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ARTICLE

Analyzing Potential Water Harvesting from Atmosphere in Near Coastal Area

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ABSTRACT

Water is a basic need. However there are many near coastal regions which have very limited access to fresh water. The water in area close to coastal is mainly affected by ocean, indirectly by weather/climate conditions and directly from seawater intrusion. While abundant fresh water is actually available in the atmosphere in the form of moisture. Recent technology, such as Atmospheric Water Generator (AWG), is a possible solution to gain water from our atmosphere. However, comprehensive study is needed to understand the potential water harvesting in our atmosphere. Here, we examine the water availability in the atmosphere based on several parameters like temperature and humidity. The data are collected from observation using WS1040 Automatic Weather Station in a year of 2020 with a half-hour interval. Then, we calculate the availability of water content during each season, especially in dry conditions. We also simulate the water harvesting to fulfil daily basic need of fresh water. The atmospheric parameters have shown a monsoonal pattern. Water content decrease in atmosphere during the dry season but the water deficit occurs after the dry season. Although water harvesting able to supply daily freshwater need, it is not recommended to be a single source as it requires massive water storage and high-efficient AWG.

1. Introduction

Water scarcity or drought is a growing issue in many regions. There is no standard for drought definition [1], but in general drought is the dry condition longer than normal and causes the availability of water below the need [2]. There are more than 4.3 billion people or 71% of the global population living under conditions of moderate to severe water scarcity at least 1 month of the year [3]. The report from the World Economic Forum stated that water crises as the largest global risk in terms of potential impact [4]. The water scarcity might be caused by the high demand or limited access of water.

In the case of Bali, the water crisis is dominantly caused by the conflict of different user groups [5]. The factor of growing tourism has a significant role. However, some areas like Karangasem (East Bali) have limited ac-

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cess to water [6] due to their geographical condition. Due to several research, 260 of 400 rivers in Bali had run dry and the largest lake had dropped 3.5 metres [7]. The climate has worsened the condition.

Some climate variability like El Nino Southern Oscillation (ENSO) has a significant role. Indonesia precipitation is strongly correlated with ENSO variations in the Pacific basin [8]. There are 43 drought events in Indonesia during 1884-1998, only 6 of them are not correlated with El Nino [9]. Meteorological role is more common in Bali during moderate and strong El Nino [10]. Rainfall pattern in Bali is categorized as the Monsoonal season which has the driest and longest dry season in Indonesia, compared to other types of season. The minimum mean of rainfall might reach 100 mm/month with the driest months between July and September [11]. El Nino has a significant impact on dry conditions in Bali, mainly between June-October [12]. El Nino Modoki (tripole mode of El Nino) has decreased rainfall in Bali for 8-16% [13].

Bali is a relatively small island which most of their population lives near the coastal area. The near coastal region with a high population has been threatened by saltwater intrusion. This characteristic can be found in south Bali such as Denpasar, Kuta, Jimbaran and others. For example in Jimbaran (our observation station located) has several coastal close by and the closest one is less than 3 km away. The salt groundwater in this region is mainly caused by seawater and hydrogeochemical influence [14]. In other similar near coastal region with a high population like Semarang city, salt water intrusion affects 3,44 km region from coastline [15]. However, this region might change over time depending on several factors such as aquifer withdrawal, hydraulic properties and the confining unit of coastal area [16].

There are many solutions offered to combat this water crisis. Some like rainwater harvesting, greywater reuse and solar desalination [17,18,19]. Other potential solution is harvesting the water directly from the atmosphere as our air contains lots of water. On land surface, satellite can detect the amount of water in our air is about 3,42 g/cm^2, with standard deviation 1.82 g/cm^2 [20]. However, we need tools to collect the water from the atmosphere, it is known as Atmospheric Water Generator (AWG). AWG has a similar principle with Refrigerator and Air Conditioner which is cooling through evaporation [21]. But before developing AWG, we have to understand our weather condition. How much the real water content in our area. When is the optimum condition for water harvesting. In this research we observe several atmospheric parameters. Then calculate water availability. Lastly it is simulated to model the potential of water harvesting to fulfil daily water needs.

2. Data and Method

2.1 Atmospheric Observation using WS1040

In this research we observe the atmospheric condition in our station at the Faculty of Marine Science and Fisheries, Udayana University. The observation utilizes Automatic Weather Station (AWS) as a data collector. The AWS is WS-1040 which is produced by Shenzen TianKan Electronic Technology Co., Ltd. WS-1040 is a series of wireless weather station with solar power and PC link. This can be seen in Figure 1 [22].

Figure 1. Installation of WS1040 Weather Station on Udayana University

With this equipment, we can observe several atmospheric parameters such as Temperature, Humidity, Pressure, Wind Speed, Wind Direction and Rainfall in 30 minutes timestep. The WS-1040 is placed in the open-air area with a radius of minimum 30 meters to the closest building. This is to reduce the bias of data caused by the effect of building or other possible disturbance such as trees, animals and humans.

Figure 2 shows the location of the weather station. It is located in the open area of Faculty Marine Sciences and Fisheries, Udayana University. The closest coast is less than 3 km away and there are many beaches in the radius 5 km. Thus, the potential of seawater intrusion is high and atmospheric condition is mainly affected by ocean.

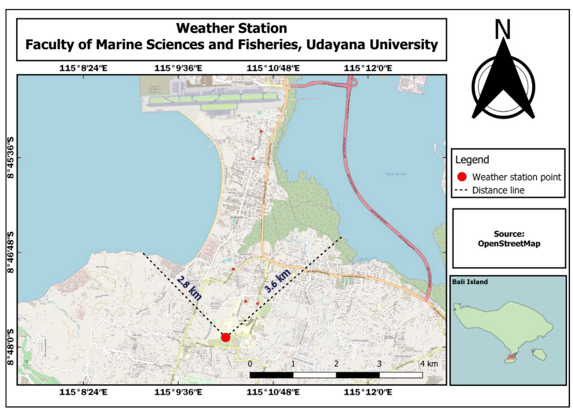

Figure 2. Location of Weather Station: Faculty of Marine Sciences and Fisheries, Udayana University

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The observation was started in November 2019. However, the data that will be used in this research is from 01 January 2020 to 31 December 2021. We only focus on 3 parameters, Station Pressure (mBar), Ambient Temperature (C) and Relative Humidity (%). As they are considered in optimization design of Atmospheric Water Generator [23,24,25].

The daily, monthly and seasonally pattern of these atmospheric parameters will be observed to gain a general understanding of the condition in our station. For the season, we divide it into 2 season, dry and rainy. This is due to the classification of Indonesia's rainy season. Bali is located in the area with Monsoonal season [11]. Dry season is in April-September, while the rainy season is October-March.

2.2 Water Content at Atmosphere

To measure the amount of water in the air, we calculate it from several atmospheric parameter such as temperature and relative humidity. From research by [26], the absolute humidity is calculated as below:

$$\rho_v = \frac{e_a M_w}{R \times T_k}$$

e_a and e_s is given by:

$$e_a = RH \times e_s$$

$$e_s = 0.611 \times \exp(\frac{b \times T}{c + T})$$

Where: ρ_v is absolute humidity or vapor pressure (g/m^3), e_a is vapor pressure (kPA), e_s is saturation vapor pressure (kPA), M_w is molecular weight of water (g/mol) equal to 18.02 g/mol, R is universal gas constant (J/ mol K) equal to 8.31 J/mol K. T is temperature in Celcius (^{o}C) while Tk is in Kelvin (^{o}K). RH is relative humidity (%). b and c both are constant, b = 17.502 and c = 240.97 for liquid.

2.3 Model of Water Surplus/ Deficit

By calculating the amount of water content in the atmosphere, we can address fluctuation of potential water harvesting. However, this information is insufficient to explain the possibility of water harvesting from the atmosphere to fulfil the daily water need. We have to consider the minimum need and optimum need of water per person.

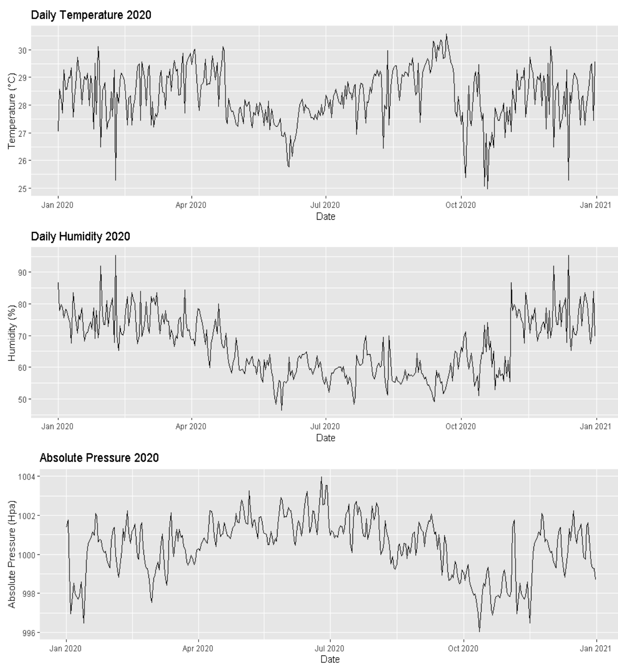
We model this condition by fitting the gap between water harvesting and water need in daily time-series. The surplus and deficit of water can be seen on our model. We simulate the extra water of each day being stored in water storage. So, the surplus/deficit water is calculated based on cumulative sum. The surplus day is when the cumulative sum is positive (above 0) and the deficit is negative (below 0). In this model we assume there is 100% efficiency and 10.000 m^3 of air is processed in a day. The sum of surplus and deficit is also calculated to evaluate the annual condition. This can address the strategy of water storage.

3. Result and Discussion

3.1 Atmosphere Variability

a. Daily and Monthly Atmosphere Variability

First, we want to understand the general variability of several atmosphere parameters during our observation time. Figure 3 shows the daily and monthly timeseries of Temperature, Humidity and Absolute Pressure in 2020 at the Faculty of Marine Sciences and Fisheries Campus using weather station WS1040. The daily mean illustrates clearly the oscillation of its variability. The monthly timeseries can show the general condition but fail to detect the detail. For example, humidity between October-December is low in monthly average but if we see the daily average it increases in general. This is because during this month the humidity is more unstable which causes more significant changes day by day.



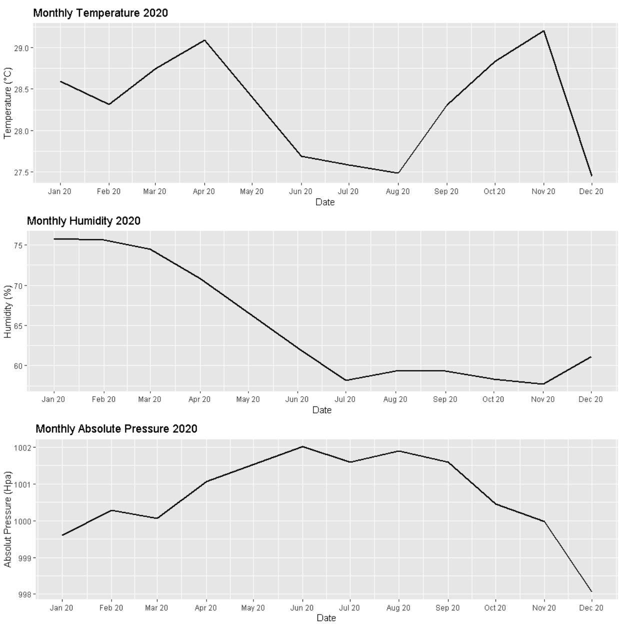


Figure 3. Daily and Monthly timeseries of Temperature, Humidity and Absolute Pressure from 01 January 2020 to 31 December 2020

Temperature has two peaks in April and November, with the lowest point in August. In general during the dry season (April-September), the temperature is dominantly low. Compared with the dry season, it has higher unstable monthly temperature. This is very clear when November mean temperature reaches more than 29^{o}C, then it drastically drops to less than 27,5 ^{o}C in December. For humidity, it starts to decrease in April (dry season) and remains low until December. So, it is generally low humidity during the dry season. The absolute pressure has an opposite pattern. It is dominantly high during the dry season between April-September. However, these three patterns have shown the similarity of unstable conditions between October-December. It is clear when we compare daily average and monthly average. While the monthly average is going down, the daily average is generally increasing.

b. Day-night Mean during Rainy Season

To get a deeper understanding of when is the optimum time to generate water from the atmosphere. Here we compare the day-night mean of atmosphere parameters in the rainy and dry season with a 30 minutes interval. We calculate the mean of parameter at the same time during a season. For example, the mean temperature at 7 a.m. in the morning in each day during the rainy season. The dry season will be discussed in the next section. Day-night mean in the rainy season (October-March) can be seen in Figure 4 as below:

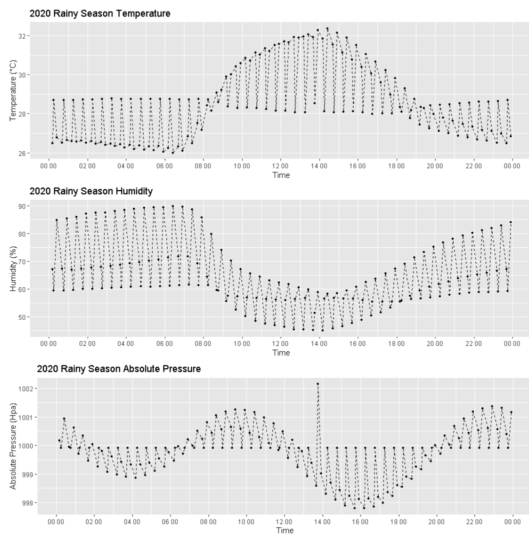


Figure 4. Day-night mean variability of Temperature, Humidity and Absolute Pressure during Rainy season

General day-night variability is clearly shown for all parameters in the rainy season. Temperature and Humidity have an opposite pattern. While temperatures increase between 08.00 to 14.00, humidity decreases exactly at the same time. Then temperature decreases from 14.00 to 19.00 and humidity increases. At night (19.00-08.00), both temperature and humidity day-night mean are constant. The absolute pressure is oscillating the peak around 09.00 and 23.00, the lowest point around 16.00.

c. Day-night Mean during Dry Season

Figure 5 shows day-night mean during the dry season between October-March. In general there are no significant differences between the rainy season and dry season. The cycle of increasing and decreasing temperature appears between 07.00-19.00. While the humidity shows the opposite pattern with temperature.

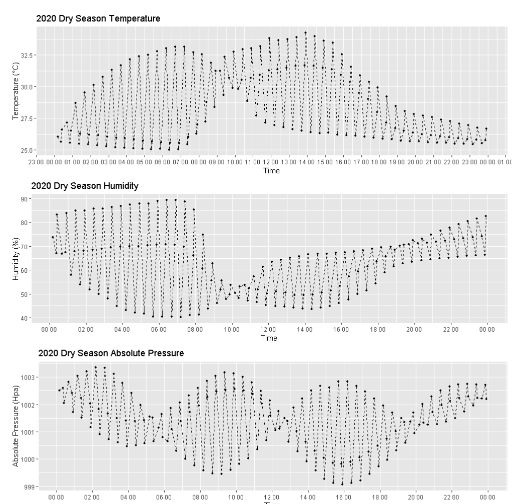


Figure 5. Day-night mean variability of Temperature, Humidity and Absolute Pressure during Dry season

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There are slight differences in the ranges. For example, in dry seasons humidity might occur less than 40%. Temperature, humidity and absolute pressure are also more unstable in the dry season compared with the rainy season. There is a typical stable time for the parameter. Temperature and Humidity are relatively stable from 09.00 to 10.00. The absolute pressure is more stable around 12.00.

3.2 Optimum Water Generation

By calculating absolute humidity, we get the amount of water in every cubic of air in the atmosphere. Although not all 100% water content can be extracted into fresh water due to the limitation of technology, we can still understand its potential by analysing the variation of absolute humidity. Here Figure 6 simulates the daily mean of water content of every 10.000 m^3 air for each month. As water is a daily need, we need water availability on a daily basis. Here we plot daily mean of water content, based on absolute humidity calculation, in Figure 6.

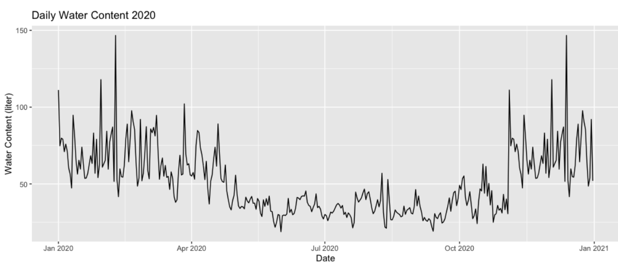

Figure 6. Daily mean of absolute humidity

Here we can see the detailed daily water content. Although the monthly mean is high, it does not mean that the water is available in the very high concentration every day. For example, between January and March the water content is changing drastically day-by-day. The highest reaches almost 150 litres per day, while the lowest is less than 25 litres per day. In the dry season, the variation of water content is lower. It is constant around 20-50 litres per day.

To collect water from the atmosphere, AWG (Atmospheric Water Generator) is the tool. There are many types of AWG. However, the efficiency of water generation is mainly caused by 3 factors, Temperature, Humidity and Flow rate. For example, AWG with a thermoelectric cooling method able to produce 11-25 gram/hour [27]. The water generation increases with humidity and air flow rate, optimum in 90% RH and 30 m^3/h flow rate [28].

3.3 Daily Fresh Water Simulation

To fulfil their fundamental water need, humans require about 50 litres of water per person per day, although in humid climates humans can survive with 10 to 20 litres per person per day [29]. In Figure 7, we illustrate the gap between daily water need (50 litres/day/person) and daily water supply/availability. We assume there is water storage which is able to store all surplus water in previous days. So we can understand the surplus (positive) and the deficit (negative) of water on a daily basis.

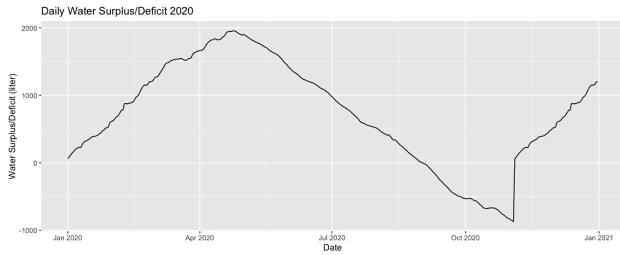

Figure 7. water surplus/deficit simulation

Between January and May, the water supply is higher than water demand. The excess water can be stored in water storage. The minimum capacity of water storage needed is 2.000 litres which is seen from the peak of the graph. Then in the period May-November, the water supply decreases below the daily fundamental water need. This caused a drop in water storage until the water deficit in September-November. The water deficit is not in the dry season, but months after the dry season.

In total, we can extract 14.528 litres of water in a year if we process 10.000 m^3 of air every day and gain 100% efficiency. Unfortunately, it is not enough to fulfil water needs of a person in a year, as it still deficit around 871 litres of water.

4. Conclusions

Our atmosphere observation with WS1040 automatic weather station has shown the variability of several parameters in our location. The data with intervals 30 minutes provide detailed observation. Temperature is more stable during the dry season from April to September which increases periodically every month. While in the rainy season, the unstable condition might be caused by some disturbance such as heavy rain or strong wind. The humidity has the opposite general pattern with temperature during the dry season. However in the rainy season, both temperature and humidity are generally high.

These two parameters are utilized to calculate the water content in atmosphere. Between January and May is the highest water content in the atmosphere. The daily water content in November-May fluctuates heavily in the day to day basis, while in other months it is consistently low.

The water harvesting potential might reach as high as 100 litres per day.

Our model shows that harvesting 100% water from 10.000 m^3 air per day is not sufficient to fulfil a person's fundamental daily water need (50 litres/person/day) between September and November. In the other months, we need water storage with a minimum capacity of 2.000 litres to save the water surplus. However, with this simulation, humans in the near coastal region of south Bali are able to survive by harvesting water from the atmosphere although not all of their fundamental daily water needs are fulfilled. The use of water harvesting methods as a single source of water is not recommended.

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