every 00:00 UTC or 07:00 AM. The amount of rainfall is obtained from equation (1).

(a) OBS type (b) Hellman type (c) TB type

Figure 1. Three Kinds of Rainfall Sensors Installed at field

$$\text{Amount of rainfall} = \frac{\text{Beurrete volume}}{\text{Sensor mounth area}} ...(1)$$

A Hellman rainfall sensor mainly comprises three parts, i.e. a collecting funnel, a float chamber, and a recorder, and works based on rainfall intensities. When rainfall drops on the collecting funnel, this water enters the float chamber. If the water level in this chamber rises, the float will be lifted in proportional way with the rainfall depth. In the float chamber, there is a siphon that automatically discharges the water in the chamber as soon as the maximum water level (equal to 10 mm rainfall depth) is reached. This process is repeated continuously. Meanwhile, the float in the chamber is connected to a pen on the recorder b that traces the rainfall depth on a cylindrical paper attached on the recorder. Hence, if the water in the chamber drains away, the penholder moves down the pen to its zero scale.[12,13] This paper moved in rotation way, one turn every day, and replaced at the same time every day. Thus, now, this sensor presents rainfall intensity measurements automatically, but still manually in the data storage processing.

TB is a name of rainfall sensor that uses weighing and automation principles in measuring and recording rainfall data. If rainfall is coming, the sampling water of the rainfall will enter through a large funnel and then a small funnel before reaching the core of this sensor called a tipping bucket. The rainfall number is measured by calculating the number of the tipping bucket movements. In this tipping bucket, there are two cups filled with rainfall water alternately. Each time one of the cups is fully filled, this pair of buckets will turn right (or left). This process will spill the collected water on one side of the buckets and will be counted as one pulse.[2] This process is repeated for the other cup. With this TB sensor, the observer can know the value of rainfall number and rainfall intensity simultaneously. Calculation of rainfall using this sensor is strongly influenced by the amount of tipping, tipping volume, and funnel area of the sensor[13], namely:

$$Rn = \frac{Nt \times V}{A} \qquad ...(2)$$

where:

Rn : rainfall number (mm)
Nt : tipping number
V : volume of the cup (cc)
A : the mouth of sensor funnel (cm)

The above three types of rainfall sensor are expected to provide the same results. The result similarity is proved using their measurement data analysis.

METHODOLOGY

a. Data Gathering

For this study, the authors needed a long series data, therefore, the data gathering were not done directly, but utilized secondary data. The secondary data used in this study were collected by the Marine Meteorology Station in Pontianak.

The collected data were then analyzed. The similarities among measurement data of observatory, Hellman, and tipping bucket sensors were tested using statistical testing methods, while their correlation was tested using correlation methods.

b. Data Analysis Using ANOVA Test

Analysis of variance (ANOVA) test is a statistical test used to determine the difference among the tested method or type by comparing their population means.[14] One factor of ANOVA test is used to determine whether there are significant differences among three or more different populations.[15] The hypothesis for ANOVA test in the analysis of rainfall data is stated on the following formula.

$H_0 : \forall(h, i, ...k),$

$h \neq i \neq ... \neq k, \mu_h = \mu_i = ... = \mu_k$

(There are no differences among the three types of tested sensors.)

$H_1 : \exists(h, i, ...k),$

$h \neq i \neq ... \neq k, \mu_h \neq \mu_i \neq ... \neq \mu_k$

(At least, there is one difference.)

If j is the number of sampled data with different treatments, the means of sample are represented by $\mu_1, \mu_2 ...., \mu_j,$ sample sizes are $n_1, n_2, \ldots n_j$, and the overall amount of data is $N = n_1 + n_2 + \ldots + n_j$, then the means of sample is,

$$\mu_j = \frac{\sum_{i=1}^{n_j} X_{ij}}{n_j} \quad .....(3)$$

and the mean of the total population is,

$$\mu = \frac{\sum_{i=1}^{N} X_i}{N} \quad .....(4)$$

Sum of Square (SS) and Sum of Square Error (SSE) are the diversity of the sample means and errors respectively, which are calculated from:

$$SS_j = \sum_{j=1}^{J} I_j \overline{X}_j^{\,2} - N\overline{X}_j^{\,2} \quad .....(5)$$

$$SSE = \sum_{j=1}^{J} \sum_{i=1}^{I} I_j X_{ij}^{\,2} - \sum_{j=1}^{J} I_j \overline{X}_j^{\,2} \quad .....(6)$$

The degree of freedom (*df*) of SS_j is (*J*-1) and df of the SSE is a (*N-1*). The mean square (*MS*) from each sample is:[14]

$$MS_j = \frac{SS_j}{j-1} \quad .....(7)$$

and the mean square error (MSE) is:[14]

$$MSE = \frac{SSE}{N-1} \quad .....(8)$$

The *f* value is given as follows:[15]

$$f = \frac{MS}{MSE} \quad .....(9)$$

c. Data Analysis Using Correlation Test

There are two kinds of correlation. If the increase in *X* variable values is always accompanied by the increase in *Y* variable values and the falling values of variable *X* are always followed by the decline values of variable*Y*, then the relationship is called as a positive correlation. On the contrary, if the rise in the values of the variable *X* is always accompanied by the decline in the values of the variable *Y*, or if the decline in the values of the variable *X* is always followed by the rise in the value sof variable *Y*, then the relationship between the two variables is negative.[15]

Correlation test is used to determine the closeness value between two types. The correlation between type I and type II with a population of *X* and *Y* respectively can be calculated through the following formula.[17, 18, 19]

$$r_{(X,Y)} = \frac{\sum_{i=0}^{n} (X_i Y_i) - (n\overline{X} \cdot \overline{Y})}{\sqrt{\left(\sum_{i=0}^{n} X_i^2 - n\overline{X}^2\right)\left(\sum_{i=0}^{n} Y_i^2 - n\overline{Y}^2\right)}} \ldots(10)$$

According to Syayib[11], the value of the correlation coefficient (*r*) ranges between -1 to 1, namely:

1) If *r* = 1, a perfect linear positive correlation between both types.
2) If *r* = -1 a perfect linear negative correlation between both types.
3) If *r* = 0, no mutual influence between both types.
4) If *r* approaches 1, a strong positive linear relationship between both types.
5) If *r* almost -1, a strong negative linear relationship between both types.

RESULT AND DISCUSSION

a. Raw Data

Rainfall measurement data differences were measured on Marine Meteorology Station in Pontianak in January 2016 and it can be seen from the color differences on the graph (Figure 2). The differences were rather irregular. The maximum data, for example, sometimes were held by Hellman (55.3, January 14th), but on other time by OBS (86.5, January 20th), or TB (88, January 27).

From data recording uniformity in one month in Table 1, it can be seen that all sensors worked well. All sensors gave no results (0.00 mm) when there was no rain and if one sensor displayed small data value, the other sensors showed almost the same and vice versa.

b. ANOVA Test

The hypothesis test used in this study was *F* statistical test with the hypothesis as follows:

$$H_0 : \forall (i, j, k),\ i \neq j \neq k,\ \mu_i = \mu_j = \mu_k$$

(There are no differences among the three types of tested sensors)

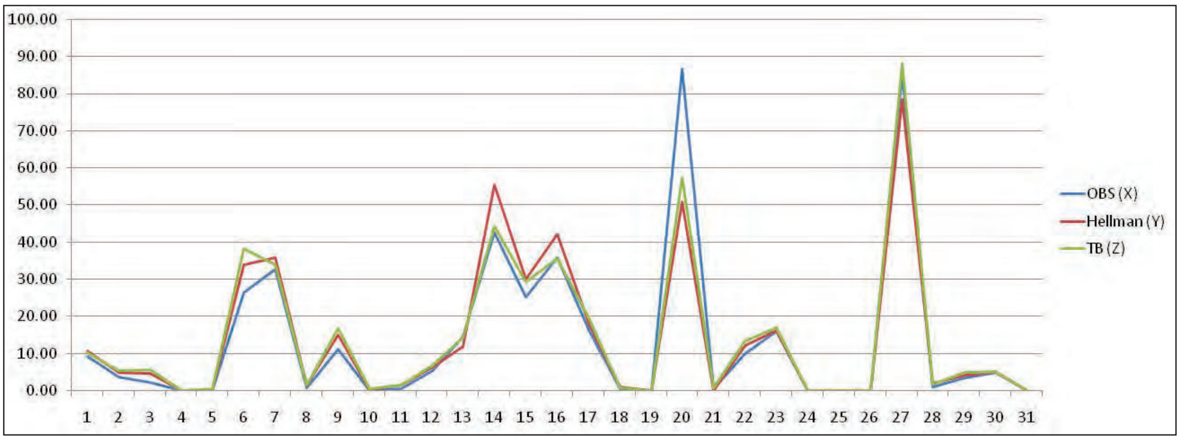

Figure 2. Graphical Form for Rainfall Measurement Data

Table 1. Rainfall Measurement Data for Three Types of Sensors

No	Date	Rainfall (mm)		
		OBS (X)	Hell-man (Y)	TB (Z)
1	1/1/2016	9.10	10.70	10.20
2	2/1/2016	3.60	4.90	5.40
3	3/1/2016	2.20	4.70	5.60
4	4/1/2016	0.00	0.00	0.00
5	5/1/2016	0.10	0.30	0.40
6	6/1/2016	26.30	33.90	38.20
7	7/1/2016	32.50	35.70	33.80
8	8/1/2016	0.80	1.40	1.40
9	9/1/2016	11.00	15.10	16.80
10	10/1/2016	0.10	0.20	0.40
11	11/1/2016	0.50	1.40	1.40
12	12/1/2016	5.30	6.40	6.80
13	13/1/2016	14.60	11.90	14.20
14	14/1/2016	42.50	55.30	44.20
15	15/1/2016	25.20	29.90	29.20
16	16/1/2016	35.70	42.10	35.60
17	17/1/2016	16.40	18.10	19.60
18	18/1/2016	0.40	1.00	0.80
19	19/1/2016	0.00	0.00	0.00
20	20/1/2016	86.50	50.70	57.40
21	21/1/2016	0.50	0.00	0.80
22	22/1/2016	9.90	12.00	13.20
23	23/1/2016	16.00	16.30	17.00
24	24/1/2016	0.00	0.00	0.00
25	25/1/2016	0.00	0.00	0.00
26	26/1/2016	0.00	0.00	0.00
27	27/1/2016	85.00	78.40	88.00
28	28/1/2016	1.00	1.90	1.80
29	29/1/2016	3.30	4.20	4.80
30	30/1/2016	4.80	5.10	5.00

$$H_1 : \exists(i,j,k),\ i \neq j \neq k,\ \mu_i \neq \mu_j \neq \mu_k$$

(At least, there is one difference)

After some calculation, the summary of the ANOVA test result was obtained as it is shown in Table 2.

A box plot (Figure 3) was used to compare the distribution or variation among data variable groups and identify data outlier occurrences.[17] Outlier is an individual data value that deviates too much from the spread of observational data. [17]

Table 2. ANOVA Test Summary

ANOVA: Single Factor				
SUMMARY				
Groups	Count	Sum	Average	Variance
OBS	31	433.3	13.98	507.89
Hellman	31	441.6	14.25	397.85
TB	31	452.0	14.58	424.08

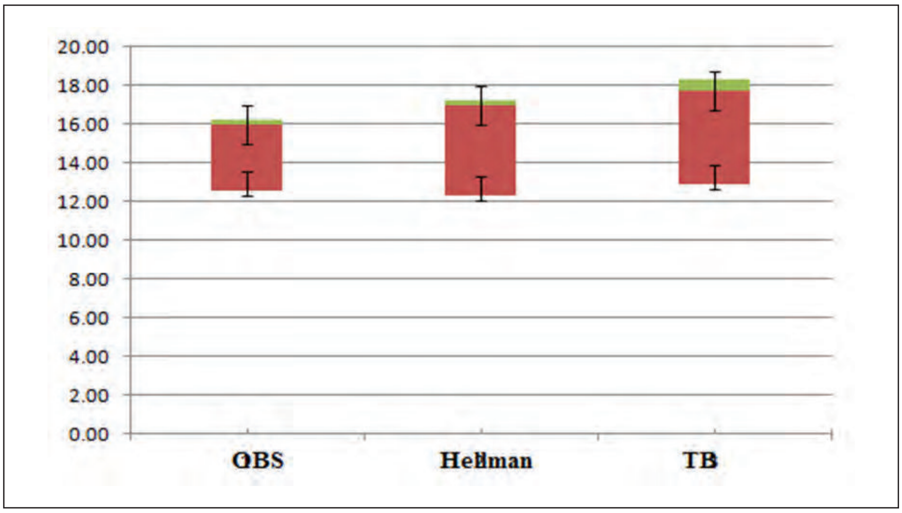

Figure 3. Boxplot of Rainfall Values for Three Type of Rainfall Sensor

Table 3. Display of ANOVA Testing Calculation

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.663871	2	2.831935	0.006389	0.993632	3.097698
Within Groups	39894.52	90	443.2724			
Total	39900.18	92				

Some findings were obtained from Figure 3 as it can be seen that the OBS type has the smallest variance.TB sensor showed the highest result compared to the other types. This finding is in agreement with a hypothesis raised by some operators at field that the measurement value of TB is higher than the OBS and Hellman sensors. This is predicted due to the lagging response of TB sensor at high intensity rainfall.

ANOVA test results were summarized in Table 3. For α = 0:05 or the confidence level was equal to 95%, the F value was 0.006389, while the value of p was 0.993632. Because $F < p$, then H_0 was accepted and this means that there was no difference in the results of measurement among the three types of utilized sensors.

c. Correlation Tests

It has been mentioned before that there were three kinds of sensor data. Therefore, the correlation tests were performed three times, namely correlation tests between OBS and Hellman data, between Hellman and TB data, and between OBS and TB data.

1. Correlation between OBS and Hellman data

$$r_{OBS-Hellman} = \frac{n\sum X_iY_i - (\sum X_i)(\sum Y_i)}{\sqrt{\left(n\left(\sum X_i^2 - (\sum X_i)^2\right)\right)\left(n\left(\sum Y_i^2 - (\sum Y_i)^2\right)\right)}}$$

$$=0.9457$$

The correlation (0.9457) was higher than 0.7. The above calculation showed that there was a strong correlation between the measurement results using OBS sensor and Hellman sensor.

2. Correlation between Hellman and TB data

$$r_{Hellman-TB} = \frac{n\sum Y_iZ_i - (\sum Y_i)(\sum Z_i)}{\sqrt{\left(n\left(\sum Y_i^2 - (\sum Y_i)^2\right)\right)\left(n\left(\sum Z_i^2 - (\sum Z_i)^2\right)\right)}}$$

$$=0.9651$$

The computation indicates that there was a strong correlation between the measurement results using Hellman sensor and TB sensor. This correlation result was even higher than the correlation between OBS sensor and Hellman sensor.

3. Correlation between OBS and TB Data

$$r_{OBS-TB} = \frac{n\sum X_i Z_i - \left(\sum X_i\right)\left(\sum Z_i\right)}{\sqrt{\left(n\left(\sum X_i^2 - \left(\sum X_i\right)^2\right)\right)\left(n\left(\sum Z_i^2 - \left(\sum Z_i\right)^2\right)\right)}}$$

$$= 0.9869$$

It can be seen clearly from the calculation that there was a strong correlation between rainfall measurement results using OBS sensor and TB sensor. This correlation was the highest among the three correlations.

CONCLUSION

Based on the virtue of the data analyses, it can be concluded that:

1) There were no significant differences among measurement results of OBS, Hellman, and TB sensors.
2) There were strong correlations between the measurement results of OBS and Hellman (0.9457), OBS and TB (0.9869), and Hellman and TB (0.9651).

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