GIS-BASED SITE SUITABILITY ANALYSIS OF SMALL WATER IMPOUNDING PROJECTS (SWIP) IN ORIENTAL MINDORO, PHILIPPINES UNDER DIFFERENT CLIMATE CHANGE SCENARIOS

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ABSTRACT: Rainwater harvesting is one of the adaptive measures that can address the shift in rainfall patterns in the Philippines brought about by climate change. This study investigated the suitability ratings of the potential sites for Small Water Impounding Projects (SWIPs) in Oriental Mindoro under two climate change scenarios (RCP 4.5 and 8.5) in the mid-21st century period (2036-2065). Lower and upper bound conditions representing the driest and wettest possible change in rainfall, respectively, per climate change scenario, were also considered. QGIS was used to model the suitability ratings of the sites based on different suitability scales. Results show that the lower bound conditions have increased the percentage of marginally suitable sites from 42% in the baseline (1971-2000) condition to 49% in RCP 4.5, and 51% in RCP 8.5. Meanwhile, upper bound conditions increased the percentage of moderately suitable sites from 56% in the baseline condition to 62% in RCP 4.5, and 61% in RCP 8.5. Upon analyzing the change in SWIP suitability ratings of the sites from the baseline to the mid-21st century period, it was found out that the municipalities of Victoria, Soccoro, Bansud, and Mansalay are the most recommended areas for SWIP development since these areas exhibited an increase in suitability rating over time regardless of climate change scenarios in both lower and upper bound conditions. Local Government Units can use the results of the study as an additional basis in SWIP site selection in Oriental Mindoro.

1. INTRODUCTION

Significant changes in climate patterns have already been recorded because of global warming. These were observed by (Schewe and Levermann, 2012) and (Reuter et al., 2012) on monsoon patterns in southeast Asia. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has reported that northern regions in the Philippines have experienced a decreasing trend of annual rainfall from 1951-2010. Contrastingly, an increasing trend ranging from 10 mm/decade to 40 mm/decade was observed in the southern and eastern regions (PAGASA, 2018). Moreover, most areas in the Philippines have shifted their hottest and wettest month from 1951-1980 and 1986-2015 (Salvacion et al., 2018). This was further supported by Cinco et al. (2014) who observed a significant increase in the frequency of hot days and a decrease in the frequency of cold nights in 16 out of 30 synoptic weather stations in the Philippines.

The Intergovernmental Panel on Climate Change (IPCC) introduced climate change scenarios using Representative Concentration Pathways (RCPs). These RCPs differ from each other in terms of its radiative forcing, or the net amount of radiation at the tropopause (IPCC, 2013). PAGASA (2018) analyzed future rainfall trends in the Philippines under different climate change scenarios using the Climate Information Risk Analysis Matrix (CLIRAM) tool. It was found out that under high greenhouse gas emissions in 2065, the driest possible change would decrease rainfall by as much as 40% while the wettest possible change will increase rainfall by 40%. The significant shift in rainfall patterns could increase losses in agriculture. Therefore, there is a need for reliable structures that will provide additional water when rainfall is not sufficient.

Rainwater harvesting structures adapt to the effects of climate change by diverting and storing excess rainwater for future use (Oni et al., 2008). Numerous types of rainwater harvesting structures are present in the Philippines such as Small Water Impounding Projects (SWIP). These earth-filled impoundments are 5-15 m high and have an average service area of 60 ha. Having a smaller volume compared to most concrete dams, SWIPs are cheaper, have a lesser environmental impact, and can be utilized directly by farmers in areas with low annual rainfall (Naval, 2016). Additionally, a large proportion of rice farmers serviced by SWIP were able to use the water directly for irrigation, which increased their harvest (Contreras et al., 2013). Naval (2016) reported a positive impact of SWIPs on the socio-economic aspect in the agricultural sector by the creation of more Irrigation Associations (IAs), particularly Small Water Impounding Systems Associations (SWISAs).

In recent years, Geographic Information System (GIS) has been an effective tool for numerous researches on land utilization analysis (Mazahreh et al., 2019; Constantino, Jr. et al., 2017) and hydrologic modeling (Stuebe and Johnston, 1990). Site selection is one of the important aspects considered in the development of rainwater harvesting structures. There are numerous approaches in performing site suitability analysis to determine which sites are the best fit for construction. Mugo and Odera (2019), Durbude and Venkatesh (2004), and Adham et al. (2018) used a geospatial approach in which different parameters for site selection such as rainfall, slope, temperature, soil type, and land cover were considered. Different percentage weights were assigned for these parameters. Using GIS, weighted overlay analysis was used to categorize a specific area based on their degree of suitability. In Oriental Mindoro, Philippines, site suitability analysis for SWIP, as well as other forms of Small-Scale Irrigation Projects (SSIPs), was done by Amongo et al. (2020). Moreover, the study has identified SWIP potential sites using combined screener maps. However, Amongo et al. (2020) did not show how the suitability of these potential sites would change in the future. This study extends the research output of Amongo et al. (2020) by analyzing the effect of different climate change scenarios on the suitability ratings of SWIP potential sites in Oriental Mindoro in the mid-21st century period, with rainfall as the dependent parameter. Local Government Units (LGUs) can use the results of this study as an additional basis on which potential sites in Oriental Mindoro should be prioritized for construction. As more SWIPs in Oriental Mindoro are constructed, water resources would be maximized and the livelihood of those in the agricultural sector would improve.

2. METHODOLOGY

2.1. Study Area

Oriental Mindoro is one of two provinces of Mindoro island located in the southwest region of the Philippines as shown in Figure 1. Its topography is dominated by rugged mountain ranges on the west side and fertile valleys on the eastern side. Its watershed areas comprise 71% of its total land area while its forests cover around 60% (De Alban, 2010). There are 20 watersheds in Oriental Mindoro that have a watershed area greater than or equal to 100 km^2. Following the modified Corona classification by PAGASA (2018), Oriental Mindoro has a type III climate in which there is no maximum wet season, with a short dry season lasting one to three months. Calapan City, the provincial capital, has an average temperature of 27.3 °C with 1,948 mm of annual rainfall. Oriental Mindoro has a population of 844,059 as noted by the Philippine Statistics Authority (2018). Different rainwater harvesting structures are present in Oriental Mindoro such as SWIP, Small Farm Reservoir (SFR), Shallow Tube Well (STW), and other forms of SSIPs.

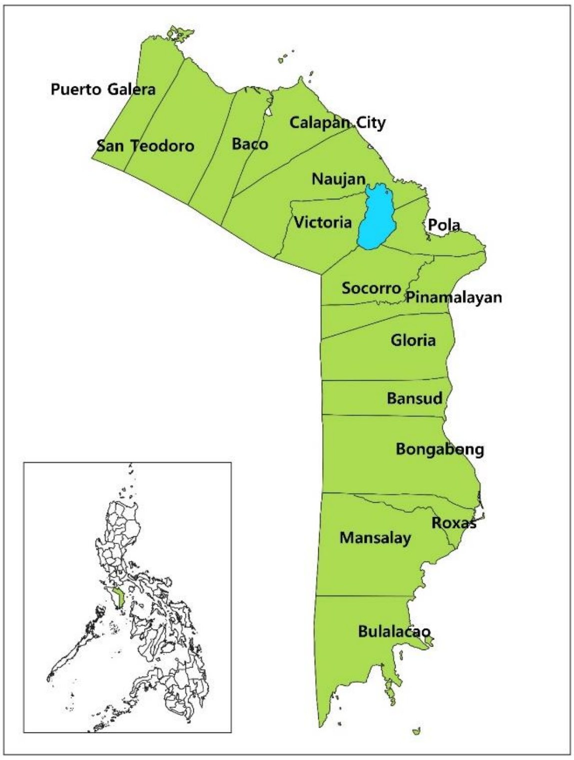

Figure 1. Overview of the study area

2.2. Data Acquisition and Processing

The parameters considered in this study were rainfall, soil texture, slope, and road proximity. These were also used by Amongo et al. (2020) in the identification of 71 SWIP potential sites in Oriental Mindoro. It was assumed in this study that from the four parameters mentioned, rainfall was the only dependent parameter. This means that the topography of the study area will not change over time. For rainfall, the raster maps containing the monthly average baseline (1971-2000) rainfall data were acquired from WorldClim.org (2018) through the research output of Fick and Hijmans (2017). These raster maps have a resolution of 1 km. The baseline rainfall maps of Oriental Mindoro were isolated using the clip raster function of Quantum GIS software or QGIS. Two climate change scenarios, namely, the moderate emission scenario (RCP 4.5) and the high emission scenario (RCP 8.5) were considered in this study. Additionally, the lower and upper bounds which represent the driest (10^{th} percentile) and wettest (90^{th} percentile) possible change in rainfall of each RCP were considered. The projected rainfall data for both RCPs and their conditions in the mid-21^{st} century period (2036-2065) were obtained from PAGASA (2018). The projections are expressed in terms of percentage changes. These were incorporated into their corresponding average monthly baseline rainfall map using the QGIS raster calculator function. Finally, the maps were added to produce an annual rainfall map. This process generated five rainfall thematic maps- one map for the baseline condition, and two maps for the projected rainfall under RCP 4.5 and RCP 8.5 -lower and upper bound conditions.

For the thematic maps of soil texture, slope, and road proximity, this study utilized the datasets used by Amongo et al. (2020). The soil texture map was derived from a soil-series map of Oriental Mindoro province from the Department of Agriculture Region IV-B and the Bureau of Soils and Water Management– Agricultural Land Management and Evaluation Division (BSWM-

ALMED). The slope map of Oriental Mindoro was derived from a Digital Elevation Model (DEM) with a resolution of 30 m. A *GRASS* r. slope. aspect algorithm was used to generate the slope map of the study area. The road proximity map was generated by using a QGIS plugin called OpenStreetMap.

2.3.Suitability analysis

The thematic maps containing data from the four parameters considered in the study were first reclassified according to their corresponding suitability scale using the QGIS raster classification function. From the reclassified maps, the weighted average for SWIP suitability was then calculated by assigning a percentage weight for each parameter. The suitability scales and percentage weights for SWIP suitability listed in Table 1 were adopted from Amongo et al. (2020). These scales were a product of consultative meetings held by various experts in water resources management in the Philippines. The resulting raster maps were again reclassified based on their weighted average for SWIP suitability shown in Table 2 to get the final SWIP suitability rating. The individual SWIP suitability rating of the 71 SWIP potential sites was obtained using the QGIS sample raster values function. This suitability analysis procedure was done for the baseline condition and both RCPs. This procedure generated five suitability maps containing the SWIP suitability ratings of the 71 SWIP potential sites in Oriental Mindoro under the baseline rainfall condition, and under RCP 4.5 and 8.5 (lower and upper bound conditions). A visual summary of the whole process for the development of suitability maps for SWIP in Oriental Mindoro under two climate change scenarios is shown in Figure 2.

Table 1. Suitability factors used for the identification of potential sites for SWIP.

Factor	Weight (%)	Description	Suitability Scale
Average annual rainfall	40	<1200 mm	1
		1200-2400 mm	2
		>2400 mm	3
Soil texture	25	Sand, loamy sand, and silt	0
		Sandy loam	1
		Silt loam and mountain soils	2
		Clay and clay loam	3
Slope	15	>18%	0
		8-18%	1
		3-8%	2
		0-3%	3
Road proximity	20	>1000 m	0
		500-1000 m	1
		200-500 m	2
		<200 m	3

Source: Amongo et al.,2020.

Table 2. Classification of SWIP suitability based on weighted averages calculated.

Weighted Average	Suitability Rating	Suitability Scale	Description
0-0.9999	Not Suitable	0	Areas that do not satisfy the set of factors/criteria or permanently not suited for the given use usually because of physical limitations.
1-1.9999	Marginally Suitable	1	Areas having low potential as they satisfy some of the set of factors or criteria but most of the factors are not satisfied and with severe restrictions or limitations or required additional inputs to sustain application of a given use.
2-2.9999	Moderately Suitable	2	Areas that satisfy most of the factors or criteria, but some factors are not satisfied and with moderately severe restrictions or limitations to sustain the application of a given use.
3-3.0001	Highly Suitable	3	Areas that satisfy all the factors or criteria set up and with no significant restrictions or limitations to sustain the application of a given use.

Source: Amongo et al.,2020.

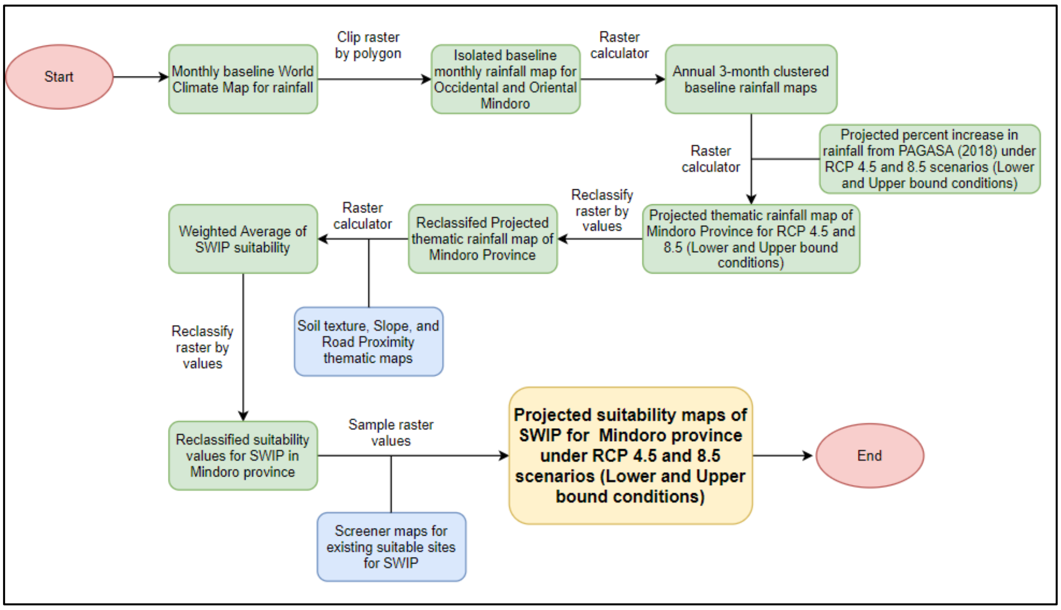

Figure 2. Process flow for the generation of projected suitability maps of SWIP in Oriental Mindoro Province under different climate change scenarios

3. RESULTS AND DISCUSSION

The primary outputs of this study are the projected suitability maps showing the suitability ratings of the 71 SWIP potential sites in Oriental Mindoro under RCP 4.5 and RCP 8.5. A suitability map for the baseline condition was generated for comparison. The baseline and projected suitability maps are shown in Figures 3, 4, and 5. Table 3 shows the distribution of SWIP potential sites for each suitability rating under the baseline condition and different climate change scenarios.

Most of the potential sites fall under moderate suitability for both RCPs. It is observed that the number of highly suitable sites increased under the upper bound condition of RCP 8.5. This means that the wettest possible change in rainfall under RCP 8.5 will increase the overall suitability rating of some SWIP potential sites. Lower bound conditions of RCP 4.5 and 8.5 increased the number of marginally suitable sites from 30 (42.25%) in the baseline condition to 35 (49.30%) in RCP 4.5 and 36 (50.71%) in RCP 8.5. This implies that further decrease in rainfall for both climate change scenarios will generally decrease the number of moderately suitable SWIP sites. On the other hand, the upper bound conditions favored an increase in moderately suitable sites from 40 (56.33%) in the baseline condition to 44 (61.97%) in RCP 4.5 and 43 (60.56%) in RCP 8.5.

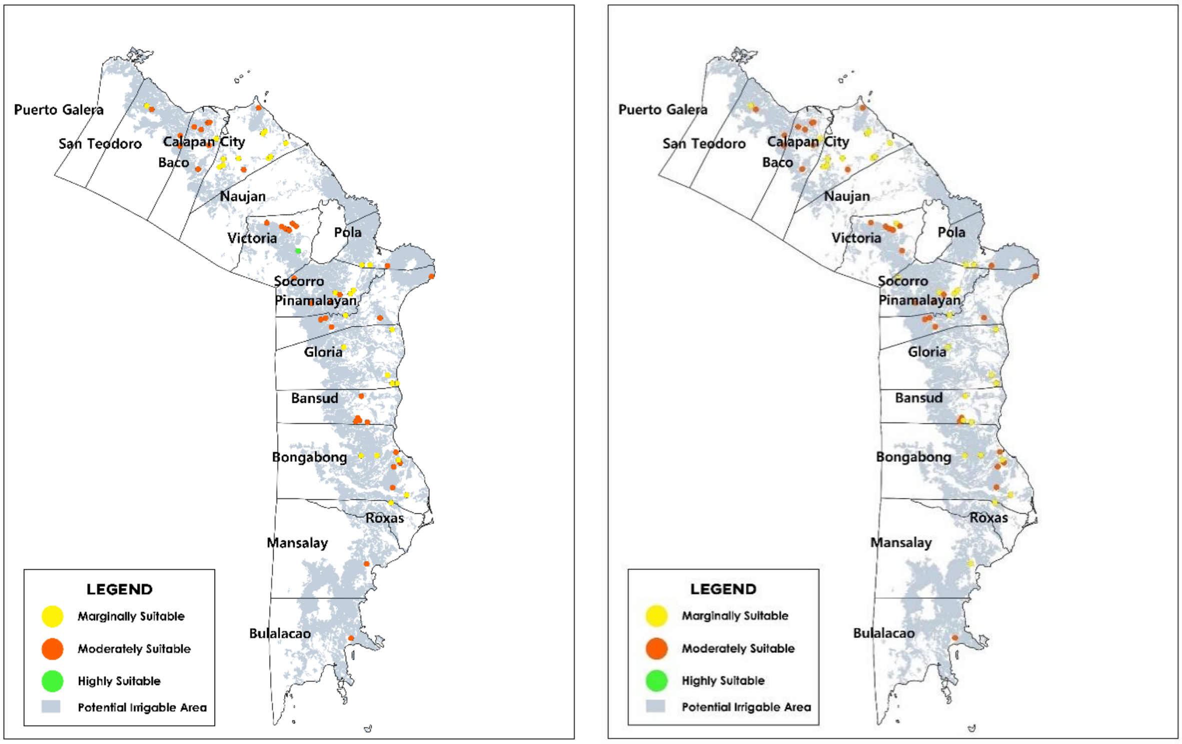

Figure 3. Overall SWIP suitability map of Oriental Mindoro for Baseline Condition (left) and RCP 4.5 scenario- lower bound condition. (right)

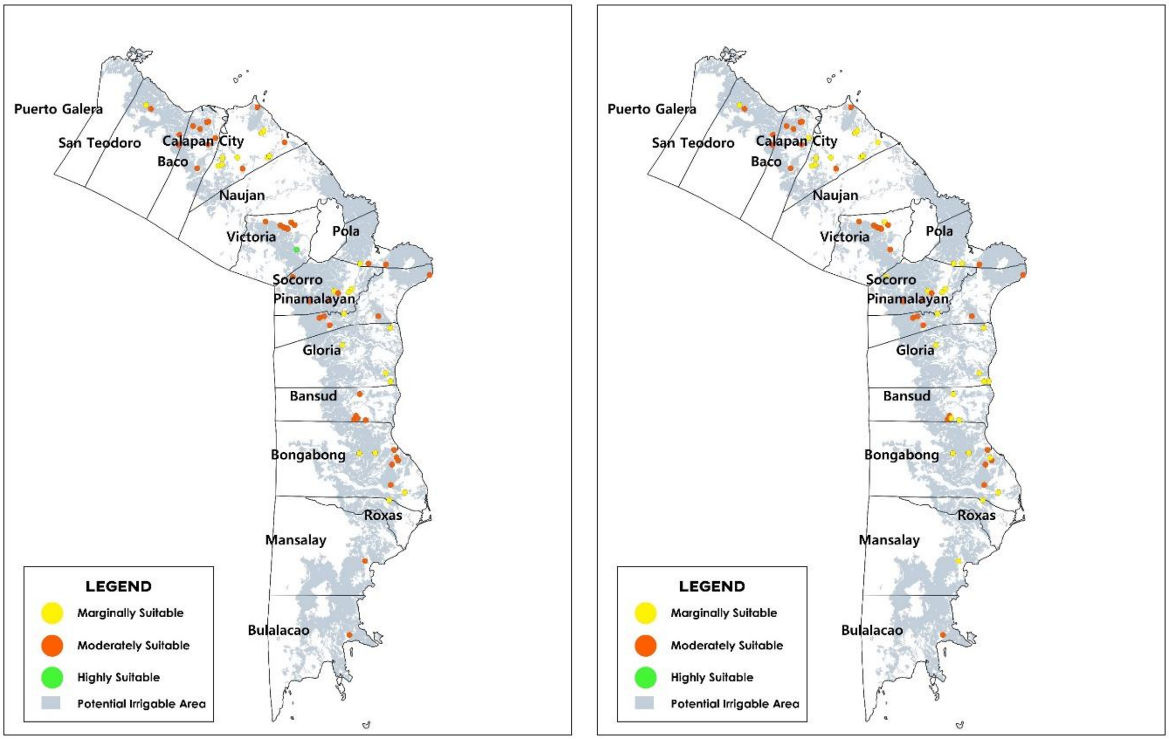

Figure 4. Overall SWIP suitability map of Oriental Mindoro for RCP 4.5 scenario- upper bound condition. (left) and RCP 8.5 scenario- lower bound condition (right)

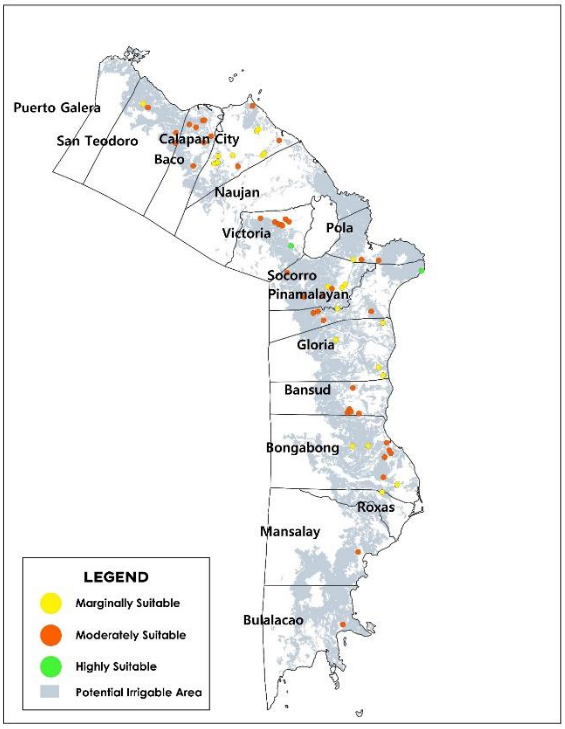

Figure 5. Overall SWIP suitability map of Oriental Mindoro for RCP 8.5 scenario- upper bound condition.

Table 3. Distribution of SWIP sites under each suitability rating for baseline and different climate change scenarios.

SWIP Suitability Rating	Baseline	%	RCP 4.5			
			Lower bound	%	Upper bound	%
1 (marginally suitable)	30	42.25	35	49.30	26	36.62
2 (moderately suitable)	40	56.34	36	50.70	44	61.97
3 (highly suitable)	1	1.41	0	0	1	1.41
SWIP Suitability Rating	**Baseline**	**%**	**RCP 8.5**			
			Lower bound	%	Upper bound	%
1	30	42.25	36	50.71	26	36.62
2	40	56.34	35	49.30	43	60.56
3	1	1.41	0	0	2	2.82

Total number of SWIP potential sites= 71

The shift in SWIP suitability ratings of the potential sites is explained by the change in projected rainfall at different climate change scenarios. When the rainfall maps were analyzed, it was observed that the projected rainfall under the lower bound scenarios of RCP 4.5 and 8.5 are lower compared to the baseline condition. Contrastingly, the projected rainfall under the upper bound scenarios of RCP 4.5 and 8.5 are higher than the baseline condition in most potential sites. The evaluation of the lower and upper bound conditions for each of the climate change scenarios is important because it gives a more accurate representation of the effect of each climate change scenario on SWIP suitability. If only the lower bound condition was considered, one might have overlooked the possible significant increase in rainfall, which could also increase its SWIP suitability rating. This could result in SWIPs that are under-designed. The excess rainfall that these SWIPs would have collected could be beneficial to other potential irrigable areas.

Looking at the SWIP potential sites in each municipality, it was observed that the number of moderately suitable sites in a municipality does not depend on the size of its potential irrigable area. The municipality of Mansalay has a larger potential irrigable area than Baco, but the latter has a greater number of moderately suitable sites. This could be explained by other factors that contribute to SWIP site selection such as the soil texture, slope, road proximity, geology, watershed area, and reservoir area, as well as the presence of other SSIPs. Map visualization of the changes in SWIP suitability ratings improves SWIP development because it serves as an additional decision tool in site selection. When the changes in suitability rating of the SWIP potential sites from the baseline period to the mid-21st century period were analyzed, it was found out that the potential sites with an increase in suitability rating over time are distributed throughout the province and are not concentrated in only one area. The recommended sites for SWIP development are the ones whose potential sites will increase in suitability rating in the future under a climate change scenario regardless if it is in the upper or lower bound condition. This means that whether climate projection falls into the upper or lower bound condition, the suitability ratings of potential sites are guaranteed to increase. It was found out that out of the 15 municipalities in Oriental Mindoro, the municipalities of Victoria and Bansud have the largest number of sites that will increase in overall SWIP suitability rating regardless of the upper and lower bound conditions under RCP 4.5. The same municipalities also have the highest number of the said sites under RCP 8.5. Furthermore, it can be said that regardless of climate change scenario and upper or lower bound condition, the municipalities which should be prioritized for SWIP development are Victoria, Soccoro, Bansud, and Mansalay because these municipalities have sites that are guaranteed to increase its suitability rating in the mid-21st century period.

4. SUMMARY AND CONCLUSION

With the shift in rainfall patterns in the Philippines brought about by climate change, there is a need to invest in rainwater harvesting structures for agriculture such as Small Water Impounding Projects (SWIPs). Potential sites for SWIP development must be evaluated by modeling their SWIP suitability rating under different climate change scenarios. In this study, GIS was used to evaluate the suitability of SWIP in Oriental Mindoro and to determine its suitability rating in the mid-21st century period (2036-2065) under RCP 4.5 and 8.5, considering the upper and lower bound conditions. Results show that the lower bound conditions for both RCP 4.5 and 8.5 increased the number of marginally suitable sites from 42% in the baseline condition to 49% in RCP 4.5 and 51% in RCP 8. In contrast, the upper bound conditions increased the moderately suitable sites from 56% in the baseline condition to 62% in RCP 4.5, and 61% in RCP 8.5. Further analysis showed that the municipalities of Victoria, Soccoro, Bansud, and Mansalay should be prioritized for SWIP development because these municipalities have potential sites that will increase its SWIP suitability rating in the future based on climate change projections of PAGASA. The results of this study showed that GIS can be used as a reliable method for SWIP site suitability analysis. It can also be used as a decision tool for SWIP development.

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