EFFECT OF CLIMATE CHANGE ON SITE SUITABILITY AND RELIABILITY OF SMALL FARM RESERVOIR IN ORIENTAL MINDORO, PHILIPPINES

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ABSTRACT: Despite of its abundance of water resources, the Philippines is confronted with issues pertinent to the availability and distribution of irrigation facilities. The use of GIS can revolutionize the method of identification and assessment of water resources and, therefore, maximize its utilization. The province of Oriental Mindoro, which is one of the major rice-producing provinces of the country, receives a total precipitation of 2,215 mm annually but the irrigation development remained slow at roughly 58% of the potential irrigable areas as of 2017. To combat the threats posed by drought, water conservation measures such as construction of rainwater harvesting structures for small farms, also known as small farm reservoirs (SFR), are widely adopted in the Philippines. In this study, a GIS-based framework was adopted in assessing the impact of climate change on suitability and reliability of SFR development in Oriental Mindoro. The suitability for SFR development was evaluated for a baseline period of 1970-2000 using annual rainfall, soil texture, and slope as factors. The weights applied to each factor were based on the criteria developed during the national consultation of researchers and experts on small-scale irrigation projects. The baseline and future climate data from an ensemble of six general circulation models (GCMs), namely CMCC-CM, IPSL-CM5A-LR, MIROC5, MPI-ESM-LR, MPI-ESM-MR, and MRI-CGCM3, under the Representative Concentration Pathways (RCP) 4.5 greenhouse gas emission scenario, were retrieved and downscaled using delta method to represent climatic conditions under a number of climate policy scenarios and strategies in 2050s (2041-2060) and 2070s (2061-2080). Reliability index (RI), which is defined as the ratio between the total storage capacity of SFRs and total crop water demand, was calculated for the same baseline period and future time horizons. The result of suitability analysis showed that 35.72%, 15.40%, and 47.56% of the total land area were classified as moderately suitable, highly suitable, and not suitable, respectively, during the baseline period. Field validation also showed that 87% of the existing SFRs sites were located in moderately suitable areas, and the remaining 13% were situated in highly suitable areas. Projected mean annual rainfall in the province decreased by 90 mm and 70 mm in 2050s and 2070s, respectively. However, these changes in annual rainfall have no significant effect on the spatial distribution and extent of suitable areas for SFR. Also, reliability analysis showed RI values of 2.90, 3.25, and 2.91 for baseline, 2050s, and 2070s respectively. These values indicate that the potential water supply from SFRs is more than enough to meet the crop water demand. This study suggests that GIS can be an effective tool in evaluating potential areas for SFRs and other small-scale irrigation projects as well as in planning for future irrigation development.

1. INTRODUCTION

While the Philippines has been ravaged by myriad of disasters as it is situated in the most tropical cyclone-prone area, the country has been also endowed with a profusion of water resources to fuel and stabilize agricultural production. The country receives mean annual total rainfall that varies from 965 to 4064 mm (PAGASA, 2011). The projections of rainfall in 2030, 2050 and 2070 indicate that the precipitation will increase by 3.2%, 4.9%, and 5.7% on average, respectively (Dikitanan et al., 2017). However, one of the most pressing issues pertinent to the availability of water resources is the high variability of climate (Cinco et al., 2013; Stuecker et al., 2018). Climate change can further exacerbate the vulnerability of the country due to its geographic and archipelagic setting.

Although climate plays a vital role in agriculture, the interplay of factors unrelated to climate such as existing water management practices, technological advances and agricultural policies, reflects an immediate (Dikitanan et al., 2017) and more profound effect than those caused by climate on the performance of agricultural production (Bates et al., 2008). The expansion of irrigation base is often constrained by several factors, one of which is the existing biophysical setting and characteristics and setup of farms. Farms in the Philippines are mostly small-scale and fragmented, as these parcels of land have been divided and dispersed for inheritance of new generation of farmers (Dikitanan et al., 2017), with less than two hectares on average (Koirala et al., 2016) and commonly found in 0-3% slopes. Hence, the development and implementation of strategies and interventions to respond and build resilience to water scarcity, and climate variability must be done at all levels, especially at the basic unit. One of the most notable approach in building resilience on farm level is the adoption of on-farm water storage structures such as rainwater harvesting systems (Dikitanan et al., 2017).

Recent studies have highlighted the key features of a rainwater harvesting structure to address irrigation challenges at the present time horizon: water resources are made available for areas where there is no access to permanent streamflows and groundwater (FAO, 2014; Bitterman et al., 2016; Milkias et al., 2018) or with diminishing surface water (Adham et al., 2018), and increased availability of on-farm water during periods of low rainfall on farms with two hectares or less (FAO, 2014). Predominant systems and techniques employed to collect rainwater are not limited to tanks, concrete surfaces, small reservoirs, pits, bunds, ponds and even roofs of farm structures (FAO, 2014; Bitterman et al., 2016). With different forms tailored to address the need of water resources in varying settings and conditions, rainwater harvesting structures have been long implemented in arid, semi-arid and tropical areas. However, suitability assessment is important to anticipate high performance and success of rainwater harvesting structures.

In the Philippines, small farm reservoirs (SFRs) are small water impounding structures specifically tailored for on-farm rainwater collection and storage (Figure 1). Typically, SFRs, which can supplement irrigation for small and remote farms, have an area of about 300 to 2,000 square meters (WOCAT, 2017). With rainfall as one of the primary factors, it is therefore vital not only to determine the suitability and reliability of SFRs in the present but also to evaluate in the future time horizons. These aforementioned goals are the main objectives of this study**.**

Figure 1. Small Farm Reservoir located in Oriental Mindoro.

2. STUDY AREA

Oriental Mindoro lies in the eastern half of Mindoro Island, which is known as the seventh largest island in the Philippines. The province consists of 14 municipalities and has a total population of 844,059 as of 2015 (PSA, 2018). It has a total land area of approximately 4364.72 km^2, 52% of which are devoted to cultivation of crops, 22% are forest areas and 2% are built-up areas as of 2015. Almost 70% of the total population in the province is engaged in agriculture. Rice production in Oriental Mindoro is 420,465 MT/year in 2017, which accounts for 2.18% of the total national production (PSA, 2018).

Roughly having an almost equal share of mountainous lands, sloping areas and flat lands, where the irrigated rice areas are closely knitted, the diversified topography of the province play a pivotal role in a variety of complex land-water interactions. In addition, Oriental Mindoro soils are dominated mostly by clay and clay loam types. These soil types (clay and clay loam) have relatively high water-holding capacities of 1.4-2.1 mm/cm and 1.0-1.25 mm/cm, and slow infiltration rates of 4 mm/hr and 7.5 mm/hr, respectively (Oweis et al., 2012). Oriental Mindoro soils are nonetheless conducive for construction of small on-farm reservoirs as these soil types promote water storage. The land cover, elevation and soil texture maps are shown in Figure 2.

A baseline annual total precipitation of 2215 mm is observed in Oriental Mindoro using the historical records for the period of 1971 to 2000 mm. The maximum baseline seasonal rainfall of 894. 3 mm occurs from July to August, when the onset of wet season coincides. This rainfall is ultimately received by watersheds in Oriental Mindoro, including the watersheds surrounding Naujan Lake, which is the fifth largest lake in the Philippines and considered as a potent source of water for irrigation. Furthermore, the province receives an abundance of heat and solar radiation– favorable conditions for agricultural production in the area.

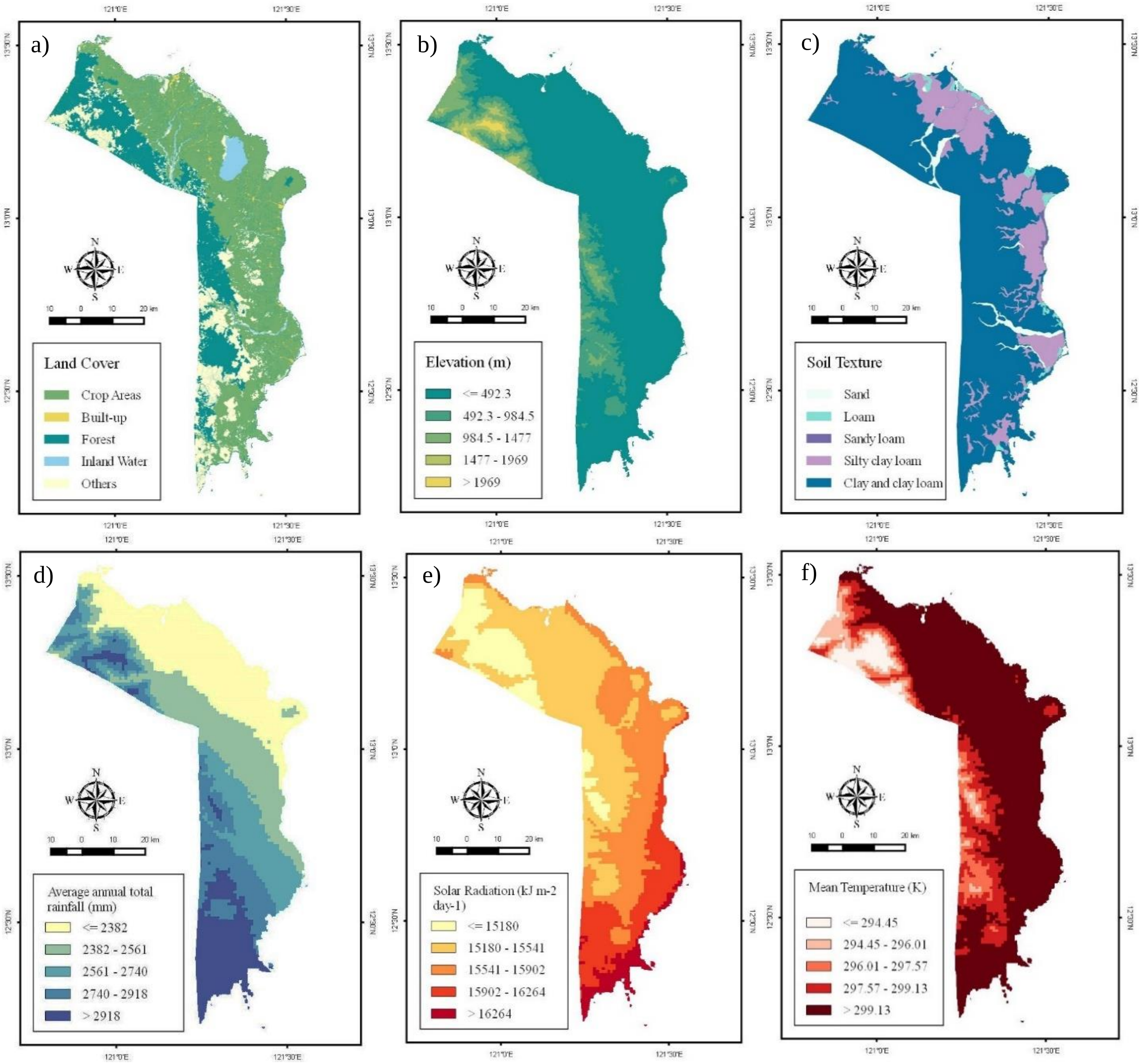

Figure 2. Land cover (a), Digital Terrain Model (DTM) (b), soil texture (c), average annual total rainfall (d), solar radiation (e), and mean temperature (f) maps of Oriental Mindoro.

3. SOURCES OF SECONDARY DATA

3.1. Present time horizon

The average annual total rainfall thematic map was derived from WorldClim (accessed from http://worldclim.org/version2) gridded monthly average rainfall datasets with a spatial resolution of 1 km and temporal coverage of 1970 to 2000 (Fick & Hijimans, 2017). The slope and soil texture thematic maps were derived from Interferometric Synthetic Aperture Radar (IFSAR) provided by National Mapping and Resource Information Authority, and land management unit maps provided by Bureau of Soils and Water Management (BSWM) under the Department of Agriculture (DA), respectively.

The potential evapotranspiration (PET) data, with spatial resolution of about 1 km, was obtained from the Consultative Group on International Agricultural Research – Consortium for Spatial Information (CGIAR-CSI). The dataset was modeled using the Hargreaves model, which uses mean monthly temperature (T_{mean}), mean monthly temperature range (TR) and top of atmosphere radiation (R_A), and represent the PET for the baseline period of 1970-2000 (Zomer et al., 2006). Hargreaves model requires less parameterization but provides good estimates of PET when compared to the estimates produced from using the Food and Agriculture Organization (FAO) Penman-Monteith (Hargreaves and Allen, 2003; Zomer et al., 2006).

$$PET = 0.0023 * R_A * (T_{mean} + 17.8) * TR^{0.5} \quad (1)$$

3.2. Future time horizon

The climate data for future time horizons was derived from the downscaled and bias-corrected General Circulation Models (GCM), which were obtained from Coupled Model Intercomparison Project (CMIP5). Rainfall, extraterrestrial radiation, and mean, minimum and maximum temperatures data in present condition, 2050s (2041-2060) and 2070s (2061-2080) were retrieved from an ensemble of six GCMs, as shown in Table 1, under the Representative Concentration Pathways (RCP) 4.5. RCP 4.5 is a stabilization scenario wherein a range of interventions and strategies for reducing greenhouse gas emissions takes into effect (Thomson et al., 2011). Using delta method, the changes were retrieved between the baseline and future time horizons and the changes were applied to the baseline high-resolution datasets to garner the projected climate with high resolution. Future projections of PET were also obtained by using the Hargreaves model to calculate representative values for all time horizons and downscaled by applying the changes on the baseline high-resolution data as well.

Table 1. General Circulation Models (GCMs) used in the study.

GCM	Name	Reference
CMCC-CM	Centro Euro-Mediterraneo sui Cambiamenti Climatici Climate Model	Scoccimarro et al. 2011
IPSL-CM5A-LR	Institut Pierre Simon Laplace Model	Dufresne et al., 2013
MIROC5	Model for Interdisciplinary Research on Climate	Watanabe et al., 2010
MPI-ESM-LR	Max-Planck-Institute Earth System Model	Giorgetta et al., 2013
MPI-ESM-MR		
MRI-CGCM3	Meteorological Research Institute – Coupled General Circulation Model	Yukimoto et al., 2012

4. SUITABILITY ANALYSIS

Several meteorological (e,g,, rainfall, and evapotranspiration), biophysical (e.g., land cover, land use, soil-texture, slope, and runoff) and socio-economical (e.g. accessibility to road) factors have been considered in the suitability analysis of SFRs. These set of factors are narrowed down depending on actual experiences and availability of data. With the use of RS and GIS as tools, data acquisition and processing are elevated for suitability analyses.

Average annual rainfall, soil texture and slope are among the factors considered in the assessment of suitability of rainwater harvesting structures, in general (Bhuiyan, 1994; Naseef & Thomas, 2015; Adham et al., 2016). In the Philippines, SFRs have been constructed in flat areas where the average annual rainfall exceeds 1,500 mm. However, the SFRs, like any other forms of rainwater harvesting structures, are most suitable in sloping land with undulating topography, and dominated by loam, sandy clay loam and clayey soils (Mugo, 2019). Sloping lands heightens runoff potential and the soils with slow infiltration rates and high water-holding capacities promote water storage from rainfall. These factors play an important role and govern the storage capacity and reliability of SFRs. During the national consultation of researchers and implementers of the nationwide mapping of small-scale irrigation projects (SSIPs), the suitability scales were assigned to each of the key factors, namely average annual total rainfall, slope and soil texture, and the criteria for evaluating the suitability for SFR development was established and shown in Tables 2 and 3.

Table 2. Suitability scales in each of the key thematic maps applied in suitability analysis.

Thematic map	Description	Suitability scale
Average Annual Total Rainfall (mm)	<1000 mm	1
	1000 mm – 1200 mm	2
	>1200 mm	3
Soil Texture	Sand, loamy sand, silt, sandy loam	0
	Silt loam	1
	Sandy clay loam and sandy clay	2
	Clay, clay loam, silty clay and silty clay loam	3
Slope (%)	>18%	0
	0-3%	1
	3-8%	2
	8-18%	3

Table 3. Suitability ratings and corresponding weighted scale range.

Suitability rating	Weighted scale range
Not suitable	0-0.5
Marginally suitable	0.5-1.5
Moderately suitable	1.5-2.5
Highly suitable	2.5-3.0

5. RELIABILITY ANALYSIS

Reliability analysis of rainwater harvesting structures was performed to determine the degree to which irrigation projects conform to the predetermined needs and expectations of the users (Renault & Vehmeyer, 1999). According to Adham et al. (2016), the ratio of irrigation demand and water supply available is a good indicator of rainwater harvesting structure reliability.

5.1. Crop water demand

If the precipitation is high, a large fraction of the water becomes part of the losses through percolation beyond the root zone and through surface runoff (FAO, 1978). The other fraction of water that is being absorbed by the crop root zone represents the effective fraction of rainfall. For this study, a simplified equation of the crop water demand was established as shown in Equation (3). The crop water demand (D) was garnered by obtaining the difference between the effective rainfall (R_E) and potential evapotranspiration (PET) for present and future time horizons. The estimates of effective rainfall were retrieved using the method of estimation developed by FAO-AGLW, as shown in Equation (2), that is a function of monthly total rainfall (P_{Total}) (Smith, 1992).

$$\begin{aligned} R_E &= 0.6P_{Total} - 10 \quad \begin{cases} P_{Total} \leq 70 \text{ mm} \\ P_{Total} > 70 \text{ mm} \end{cases} \\ R_E &= 0.8P_{Total} - 24 \end{aligned} \tag{2}$$

$$D = R_E - PET \tag{3}$$

5.2. Reliability Index

In this study, the reliability index (RI), which is the simplified ratio of the storage capacity of SFRs and crop water demand in service areas (A_{SA}), was garnered for present and future time horizons. The storage capacity of SFR is obtained by getting the product of the depth of rainfall (R) and total areas devoted to SFRs (A_{SFR}). A reliability index of at least one (1) indicates that the supply can suffice the demand for crop growth only, while a value lower than one indicates that the available water resources can only suffice a fraction of the demand. The equation for computing the reliability index was presented in Equation (4). In this study, it is important to emphasize that the demand garnered for the calculation of reliability index does not encompass all the water needs to compensate for all losses encountered in the course of crop production.

$$RI = \frac{R}{R_E - PET} * \frac{A_{SFR}}{A_{SA}} \tag{4}$$

6. SUMMARY OF GIS PROCEDURES

GIS features and packages provide cost-effective and quick tools for analysis of spatial data and derive information for various applications. Geographic Information Systems (GIS) and Remote Sensing (RS) have been employed to assess water resources and suitability of rainwater harvesting structures (Weerasinghe et al., 2011; Adham et al., 2016; Adham et al., 2018; Worqlul et al., 2018) and have transcended the limitations of traditional and fragmented approach. Quantum GIS (QGIS), which is an open-source GIS, was used as the primary GIS software for this study. The overall flowchart of the GIS procedures employed is shown in Figure 3.

6.1. Preparation of thematic maps

Raster data (.tif format) and vector data (.shp format) are two of the most common formats of data made available to the GIS community. The former is used in overlay analysis that is usually performed in suitability analysis involving two or more layers. The average annual total rainfall data (in .tif format), which was acquired from WorldClim, was clipped using the shapefile of the study region, and resampled to match the resolution of the available Digital Terrain Model (DTM) of the area. The slope distribution of the area was determined using the algorithm r.slope in QGIS and

DTM as input. On the other hand, the soil texture data obtained from the BSWM comes in shapefile (.shp) format, which requires editing of the associated attribute table prior to the rasterization.

6.2. Reclassification of data based on suitability scale

Each of the thematic maps was reclassified using the System for Automated Geoscientific Analyses (SAGA) values reclassification algorithm in QGIS with the established suitability scale as shown earlier in Table 2 as the basis. The assigned values were keyed in as decimal values (float) to reflect the precision required in the calculation of weighted average. The reclassified data of average annual total rainfall, soil texture, and slope are shown in Figure 4.

6.3. Overlay analysis and classification of suitability

Three conditions were met prior to the overlay analysis and reliability calculations using the Geospatial Data Abstraction Library (GDAL) raster calculator algorithm: all input layers must have the same pixel size, same raster extent, and same pixel alignment. The associated algorithms in QGIS were used to meet the conditions for the suitability and reliability analyses. The weights of each thematic map were keyed in the expression for the calculation involved in overlay analysis. The output values were reclassified according to its suitability rating and corresponding weighted scale shown earlier in Table 3.

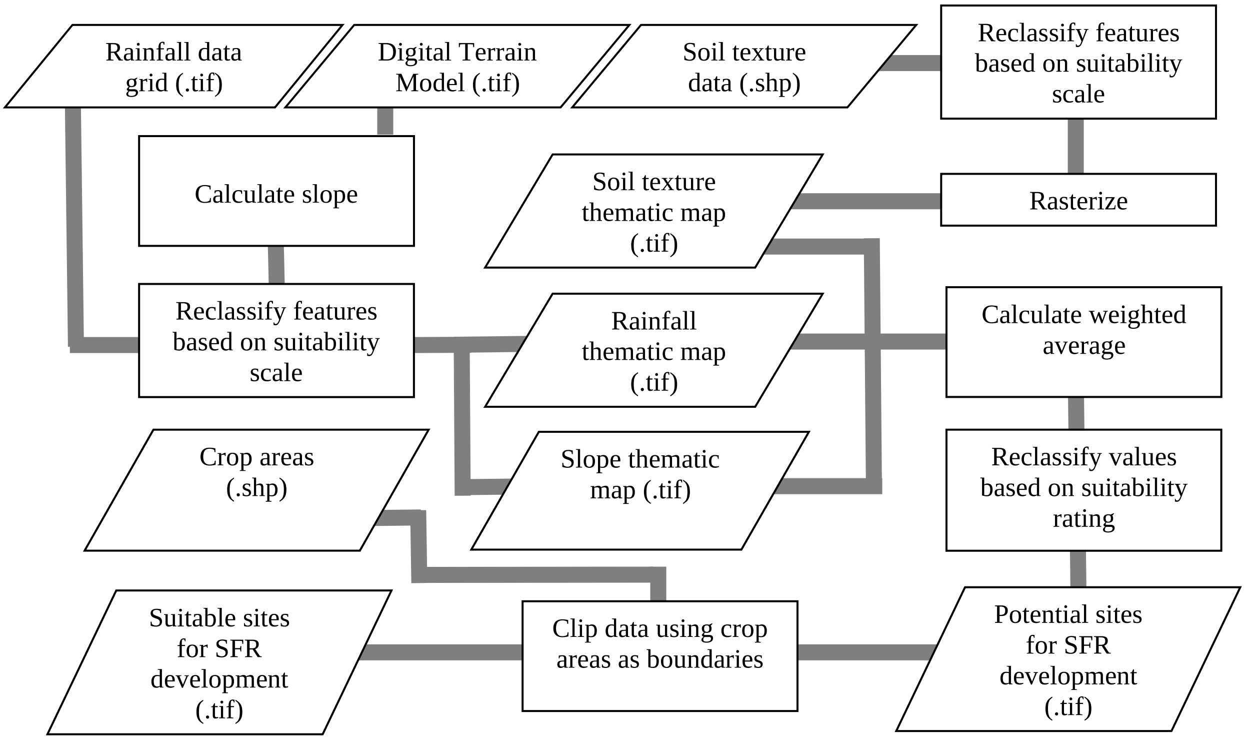

Figure 3. Overall flowchart of suitability analysis for SFR development in GIS.

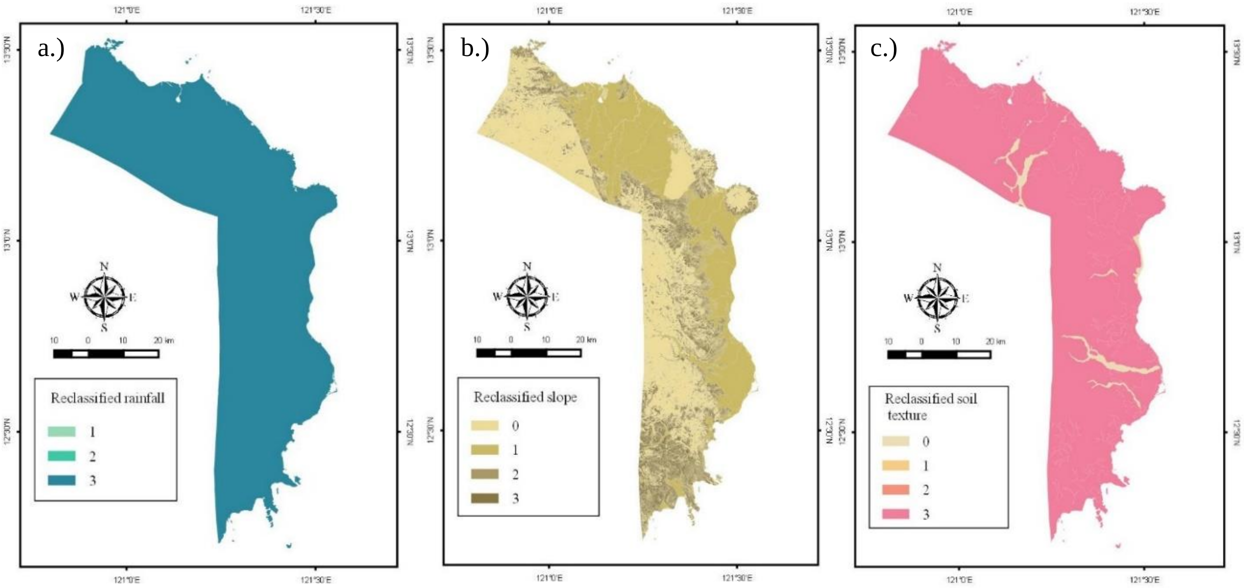

Figure 4. Thematic maps used in suitability analysis for SFR development: rainfall (a), slope (b), and soil texture (c).

7. RESULTS AND DISCUSSION

Most of the areas in the province are highly suitable in terms of average annual total rainfall and soil texture; the rainfall exceeds 1200 mm, and the province is dominated by soils with high water-holding capacity and slow infiltration rates, which promotes water storage. Hence, the spatial variability of the slope greatly influenced the variability of suitable areas. With an assumption that the soil texture and slope will not change significantly, considering the time horizons included in the study, the suitable areas will not change. It is known that Mindoro provinces are endowed with total precipitation of at least 2000 mm annually. The Climate Information Risk Analysis Matrix (CLIRAM) most recent provisions of climate projections indicate decrease in mean annual total rainfall by 186 mm from the baseline period in the mid-21st century (2036-2065) (DOST-PAGASA, 2018). However, the province still falls within the range of high suitability, in terms of rainfall. Hence, there will be no significant changes with the spatial distribution and extent of suitable areas.

7.1. Suitable areas for SFR Development

Figure 5 shows the suitable areas with corresponding suitability rating: not suitable, marginally suitable, moderately suitable and highly suitable areas. Basically, the areas not suitable for SFR development are non-agricultural areas (e.g., forest, built-up, and inland waters) and these areas constitutes 47.56% of the total land area. Since the average annual total rainfall bears the highest weight (40%) and the province registers high suitability in terms of rainfall, the crop areas are virtually suitable for SFR development with a large fraction (35.72%) rated as moderately suitable. Highly suitable areas, which reflects 15.40% of the total land area, are situated in undulating to gently rolling areas with slope range of 8-18%. Slope classes greatly influenced the spatial extent and distribution of highly suitable areas. While rainfall dictates the amount of supply, slope mainly governs the runoff volume and infiltration rates. Slope plays an important role in the selection of different forms of rainwater harvesting technologies (Mugo, 2019). The existing SFRs are included in the overlay to validate the results of the suitability analysis, also shown in Figure 5.

Table 4. Extent and the corresponding percentage of areas with different suitability ratings.

Suitability Rating	Area (km^2)	Percentage (%)	Existing SFRs (%)
Highly suitable areas	672.21	15.40	13
Moderately suitable areas	1,559.12	35.72	87
Marginally suitable areas	57.45	1.32	0
Not suitable areas	2,075.94	47.56	0

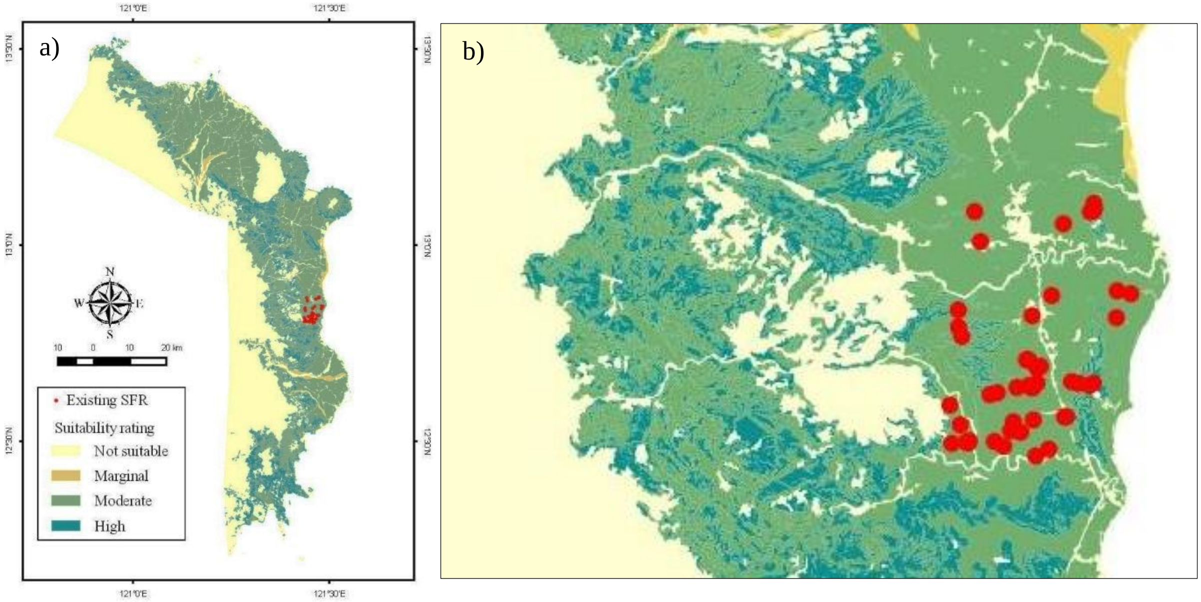

Figure 5. Suitability analysis for SFR development: suitability map showing existing SFRs (a), close-up of the area with existing SFRs (b).

Marginally suitable sites are located in areas dominated by sandy soils (e.g. beach sand, sandy loam, alluvial sands), which have fast rates of infiltration and low water-holding capacity. As seen from Figure 5, marginally suitable areas are located along the stretch of rivers and near the coastline. As shown in Table 4, in moderately suitable areas, 87% of the total existing SFRs are located, whereas, 13% of the existing total SFRs are in highly suitable areas. This study demonstrates the capability of using GIS tools and algorithms to accurately pinpoint areas where it would be suitable to construct SFR systems; it transcends the limitations of fragmented and traditional approach of identifying suitable sites that is arduous to implement.

7.2. Reliability of SFRs

It is of paramount importance to evaluate the influence of meteorological factors, such as rainfall, temperature and solar radiation, on water balance, specifically on the availability and consumption of water resources for crop irrigation. Considering the bearing of evapotranspiration and effective rainfall, a simplified approach of evaluating the reliability of SFRs was formulated and employed for this study. The reliability of SFRs in different time horizons was presented in Figure 6, with rainfall, effective rainfall and PET juxtaposed for comparison. All areas reflect a reliability index exceeding one (1), which means that the supply is more than the quantity demanded for crop growth consumption only.

Table 5. Comparison of reliability indices and associated parameters between present and future time horizons.

Parameters	Change (2050s - baseline), %	Change (2070s - baseline), %
Average annual total rainfall	-2.98	-2.60
Potential evapotranspiration	-0.50	-2.50
Effective rainfall	-2.98	-2.60
Reliability index	11.59	0.42

The reliability analysis showed RI values of 2.90, 3.25, and 2.91 for baseline, 2050s, and 2070s respectively. As seen in Table 5, the reliability indices of SFRs in the province increased by 11.6% and 0.42% in 2050s and 2070s, respectively, due to decrease in potential evapotranspiration and effective rainfall. Given that the service areas will not change across time horizons, crop water demand in the province constitutes about 34.48%, 30.86%, and 34.36% of the potential water supply from highly suitable SFR areas in baseline, 2050s and 2070s, respectively. It can be inferred as well that across the time horizons, roughly 65-70% of the remaining supply of water from the rainfall can be utilized to compensate for field and irrigation conveyance losses in crop production.

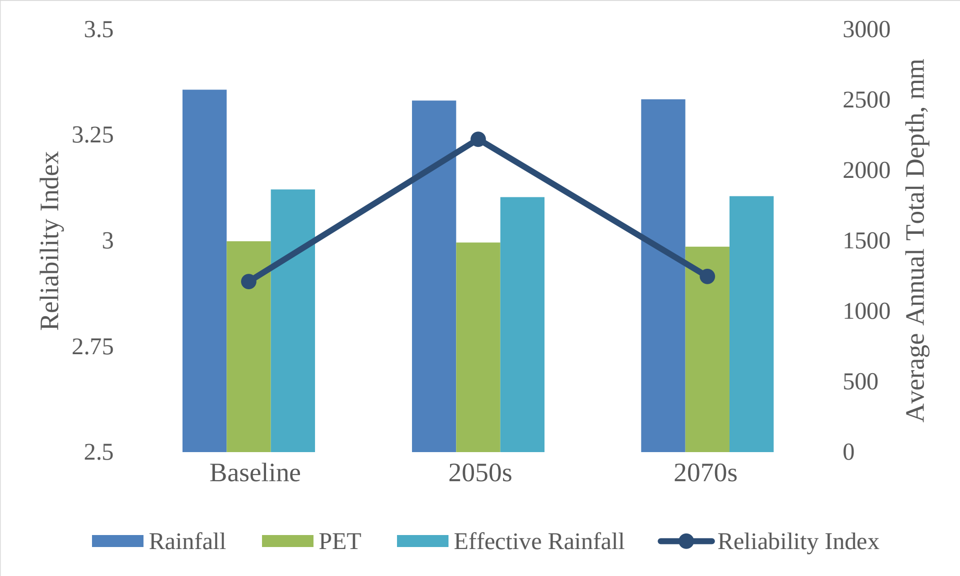

Figure 6. Reliability indices garnered using baseline and future climatic conditions.

8. CONCLUSION

One of the most pressing issues in the Philippines is the availability and distribution of water resources despite of the abundance of rainfall the country receives. The fragmentation of the farms further constrains the implementation of large-scale irrigation systems. The development of small farm reservoir (SFR), one of the small-scale irrigation projects (SSIPs) promoted in the country, addresses the irrigation needs of small farms even in the far-flung and remote areas within the slope ranges of 0-18%. This study analyzed the suitability and reliability of SFR in the province of Oriental Mindoro, considering the climatic conditions as well, in the baseline, and future time horizons, specifically 2050s (2040-2060) and 2070s (2060-2080). The suitability analysis showed that 15.40%, 35.72% and 1.32% of the total land area, constitutes the highly suitable, moderately suitable and marginally suitable areas for SFR development. The reliability analysis reflected RI values of 2.90, 3.25, and 2.91 for baseline, 2050s, and 2070s respectively. The RI of SFRs in the province increased by 11.6 % and 0.42% in 2050s and 2070s, respectively, due to decrease in crop water demand. The reliability analysis showed that the climatic conditions in the period of 2050s provide an opportunity to maximize the potential of SFRs; the crop water demand will only take about 31% of available supply of water resources. The capability and accuracy of GIS tools and algorithms were demonstrated in the results of the validation as 87% of the existing SFRs are moderately suitable and the remaining 13% are highly suitable.

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