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# Location Suitability for Small Reservoirs at the Bodri-Kuto River Basin Based on Spatial Monthly SPI

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Received: 28 January 2020; Accepted: 14 March 2020; Published: 1 April 2020

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**Abstract:** Despite efforts to develop and conserve water resources, almost every year during the dry season, some areas in Central Java province in Indonesia still experience a lack of water, especially in rural villages. These areas require water supply via water trucks and/or portable pumps to obtain water from rivers and groundwater. The Central Java government committed to implementing a program involving the construction of 1000 small reservoirs by 2020 to overcome water shortages. However, the technically ideal sites are mostly privately owned, which requires lengthy and costly land acquisition. To avoid the uncertainty of land acquisition, some small reservoirs were placed on state-owned land, which did not require land acquisition. The consideration of putting more emphasis on state-owned land rather than technically ideal sites for the construction of small reservoirs raise the issue on the location suitability of those reservoirs. In this study, we evaluated the suitability of the location of small reservoirs in the Bodri-Kuto river basin using the monthly standardized precipitation index (SPI). We used rainfall records of 25 stations in the river basin from 2000 to 2016 and analyzed yearly and monthly rainfall data. The yearly analysis shows that the dry conditions (SPI $< -0.5$) from 2005 to 2009 affected more than half of the rainfall stations (>50%), whereas the rainfall stations that experienced more dry years included Kedung Wungu, Babadan, Bojong, Ketapang, Sekopek, and Podowaras (more than 9 out of 17 years). The monthly SPI shows that during July, August, and September, all the rainfall stations experience moderately dry or worse conditions (SPI $< -0.50$). Using 25 rainfall stations, we determined the spatial spread of dry conditions using monthly SPI values from July, August, and September. Overlay of the spatial spread of dry conditions with the location of small reservoirs can be used to evaluate the suitability of small reservoir locations. We found that 1 (3%) location is very suitable, 7 (21%) locations are suitable, 24 (73%) locations are moderately suitable, and 1 (3%) location is less suitable. The findings indicate that the spatial distribution of SPI can be used as an additional criterion for evaluating the suitability of small reservoirs' locations should technically ideal locations be unavailable.

**Keywords:** SPI; drought index; Bodri-Kuto river basin; location suitability

## 1. Introduction

Since the issuance of water resources law No. 7/2004 in Indonesia, as modified by law No. 17/2019, the development of water resources has been intense, including efforts to conserve and develop water resources, as well as implementing programs for mitigating water-related disasters, developing water resources information systems, and encouraging stakeholders' participation in water resources development.

In Central Java province, two river basins are managed by the provincial government: Bodri-Kuto and Pemali-Comal. However, water deficiency still occurs in the areas, especially during the dry season. Since 2015, some regencies in Central Java experienced drought problems, a lack of clean water supply, and a lack of irrigation water. Some emergency actions were undertaken, such as supplying clean water by deploying water trucks and using portable pumps to pump water from rivers or ground water for irrigation. Some artificial rainfall efforts were also implemented with less success. Kendal Regency, one of regencies in the Bodri-Kuto river basin, was declared by the Provincial Disaster Mitigation Agency as experiencing a drought emergency in 2015, 2017, and 2019.

One effort of the provincial government to overcome the dry condition was the commitment to develop 1000 small reservoirs throughout the province. In the Bodri-Kuto river basin, there are 33 reservoirs (10 already operating and the other 23 are undergoing design and construction). Small reservoirs are reservoirs with a storage capacity of <1 million $m^3$, a height <15 m, or a crest length <500 m. Out of the 33 reservoirs there are 30 reservoirs (90.91%) with a capacity of less than 100,000 $m^3$. They are mostly rain-fed field storage whose locations are in proximity to the demand point. Meanwhile, the other three reservoirs (= 9.09%) have a capacity of more than 1 million $m^3$, which are using river flow as the water sources. The locations of these three reservoirs depend on criteria such as the river flow, rainfall, topographical capacity, geology of the site, etc., as explained in [1,2].

During implementation, the construction progressed poorly primarily due to delays in land acquisition. Land acquisition has historically delayed many projects [3]. This land acquisition is causing major delays in the construction of some public infrastructure. The factors causing a delay in land acquisition can be grouped into four principal factors: political interference, high cost of land transactions, weak planning institutions, and rehabilitation issues with extensive legal delays [4].

To avoid the uncertainty of land acquisition, some small reservoirs were instead constructed on the closest state-owned land, which avoided the lengthy land acquisition process. The consideration to give more priority to state-owned land rather than technically ideal sites for the construction of small reservoirs may influence the location suitability of these reservoirs.

A study of the location suitability of small reservoirs in the Bodri-Kuto river basin indicated their low suitability [5]. However, the authors used the average of each month's rainfall data as reference for its respective month's standardized precipitation index (SPI) calculation. They used the drought vulnerability criterion, which is defined as the joint occurrences of dry spells in consecutive months for evaluating the location suitability. The use of the mean of each month's rainfall indicates the SPI with respect to each month's deviation only. As a consequence, the same dry spell in one month differently impacts the dryness in other months, which must be avoided. Secondly, the use of drought vulnerability, which combines the joint occurrences of frequencies of dry and very dry spells in consecutive months, changes the probability of drought condition so that it does not reflect actual field conditions.

In this study, we evaluated the suitability of locations for small reservoirs at the Bodri-Kuto river basin using the monthly SPI [6]. To calculate monthly SPI, we used the average monthly rainfall. We used the envelope spatial dryness condition to justify the location suitability.

## 2. Materials and Methods

### 2.1. Location

The location of the study was the Bodri-Kuto river basin in the Central Java province, which includes the regencies of Kendal, Semarang, Batang, and Temanggung, as shown in Figure 1. Figure 2 shows the locations of the constructed small reservoirs, reservoirs under construction in 2017, rainfall stations, and areas supplied with emergency water by water truck and pumped irrigation in the Bodri-Kuto river basin.


**Figure 1.** Location of the study area in the Central Java province.


**Figure 2.** Locations of small reservoirs in the Bodri-Kuto river basin.

## 2.2. Data

We used secondary data of 17 years (2000–2016) of rainfall records from 25 stations in the catchment obtained from the Water Resources Agency in Central Java; the location of emergency water supply and irrigation data were obtained from the Kendal Disaster Management Agency; and the location of the small reservoirs that 1) have been completed (Tables 1 and 2) are undergoing construction and are planned (Table 2) were collected from the Water Resources Agency in the Central Java province, the Agricultural Department, and the Forestry Department. Other data included information on the occurrences of drought in the field obtained from governmental offices, villages, and newspapers.

**Table 1.** Constructed small reservoirs in the river basin.

| No. | Small Reservoir | Source of Water | Capacity ($\times 10^6$ m$^3$) | Constr. | Dry Area |
|---|---|---|---|---|---|
| 1 | Kedungasri | Rain-fed | 0.02 | 2016 | - |
| 2 | Bumiayu | Irrig. and Rain-fed | 0.025 | 2013 | - |
| 3 | Triharjo | Irrig. and Rain-fed | 0.02 | 2012 | yes |
| 4 | Sojomerto | Irrig. and Rain-fed | 0.025 | 2016 | yes |
| 5 | Rowobraten | Rain-fed | 0.02 | 2017 | - |
| 6 | Ringinarum | Rain-fed | 0.03 | 2017 | - |
| 7 | Tejorejo | Rain-fed | 0.05 | 2017 | - |
| 8 | Ngerjo | Rain-fed | 0.02 | 2016 | - |
| 9 | Harjodowo | Rain-fed | 0.02 | 2016 | yes |
| 10 | Sidokumpul | Spring | 0.02 | 2013 | yes |

**Table 2.** On-going small reservoir developments (under construction or planned).

| No. | Small Reservoir | Source of Water | Capacity ($\times 10^6$ m$^3$) | Constr. | Dry Area |
|---|---|---|---|---|---|
| 1 | Wonoboyo | Spring | 0.1 | - | yes |
| 2 | Trisobo | Irrig. and Rain-fed | 0.04 | - | - |
| 3 | Kedunggading | Rain-fed | 0.04 | - | - |
| 4 | Tamanrejo | Rain-fed | 0.02 | - | yes |
| 5 | Kedungboto | Rain-fed | 0.08 | - | yes |
| 6 | Blumah | Rain-fed | 0.02 | - | yes |
| 7 | Karangtengah | Rain-fed | 0.02 | - | yes |
| 8 | Wonosari | Rain-fed | 0.02 | - | yes |
| 9 | Jatirejo | Rain-fed | 0.02 | - | yes |
| 10 | Wonotenggang | Rain-fed | 0.02 | - | - |
| 11 | Nglarangan | Rain-fed | 0.1 | - | yes |
| 12 | Gemawang | Rain-fed | 0.08 | - | yes |
| 13 | Bejen | Rain-fed | 0.07 | - | yes |
| 14 | Sumowono | Rain-fed | 0.05 | - | - |
| 15 | Sawangan | Rain-fed | 0.1 | - | yes |
| 16 | Ngaliyan | Rain-fed | 0.1 | - | yes |
| 17 | Gringsing | Rain-fed | 0.08 | - | yes |
| 18 | W. Cening | Kali Putih River | 10.00 | - | - |
| 19 | W. Bodri (Banyuwaringin) | Kali Putih River | 42.00 | - | - |
| 20 | W. Kedungsuren | Blorong River | 24.48 | - | yes |
| 21 | Kedunggading 2 | Rain-fed | 0.02 | - | - |
| 22 | Sojomerto 2 | Irrig. and Rain-fed | 0.02 | - | yes |
| 23 | Triharjo 2 | Irrig. and Rain-fed | 0.02 | - | yes |

### 2.3. Analysis

The nature of droughts is complex, and any drought index should realistically consider climatological factors such as rainfall, temperature, air humidity, wind, and soil conditions. The selection of a drought index for analysis is dependent on the specific region, available information (data base), and the objective of the analysis [7]. Hao and Singh [8] comprehensively reviewed some drought indices, addressing the principles of the methods along with their limitations and strengths. Svoboda et al. [9] reported that no singular index can portray drought conditions for all of space and time. Droughts are multidimensional in nature, manifested on different temporal scales, and cannot be fully characterized using a single indicator [10].

The use of SPI [11] has been popular, primarily due to its less complicated formulation and requiring only rainfall time series, as well as being capable of characterizing both temporal and spatial climatological drought conditions [12].

Sayari et al. [13] applied three drought indices: SPI, precipitation index percent of normal (PIPN), and agricultural rainfall index (ARI) using databases from 1990 to 1961 in Northeast Iran. The future drought conditions in the Kashafrood basin, Iran, due to climate change resulting from low and high greenhouse gas emission scenarios (Special Report on Emission Scenarios or SRES B2 and SRES A2, respectively) were predicted using all three indices. All indices indicated higher drought frequency as a result of climate change under both scenarios. The findings support that even the simple SPI can provide equally good results compared with the more detailed indices (PIPN and ARI).

Saada and Abu-Romman [14] studied the use of contemporaneous autoregressive moving average (CARMA) time series analysis to model the SPI at a time scale of 12 months (SPI-12) in the northwest mountainous region in Jordan. They used a rainfall database recorded from five rainfall stations from 1983 to 2013 (30 years). The results demonstrated that CARMA (1,1) can model the SPI in the region and that the cross-correlation structures between the stations were well preserved.

Setiawan et al. [15] applied the normalized monthly precipitation and SPI to study the influence of El Niño events using rainfall data based on 1950–2010 in Indonesia. They found that the influence of El Niño events is better represented by use of SPI. The use of temporal and spatial SPI in more regions and seasons affected by El Niño can more accurately reflect drought outlook.

Tshiabukole et al. [6] applied SPI to analyze the influence of climatic variability to the seasonal rainfall pattern in Southwestern Congo. They found that the frequency of occurrence of dry periods in successive years is relatively low, although 25 years over the last 50 years have experienced droughts.

Recently, Theresia et al. [5] used SPI to evaluate the correlation between drought area and the location of small reservoir construction in the Bodri-Kuto river basin In Indonesia. They reported the low suitability of the locations of small reservoirs given the drought conditions. However, Theresia et al. [5] used SPI defined as the standardized deviation from its respective month [5]. This use of SPI only indicates each month's deviation, resulting in different dry spell definitions in different months despite having equal SPI values. Secondly, they applied drought severity criteria based on simultaneous drought frequencies of dry and very dry spells in consecutive months. This joint drought severity definition means the probability of drought conditions may not reflect field conditions.

The SPI in this study was calculated both yearly and monthly. For yearly SPI, we used the mean of yearly rainfall data as the reference; for monthly SPI, we used the mean of monthly rainfall data as the reference applicable throughout the months. In principle, the index calculates the standardized rainfall. When the SPI is less than the average, the index is negative. The larger the negative value, the larger the deviation (smaller than) from its average or reference value, indicating a more severe drought index. The SPI formula is as follows [5,16,17]:

$$\mathrm{SPI} = \frac{X_i - \overline{X}}{\sigma}$$

where $X_i$ is rainfall (mm) at time period $I$, $\overline{X}$ is average rainfall (mm), and $\sigma$ is the standard deviation (mm).

Based on the SPI calculated above, the drought condition was classified as shown in Table 3.

The analysis performed in this study was as follows:

(1) SPI calculation: The SPI was analyzed for 17 years of rainfall records (2000–2016) from 25 rainfall stations in the river basin. Before the SPI analysis, the missing data were filled with inversed square distance values [18] and the data were checked for consistency using the double mass curve with correction [19].

(2) The dry months were also crosschecked using Oldeman's method [20]. We confirmed that July to September are the driest months.

(3) Spatial interpolation was performed based on the SPI at 25 rainfall stations. The spatial interpolation throughout the river basin was performed using multi-dimension inverse distance weighting (IDW) in ArcMap by Environmental Systems Research Institute (ESRI) [21] to obtain the spatial distribution of SPI [22]. Other approaches to define spatial distribution include using principle component analysis for clustering homogenous regions based on SPI [23].

(4) Drought classification and mapping: Based on the spatial SPI, drought conditions were spatially classified based on Tshiabukole et al. [4], as shown in Table 3.

(5) Severity of drought: The severity of drought is based on monthly SPI. The longer the dry condition (as indicated by SPI), the more severe the drought. Severe drought conditions are experienced when the location is continuously dry condition for three months. The criteria for drought severity are shown in Table 4.

(6) Location suitability: The suitability of reservoir locations based on the SPI was obtained from overlying the spatial mapping of the drought classification with the locations of the small reservoirs (constructed or planned).

**Table 3.** Drought classification based on SPI values [6].

| Value of SPI | Drought Condition |
|---|---|
| −0.49 to 0.49 | Normal |
| −0.50 to −0.99 | Moderately dry |
| −1.00 to −1.49 | Dry |
| −1.50 to −1.99 | Very dry |
| <−2.00 | Extreme dry |

**Table 4.** Drought duration, severity, and location suitability.

| No. | Duration * | Drought Severity | Suitability |
|---|---|---|---|
| 1 | 3 months | Very High | Very Suitable |
| 2 | 2 months | High | Suitable |
| 3 | 1 months | Moderate | Moderately Suitable |
| 4 | - | Low | Less Suitable |

* Monthly SPI < −0.50 (moderately dry or worse).

## 3. Results

### 3.1. Yearly SPI

The yearly SPI was used to identify the driest years, which was achieved by counting the number of rainfall stations whose records showed dry conditions. Figure 3 shows the number of rainfall stations (out of 25) that experienced moderately dry or worse conditions (SPI < −0.50) every year. In 2000, for example, four stations experienced moderately dry conditions, three experienced dry conditions, and two experienced very dry conditions. In total, nine stations (out of 25) experienced moderately dry or worse conditions in 2000. Figure 3 shows that the driest years were observed in 2005, 2006, 2007, 2009, 2012, and 2015, where more than 10 rainfall stations simultaneously experienced moderately dry or worse conditions (SPI < −0.50).

Figure 4 shows the frequency of moderately dry or worse conditions at the various stations. The worst rainfall record was observed at Podowaras station, which experienced nine years of dry conditions and eight years of very dry conditions out of the 17 years of records (2000–2016). Other rainfall records showing moderately dry or worse conditions included Kedung Wungu (13 years), Babadan (9 years), Bojong (12 years), Ketapang (10 years), and Sekopek (10 years).

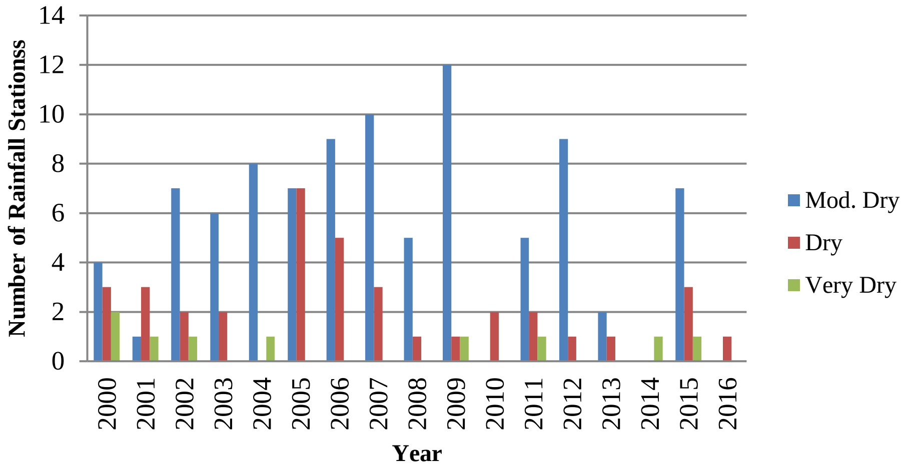


**Figure 3.** Number of rainfall stations experiencing moderately dry or worse conditions.

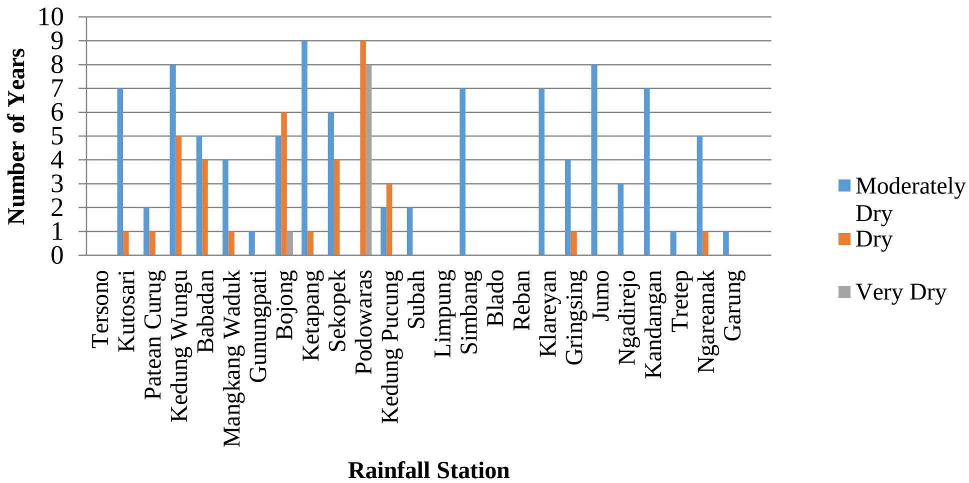


**Figure 4.** Rainfall stations experiencing moderately dry or worse conditions.

### *3.2. Monthly SPI*

The result of monthly SPI for all 25 rainfall stations is shown in Table 5. On average, the moderately dry months were June to October, with SPI values below −0.5 (moderately dry or worse). In this analysis, we used the driest three months: July, August, and September.

**Table 5.** Monthly SPI at 25 rainfall stations.

| No. | Rainfall Station | Monthly SPI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **January** | **February** | **March** | **April** | **May** | **June** | **July** | **August** | **September** | **October** | **November** | **December** |
| 1 | Tersono | 1.82 | 2.87 | 0.83 | 0.70 | −0.22 | −0.55 | −0.76 | −1.06 | −1.00 | −0.57 | 0.19 | 1.41 |
| 2 | Kutosari | 1.18 | 1.30 | −0.32 | −0.33 | −0.45 | −0.71 | −0.91 | −1.10 | −0.96 | −0.80 | −0.03 | 0.27 |
| 3 | Patean Curug | 1.08 | 1.05 | 0.81 | 0.40 | −0.12 | −0.58 | −0.79 | −1.06 | −0.94 | −0.40 | 0.43 | 0.72 |
| 4 | Kedung Wungu | 0.81 | 0.75 | −0.18 | −0.24 | −0.46 | −0.72 | −0.88 | −1.20 | −1.10 | −0.90 | −0.54 | −0.05 |
| 5 | Babadan | 0.76 | 1.06 | −0.14 | −0.44 | −0.42 | −0.77 | −1.01 | −1.16 | −0.96 | −0.75 | −0.36 | 0.11 |
| 6 | Mangkang Waduk | 1.34 | 1.30 | 0.23 | 0.14 | −0.21 | −0.55 | −0.75 | −1.12 | −0.89 | −0.60 | −0.01 | 0.32 |
| 7 | Gunungpati | 1.66 | 1.04 | 1.00 | 0.55 | −0.20 | −0.69 | −0.97 | −1.10 | −0.81 | −0.43 | 0.74 | 0.88 |
| 8 | Bojong | 0.70 | 0.50 | −0.29 | −0.30 | −0.59 | −0.80 | −1.01 | −1.16 | −0.95 | −0.83 | −0.51 | 0.11 |
| 9 | Ketapang | 1.10 | 1.13 | −0.22 | −0.40 | −0.62 | −0.68 | −1.03 | −1.15 | −0.93 | −0.60 | −0.25 | 0.14 |
| 10 | Sekopek | 0.87 | 0.86 | −0.17 | −0.27 | −0.53 | −0.71 | −0.96 | −1.13 | −0.97 | −0.71 | −0.39 | 0.12 |
| 11 | Podowaras | −0.34 | −0.17 | −0.71 | −0.70 | −0.93 | −0.93 | −1.10 | −1.20 | −1.10 | −1.03 | −0.81 | −0.56 |
| 12 | Kedung Pucung | 1.15 | 0.87 | 0.35 | 0.38 | −0.25 | −0.57 | −0.73 | −1.14 | −1.06 | −0.73 | 0.04 | 0.33 |
| 13 | Subah | 2.03 | 2.48 | 0.18 | −0.12 | −0.49 | −0.64 | −0.70 | −1.08 | −0.91 | −0.62 | −0.08 | 0.28 |
| 14 | Limpung | 2.09 | 2.25 | 0.73 | 0.57 | −0.19 | −0.41 | −0.76 | −1.01 | −0.90 | −0.43 | 0.29 | 0.87 |
| 15 | Simbang | 1.59 | 2.09 | −0.09 | −0.28 | −0.60 | −0.74 | −0.81 | −1.04 | −0.98 | −0.77 | −0.39 | −0.06 |
| 16 | Blado | 3.52 | 3.37 | 2.23 | 1.55 | 0.88 | 0.07 | −0.53 | −0.84 | −0.76 | 0.25 | 1.26 | 2.05 |
| 17 | Reban | 3.73 | 4.20 | 2.39 | 2.08 | 1.02 | −0.07 | −0.60 | −0.58 | −0.53 | 0.01 | 1.14 | 2.59 |
| 18 | Klareyan | 1.57 | 1.12 | 0.40 | −0.20 | −0.68 | −0.56 | −0.78 | −0.97 | −0.71 | −0.91 | −0.43 | 0.48 |
| 19 | Gringsing | 1.33 | 1.87 | −0.14 | −0.27 | −0.43 | −0.65 | −0.85 | −1.09 | −0.97 | −0.72 | −0.09 | 0.37 |
| 20 | Jumo | 0.41 | 0.53 | 0.76 | 0.28 | −0.37 | −0.91 | −0.90 | −1.11 | −0.91 | −0.44 | 0.14 | 0.39 |
| 21 | Ngadirejo | 0.80 | 0.66 | 0.72 | 0.39 | −0.38 | −0.82 | −1.03 | −1.09 | −0.88 | −0.62 | 0.11 | 0.78 |
| 22 | Kandangan | 0.74 | 0.16 | 0.42 | 0.15 | −0.53 | −0.97 | −0.87 | −1.03 | −0.87 | −0.31 | 0.37 | 0.64 |
| 23 | Tretep | 1.47 | 1.20 | 1.09 | 0.99 | 0.04 | −0.60 | −0.83 | −1.06 | −0.73 | −0.24 | 0.70 | 1.52 |
| 24 | Singorojo | 0.98 | 0.57 | 0.32 | 0.17 | −0.50 | −0.81 | −1.03 | −1.18 | −1.01 | −0.53 | 0.06 | 0.77 |
| 25 | Garung | 1.75 | 1.47 | 1.90 | 1.35 | 0.36 | −0.50 | −0.77 | −0.89 | −0.62 | 0.39 | 1.45 | 1.92 |
| | Max | 3.73 | 4.20 | 2.39 | 2.08 | 1.02 | 0.07 | −0.53 | −0.58 | −0.53 | 0.39 | 1.45 | 2.59 |
| | Min | −0.34 | −0.17 | −0.71 | −0.70 | −0.93 | −0.97 | −1.10 | −1.20 | −1.10 | −1.03 | −0.81 | −0.56 |
| | Average | 1.37 | 1.38 | 0.48 | 0.25 | −0.27 | −0.63 | −0.85 | −1.06 | −0.90 | −0.53 | 0.12 | 0.66 |

Figure 5 shows the driest rainfall stations based on monthly SPI. The driest month was August followed by July and September, which showed moderately dry and dry conditions. The rainfall records showing the driest conditions were those from the Kedung Wungu, Ketapang, Sekopek, Podowaras, Simbang, Klareyan, and Singorojo stations based on both monthly and yearly SPI.

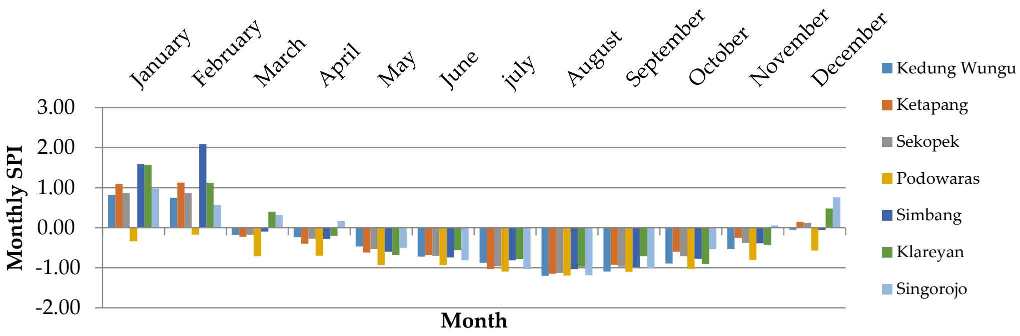


**Figure 5.** Monthly SPI at the driest rainfall stations.

Figure 6 shows the number of rainfall stations that were experiencing moderately dry or worse conditions. During the driest months of July, August, and September, all rainfall records indicated moderately dry or worse conditions. Figure 7 shows the number of months in the year where the rainfall records showed moderately dry or worse conditions. Figure 8 shows the monthly SPI during the driest months of July, August, and September.

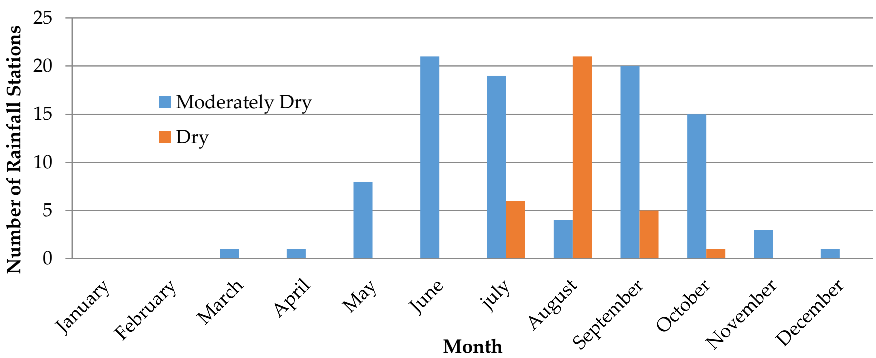


**Figure 6.** Number of rainfall stations experiencing moderately dry or worse conditions.

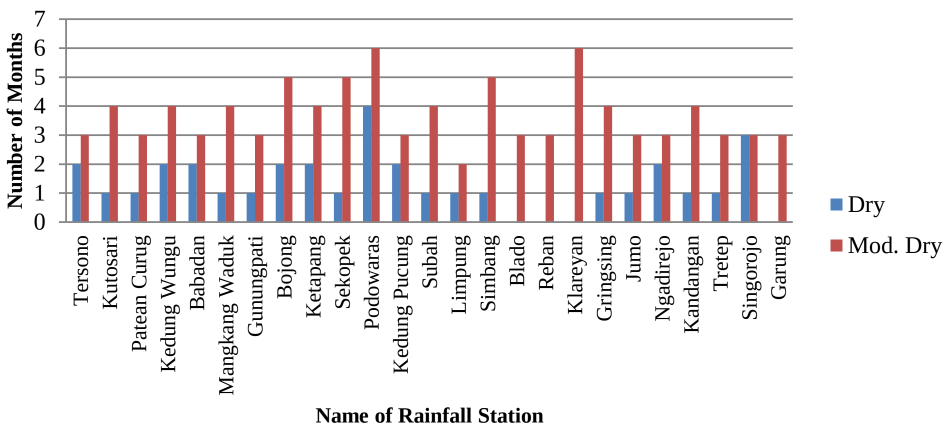


**Figure 7.** Frequency of rainfall stations experiencing moderately dry or worse conditions in the Bodri-Kuto river basin.

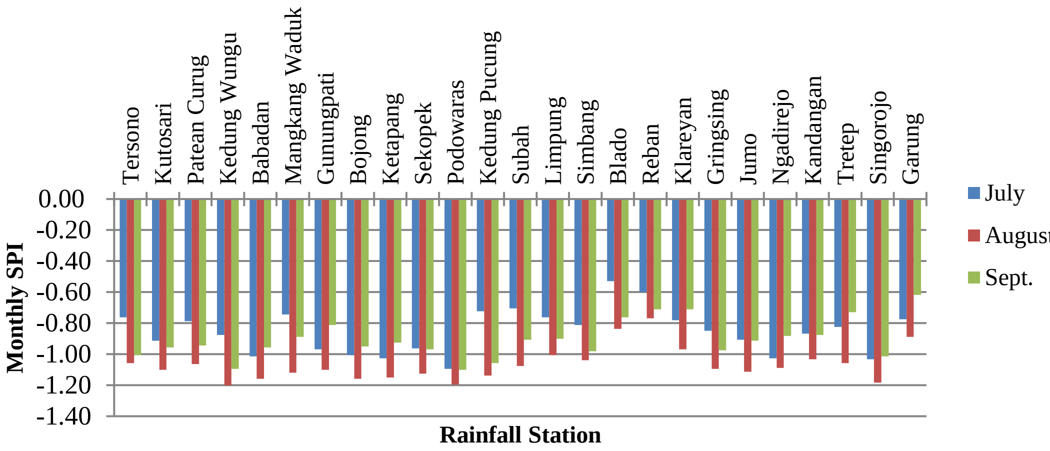


**Figure 8.** Monthly SPI of the driest months of July, August, and September in the Bodri-Kuto river basin.

## 4. Discussion

### *4.1. Spatial Distribution of Drought*

The spatial distribution of monthly drought in the Bodri-Kuto river basin during July, August, and September is shown in Figure 9, where yellow indicates moderately dry areas and the dark yellow indicates dry conditions. In July, 19 stations were moderately dry and six stations were dry. The six stations reporting dry conditions in July were Babadan, Bojong, Ketapang, Podowaras, Ngadirejo, and Singorojo, which are mostly located in the center of the river basin (dark yellow area). In August, only four stations reported moderately dry conditions (Blado, Reban, Klareyan, and Garung), which are located at the northeast part of the river basin (yellow area). In September, five stations (Tersono, Kedungungu, Podowaras, Kedung Pucung, and Singorojo) experienced dry conditions (dark yellow).

The severity of drought was determined on the basis of the criteria in Table 2 and is shown in Figure 10. The Podowaras and Singorojo stations experienced continuous dry conditions in July, August, and September. The areas shown in Figure 10 in dark brown are most suitable for the construction of small reservoirs. The areas indicated in brown are suitable, whereas the areas indicated in light brown are moderately suitable. The drought severity map in Figure 10 is overlaid with the locations of the small reservoirs (constructed and under construction) and locations of emergency water supplies (water truck and pumped irrigation). The figure shows that the emergency water supply in Curug Sewu, Sidodadi, Jatirejo, Pekuncen, and Wonosari aligns with the drought-affected areas.

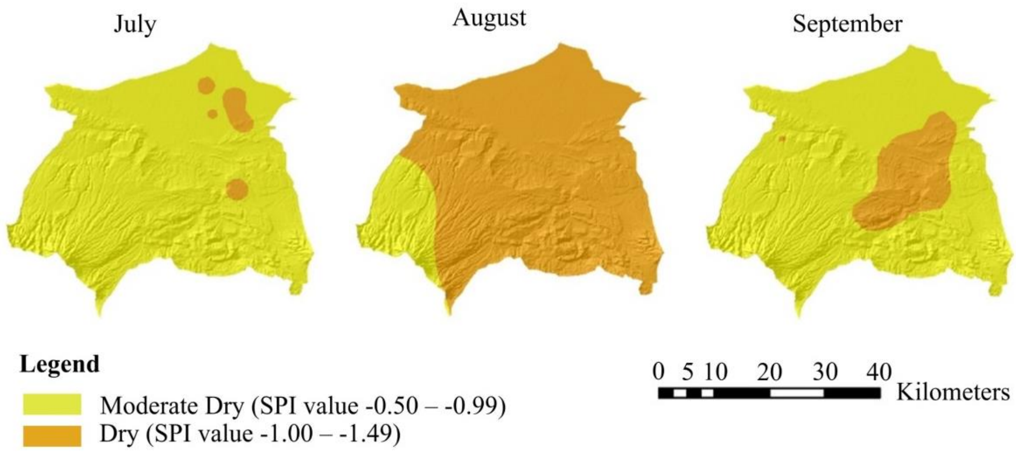


**Figure 9.** Spatial monthly SPI distribution in the Bodri-Kuto river basin.


**Figure 10.** Overlay of small reservoir locations and drought severity map.

### *4.2. Location Suitability of Constructed Reservoirs*

The locations of some constructed reservoirs overlaid with the drought severity map are shown in Figure 10 and the location suitability is listed in Table 6. Only one reservoir (No. 10, Sidokumpul) is located in a suitable area (i.e., with high severity drought). The Sidokumpul small reservoir was constructed in 2013 and uses springs as its sources of water. It is located at the sub-regency Patean, which experiences drought and water shortage every year and is thus dependent on water tank supply (see Figure 2). The result aligns with the field conditions where the Sidokumpul small reservoir is used for supplying domestic water needs, cattle, and irrigation. The Sidokumpul reservoir is also used to supply water to the Sojomerto Weir, thus extending its services to the irrigation area. This finding agrees with the field conditions and is in concordance with that previously reported [3].

The other nine reservoirs (90%) are located in moderately dry areas, which are thus in moderately suitable locations. In the field, there are six reservoirs located in dry areas that required water truck supply. They are Sidokumpul, Triharjo, Sojomerto, Harjodowo, Ringinarum, and Tejorejo. Compared with a previous study [3], only 80% of small reservoirs were constructed in less suitable locations.

### 4.3. Location Suitability of Reservoirs Under Construction

The locations of reservoirs under construction overlaid on the drought severity map are shown in Figure 10 and their suitability is listed in Table 7. Of the 23 reservoirs under construction, one reservoir (4%) is in a very suitable location (Karangtengah, No. 7), six reservoirs (26%) are in suitable locations, 15 reservoirs (65%) are in a moderately suitable location, and only one reservoir (Blumah) is located in a less suitable location. In total there are 22 (=95.65%) reservoirs located in areas of moderately suitable to very suitable locations. Another study [3] showed that 57% of the small reservoirs under construction were in less suitable locations.

**Table 6.** Location suitability of the constructed small reservoirs.

| No. | Name | Drought Severity | Suitability |
|---|---|---|---|
| 1 | Kedungasri | Moderate | Moderate |
| 2 | Bumiayu | Moderate | Moderate |
| 3 | Triharjo | Moderate | Moderate |
| 4 | Sojomerto | Moderate | Moderate |
| 5 | Rowobranten | Moderate | Moderate |
| 6 | Ringinarum | Moderate | Moderate |
| 7 | Tejorejo | Moderate | Moderate |
| 8 | Ngerjo | Moderate | Moderate |
| 9 | Harjodowo | Moderate | Moderate |
| 10 | Sidokumpul | High | Suitable |
| | | Total: | |
| | | Very Suitable | 0 (0%) |
| | | Suitable | 1 (10%) |
| | | Moderately Suitable | 9 (90%) |
| | | Less Suitable | 0 (0%) |

**Table 7.** Location suitability of the small reservoirs under construction.

| No. | Name | Drought Severity | Suitability |
|---|---|---|---|
| 1 | Wonoboyo | Moderate | Moderate |
| 2 | Trisobo | Moderate | Moderate |
| 3 | Kedunggading | Moderate | Moderate |
| 4 | Tamanrejo | Moderate | Moderate |
| 5 | Kedungboto | Moderate | Moderate |
| 6 | Blumah | Low | Less |
| 7 | Karangtengah | Very High | Very |
| 8 | Wonosari | High | Suitable |
| 9 | Jatirejo | High | Suitable |
| 10 | Wonotenggang | Moderate | Moderate |
| 11 | Nglarangan | Moderate | Moderate |
| 12 | Gemawang | Moderate | Moderate |
| 13 | Bejen | High | Suitable |
| 14 | Sumowono | Moderate | Moderate |
| 15 | Sawangan | Moderate | Moderate |
| 16 | Ngaliyan | Moderate | Moderate |
| 17 | Gringsing | Moderate | Moderate |
| 18 | W. Cening | Moderate | Moderate |
| 19 | W. Banyuwaringin | High | Suitable |
| 20 | W. Kedungsuren | High | Suitable |
| 21 | Kdg Gading2 | Moderate | Moderate |
| 22 | Sojomerto2 | Moderate | Moderate |
| 23 | Triharjo2 | High | Suitable |
| | | Total: | |
| | | Very Suitable | 1 (4%) |
| | | Suitable | 6 (26%) |
| | | Moderately Suitable | 15 (65%) |
| | | Less Suitable | 1 (4%) |

Overall, Table 8 shows that out of a total of 33 reservoir locations, one (3%) is very suitable, seven (21%) are suitable, 24 (73%) are moderately suitable, and only one (3%) location is less suitable.

**Table 8.** Overall location suitability.

| No. | Suitability | Constructed | Under Construction | Total | |
|---|---|---|---|---|---|
| 1 | Very Suitable | 0 (0%) | 1 (4%) | 1 | 3% |
| 2 | Suitable | 1 (10%) | 6 (26%) | 7 | 21% |
| 3 | Moderately Suitable | 9 (90%) | 15 (65%) | 24 | 73% |
| 4 | Less Suitable | 0 (0%) | 1 (4%) | 1 | 3% |
| | Total | 10 (100%) | 23 (100%) | 33 | 100% |

## 5. Conclusions

For the locations of existing small reservoirs, one (10%) is suitable and nine (90%) are moderately suitable. For small reservoirs under construction, one (4%) is very suitable, six (26%) are suitable, 15 (65%) are moderately suitable, and one (4%) is less suitable. This is an improvement in the suitability percentage compared to the findings reported previously [3].

Overall, of 33 reservoirs under construction in the Bodri-Kuto river basin, eight (24%) are either very suitable or suitable. The locations of the other 24 small reservoirs (73%) are only moderately suitable as they are located in drought-prone areas. We also found that the suitability of the under-construction and planned small reservoirs is increasing.

The small reservoirs constructed in available land locations instead of technically ideal locations are still located within suitable dry or moderately dry areas.

To improve the effectiveness of reservoir construction, the drought severity in the areas surrounding the reservoir should be considered in addition to the technically sound criteria.

The use of spatial and temporal SPI can help determine suitable locations for small reservoirs. However, the quality of the results is also influenced by the spatial distribution of the rainfall stations. The higher the density of rainfall stations, the better the spatial SPI distribution.

**Author Contributions:** Conceptualization and methodology: S.S. and T.N.S.H.; software: T.N.S.H. and I.S.; validation, formal analysis, investigation, resources: S.S., I.S., T.N.S.H. and F.S.; data T.N.S.H.; writing—original draft preparation: S.S. and I.S.; writing—review and editing: S.S., I.S., and F.S.; visualization: I.S., T.N.S.H. and F.S. All authors have read and agree to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** The authors express their sincere thanks to the office of Water Resources Agency Central Java Province, Central Java Agricultural Department, and Kendal Disaster Management Board for providing data used in the analysis.

**Conflicts of Interest:** The authors declare no conflict of interest.

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