Identification of suitable sites for rainwater harvesting using GIS-based multi-criteria approach in Nusa Penida Island, Bali Province, Indonesia

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Abstract. The critical step in increasing water availability and land productivity in areas with freshwater scarcity, such as arid and semi-arid, is identifying suitable sites for Rain Water Harvesting (RWH). Identifying RWH suitable sites is site-specific due to a wide variety of a region’s characteristics. Biophysical (slope, soil texture, drainage density, land use), hydrological (runoff potential), and socio-economic (distance to road, distance to river, distance to settlement) parameters of the study area were implemented integrating multi-criteria decision analysis (analytical hierarchy processes) and Geographic Information System (GIS) to evaluate RWH suitable sites in Nusa Penida Island, Indonesia. This study's parameters and hybrid method were effective tools for identifying RWH suitable sites. The result also indicated that approximately 38% of the Nusa Penida Island is highly suited for RWH. These areas are characterized by dryland farming as the dominant land use, gentle slope, high runoff potential, high drainage density, and moderately fine soil texture. The initial identification of RWH potential sites could be valuable information in completing water conservation programs for several purposes. This study's approach also contributes to developing a suitable RWH identification methodology, especially for dry regions in Indonesia.

1. Introduction

The freshwater scarcity effect could significantly worsen in the following decades. It is caused by rapid change of climate, population, intensive agricultural practices, and industrialization, which is continued water supplies degradation [1][2][3]. The effects are more serious in arid and semi-arid regions, especially in developing countries [4]. Furthermore, the increasing demand for water access necessitates exploring alternate sources of supply suitable for household and agricultural use [5]. In this regard, water capture and storing in rainwater harvesting (RWH) systems has been an effective approach for mitigating the impacts of freshwater scarcity [6].

RWH can be defined as the way to collect the rainwater through surface runoff and store it as additional water supplies for proper utilization, especially in the dry season [7][8][9]. It is an essential technology in utilizing rainwater to support various needs, such as household, livestock, and agricultural activities. RWH is also an important technology to increase and secure water supply in arid and semi-arid regions. In addition, the RWH system is a more cost-effective and environmentally friendly solution due to low maintenance, low cost, and low community preference over reclaimed water [10][11][12][13].

Identifying RWH suitable sites is a complex problem because this process depends on several parameters, such as environmental and social-economic conditions [14]. Generally, there are two groups of criteria used for RWH suitability analysis. The first focuses on the biophysical criteria, including morphology, climate condition, land use/cover, and soil properties [15][16]. The second group integrates biophysical characteristics and socio-economics conditions, such as population, associated cost, and buffered distance from streams, settlement, roads, and agricultural area [17][18]. The criteria...
integration aimed to obtain the result more reliable and applicable, especially in the context of RWH techniques selection such as ponds, percolation tanks, terracing, check dams, and gully plugs [19][20]. The methods/tools to identify RWH suitable sites have been developed with limitations and advantages. They could be sorted into four groups based on previous studies: Geographic Information System (GIS) and remote sensing (RS) [11][4]; integration of GIS/RS and Hydrological Modeling (HM) [5][15][21][22]; Multi-Criteria Decision Analysis (MCDA) integrated with GIS/RS [10][23][24]; and hybrid methods of MCDA, HM, and GIS/RS [25][26][27]. Integration of MCDA, HM, and GIS/RS provides a more comprehensive understanding of the relationship and importance of criteria used. It is also a powerful and effective approach, particularly in developing the analysis framework. This approach can cope with various datasets (in the context of the source, scale, and temporal dataset), encompassing a wide-ranging region, and designing, analyzing, and weighing the used criteria [16][28][29][30].

Singhai et al. [31] employed the integration of GIS, MCDA, and HM in the frame of spatial analysis using GIS to prioritize the potential zones for RWH. The study used the Analytical Hierarchy Process (AHP) to assign criteria weight. The Soil Conservation Service-Curve Number (SCS-CN) hydrological model was utilized for runoff estimation. Karimi and Zeinivand [27] concluded that GIS and AHP tools were effective and practical in locating RWH sites. WetSpa model was employed to establish runoff map as the essential criteria in the study. Identification of potential RWH sites using AHP, SCS-CN model, and geospatial approach was also held by Rajasekhar et al. [32] in Southern India. The study used AHP to design the weight of criteria used, while surface runoff calculation employed the SCS-CN model. Mahmoud and Alazba [32] identified in situ RWH suitable sites through a GIS-based decision support system using GIS for spatial analysis, MCDA for assigning criteria weight, and HM for runoff potential estimation. According to all the studies, the primary role of MCDA is to determine the weight of each criterion. It is assumed that every criterion has a different contribution to define RWH suitable sites rather than to assume equal importance for all criteria. The use of HM generally estimates runoff in the study area as the critical factor in RWH site identification. The whole analysis was held in the GIS environment [33][34][35].

Identification of RWH suitable sites is site-specific due to a wide variety in the characteristics of a region. Therefore, the approach used to identify RWH suitable sites in one place cannot automatically be implemented in other areas [12]. This paper aims to offer an approach to determine RWH suitable sites. The objective was achieved by implementing and examining RWH suitable site analysis using hybrid methods, GIS, MDCA, and HM, in Nusa Penida Island. Nusa Penida is a small island laid to the Southeast of Bali Island, Indonesia. Subsistence farmers are the majority livelihood of Nusa Penida inhabitants that depend on rainwater to cultivate their rainfed dryland farming. Climatic condition is one of the constraint factors in fulfilling the water need for several activities, including agricultural requirements. The adaptation pattern of Nusa Penida inhabitants to meet their water need is by capturing and utilizing the rainwater. Every household in Nusa Penida has an underground tank to restore rainwater in the wet season and use in the dry season. Several RWH tanks also have built-in dryland farming or orchard for cultivation purposes. However, the number of RWH tanks in agricultural areas is insufficient to meet agricultural needs, especially in the dry season [36]. Therefore, information on the appropriate location for RWH is needed as a basis for the subsequent development of RWH construction.

The result of the present study is expected to be useful for local institutions and decision-makers in local/regional future planning related to water management, especially rainwater utilization through RWH technology. For the research field, the obtained results contribute to the context of integrated methods and criteria (biophysics, hydrology, and socio-economics) for RWH analysis and in a small island or arid/semi-arid regions. The study results also provide guidance for future works, such as the determination of rainwater harvestable amount and executable RWH techniques.
The study area, Nusa Penida Island, is a small island covering 19,272 ha of area located in the Southeast of Bali Island, Indonesia. Geographically, it is laid between 08°40'18.9"S-08°49'10.8"S and 115°26'47.6"E-115°37'41.8"E (Figure 1). Nusa Penida is part of Nusa Penida Sub-District, Klungkung District, Bali Province, Indonesia, administratively. It has a dry climate with E type based on Schmidt-Fergusson classification and low annual rainfall. According to multi-year rainfall data, the average rainfall of Nusa Penida is 1,247 mm/year, with the lowest rainfall being 589 mm/year and the highest is 2,580 mm/year. Temporally, rainfall distribution mostly occurs between November and March [37][38].

According to Geomorphology Map, Nusa Penida is dominated by the karst region, located mostly in the south, from west to east, and is characterized by exokarst and endokarst [37]. Hilly regions with a steep slope dominate the island's topography. Nusa Penida's dominant soil type is reddish brown mediterran soil, created mainly by weathering limestone. The soil structure is predominantly granular, whereas the soil texture is predominantly sandy loam. These soil conditions lead to relatively high infiltration and
permeability. The island's soil layer is typically classified as thin soil (<60cm). Surface rock and outcrop rock average are around 50% and 60%, respectively. It indicates that Nusa Penida has a significant amount of erosion. The soil is characterized by a slightly alkaline soil pH, low micro and macro soil elements, and low C-organic content as the critical indicator for soil fertility [37]. The land cover of Nusa Penida Island is dominated by dryland farming and pasture. Dryland farming is primarily found in the northern portion of the island. In contrast, pastures are mostly found in the southern part.

3. Methods
Identification of RWH suitable sites in this study used biophysical and hydrological parameters, i.e., slope gradient, soil texture, drainage density, land use, and runoff potential. These parameters were utilized to evaluate potential RWH sites through AHP analysis. Furthermore, distance to road, river, and settlement was the additional socio-economic parameter utilized in determining the unsuitable location for RWH. Following that, the obtained RWH potential map and unsuitable RWH map were combined to produce the final map of RWH suitable sites. The conceptual framework of methodology is presented in Figure 2.

Figure 2. Conceptual framework of determining RWH suitable map

3.1. Data used and acquisition
The parameters selection was based on a review of several previous studies related to RWH evaluation. Parameters used in this study were considered according to the higher probability of runoff generation. The majority of the biophysical and hydrological parameters selected for this study have been widely used in prior studies. For example, Ammar et al. [35] evaluated 48 research on RWH potential using GIS. The slope, land use/cover, soil type, and rainfall criteria were the most frequently utilized
parameters. Therefore, this study used slope, land use/cover, soil texture, runoff potential, and drainage density as additional parameters [16][39] for RWH potential site determination. The description, justification, and acquisition of the parameters used are described in brief below.

3.1.1. Slope
Slope gradient has a significant influence on runoff generation and infiltration process. The opportunity time for harvesting the rainwater decrease along with the increase of slope [16]. It is caused by the flow rates tend to grow at the steeper slope while the infiltration is relatively low. Therefore, RWH potential is relatively high for as mild as feasible of slope gradient. On the other hand, it is required to consider the implementation of erosion control due to high potential erosion at the slope higher than 5% [33]. The slope map in this study (Figure 3a), articulated as a percentage, was derived from a 12.5 m resolution of Digital Elevation Model (DEM) generated from the topographic map of Nusa Penida Island with a 1:25.000 scale.

3.1.2. Soil texture
Soil texture is a critical parameter for RWH suitable site evaluation, especially RWH system for household, livestock, and cultivation purposes. It influences infiltration and surface runoff behavior. Soil texture value is defined by sand, silt, and clay percentages. Fine and medium textures tend to have higher water retention and are more advantageous for RWH suitable sites [35][40]. In this study, the soil texture data was extracted from the Land System map of Nusa Penida Island (Figure 3b) [41].

3.1.3. Drainage Density
The importance of drainage density in RWH suitable sites analysis is related to its role in the time concentration of flow. Areas with a higher drainage density tend to have a higher runoff harvested through the RWH system [40][33]. Figure 3c shows the drainage density of Nusa Penida Island generated from the DEM and drainage networks dataset in the GIS environment.

3.1.4. Land use/cover
Land use types and vegetation coverage influence the generation of runoff (volume and velocity) that flows to the lower areas [33][42]. The area with a higher density of vegetation coverage tends to have higher infiltration and abstraction. In contrast, the area with sparse vegetation cover increases the portion of runoff [43]. Remotely sensed data of SPOT was analyzed and classified to determine land use/cover in the Nusa Penida Island. The study area's land use/cover was classified into six classes: pasture, orchard, settlement, rainfed paddy field, shrub, and dryland farming. The obtained classes were evaluated on the accuracy level by comparing random regions of interest and direct measurement. The resulting classes of land use/cover had an overall accuracy of 95% and a Kappa coefficient of 0.85. Figure 3d shows land use/cover classification in Nusa Penida Island.
Figure 3. Biophysical parameters of Nusa Penida Island: a. slope; b. soil texture; c. drainage density; d. land use; and e. runoff potential.
3.1.5. Runoff potential

Runoff potential indicates the potential water supply to collect and store through a particular RWH structure. Therefore, the area with higher runoff potential is more suitable for the RWH system [32][44]. In this study, runoff potential modeling utilized the SCS-CN model (Soil Conservation Service-Curve Number). This model is sensitive to the values of CN, requiring accurate calculation to quantify runoff. However, the SCS-CN model is also a simple, flexible, and handy model broadly implemented in several studies [5][45]. CN is determined as the relationship between land use/land cover, Hydrological Soil Group (HSG), and antecedent moisture conditions [46]. Based on the SCS-CN model [46], runoff is expressed by:

\[ Q = \frac{(P - I_a)^2}{P - I_a + S} \]  

(1)

\[ I_a = \lambda S \]  

(2)

\[ S = \frac{25400}{CN} - 254 \]  

(3)

where Q is runoff (mm), P is precipitation (mm), S is potential maximum retention of water by the soil, I_a is an initial abstraction (mm), and \( \lambda \) is initial abstraction ratio. The last version of the SCS-CN model considers the value of \( \lambda \) equal 0.2 [24] for practical application. Depending on the application, other values can be used for \( \lambda \) since the initial abstraction represents the water losses before runoff begins. Substituting the value of I_a in Equation 2, the equation for Q calculation is obtained in Equation 4.

\[ Q = \frac{(P - 0.2S)^2}{P + 0.8S} \]  

(4)

The potential maximum retention (S) is the function of CN using Equation 3. The SCS-CN model was the single even model, but it can be scaled for annual analysis based on all rain events. The rain event used in this study was the 2020 rainfall data. Figure 3e illustrates the distribution of runoff potential in the study area.

3.2. Multi-criteria decision analysis

Multi-criteria decision analysis aimed to define the weight of each biophysical parameter through the analytical hierarchy process (AHP). It is assumed that the parameters have an unequal contribution to the RWH suitable sites decision. Relative importance for every parameter was defined based on related theories, expert opinion, previous studies, and professional judgment [14][33]. Table 1 shows the comparison matrix with parameters grade in the context of relative importance. The normalized pairwise matrix was calculated based on relative importance values (Table 1) in order to allow comparison across columns. The final weight of each parameter was determined by averaging the normalized relative importance on every row. Table 2 presents the normalized relative importance and the final weight of parameters.

| Parameter          | Runoff potential | Slope | Soil texture | Land use | Drainage density |
|--------------------|------------------|-------|--------------|----------|-----------------|
| Runoff potential   | 1                | 2     | 2            | 3        | 3               |
| Slope              | 0.50             | 1     | 2            | 2        | 3               |
| Soil texture       | 0.50             | 0.50  | 1            | 3        | 3               |
| Land use           | 0.33             | 0.50  | 0.33         | 1        | 3               |

Table 1. Comparison matrix and relative importance of the parameters utilized in analytical hierarchy process.
Drainage density | 0.33 | 0.33 | 0.33 | 0.33 | 1
---|---|---|---|---|---
Column Sum   | 2.67 | 4.33 | 5.67 | 9.33 | 13.00

### Table 2. Normalized of relative importance for each parameter based on values in Table 1.

| Parameter         | Runoff potential | Slope  | Soil texture | Land use | Drainage density | Weight |
|-------------------|------------------|--------|--------------|----------|------------------|--------|
| Runoff potential  | 0.375            | 0.462  | 0.353        | 0.321    | 0.231            | 0.35   |
| Slope             | 0.188            | 0.231  | 0.353        | 0.214    | 0.231            | 0.24   |
| Soil texture      | 0.188            | 0.115  | 0.176        | 0.321    | 0.231            | 0.21   |
| Land use          | 0.125            | 0.115  | 0.059        | 0.107    | 0.231            | 0.13   |
| Drainage density  | 0.125            | 0.077  | 0.059        | 0.036    | 0.077            | 0.07   |

The final weight of each parameter was also evaluated to ensure its consistency using the Consistency Ratio (CR) proposed by Saaty [47] with the following equation:

$$CR = \frac{CI}{RCI} \quad (5)$$

where, RCI is random consistency index (1.15 for five parameters), and CI is consistency index that is calculated by:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

where $\lambda_{max}$ is principle eigenvalue calculated using eigenvector technique, and n is the number of parameters. A consistent weight of each parameter is indicated by less than 10% of the CR value. Re-evaluation of weighted value is needed when CR value is greater than 10% [47].

### 3.3. RWH potential map

RWH potential map was generated using biophysical and hydrological layers (slope, land use/cover, soil texture, drainage density, and runoff potential). The obtained weight from AHP analysis was assigned to each parameter. The weight of every feature of each parameter was also assigned (Table 3) based on professional judgment using Saaty’s scale [47]. Then, all five parameter layers were overlaid using Weighted Linear Combination (WLC) in the GIS environment. Finally, the RWH potential map was computed in the GIS environment based on the following RWH index equation:

$$RWHI = (S)_p(S)_f + (T)_p(T)_f + (Lu)_p(Lu)_f + (DD)_p(DD)_f + (R)_p(R)_f \quad (7)$$

where RWHI is rainwater harvesting index, the subscript ‘p’ represents the normalized weight of the corresponding parameter, the subscript ‘f’ represents normalized weight of each feature class of the corresponding parameter, S is the slope, T is soil texture, Lu is land use/cover, DD is drainage density, and R is runoff potential. RWH potential was classified into three classes based on the Jenks Natural Breaks method [48].

### 3.4. Socio-economic parameters and unsuitable RWH map

The addition of socio-economic parameters aimed to consider indirect socio-economic effects on RWH suitable site selection. In this study, socio-economic parameters consisted of distance to road, distance to river, and distance to settlement. Implementation of RWH structure cannot be executed within an acceptable distance of road, river, and settlement with several reasons, such as economic or environmental cost consideration, preventing a conflict of interest between road development and RWH structure implementation, and safety consideration (e.g., flooding and land uses conflict) [19][33]. The boolean method was utilized in this study to determine unsuitable sites as the constraints for RWH based
on these socio-economic parameters. The buffers of parameters (Table 4) were then implemented and overlaid in the GIS environment, getting the result 0 and 1 values indicating unsuitable and suitable for RWH, respectively.

### Table 3. Weight of feature class for each parameter

| Parameter                | Parameter weight | Feature Class | Assigned Weight | Normalized weight |
|--------------------------|------------------|---------------|-----------------|------------------|
| Runoff potential (mm)    | 0.35             | >550          | 8               | 0.35             |
|                          |                  | 350-550       | 7               | 0.30             |
|                          |                  | 150-350       | 5               | 0.22             |
|                          |                  | <150          | 3               | 0.13             |
| Slope (%)                | 0.24             | 0-8           | 8               | 0.32             |
|                          |                  | 8-15          | 7               | 0.28             |
|                          |                  | 15-30         | 5               | 0.20             |
|                          |                  | 30-45         | 3               | 0.12             |
|                          |                  | >45           | 2               | 0.08             |
| Soil texture             | 0.21             | Fine          | 9               | 0.32             |
|                          |                  | Moderately fine | 8          | 0.29             |
|                          |                  | Medium         | 6               | 0.21             |
|                          |                  | Moderately coarse | 3         | 0.11             |
|                          |                  | Coarse         | 2               | 0.07             |
| Land use                 | 0.13             | Rainfed paddy field | 2        | 0.08             |
|                          |                  | Orchard        | 3               | 0.12             |
|                          |                  | Shrub          | 5               | 0.20             |
|                          |                  | Pasture        | 7               | 0.28             |
| Drainage density (km/km²) | 0.07             | Very low (<1)  | 2               | 0.08             |
|                          |                  | Low (1-2)      | 3               | 0.12             |
|                          |                  | Medium (2-3)   | 5               | 0.20             |
|                          |                  | High (3-4)     | 7               | 0.28             |
|                          |                  | Very high (>4) | 8               | 0.32             |
Table 4. Socio-economic parameter and the assigned value, where 1 and 0 imply that RWH is permitted and unsuitable, respectively

| Parameter            | Condition | Assigned value |
|----------------------|-----------|----------------|
| Distance to road (m) | >50       | 1              |
|                      | <=50      | 0              |
| Distance to river (m)| >100      | 1              |
|                      | <=100     | 0              |
| Distance to settlement (m) | >200 | 1 |
|                      | <=200     | 0              |

3.5. Final RWH suitable site map
The final RWH suitable site map was obtained by integrating the RWH potential map computed using RWHI and unsuitable RWH map in the GIS environment. The integration aimed to exclude the unsuitable area from the RWH potential map through the overlay method.

4. Result and discussion
4.1. Features of Biophysical and hydrological parameters for RWH potential
Five biophysical and hydrological parameters were used in this study for RWH potential site determination. The slopes in the study area were categorized into five classes (Figure 3a): less than 8%, 8 to 15%, 15 to 30%, 30 to 40%, and greater than 40%. The slope of less than 15% is deliberated as the most appropriate site for RWH. It encompasses 35% of the total area (6,768.4 ha). The moderately fine soil texture dominates the study area, approximately 15,591.2 ha (81%). The spatial extent of other soil texture classes is 18% (3,380.2 ha) and 2% (300.5 ha) for fine and medium soil texture, respectively. The medium soil texture covers a portion of the north part of Nusa Penida Island. Moderately fine and fine soil texture allows for a higher runoff generation and is more suitable for RWH system development [22]. Drainage density in the study area ranges between 0.27 and 7.14 km/km². It is divided into five feature classes, <1 km/km², 1-2 km/km², 2-3 km/km², 3-4 km/km², and >4 km/km². High and very high drainage density have a high portion in the study area, which comprise 31% (6,033.5 ha) and 27% (5,122.9 ha), respectively. The very low drainage density occupies the smallest portion of the study area, 252.2 ha (1%). Other drainage density classes, medium and very low, cover 41% (9,862.6 ha) of the study area. A portion of the study area with a very high drainage density makes a scheme where the surface runoff flows and can be harvested instantly [33].
Regarding land use distribution, 48% and 41% of the study area are covered by dryland farming and pasture, respectively, which are relatively high suitable for the RWH system. Another 11% of the study area comprises rainfed paddy fields (6%), shrub (2%), settlement (2%), and orchard (2%). Shrub and pasture are also considered favorable sites for RWH system development. The pasture takes up the most reference. Settlement and rainfed paddy fields are less priority land use for RWH suitable sites. Runoff generation is basically controlled by several factors, such as land use, soil properties, surface morphology, and rainfall. Therefore, the determination of runoff takes into account such factors for a more comprehensive calculation. In the study area, the runoff potential for the year 2020 rainfall dataset was classified into four classes. Approximately 8% and 83% area of Nusa Penida Island has very high (>550 mm) and high runoff potential (350 – 550 mm), respectively, where RWH development is preferable. On the other hand, only a 9% portion of the study area with low runoff potential is considered less preference for RWH.
4.2. RWH suitable site

The RWH suitable sites determination in this study integrated RWH potential map and unsuitable RWH map. The generation of the RWH potential map used biophysical and hydrological parameters through multi-criteria decision analysis (AHP method). The unsuitable RWH map represents the buffer distance for river, road, and settlement where RWH structure development could not be implemented.

The RWH potential map was defined based on RWHI values computed by incorporating the weight of all parameters and their feature classes. The consistency analysis found that the assigned weight of all parameters (Table 2) is consistent that indicated by less than 10% of CR value (6%). By assigning weight to parameters and their features classes, it is implied that the important parameters have a greater weight and influence on the RWH potential site selection [49]. Figure 4 shows the RWH potential map of the study area. There are three classes of RWH potential division based on RWHI values, poor (RWHI = 0.039-0.094), moderate (RWHI = 0.095-0.223), and good (RWHI = 0.224-0.304). RWH potential site with good class covers more than half (54%) of the study area or 10,454.1 ha. Moreover, the moderate and poor classes only encompassed 38% (7,352.2 ha) and 8% (1,465.7 ha), respectively.

![Figure 4. RWH potential sites map of the study area](image_url)

The unsuitable RWH map in this study (Figure 5) is the constraint for implementing the RWH system. The constraints area for the RWH site comprises 34% (6,557.4 ha) of the study area. It is characterized
by less than 50 m of distance from the road, less than 100 m of distance from the river, and less than 200 m of distance from the settlement.

![Figure 5. Unsuitable RWH map of the study area](image)

After the elimination of unsuitable RWH sites from the RWH potential map, the final RWH suitable map was obtained. RWH suitable map consists of 7,387.6 ha (38%) for the good class, 4,799.4 ha (25%) for the moderate class, and 527.5 ha (3%) for the poor class. Figure 6 shows the RWH suitable site map, and figure 7 shows the comparison of the area of RWH classes before and after unsuitable RWH removal. Good RWH suitable site is the highest proportion of the study area. It is characterized by a gentle slope (0-15%), high runoff potential (350-550 mm), high drainage density (>3 km/km²), moderately fine soil texture, and dryland farming as the dominant land use. The moderate class of RWH suitable site is dominated by: fine and moderately fine soil texture, moderate slope (15-30%), low to moderate drainage density (1-3 km/km²), moderate runoff potential (150-350 mm), and pasture of land use. These results are in line with the finding of Mbilinyi et al. [40] study that the suitable area for RWH has a relatively gentle slope and clayey soil texture with a high capacity for holding water. Haile and Suryabhagavan [49] also confirmed that the area with: high runoff potential (>500 mm), high drainage density (>2 km/km²), relative flat slope (2-5%), and having high clay content of soil texture, was very suitable for RWH system development.
Based on the good and moderate classes of suitable sites and the potential runoff in Nusa Penida, it could be estimated the potential volume of water that can be captured. The potential captured water through the RWH system was 25,592,742 m$^3$/year with a suitable area of 12,187 ha, average potential runoff of 350 mm/year, and an RWH system efficiency of 58%, according to Zhang and Hu [50]. Compared to the water demand of dryland farming, the water availability from the RWH system was sufficient to support cultivation activities in the dry season. The water demand for dryland farming was 25,150,208 m$^3$/year using several assumptions: the total area of dryland farming was 9,823.3 ha, water demand was only for one growing season in the dry season (the water demand in the rainy season had been fulfilled), and the average water demand for corn cultivation (the main commodity in Nusa Penida) was 256 mm/growing season, according to Sirait et al. [51]. However, the water balance between water supply...
through the RWH system and demand for dryland farming fluctuates. It is influenced by the amount of dryland farming, the type of agricultural commodities, the amount of annual precipitation, and the RWH structures.

Regarding the RWH suitable map, it is recognized that the areas with good and moderate suitability classes are relevant for RWH construction development. The RWH structure selection depends on several factors, including surface morphology, soil properties, and land use [35]. The common structures that can be implemented could be percolation tanks, terracing, gully plug, pond, and pans [33]. Meanwhile, including unsuitable RWH map as the socio-economic buffer assist in avoiding conflict of interest between RWH structure development and infrastructures development, disaster risk, or other land utilization [22][33]. In addition, minimizing losses and maximizing harvested rainwater quantitatively could be achieved by combining recent technology to produce higher harvested water and localized design and configuration and appropriate operation and maintenance [33].

The current study examined a variety of parameters (biophysical, hydrological, and socio-economics) for identifying RWH suitable sites. Additionally, this study also provides a framework for determining RWH suitable sites by integrating selected parameters, MCDA using AHP, and hydrological modeling (SCS-CN) in the frame of the GIS environment. The selected parameters with their weight and feature classes with their weight have to be used for the implementation of RWH suitable site evaluation. However, a review of the weight (parameters and their feature classes) and distance threshold is needed to be executed by local experts in transferring this framework to other case studies of different regions. In cases where it is necessary to delete or enhance additional parameters, it is required to re-rationalize the latest parameters, including their weights and thresholds [33].

Determination of RWH suitable sites in this study used a relatively practical approach that can be utilized as a basis for effective water management and RWH project planning and implementation. However, uncertainties exist in the obtained results. The uncertainties can be overcome using analysis of sensitivity during the RWS analysis. Another effort to minimize the uncertainties is the pre-analysis discussion related to the how and what effect of uncertainty regarding the methods and parameters used in the study [52]. On the other hand, the parameters and methods used in this study have a good scientific and theoretical justification and abundant application experiences.

5. Conclusions

RWH system is a potential method for successfully addressing water shortage issues by collecting and storing rainwater for various purposes, especially agricultural use. Defining RWH suitable sites is essential in supporting RWH system development. This study showed a viable methodology for identifying RWH suitable sites through a case study in Nusa Penida Island. The approach used in this study was the hybrid method: MCDA (AHP method), hydrological modeling (SCS-CN), and the GIS framework. The parameters used in this study consisted of slope gradient, soil texture, drainage density, land use, runoff potential, and additional socio-economic (distance to river, road, and settlement) as the constraint of RWH development. The availability of accurate datasets of the study area will be more beneficial in implementing the proposed methodology. The methodology can also be carried out in the different regions with a proper weight and thresholds adjustment review.

Based on the implementation methodology in Nusa Penida Island, the suitable site for RWH development covers about 38% of the study area. These areas are characterized by dryland farming as the dominant land use, gentle slope, high runoff potential, high drainage density, and moderately fine soil texture. Therefore, these suitable sites for RWH provide an excellent chance to retain rainwater for utilization, especially in the dry season. Furthermore, adding socio-economic parameters could avoid the socio-economically constrained area and minimize potential disaster risk and conflict of interest.

Evaluation of RWH suitable sites in this study used the historical data, including land use and rainfall, for SCS-CN model input. In fact, land use and rainfall vary temporally, and the effects of these parameters change were not considered. Future works are needed regarding the effect of climate changes and land use change on RWH suitable sites. In addition, a more detailed hydrological processes
analysis (i.e., evapotranspiration and infiltration) is required to determine definite harvestable of rainwater for certain RWH systems in the good or moderate suitable sites.

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Author Contributions
O Setiawan: Conceptualization; field observation and measurement; software and data analysis; drafting, review, and editing manuscript. R Nandini: field observation and measurement; review and editing manuscript. Both authors read and approved the final manuscript.

Conflicts of Interest
The authors declare no conflict of interest.

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