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Characteristics of Stable Isotope Compositions ($\delta^{18}O$ and $\delta^{2}H$) of Surface Water in Bengkulu City

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ABSTRACT

Indonesia as an archipelagic country has a unique location and topography, and the El Niño-Southern Oscillation (ENSO) is observed in this region, resulting in complex weather and climate variability. As a result, Indonesia including Bengkulu experiences regular natural disasters. Stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) have been used as natural tracers in solving water resources and water-related problems. The aim of this research is to investigate the variations of stable isotopes in Bengkulu City from three locations, namely Serut and Hitam Rivers and the Universitas Bengkulu (UNIB) lake, and to understand the hydrological processes in Bengkulu City. In this research, samples of surface water from Serut and Hitam Rivers and UNIB Lake in Bengkulu City were collected over five months between December 2018 and April 2019. Stable isotope compositions of these water samples were examined to understand the local hydrological processes. The result shows that the water samples are generally situated at the right side of Local Meteoric Water Line (LMWL) in $\delta^{18}O$ and $\delta^{2}H$ plot, indicating that water samples are more enriched in ^{18}O and ^{2}H as compared with the rainwater due to fractionation processes. The surface water samples define a local evaporation line with a slope of 6.536 while the LMWL has a slope of 7.848. This result indicates a significant evaporation effect on water bodies. Moreover, the slope of the regression line in all water samples was lower than the LMWL, in order of Serut River (7.696) > Hitam River (6.851) > UNIB Lake (6.436), indicating that UNIB Lake experienced more significant evaporation than river waters, resulting in enrichment in heavy isotopes. Serut River, one of largest river in Bengkulu City, which also plays an important role in flooding in Bengkulu City, has a regression equation similar to the regression line of rainwater (LMWL). It may be indicated that surface water from Serut River is strongly influenced by rainwater. Consequently, high amount of rainfall can affect the water level of Serut River, and can be associated with flooding. Therefore, long-term monitoring of stable isotopes is very important in the future to provide the pattern of changes in isotopic variation, particularly during flood and drought events as climate-disaster mitigation effort.

INTRODUCTION

Indonesia is located in the Southeast Asia region, with the latitude range of 6° N to 11° S and the longitude range of 95° E to 141° E. As an archipelagic country, it consists of several thousand islands surrounded by warmer seawater. Its unique location and topography result in complex weather and climate variability [1]. Overall, Indonesia has a tropical climate with two distinct seasons, monsoon wet and dry, which is clearly reflected by its rainfall.

Furthermore, the El Niño-Southern Oscillation (ENSO) can significantly affect the rainfall in Indonesia. During the cooling phase of ENSO, that is, La Niña, the availability of water can become *excessive* and cause flooding [2]. In contrast, during the warming phase, *i.e.*, El Niño, water availability is reduced or temporary drought occurs. As a result, many regions of Indonesia, including Sumatra Island, experiences regular natural disasters, such as floods and severe droughts [3]. In Bengkulu area, flooding often occurs in December or January and affects the water resources of the region. As an agricultural country, Indonesia finds management of water resources critical.

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Therefore, understanding the regional hydrology and its variations with climate change is very important.

Climate changes could have impacts on hydrology, as indicated in previous studies of the linkages between patterns of climatic variability and hydrological behavior of river and lake water over time by using water stable isotopes. Water stable isotopes can be used as natural tracers of hydrological processes because oxygen and hydrogen isotopes in water retain their distinctive fingerprints. During phase changes, stable isotopes of water become enriched in one phase and depleted in the other [4]. For example, during evaporation and condensation processes, heavy isotopes are preferentially enriched in the liquid phase, and therefore removed from the atmosphere with precipitation. The level of isotopic depletion of the remaining water vapor can, therefore, provide insight into the origin and transport conditions of water vapor and precipitation. This separation of isotopes between reservoirs is termed isotopic fractionation [4], which describes the separation of heavier and lighter isotopes [1]. This separation will result in abundance variations of isotopes.

Water stable isotopes have successfully been used to determine water sources and regional lake water balance, reconstruct past climate variability [4], and study hydrological processes. For example, studies of water isotopes ($\delta^{18}O$ and $\delta^{2}H$) to determine the origin of groundwater and recharge area have been conducted in springs and river basins [5,6]. Relationship between $\delta^{18}O$ and $\delta^{2}H$, as shown by example of Meteoric Water Line (MWL) in Fig. 1, constructed in local meteoric water line (LMWL), its slope and intercept of LMWL depends on hydrological parameters and environmental conditions [7]. Thus, stable isotopes can be used to understand local climate and hydrological compositions and also can help to understand water-related problems such as floods and droughts.

In addition, investigations of stable isotopes in surface water to assess of lake water balance study by using the isotopic characterization of precipitation and surface water (inflow and outflow of lakes) have also been carried out [8,9]. The linear relationship of $\delta^{18}O$ and $\delta^{2}H$ values of collected samples from inflow streams reflects the evaporation level of water before entering the lake. The Asahan River, as an output of Lake Toba, was found to exhibit very close $\delta^{18}O$ and $\delta^{2}H$ to the lake because almost all the water flowing in the Asahan River comes from the lake. The previous studies showed that isotopic characterization of surface water can be used to explain the local hydrology. It is important to characterize the stable isotopes compositions in Serut and Hitam Rivers and University of Bengkulu (UNIB) lake water to understand hydrology processes in solving water resources and water-related problems. The isotopic characterization will be done through the relationship interpretation of $\delta^{18}O$ and $\delta^{2}H$ values of water samples to explain the local hydrological processes.

The samples of surface water were collected from three different sampling locations, *viz*., Serut and Hitam Rivers and UNIB Lake, for 5 months. The samples were analyzed using Picarro L2140-i analyser in the Geochemistry Laboratory at the Earth Observatory of Singapore. The objectives of this research are: (1) to investigate the variations in stable isotopes of Serut and Hitam Rivers and UNIB Lake during the study period, and (2) to understand the hydrological processes in Bengkulu City and link them to local weather and geographical settings.

THEORY

The results of stable isotope measurements have been expressed in terms of δ-values. The δ-value is defined as the relative difference of heavier to lighter isotope abundance ratio in the sample and the standards. For atmospheric applications, the usual standard is the Vienna Standard Mean Ocean Water (VSMOW), published and distributed regularly by the IAEA, Vienna. The delta (δ) notation is used to quantify stable isotope as relative ratios. A positive δ-value means that the quantitative relation of heavy to light isotope is higher in the sample than it is in the standard, and a negative δ-value has the opposite meaning.

Isotopic compositions of seawater, polar ice, atmospheric water vapor, and meteoric water differ [10]. The Global Meteoric Water Line (GMWL), which defines the correlation between ^{18}O and ^{2}H seen in rainwater globally, and the local meteoric water line can be established from isotopic composition of rainwater collected locally [11].

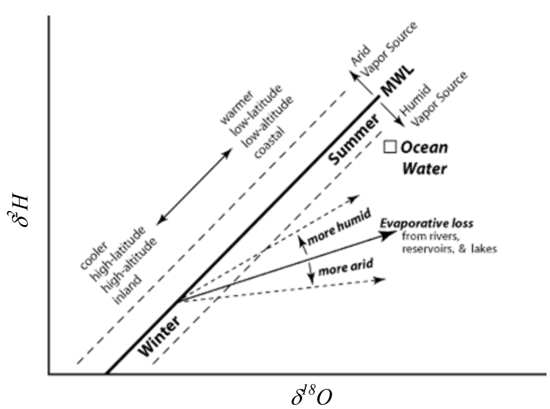

Fig. 1. Meteoric Water Line (MWL) [11].

Generally, in most rivers, water has two main components: (i) recent precipitation that has reached the river either by surface runoff, channel precipitation, or by rapid flow through shallow subsurface flow paths; and (ii) groundwater. Whereas, lake waters are regarded as important nodes in water resources, and also play pivotal roles in the regional hydrological cycle, that can be used as samples to exploit the characteristics of hydrological supply and lake water balance [12]. Isotope compositions of lake water provide a sensitive indicator of climate change [12].

RESEARCH METHODOLOGY

The water samples were collected from surface water bodies around Bengkulu City. Three locations have been selected for sampling, namely Serut and Hitam Rivers and UNIB Lake, as shown in the map in Fig. 2. Serut River has a dark-brown color and its length connects across districts in Bengkulu Province. Hitam River has a black color and shorter in length than Serut River. Meanwhile, UNIB Lake has a green-white color and its length is 307 meters. It is located in the University of Bengkulu.

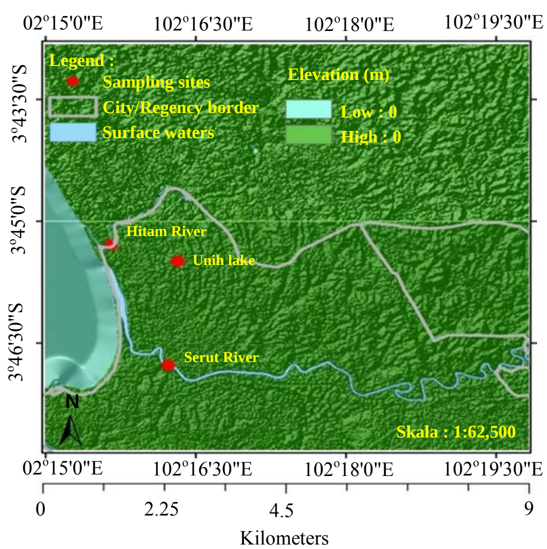

Fig. 2. Research map, showing the location of samples of surface waters in Bengkulu (red dot).

The samples of surface water were collected twice a week for 5 months between December 2018 to April 2019 in the rivers and UNIS lake. Around 10 ml of water was sampled and then immediately transferred in glass bottles with rubber and bottles cap to avoid the possible evaporation. During sampling, the local conditions will be recorded as well, such as rain event, flooding, and other related information. These samples were sent to the Geochemistry Laboratory, Earth Observatory of Singapore (EOS), Nanyang Technological University (NTU), Singapore, for isotope analysis.

Stable isotope compositions from water samples in this study were analyzed using a Picarro L2140-*I* analyzer. The analyzer was coupled with peripherals such as a high-precision vaporizer and an autosampler, as shown in Fig. 3. The vaporizer converted the water samples injected to vapor, which was then delivered into the cavity of the water analyzer for isotope analysis. Water samples were loaded into the sample tray according to an optimized sequence layout in order to facilitate the post-analysis correction.

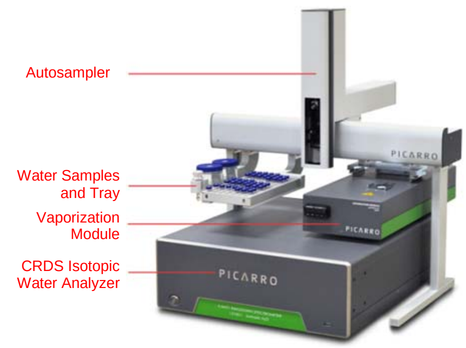

Fig. 3. Picarro L2140-i analyser coupled with an autosampler and vaporizer [13].

The data were calibrated using two in-house standards, TIBET ($\delta^{18}O$ value of -19.1 ‰ and $\delta^{2}H$ value of -143.89 ‰) and KONA ($\delta^{18}O$ value of 0.12 ‰ and $\delta^{2}H$ value of 0.87 ‰). These two standards were well normalized against VSMOW and Standard Light Antarctic Precipitation (SLAP) and their isotope values cover the range of the samples analyzed.

RESULTS AND DISCUSSION

The $\delta^{18}O$ values of surface water samples, *viz*., Serut and Hitam Rivers and UNIB Lake, range from -9.63 ‰ to -6.58 ‰, -10.05 ‰ to -3.26 ‰, and -11.54 ‰ to -3.39 ‰ respectively. The $\delta^{2}H$ in Serut and Hitam Rivers and UNIB Lake ranges from -63.9 ‰ to -40.2 ‰, -67.4 ‰ to -20.7 ‰ and -79.0 ‰ to -28.0 ‰ respectively. The $\delta^{18}O$ values of surface water samples (rivers and lake) ranged from -11.54 ‰ to -3.26 ‰ (average ratio of -6.69 ‰ and standard deviation of 0.01). The $\delta^{2}H$ values ranged from -79.0 ‰ to -20.7 ‰ (average ratio of -43.63 ‰ and standard deviation of 0.09). The ratios of stable isotope compositions are relative to VSMOW.

The local LMWL of Bengkulu, as shown in the steeper blue line in Fig. 4, was established based on $\delta^{18}O$ and $\delta^{2}H$ of precipitation samples collected during the study period at the University of

Bengkulu; the resulting linear equation is expressed by Eq. (1).

$$\delta^2 H = 7.848\delta^{18}O + 12.01 \qquad (1)$$

The LMWL slope is 7.848 similar to the GMWL with a slope of 8. The $\delta^{18}O$ and δ^2H of water samples in Serut and Hitam Rivers and UNIB Lake are plotted together with Bengkulu LMWL in Fig. 4. These water samples tend to form a line right to LMWL. The slope can be called the Surface Water Line (SWL). The regression equation of SWL is given in Eq. (2) and shown by Fig. 4 as the less steep, red line.

$$\delta^2 H = 6.536\delta^{18}O + 0.13 \qquad (2)$$

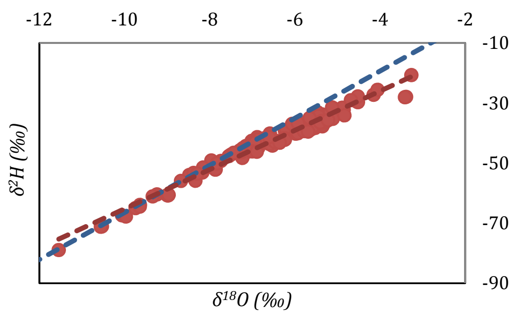

Fig. 4. Relationship between $\delta^{18}O$ and δ^2H of surface waters for all data with LMWL.

The slope of SWL is much smaller, indicating the evaporation in water bodies. Water samples close to the LMWL indicated that surface water in Bengkulu City has the character of meteoric water or rainwater. Serut River water samples have more negative isotopes value than Hitam River and UNIB Lake samples. It may be caused by the greater length of Serut River. As a result, water in most of Serut River is strongly influenced by precipitation, as indicated by regression line of Serut River, which is similar to LMWL, as shown in Fig. 5.

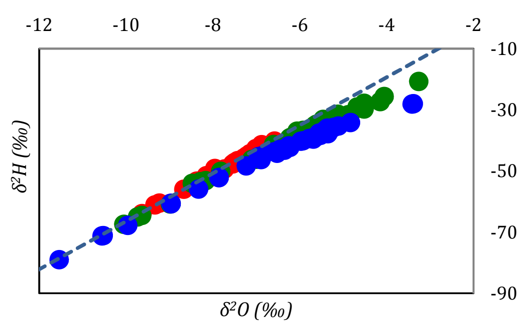

Fig 5. $\delta^{18}O$ and δ^2H of surface water samples with LMWL, for Serut River (red dot), for Hitam River (green dot and for UNIB lake (blue dot), dash line is Linear trend of LMWL.

River and lake samples define individual SWLs with distinct slopes as follows, in decreasing order: Serut River (7.696) > Hitam River (6.851) > UNIB Lake (6.436). Comparisons of these SWLs with the LMWL are presented in Fig. 6 through Fig. 8. The slope of UNIB Lake is much less than to LMWL, indicating that UNIB Lake experienced the strongest evaporation processes. A previous study by Ala-aho *et al.* [14] also observed that lakes showed the most pronounced enrichment of heavy isotopes, which was most likely primarily caused by evaporation fractionation, and typically soils were also more enriched than rivers.

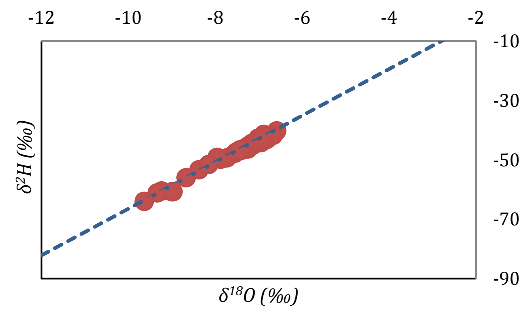

Fig. 6. Comparison between $\delta^{18}O$ and δ^2H at Serut River with LMWL red dash line is LMWL for Serut River data only, and blue dash line is LMWL for Bengkulu City.

The slope of the linear regression line for δ^2H of water samples is less than GMWL slope, which indicates local evaporation process. The local effects such as evaporation, condensation, and precipitation affect variations of stable isotope compositions in water bodies [9]. Slopes of both the SWL and LMWL were less than the GMWL slope of 8, indicating the local conditions. Samples with values <10 plot below the GMWL and signal a deviation from the equilibrium fractionation conditions, *i.e.*, the sampled water has been subjected to evaporation [1]. The slope can be different from 8, particularly in the tropical region due to fractionation effect [9]. Most of the surface water in Bengkulu City comes from precipitation, as indicated by water samples whose δ^2H values are close to LMWL.

In Figs. 6-8, Red spherical markers signify values from surface water samples from Serut and Hitam Rivers and UNIB Lake. The blue line is the LMWL of the Bengkulu City, formulated from rainwater samples.

In contrast, the red line is a SWL, which means evaporation line that occurred in water bodies. Evaporation can also be inferred from the deviation of lake water isotopes from local meteoric water line. The isotopic composition of the surface water is plotted on a Local Evaporation Line (LEL). Its slope is less than GMWL slope, showing the evaporation level and environmental conditions.

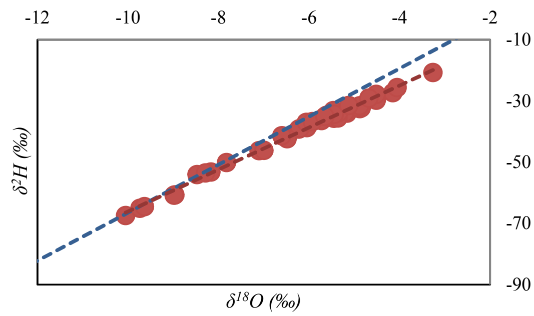

Fig. 7. Comparison $\delta^{18}O$ and $\delta^{2}H$ at Hitam River with LMWL, red dash line is LMWL for Hitam River data only, and blue dash line is LMWL for Bengkulu City.

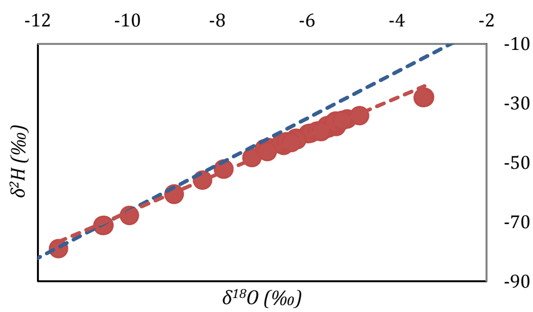

Fig. 8. Comparison $\delta^{18}O$ and $\delta^{2}H$ at UNIB Lake with LMWL, red dash line is LMWL for UNIB lake data only, and blue dash line is LMWL for Bengkulu City.

The Serut River water has similar characteristics as precipitation water, as evidenced by similar regression line equation. Its slope and intercept indicated that most water in Serut River originated from precipitation. Therefore, changes in isotopic compositions of precipitation can affect the isotopic composition in Serut River. Furthermore, Regression lines of Hitam River and UNIB Lake have lower slopes than GMWL and LMWL, indicating that the water has undergo evaporation processes. Regression line of UNIB Lake shows that the water in UNIB Lake experience significant evaporation than the rivers' water, resulting in enrichment in heavy isotopes. It also may be caused by run-off water that has undergone evaporation before entering the lake water.

CONCLUSION

Research on characteristics of stable isotopes of surface waters in Bengkulu City has been conducted. Samples of surface water from three different locations, namely, Serut and Hitam Rivers and UNIB Lake in Bengkulu City, were collected for isotope monitoring. We observed that the water samples lie on the right side of LMWL, indicating that the water samples are more enriched in $\delta^{18}O$ and $\delta^{2}H$ as compared to the rainwater due to fractionation processes at the water bodies. Its slope is close to the LMWL, which is likely indicated that mostly water samples are mostly originated from precipitation. The slope of the regression line in all water samples was lower than the LMWL which indicated evaporation processes in water bodies with different distinct slopes, namely, in decreasing order: Serut River (7.696) > Hitam River (6.851) > UNIB Lake (6.436), indicating that UNIB Lake suffers more evaporation than rivers.

Moreover, we found that the SWL of Serut River waters is similar to LMWL because they experienced less evaporation due to the large size of the water body. The regression line of Hitam River has a slope less than GMWL and LMWL, indicating that water has undergo significant evaporation during transit, whereas regression line of UNIB Lake shows that the water in UNIB Lake experience significantly more evaporation than the rivers' water, resulting in enrichment in heavy isotopes. In addition, positive and linear correlations between ^{18}O and ^{2}H isotopes was observed. This study shows that water stable isotopes can be used to studying hydrology and climatology since isotopes vary depending on environmental conditions. More robust continuous monitoring of stable isotopes of surface waters in Bengkulu City is very important in the future both spatially and temporally, especially during flood or drought seasons, in order to provide better understanding on climate variability and hydrological behaviors through study of the pattern of stable isotopes in this region.

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