Potential of rainwater harvesting (RWH) to overcome the problem of water scarcity at the airports: a case study in I Gusti Ngurah Rai Airport, Bali

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Abstract. Indonesian airport in general relies dominantly on the surface and underground water to fulfil its water demand. Although groundwater systems are generally more resilient to climate change than surface water sources, their overuse might damage those water systems. One alternative to overcome this problem is rainwater harvesting (RWH) which could be implemented to increase the availability of raw water supply. However, in Indonesia, the study of the potential of RWH at a regional scale is still limited, so it does not provide sufficient information for practical application. Therefore, as the objective, this research will utilize a simulation analysis method to calculate the volume of rainfall storage, water requirements and reliability levels at I Gusti Ngurah Rai Airport regarding variations of the catchment area. This scheme would be applied not only during the dry and rainy seasons but also during the El Nino event. Moreover, the rainfall return periods would be determined to define the potential size of a rainwater harvesting system yearly. As a result, RWH at I Gusti Ngurah Rai Airport has the potential to substitute the surface water (PDAM) and groundwater usage either fully or partially depends on the season and water catchment area.

Keywords: Water usage, rainwater harvesting, capacity, effectivity, the return period

1. Introduction
Climate change causes the escalation of the intensity of extreme weather, changing rainfall patterns, rising sea surface temperatures, and melting polar ice caps [1]. Moreover, climate change can disrupt the water supply balance due to changes in the quantity and distribution of rainwater which is the source of water supply on the earth’s surface. An increase in water demand that is higher than the water availability also catalyse an imbalance in the water supply [2]. Therefore, a strategy is needed to maintain the availability of clean water to meet the needs of the community.
The Bali region as one of the international tourism destinations would experience a water crisis where the surface water availability (lakes or rivers) is not able to keep up with the escalation of water demand due to the increasing population, tourist attractions and expansion of transportation facilities. I Gusti Ngurah Rai Airport, like most urban areas in Bali in general, relies dominantly on two main water resources such as surface water (PDAM) and underground water to fulfil its water demand [3]. Moreover, the location of this airport is in the coastal area and flanked by oceans on both sides (West and East), causing another water problem such as seawater contamination. Thus, it is important to overcome the airport dependence on water demand from these two main sources.
Water crisis occurs due to changes in land use, rising sea levels that trigger seawater intrusion into the land and massive use of underground water, without being accompanied by storing water into the ground [4]. Although, the main source of water in the form of rain will always come in the season according to the time, in certain conditions rainwater can be non-renewable. This can occur in certain geological conditions where the process of groundwater travel takes thousands of years [5]. Therefore, when groundwater is extracted excessively, it will not only cause scarcity of clean water and water crisis but also a decrease in soil level [5, 6].

The water processing process turning raw water into clean water through a series of processes, which is carried out by the Local Water Company (PDAM), also produce waste in the form of sludge. Sludge waste originating from PDAM clean water treatment could contain hazardous and toxic materials from coagulation and flocculation processes that use aluminium sulfate as a coagulant material [7]. Thus, the overuse of water from water treatment industries might be indirectly responsible for environmental disasters such as the depletion of natural resources and the direct release of pollutants into water, soil and air [8].

Subsequently, it is important to employ the Rain Water Harvesting (RWH) method to meet the needs of clean water in I Gusti Ngurah Rai Airport. RWH is a method of collecting or storing rainwater or surface runoff during high rainfall, then utilise it when the rainwater is inadequate [9]. Furthermore, the RWH strategy requires hydrological analysis, one of which was rainfall return periods analysis which is important to define the potential size of a rainwater harvesting system [9]. Information on this return period is necessary to estimate not only the maximum floods but also the characteristics of the maximum annual rainfall that has the potential to be harvested [10]. Therefore, to be implemented RWH optimally, this research would study the potential of RWH by elaborating the data of rainwater availability and the maximum rain return period in I Gusti Ngurah Rai airport.

2. Data and Methods
This study utilised 30 years’ rainfall observation data at I Gusti Ngurah Rai Meteorological Station and 30 years’ ENSO (El Nino Southern Oscillation) data from 1991-2020 (Figure 3). Then it was combined with water usage data at I Gusti Ngurah Rai Airport in 2019 because this was the year with the highest passenger movement before the Covid-19 pandemic occurred. To calculate the volume of water, data on the total area of the airport and the roof cover of the buildings at the airport are used.

![I Gusti Ngurah Rai Airport’s Monthly Rainfall 1991-2020](image-url)
This research would accommodate several simulations of potential rainwater storage, either using the total area of the airport or the roofs of the buildings at the airport including the international and domestic terminal buildings, parking buildings, General Aviation Terminal (GAT), and hangars as shown in Table 1. The majority of roof covering of the building uses galvanized metal and concrete so that the run-off coefficient is 0.8 (Table 2).

**Table 1.** The area of the building roof and I Gusti Ngurah Rai Airport.

| Catchment         | Area (m²) |
|-------------------|-----------|
| Domestic Terminal | 67,884    |
| International Terminal | 121,785 |
| Parking           | 76,970    |
| GAT               | 4,400     |
| Hangar            | 6,000     |
| **Total Roof Area** | **277,039** |
| **Entire Airport Area** | **2,856,000** |

**Table 2.** Roof type coefficient

| Roof Type            | Roof Type Coefficient |
|----------------------|-----------------------|
| Galvanized metal     | 0.7 – 0.9             |
| Clay tile            | 0.8 – 0.9             |
| Concrete             | 0.6 – 0.8             |

*Source: Global Water Partnership Caribbean*

RWH potential in detail can be searched by dividing 30 years of monthly rainfall data into average, minimum and maximum (Figure 4). Average rainfall would be utilised to determine the potential monthly average rainwater catchment in the entire airport area or on the building roof. The minimum and maximum rainfall values would be employed to define the minimum and maximum potential catchment of monthly rainwater capacity. Moreover, the average, maximum and minimum rain catchment capacity would be compared with the Total Water Usage (TWU) at the airport which consists of Surface Water Usage (SWU) and Ground Water Usage (GWU). Finally, the composite analysis would carry out during the El-Nino months, which generally causes a decrease in the amount of rainfall in Bali.

The calculation of the potential volume of Rainwater or Rainwater Supply (RWS) would operate the equation:

\[ V = RR \times k_r \times A \]  

Whereas:

- \( V \) = RWS (m³)
- \( RR \) = Rainfall including average, minimum or maximum (m)
- \( k_r \) = surface /runoff coefficient
- \( A \) = Catchment area (m²)

The analysis of the annual rain plan in this discussion would utilise the Gumbel distribution method to produce the maximum rainfall data for the annual period. The following equation to calculate the rainfall return period with the Gumbel distribution method is adopted from the 1984 Loebis’s book [11]. The first step is done by calculating the standard deviation of the rainfall data recorded at the Class I Gusti Ngurah Rai Meteorological Station with the following equation.
Whereas:

\[ S_x = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X_r)^2}{n-1}} \]  \hspace{1cm} (2)

Where:
- \( S_x \) = Standard deviation
- \( X_i \) = Average rainfall
- \( X_r \) = Average maximum rainfall
- \( N \) = Total data

Furthermore, the frequency factor (K) is calculated. K is the probability value of a rain amount that is equalized or exceeded. The calculation is carried out using rainfall data recorded at the I Gusti Ngurah Rai Meteorological Station with the following equation.

\[ K = \frac{Y_t - Y_n}{S_n} \]  \hspace{1cm} (3)

Whereas:
- \( K \) = Frequency factor
- \( Y_n \) = Average reduced variated number
- \( S_n \) = Reduce standard deviation
- \( Y_t \) = Reduced variated

\( Y_n \) value is calculated based on the reduced mean (\( Y_n \)) table of the Gumbel method, with a total of 30 data (\( n = 30 \)), then the \( Y_n \) value = 0.5362. Furthermore, the value of calculating the value of \( S_n \) according to the Reduce Standard deviation table of the Gumbel method, with the amount of data is 30 (\( n = 30 \)), then the value of \( S_n \) = 1.1124.

\( Y_t \) is calculated by the equation:

\[ Y_t = -\ln \left[ -\ln \left( \frac{\tau_r - 1}{\tau_r} \right) \right] \]  \hspace{1cm} (4)

Whereas:
- \( Y_t \) = Reduced variated
- \( -\ln \) = Natural logarithm \( 1/(-x) \)
- \( \tau_r \) = The period of the rainfall, in this study using 2 years, 4 years, 6 years, 8 years and 10 years.

Finally, the rainfall frequency factor is operated to determine the rainfall return periods. The return period in this case is a hypothetical time in which rain with a certain amount will be matched or exceeded. Where a certain return period can be statistically estimated based on a data series of long-term maximum annual rainfall (> 20 years) with a frequency distribution analysis. The equation operated is as follows.

\[ X_t = X_r + (K \cdot S_x) \]  \hspace{1cm} (5)

Whereas:
- \( X_t \) = Rainfall returns period (year)
- \( X_r \) = Average maximum rainfall (mm)
- \( K \) = Frequency factor
- \( S_x \) = Standard deviation
3. Results and Analysis

Monthly rainfall capacity (during normal and El Nino conditions), airport total water usage (TWU), as well as rainfall return periods at I Gusti Ngurah Rai Airport, will be analysed to determine their patterns and potential to meet water needs at the airport.

3.1 Rainwater harvesting capacity

The simulation result of the average rainwater volume with the assumption that the catchment area was the entire area of I Gusti Ngurah Rai Airport, shows that the average rainfall catchment capacity for most of the months exceeds the total water usage, except for the months between May to September (MJJAS). However, if the average RWH was compared to the SWU or GWU, only the August and September period were inadequate. Then for the maximum catch potential (RWH max), it showed that the entire month had the potential to meet the total water usage at the airport. As for the minimum catch potential (RWH Min), only in January and February period could keep up with each SWU or GWU at the airport.
The RWH capacity at Ngurah Rai airport when using the building roof as a catchment area was generally lower than using the entire area as shown in Figure 5a. The average, minimum, and maximum RWH capacity was unable to meet the total water usage (TWU) requirements except for the maximum potential catch in December. The small amount of potential rainwater catchment is caused by the small area of the roof of the building as a rainwater catchment area. However, if it was utilised to substitute SWU or GWU, the average rainfall in January as well as the maximum catch in almost all of January, February, March, April, September, November and December had the potential to be harnessed as a substitute for SWU and GWU (Figure 5b).

Figure 5. The capacity of Rain Water Harvesting using the entire airport (a) and building roof (b) as the water catchment area.
Figure 6. Annual effectivity of rainwater supply using the entire airport (a) and building roof (b) as the water catchment area.

Figure 6 above shows the level of effectiveness of the RWH in overcoming the annual problem of clean water at the airport could be defined by comparing the potential annual supply of rainwater with the total annual water usage. When calculated the capacity of RWH using the entire airport as the water catchment, the average and maximum RWH has the potential to fulfil all TWU needs (Figure 6a). Meanwhile, the minimum RWH was only able to meet 35%, 74% and 69% of the needs of TWU, SWU or GWU, respectively. However, for the building roof as a catchment area, the effectivity of the annual average RWH against TWU was 23% with a minimum of 3.5% and a maximum of 59.2% (Figure 6b). Furthermore, the annual average RWH is capable of fulfilling more than 40% SWU and GWU, with the lowest current supply capability of around 7% and the highest supply capability above 110%, or capable to replace one of the water supplies for each SWU or GWU.
Figure 7. Effectivity of rainwater supply using the entire airport (a) and building roof (b) as the water catchment area.

The maximum RWH effectivity of each month during a year, as shown in figure 7a, with the entire airport area as a rain catchment area, as a whole was able to meet the need of TWU, SWU and GWU at the airport (effectiveness above 100%). The average effectiveness for each month was mostly above 100% when it was utilised to fulfil SWU and GWU. However, when it was harness to fulfil TWU, only 7 months were capable, namely October to April (ONDJFMA). As for the minimum effectiveness for
TWU, SWU and GWU, only January and February were above 100%. Overall, when the roof surface of the building was utilised as the area of rainwater catchment, the minimum, average and maximum effectiveness against TWU were below 100%, except for the maximum effectivity in December (Figure 7b). As regards the effectiveness of RWH against SWU, only for eight months had maximum effectiveness value above 100%, (apart from June, July, August and October). And only one month had an average effectiveness value above 100% (January). Furthermore, the RWH maximum in November to April (NDJFMA) and September and the RWS on average for December, January and February were effective to fulfil the airport's need for groundwater.

Several studies show that the highest harvested rainwater volume was collected in the wet season and this scheme generally could cover the societies’ water demands such as for drinking water, washing, flushing and fire extinguishing [12, 13, 14]. A similar result also occurred in I Gusti Ngurah Rai Airport, when the high potential of RWH both in terms of capacity and effectiveness was calculated in the rainy season from November to March. This is due to the fact that the Bali region has a monsoonal rain type that experiences a strong influence from two seasons, namely the northwest wet season from November to March (NDJFM) and the southeast dry season from May to September (MJJAS) [15]. Thus, the NDJFM month of rainfall tends to be high with the peak of rain in January, while in MJJAS the rainfall tends to be low [15, 16].

3.2 The calculation of low RWH effectivity during El Nino Events

The calculation of the 3-month average RWH for the rain catchment area on the entire airport during the El Nino event, as shown in figure 8a, shows that RWH was effective to meet the needs of TWU, SWU and GWU for more than half the time of an El Nino event. Meanwhile, if the roof of the building was employed as a catchment area of rainwater, there was no 3-month average RWH that was capable to fulfill TWU and could only fulfil SWU and GWU for 3% of the number of 30 years El Nino events (Figure 8b).
Figure 8. Effectivity of Rainwater Harvesting during El Nino Events using the entire airport (a) and building roof (b) as the water catchment area.

The El Nino event has a strong effect on areas with monsoonal rainfall types such as Bali [15]. This is supported by research by Ryadi et. Al in 2019 which shows El Nino causes the amount of rainfall in the Bali region to decrease [17]. A stronger influence between El Nino and Bali rainfall is known in the period September-October-November (SON) [18]. With the existence of El Nino, it is likely to prompt a low volume of RWH at I Gusti Ngurah Rai Airport, where in theory the value is influenced by the strength of El Nino itself.
3.3 Rainfall Return Periods

The return period could be interpreted as a hypothetical time in which rain of a certain magnitude will be matched or exceeded. However, it does not mean that it recurs regularly every time it is repeated. For example, a 10-year return period does not mean that it will occur every 10 years, but there is a possibility that in 1000 years there will be 100 rain events in a year [11]. There was a possibility before the period of 10 years there were more than once 10 years of rain or vice versa.

| Table 3. Maximum Rainfall Return Period in I Gusti Ngurah Rai Airport |
|--------------------------|------------------|
| Period (year) | Xt (mm) |
| 2 | 502.8 |
| 4 | 567.5 |
| 6 | 601.0 |
| 8 | 623.9 |
| 10 | 641.4 |

The return period of rainfall at I Gusti Ngurah Rai Airport, as displayed in table 3, the maximum rain above 500 mm was likely to occur every two years and for rain above 640 mm the chance to occur every 10 years. This showed that the potential for maximum rainfall was high enough to meet the needs of water usage at the airport. However, it was necessary to put more attention on hydrometeorological hazards such as flooding due to the high rainfall. For this reason, a proper drainage system was needed, considering that the rainfall potential was quite high.
Figure 9. Maximum Effectivity of Rainfall Return Period using the entire airport (a) and building roof (b) as the water catchment area.

The maximum effectiveness of RWH varied according to the return period of maximum rainfall, as well as the comparison with the type of water usage, such as TWU, SWU or GWU. Figure 9a shows that the entire airport is employed as the water catchment area, for a minimum iteration every two, four, six eight and 10 years, RWH was very effective in meeting the needs of total water use at I Gusti Ngurah Rai airport. However, figure 9b displays that when the rainwater catchment is simulated using only the roof of the building, at least once every two years, RWH was less effective in fulfilling TWU at the airport. However, when it was utilised to fulfil either the monthly SWU or GWU, the maximum RWH at least every 4 years, could meet one of those water usages.
3.4 Rainwater Harvesting Potential

The utilisation of the total area of the airport as the water catchment might provide abundant rainwater reserves and has great potential to meet the need for clean water at I Gusti Ngurah Rai Airport. However, catching rainwater at all airports poses several problems. First of all, it would require the long sewer and tunnel network to channel that rainwater in all airport areas into a storage tank. Second, the cleanliness of water was low since it had passed through the soil and sewers and it was contaminated with trash and oil spills in the taxi area, aprons, ground and airside area. Therefore, it would require a more complicated catching and processing strategy to make the RWH usable. This is supported by Rizki and Kusumawati’s research in 2012 which stated that there were four sewer points in the Ngurah Rai Airport which were contaminated by liquid waste, even though the conditions were still quite safe considering they are below the quality standard requirement [19]. Moreover, it will require additional water treatment such as installing a water filter and implying physicochemical methods as the suitable option to improve the quality of harvested rainwater [20, 21]. Furthermore, the amount of rainwater that is lost due to evaporating or seeping in the re-grass area or soil would be quite massive. Thus, a very large reservoir would be needed. However, according to Suprapto in 2015, a shelter that is too large will have less benefit than its capacity. This is since a reservoir that is too large has a sparse emptying time, thus reducing the quality of the collected rainwater, also the tank that is too large will require high costs for its construction and installation [22].

On the other hand, when utilising only the building rooftop as a water catchment area, RWH would be easy to implement, has relatively low implementation and maintenance costs, and its operation does not require special training [23]. Also, this catchment area only requires a simple water treatment unit to transform the rainwater into clean water to meet the standard water quantity and quality [24]. For instance, in Bali, several areas have implemented RWH, especially in dry and barren areas that experience a shortage of clean water, such as in the eastern part of Buleleng Regency, in Kubu and Abang Districts, Karangasem Regency and on Nusa Penida Island, Klungkung Regency [25]. Therefore, RWH can be a feasible solution to be implemented in rural, urban as well as an industrial area, not only by providing clean water but also by reducing the surface water usage (PDAM) and groundwater usage [13, 26].

In addition, the Government is trying to overcome the existing water crisis. One of them is by issuing Regulation of the Minister of Environment Number 12 of 2009 concerning Utilization of Rainwater and Regulation of the Minister of Public Works Number 11 of 2014 concerning Management of Rainwater in Buildings and Their Plots of Land. This regulation can be applied as a basis for conserving water resources and controlling environmental damage. The utilization of rainwater is an effort to conserve water resources because it can reduce the rate of groundwater exploitation. Besides that, harvesting rainwater can also increase the availability of groundwater through absorption back into the soil [27, 28]. Moreover, community perception, community support and social environmental conditions would also increase the benefit and effectiveness of harvested rainwater [29, 30, 31]. Thus, it would be suitable to be implied in the airport regarding those who are working in the airport could be assumed as relatively educated and has a high perception of the environmental reserve. Regarding economic analyses, there would be a possibility that the rainwater harvesting system may invoke financial losses. Therefore, apart from cost-saving and community collaborative effort, as well as social capital value from RWH system implementation, the environmental benefit of this system should be incorporated into the feasibility analysis [31, 32].

Subsequently, with the support of a large amount of rainwater catching capacity, the RWH system has the potential to be applied at I Gusti Ngurah Rai Airport. In addition to reducing the use of surface water and groundwater, it can also protect the environment by reducing rainwater runoff out of the building plots, preventing land subsidence, cleaner air and as a part of the solution to the impact of climate change.
4. Conclusion and Recommendation

The application of RWH at I Gusti Ngurah Rai Airport has the potential to replace the usage of surface water (PDAM) and groundwater if the entire airport area is employed as a water catchment. However, this presents a bigger challenge in preparing adequate water channels, clean water, storage, and water treatment efforts when compared to using the roof of a building as a rainwater catchment area. If only the building roof as a catchment area, it is not possible to meet the TWU needs for each month (except for the maximum catchment during the rainy season), but it has the potential to fulfil the need for surface water or groundwater either partially or completely depending on the season. It is necessary to be aware of the low potential for catching rain during an El Nino event since it has a direct or indirect impact on reduced rainfall in the Bali region. The maximum potential for rain in Bali is also very large to meet the needs of TWU, SWU and GWU when referring to repetition at least every two years.

In addition, several suggestions can be given for further research. First of all, in line with the increased activity and expansion of the airport area, continuous research is needed to meet the water demand at the airport using rainfall data with a higher temporal resolution such as hourly or daily maximum rainfall data. Furthermore, it is suggested to add other types of weather phenomena to provide a broader picture of the potential for RWH in the airport. Also, it is necessary to do a cost-benefit analysis in the RWH development plan to determine the advantages and disadvantages of implementing RWH in the present and the future. Lastly, it is crucial to add the calculation of damage cost to the environment in the usage of conventional water sources.

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