

Water temperature variation of Segara Anakan, Sempu Island, South Malang, Indonesia in relation to the climate variation

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Abstract. Water temperature variation and its correlation to meteorological factors and climate variation was studied at Segara Anakan Lagoon of Sempu Island during January 2012 to December 2013. Tidbit water temperature data, ECMWF meteorological data, climatic indices were analysed statistically. The result showed that the range of water temperature was between 23.7 to 30.4°C. Pearson correlation between water temperature and meteorological factors varied seasonally. The highest water temperature (30.4°C) occurred in Northwest Monsoon, was mainly affected by precipitation ($r = -0.999$). While, the lowest ones (23.7°C) in Southeast Monsoon, was affected by all meteorological factors. Furthermore, in transitional seasons (transitional-1: $r = 0.977$; transitional-2: $r = 0.744$), it was affected by solar radiation. This study also informed that there was no difference between water temperature and satellite SST ($t < t_{tab}$: $1.288 < 2.074$; sig: $0.211 > 0.05$) which showed that satellite SST were able to substitute the limited in situ data (Tidbit water temperature). PCA analysis indicated that climate factors (mainly SOI and DMI) affected water temperature of Segara Anakan. Present study suggested that good quality with direct and continuous measurement of local water temperature data and compiled with meteorological data and climate index were important for further prediction of water temperature variation as climate adaptation in South Malang.

1. Introduction

Temperature is a very important physical characteristic of seawater, as it can be used to identify seawater bodies. According to Patty [1], the distribution of sea water temperature is influenced by many factors, including surface current, upwelling, divergence and convergence especially in estuary area and along coastline. In semi-enclosed waters, the effect of sea water circulation such as upwelling occurs in



minimum scale. However meteorological factors have more intense giving effect on water temperature variation as revealed by Takeshige [2].

Segara Anakan is one of semi-enclosed waters (lagoon) which located in Sempu Island, a small island in South Malang, East Java, Indonesia. Its water has a unique and different characteristic from other lagoons because of the existence of coral wall hole that separates inside (Segara Anakan) and outside (Indian Ocean) waters of Sempu Island. The discharge of sea water from Indian Ocean to Segara Anakan Lagoon through coral wall hole and tunnels beneath the surface water that occurred only in high tide while oppositely in low tide.

The previous study of water temperature of Segara Anakan has been done by analysing correlation between a year water temperature and some meteorological factors such as air temperature, air pressure, wind speed, and tidal current. The research showed that water temperature has very low correlation with tidal and strongly correlation with air pressure and wind speed [3]. This study only used limited meteorological parameters to determine the variation of water temperature in Segara Anakan Lagoon. As well known that meteorological parameters are not only limited as air pressure and wind speed. As a conservation area which important for sustainable marine life in Sempu Island, it is necessary to understand the variation of water temperature in detail with longer period of data, therefore this study is focused in understanding the effect of meteorological factors on temperature variations in Segara Anakan waters which based on the meteorological parameters such as air temperature, air pressure, wind speed, cloud cover, precipitation, evaporation, humidity, and solar radiation. In addition, climate data including Southern Oscillation Index (SOI), Dipole Mode Index (DMI), Niño 3.4 and Oceanic Niño Index (ONI) are also applied in this study.

The purpose of this research is to know the pattern of water temperature variation in Segara Anakan, Sempu Island, South Malang; understanding the effect of meteorological factors on water temperature variations in Segara Anakan; understanding the relation of each variable of meteorological factors with water temperature in Segara Anakan seasonally; and understanding the climate impact on water temperature variation in Segara Anakan.

2. Data and Methods

The research data includes water temperature of Segara Anakan, Sea Surface Temperature (SST) of Indian Ocean; meteorological data such as air temperature, air pressure, wind speed, cloud cover, humidity, precipitation, evaporation, and solar radiation; and climate data including Southern Oscillation Index (SOI), Dipole Mode Index (DMI), Niño 3.4 and Oceanic Niño Index (ONI). Water temperature of Segara Anakan data are collected by direct measurement using *TidBit* Temperature Data Logger (under collaboration research between Brawijaya University and Nagasaki University, Japan) which deployed at Segara Anakan Lagoon at 112°41'24"E and 08°27'19"S (Figure 1). Water temperature data collection was started from January, 2012 to December, 2013 with originally 30 minutes interval then analysed into daily and monthly mean data.

Sea Surface Temperature of Indian Ocean and meteorological data are provided by the European Centre for Medium-Range Weather Forecast (ECMWF) website. The originally 6 (six) hours interval of Indian Ocean SST and meteorological parameter (2012-2013) are analysed into daily and monthly mean data. Furthermore, climatic index data including Southern Oscillation Index (SOI), Dipole Mode Index (DMI), Niño 3.4 and Oceanic Niño Index (ONI) (2012-2013) are provided by National Oceanic and Atmospheric Administration (NOAA).

The research variables are divided into two variables, i.e. the dependent variable (water temperature) and the independent variables (meteorological and climate factors). All data were analysed using Microsoft Excel to find the mean, anomaly, and trends values based on daily mean data.

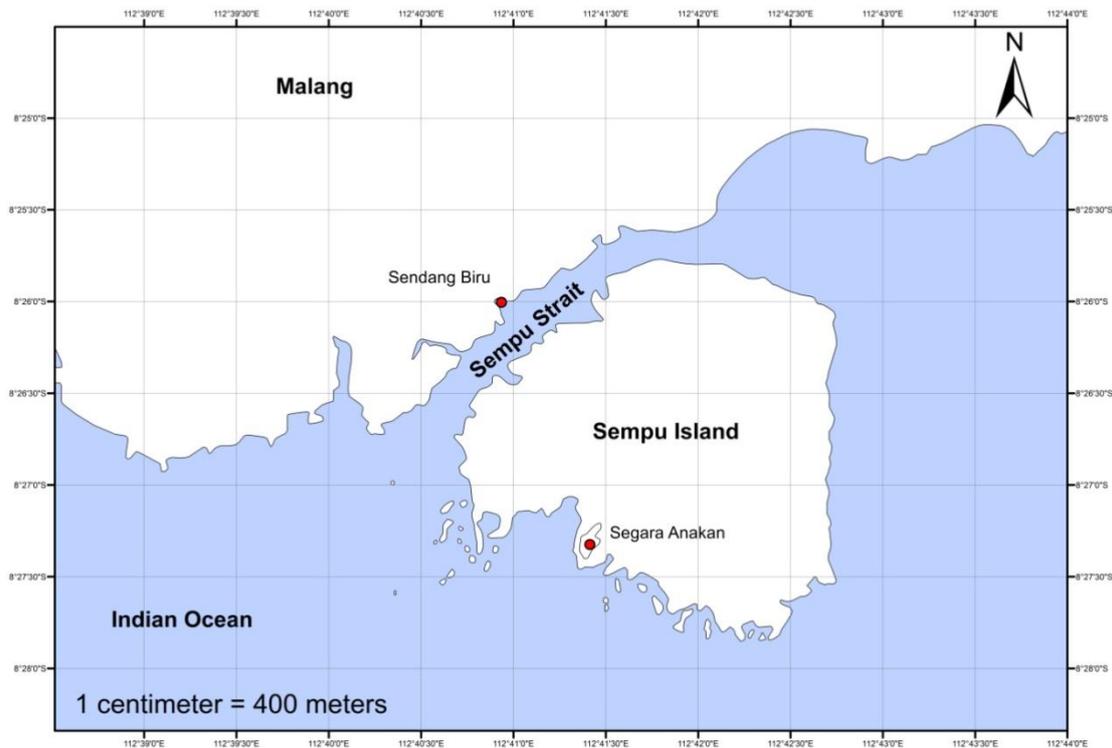


Figure 1. Map of Sempu Island, where Segara Anakan Lagoon exist. Segara Anakan Lagoon is located at the southern tip of Sempu Island and be potential affected by wider Indian Ocean.

All data are also analysed using T test of two unrelated samples of SPSS Statistics in order to know the difference between in situ water temperature of Segara Anakan Lagoon and Sea Surface temperature of Indian Ocean. Then Normality test has been done in order to know the normal distribution before done further analyses such as regression and correlation. Furthermore, Multiple linear regression analysis has been applied to determine the effect of meteorological variables on water temperature variables, while correlation analysis done to know the relationship between water temperature variables with each meteorological variable seasonally. Finally, the Principal Component Analysis (PCA) which run through XLSTAT software were applied for understanding the climate impact on water temperature of Segara Anakan Lagoon.

3. Result and Discussion

3.1 Daily Mean Variation of Water Temperature and Meteorological Factors

The two years (2012-2013) daily-mean data of water temperature and meteorological factors were analysed to obtain the mean, highest, lowest, anomaly, and trend values. The result showed that the mean value of water temperature of Segara Anakan Lagoon was about 27.84°C, with maximum value of 30.43 °C occurring on February 8, 2013 and minimum value of 23.7° C occurring on August 14, 2012. While the mean water temperature of Indian Ocean was detected as 27.08°C with maximum value on February 15, 2013 as 29.25°C and the minimum on August 14, 2012 as 23.4°C.

Then the water temperature data of Segara Anakan and Indian Ocean were analysed using T test of two unrelated samples on SPSS program. The result showed that there was no difference between mean of water temperature of Segara Anakan and SST of Indian Ocean, which shown by t value is smaller than t table ($1.288 < 2.074$) and significance (0.211) more than 0.05. It indicates that the SST data obtained from ECMWF are able to substitute in situ water temperature data of Segara Anakan.

Beside water temperature and SST, here were the mean and minimum-maximum of meteorological data provided by ECMWF as follows: mean air temperature was 26.22°C with the maximum value

occurring on April 3, 2013 at 28.73°C and the minimum value occurred on September 1, 2012 at 23.33°C. The mean air pressure value of 101.01 kPa with the maximum value occurred on October 2, 2012 was 101.42 kPa and the minimum value occurred on January 25, 2012 of 100.41 kPa (Table 1). Those values agree with Tjasyono [4] where Air pressure always decreases with increasing altitude and decreasing air temperature.

Table 1. Descriptive Analysis of Water Temperature and Meteorological Factor

Variables	Mean	Maximum	Minimum	Anomaly	Trend
Water Temperature (°C)	27.84	30.43	23.70	2.40	0.000536
SST (°C)	27.08	29.25	23.40	3.68	0.000030
Air Temperature (°C)	26.22	28.73	23.33	2.89	0.000100
Air Pressure (kPa)	101.01	101.42	100.41	0.61	0.000072
Wind Speed (m/s)	4.13	11.19	0.19	3.94	0.000878
Cloud Cover (%)	61.25	100.00	0.92	60.34	0.000511
Humidity (%)	83.85	96.88	70.01	13.84	0.001497
Precipitation (mm)	1.29	37.95	0.00	36.66	0.000163
Evaporation (mm)	0.97	2.35	0.31	1.38	0.000180
Solar Radiation (W/m ²)	44.71	72.08	12.35	27.3	0.006730

The wind velocity is obtained based on the calculation with the formula:

$$WS = \sqrt{U^2 + V^2} \quad (1)$$

where WS (wind speed) is the wind velocity value whereas U and V are the wind component value at 10m height. Based on the above equation, the result showed that maximum wind velocity (11.9 m/s) occurred on January 10, 2013, while the minimum wind velocity (0.19 m/s) occurred on December 14, 2012, with a mean wind velocity reached 4.13 m/s.

The mean cloud cover was found as 61.25%, with maximum value (100%) occurred on March 15, 2012, while the minimum value (0.92%) occurred on September 10, 2012. Furthermore, the mean humidity reached 83.85%, with the maximum value (96.88%) occurred on December 22, 2013 and the minimum value (70.1%) occurred on 13 August 2013. This high cloud cover may reduce penetration of sunlight entering the earth's surface and causes the increasing of water vapour content in the atmosphere and made it more humid [4]. High humidity may cause the declining air temperature (colder), as well as the water temperature.

As one of meteorological factors, the precipitation is important to be discussed. The mean precipitation at South Malang were recorded as 1.29 mm with maximum precipitation (37.95 mm) occurred on 23 December 2013. The minimum value (0 mm) means there was no precipitation on the day.

Furthermore, the average evaporation value reached 0.97 mm with maximum (2.35 mm) and minimum (0.31 mm) value occurred on March 15, 2012 and August 28, 2012, respectively. Precipitation that occurs on the sea usually can affect the decreasing of sea surface temperatures, while oppositely for evaporation can due to the flow of heat from the air to the surface layer of the water [4].

The value of solar radiation is obtained on the basis of the following formula:

$$Q_{NET} = Q_{SW} + Q_{LW} + Q_E + Q_H \quad (2)$$

Where Q_{NET} is the value of net heat flux, Q_{SW} is the shortwave radiation flux, Q_{LW} is the longwave radiation value radiation flux, whereas Q_E is the value of latent heat flux and Q_H is the value of sensible heat flux [2]. The average of solar radiation was 44.71 W/m², with the maximum (72.08 W/m²) and minimum (-12.35 W/m²) value occurred on 22 December 2013 (winter) and July 7, 2013 (summer), respectively. In addition, Ishii and Kondo [6] mentioned that solar radiation and horizontal heat transport

played a primary role in the heating process in summer and latent and sensible heat fluxes become dominant in the cooling process in winter. In order to make it easier to interpret and understand the seasonal variations of water temperature and meteorological factors, the standardization analysis was applied. The standardization method is a simple statistical method which commonly used to interpret complex data with different scales or level in better and simple look [5]. The standardization analysis for water temperature and meteorology are shown in graph form which divided into four monsoon seasons: Northwest Monsoon (December-February), Transition Season I (March-May), Southeast Monsoon (June-August), and Transition Season II (September-November) (Figure 2).

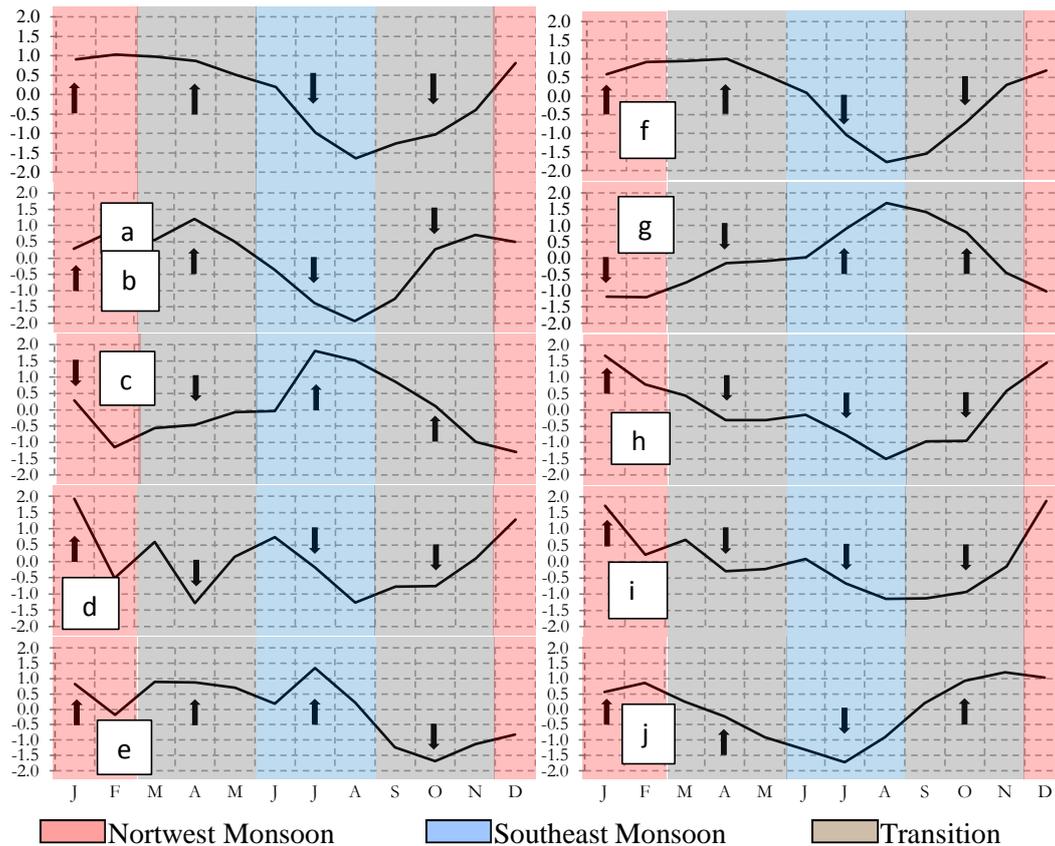


Figure 2. Standardization of Water Temperature of Segara Anakan Lagoon (a) and Meteorological Factors (air temperature (b); wind speed (c); humidity (d); evaporation (e); SST of Indian Ocean (f); air pressure (g); cloud cover (h); precipitation (i); solar radiation (j))

3.2 Annual Variations of Water Temperature and Meteorological Factors

The relationship between water temperature and meteorological factors was analysed using SPSS program with focused on multiple linear regression analysis. SPSS is the acronym of Statistical Package for the Social Science. SPSS is one of the most popular statistical packages which can perform highly complex data manipulation and analysis with simple instructions. It is designed for both interactive and non-interactive (batch) uses. Nowadays SPSS is commonly used for statistical analysis not only limited at social science. Current study we used multiple linear regression analysis using SPSS program and resulted regression equation as follows:

$$Y = 55,362 + 0,436X1 - 0,361X2 - 0,603X3 + 0,025X4 - 0,071X5 + 0,096X6 + 4,5X7 - 0,003X8 \quad (3)$$

Where X = value of air temperature; X3 = value of wind speed; X4 = value of cloud cover; X5 = humidity value; X6 = Precipitation value; X7 = value evaporation; and X8 = the value of solar radiation.

The regression equation (Eq. 3) explains that if all meteorological variables are 0, the water temperature (Y') is 84.434°C . The regression coefficient of variable air temperature (X_1) of 0.436 means that if the temperature value increases 1°C , then the temperature value of the waters will increase by 0.436°C assuming other meteorological variables are fixed. The regression coefficient of air pressure variable (X_2) of -0.361 means that if the value of air pressure increases 1 kPa, then the temperature value of the waters will decrease by 0.361°C . The wind velocity regression coefficient (X_3) of -0.603 means that if the wind speed value increases 1 m/s, then the temperature value of the waters will decrease by 0.603°C .

Wind is caused by the difference in air pressure in two adjacent directions. The greater the air pressure the faster the wind will also be generated. The driving factor of air mass movement is the difference in air pressure between one place and another. This pressure difference is caused by the temperature of the air as a result of the heating of the earth's surface by the sun. The higher the value of wind speed, the water temperature will decrease, because the faster the wind that blows on the surface of waters will affect the sea surface is bumpier. This will reduce the penetration of heat into the sea water, and result in low surface temperatures [6]. Moreover the faster the wind will decrease sea temperature due to mixing process or upwelling [8].

Cloud cover variable coefficient of cloud cover (X_4) of 0.025 means that if the cloud cover value increases 1%, then the temperature value of the waters will increase by 0.025°C .

The evaporation variable regression coefficient (X_7) of 4.5 means that if the evaporation value increases 1 mm, the temperature value of the waters will increase by 4.5°C . However, in some studies, it was found that if sea surface temperature rises then the possibility of precipitation value will be higher and vice versa [5]. Rising sea-level temperatures show an increase in ocean energy that gives rise to higher levels of evaporation in the atmosphere. Therefore it is an indirect relationship between sea level rise in temperature and precipitation and evaporation. Changes in water temperature values caused by solar radiation throughout the year are generally not very significant.

The value of R is used to determine the relationship between independent variables (meteorological factors) to the dependent variable (water temperature) simultaneously. The value of R obtained is 0.986. Since R values are in the range of 0.800-1.000, it can be suggested that there is a very strong relationship between each of the meteorological factors to the water temperature. While, the value of R^2 used to know the percentage contribution of independent variable that influence (e.g. meteorological factors) simultaneously to the dependent variable (water temperature). The value of R^2 is 0.973. The Regression coefficient test is also conducted to determine the effect of meteorological factors on the water temperature whether the influence occurs partially or together. Based on T and F value, regression coefficient shows that all meteorological variables affect water temperature together, whereas partially, each variable has no effect on changes in water temperature value.

3.3 Seasonal Variation of Water Temperature and Meteorological Factors

The relationship among water temperature and meteorological factors was approached using simple correlation analysis run by SPSS program. The result of simple correlation analysis are presented in Table 2.

Table 2. Correlation Analysis of water Temperature and Meteorological Data

		Water Temp.	Air Press.	Wind Speed	Cloud Cover	Hum.	Prec.	Eva.	Solar Rad.
Northwest Monsoon									
Water Temp.	Pearson Corr.	0.878	-0.647	-0.267	-0.938	-0.938	-0.999	-0.026	0.040

	Sig. (2-tailed)	0.317	0.552	0.828	0.226	0.226	0.024	0.983	0.975
Transition I									
Water Temp.	Pearson Corr.	0.342	-0.732	-1.000	0.670	-0.065	0.628	0.993	0.977
	Sig. (2-tailed)	0.778	0.478	0.015	0.533	0.959	0.568	0.074	0.137
Southeast Monsoon									
Water Temp.	Pearson Corr.	0.996	-0.999	-0.831	0.993	0.990	0.999	-0.115	-0.418
	Sig. (2-tailed)	0.060	0.025	0.376	0.078	0.890	0.033	0.927	0.725
Transition II									
Water Temp.	Pearson Corr.	0.700	-0.958	0.933	1.000	1.000	0.989	0.633	0.744
	Sig. (2-tailed)	0.507	0.185	0.235	0.017	0.018	0.096	0.564	0.466

Based on the four monsoonal seasons, it is concluded that It has its own characteristics in each seasons. As revealed by Wyrcki [11] Indonesia well known has two seasons as called as west season (Northwest) and east season (Southeast) and other two intermediate (1 and 2) seasons in between, which strongly influenced by monsoon. Sartimbul [8] added that Northwest monsoon occur in December to February, while Southeast monsoon occur in June to August every year. Based on the correlation analysis, it is found that the meteorological factor has highly correlation with the water temperature in Segara Anakan and varies seasonally. During Northwest monsoon, water temperature in Segara Anakan has highly significant correlation with precipitation, with correlation coefficient of -0.999. The correlation coefficient shows a negative value which means the higher the value of precipitation, the lower the temperature value of the waters in Segara Anakan. According to Wyrcki [11], during December-February, the position of the sun is in the southern hemisphere so that the Asian Continent has a higher air pressure than on the Australian Continent. This leads to the occurrence of Northwest monsoon. This monsoon passes through vast sea areas bringing plenty of water vapour and causing rainy seasons on the islands of Borneo, Sumatra, Java and Sulawesi (the peak in December).

In contrast, during In June-August, the position of the sun is in the northern hemisphere so that the Asian Continent has lower air pressure than on the Australian Continent. This condition is called the Southeast monsoon, where the monsoon travels through the vast and dry desert, and causes a drought in Indonesia. The analysis shows that the water temperature of Segara Anakan does not correlate significantly to both air pressure and precipitation. However, during Southeast monsoon, all the meteorological factors contribute to the changes of the water temperature. There is no dominant factor.

Furthermore, during the transition season-1 (March-May) water temperature in Segara Anakan has strongly correlated with the variable of wind speed, evaporation, and solar radiation, while in the transition season-2 (September-November), water temperature in Segara Anakan has highly correlated with cloud cover and moisture variables. In the same time, during transition seasons (March and September), the position of the sun is around the equator. Since Segara Anakan Lagoon, Sempu Island just located at low latitudes, therefore the effects of solar radiation are more pronounced during the transition season. During this season, the sun is at low latitudes or around the equator. This condition is

shown by the highly significant correlation between water temperature in Segara Anakan with solar radiation $R=0.977$ and $R=0.744$ in the transition season-1 and transitional season-2, respectively. The higher the value of solar radiation, the higher the temperature value of the water [8].

3.4 Variations of Water Temperature and Climate

Principal component analysis (PCA) was conducted to find out which the most principal variables influence to water temperature of Segara Anakan Lagoon. The PCA analysis shows that four existing climatic variables have been formed into 2 factors. The PCA analysis are expressed by Factor F1, F2, F3, to Fn. The F1 is defined as the most factors or component influence to the temperature variation of Segara Anakan Lagoon. Indeed, the Dipole Mode Index (DMI) and Southern Oscillation Index (SOI) are selected as the Factor 1, meanwhile factor 2 is the secondary factors were Niño 3.4 and Oceanic Niño Index (ONI). Sartimbul [8] mentioned that the Primary factor (F1) directly affect water temperature of Segara Anakan Lagoon, while secondary factor (F2) may modified the F1. Furthermore, negative DMI, Niño 3.4 and ONI affect the temperature of Segara Anakan waters as illustrated by loading factor as 0.677, 0.671 and 0.717, respectively. While positive SOI affects on Segara Anakan water temperature with loading factor as 0.677 (Table 3). The results showed that when DMI, Niño 3.4 and ONI are positive value then the temperature of Segara Anakan water become low. This mechanism was also explained by Sartimbul [8] that Niño 3.4 and a strong DMI indicated the occurrence of El Niño which lead to lower SST of South Indonesia.

Table 1. Factor Loading of Water Temperature, Meteorological Factors and Climate Indices. Principal Component or main factor in Principal Component Analysis (PCA) is expressed by Factor (F1, F2).

Variables	F1	F2
Water Temperature (WT)	0.856	0.037
Sea Surface Temperature (SST)	0.946	0.079
Air Temperature	0.776	-0.055
Air Pressure	-0.820	-0.016
Wind Speed	-0.738	0.541
Cloud Cover	0.892	0.131
Humidity	0.210	-0.565
Precipitation	0.772	0.047
Evaporation	0.094	0.904
Solar Radiation	0.153	-0.880
DMI	-0.677	0.134
SOI	0.674	-0.062
Nino 3.4	-0.313	-0.671
ONI	-0.363	-0.717

During Northwest monsoon, climatic index is found as the main factor that most influence the temperature of waters of Segara Anakan, i.e. SOI, Niño 3.4 and ONI with value 0,873; 0.576 and 0.762, respectively (Table 4). Furthermore, main climatic factors that influence water temperature of Segara Anakan during Southeast monsoon are DMI, SOI, and Nino 3.4 with a value of 0.983; 0.966 and 0.701, respectively (Table 5). In summary our study suggested that wider temperature variation modified by climate factor as shown by some climate indices which have remarkable effect on the smaller water column such as Segara Anakan Lagoon. This study consistence with previous study as mentioned by Sartimbul [5].

Table 2. Factor Loading of Water Temperature, Meteorological Factors and Climate during Northwest Monsoon. The F1, F2 are principal factors.

Variables	F1	F2
Water Temperature (WT)	-0.816	0.283
Sea Surface Temperature (SST)	0.509	0.514
Air Temperature	-0.617	0.443
Air Pressure	-0.699	-0.344
Wind Speed	-0.332	0.237
Cloud Cover	0.927	0.358
Humidity	-0.348	-0.804
Precipitation	0.931	0.250
Evaporation	0.901	0.299
Solar Radiation	-0.914	-0.135
DMI	-0.103	0.901
SOI	0.873	-0.455
Nino 3.4	-0.576	0.569
ONI	-0.762	0.446

Table 3. Factor Loading of Water Temperature, Meteorological Factors and Climate Indices during Southeast Monsoon. The F1, F2 are principal factors.

Variables	F1	F2
Water Temperature (WT)	0.990	-0.084
Sea Surface Temperature (SST)	0.980	-0.150
Air Temperature	0.956	-0.263
Air Pressure	-0.969	-0.202
Wind Speed	-0.765	-0.634
Cloud Cover	0.985	0.145
Humidity	0.558	0.783
Precipitation	0.918	0.382
Evaporation	0.326	-0.910
Solar Radiation	-0.002	0.941
DMI	-0.983	0.075
SOI	0.966	0.110
Nino 3.4	-0.701	0.607
ONI	-0.637	0.688

4. Conclusion

The water temperature in Segara Anakan varies seasonally. The highest water temperature occurs during the Northwest monsoon (30.4°C), while the lowest water temperature in Southeast monsoon (23.7°C). Meteorological factors including air temperature, air pressure, wind speed, cloud cover, humidity, precipitation, evaporation, and solar radiation together influence water temperature of Segara Anakan. While partially, they are no significant effect on water temperature of Segara Anakan. The relation

between water temperature and meteorological factors varies seasonally. During Northwest monsoon the water temperature in Segara Anakan is influenced mainly due to precipitation. While, in the Southeast monsoon, meteorological factors influence together. Furthermore, during transitional season, water temperature is primarily affected by solar radiation. The Principal Component Analysis shows that climate factors affect the water temperature in Segara Anakan (mainly SOI and DMI). Longer period of water temperature data of South Java Sea indicated the increasing trend due to climate variation. This study also suggested that good quality with direct and continuous measurement of local water temperature and compiled with indirect data of meteorological data and climate index are important for further prediction of water temperature variation for climate adaptation in South Malang.

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