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Assessing the Irrigability Index of Selected Irrigation Systems in Camarines Sur, Philippines

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Abstract: *Concerns about irrigation performance associated with water dependability and climate change threats to food security stress the need to evaluate water adequacy and understand climate impacts on irrigated environments. The study assessed the irrigability index of selected irrigation systems in Camarines Sur, Philippines. Geodatabases were processed in QGIS to determine the slope and soil-based potential irrigable areas and calibrated SWAT models simulated streamflow for water resources-based potential irrigable areas. Results revealed insufficient water in irrigation systems to support continuous flooding of service areas, especially during the dry season, highlighting vulnerability to water supply fluctuations. Climate change is projected to exacerbate water insufficiency issues. Low irrigability indices also limit further irrigation development despite high land suitability. The study recommends improving geodatabases, optimizing cropping calendars, and using water-saving technologies. The study's methodology and results can aid in irrigability index assessments and may serve as a reference in planning and managing irrigation projects.*

Keywords: irrigability index, irrigation, climate change, SWAT, GIS

1. INTRODUCTION

Rice is the staple food for Filipinos and is of immense economic, traditional, and political importance, making it an integral component of the country's food security and poverty alleviation plans. The government has heavily relied on irrigation as a policy instrument to boost agricultural production for the past decades, representing nearly a third of all public investments since the 1960s, with greater priority to the rice sector, accounting for at least two-thirds of public expenditure in agriculture and having the highest publicly funded irrigation projects [1], [2] [3]. However, these irrigation investments did not translate to a comparable cropping intensity and productivity, citing the lack of technical evaluation of available water resources and climate change as contributing factors [1], [3], [4].

The pressing concerns about the low performance of irrigation systems associated with water dependability prompted a collaborative effort to establish appropriate criteria for assessing the feasibility of the proposed irrigation projects, thus introducing the irrigability index (II), with higher values indicating greater feasibility. The irrigability index is the ratio of water resources-based potential irrigable area (WR-based PIA) to the slope and soil-based potential irrigable (SS-based PIA), which estimates the irrigable area based on available water resources and land suitability, respectively [5].

The data inputs to estimate the irrigability index can be processed using GIS software and hydrologic models. GIS-based software has been utilized to employ geospatial techniques for suitability mapping for the cultivation of crops [6], [7] and water resources assessment [8]. The Soil and Water Assessment Tool (SWAT) is a well-known hydrologic model that can simulate the quality and quantity of surface and forecast the environmental effects of land use, land management techniques, and climate change in watersheds using limited data [9]. Several studies have successfully utilized SWAT in the Philippines to model streamflow, assess the impacts of land use, land cover, and climate change on runoff and sediment yield, and simulate watershed and hydrologic responses for water resources management [10]–[15].

This study assessed the baseline and climate change scenario irrigability index of selected irrigation projects in Camarines Sur. Geodatabases were processed in QGIS to extract the SS-based PIA, calibrated SWAT models were used to simulate streamflow for WR-based PIA, and the projected change in rainfall and temperature under the Representative Concentration Pathway (RCP4.5) model from the Department of Science and Technology - Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA) were used to obtain the projected irrigability index for 2036-2065.

The methodology, results, and gaps identified in the study could help in performing irrigability index assessments, which primarily dictate the technical feasibility of irrigation projects. Its site-specific outputs may serve as a reference for systems design and planning, operation adjustments, and selection of technology options to mitigate possible effects of climate change. It can also serve as a localized basis for irrigation master plans.

2. MATERIALS AND METHODS

2.1 Study Areas

The study focused on Camarines Sur, a province in southeastern Luzon, located between 14°10' and 13°15' North Latitude and 124°10' and 122°40' East Longitude. It is the largest province in the Bicol Region, covering 526,682 hectares, and bordered by Quezon, Camarines Norte, San Miguel Bay, and the Pacific Ocean to the north; Albay to the south; Lagonoy Gulf to the east; and Ragay Gulf to the west. Camarines Sur has abundant natural resources and a high potential for rice production due to its substantial agricultural land and relatively high rainfall varying spatially at 2800 to 3300 mm annually.

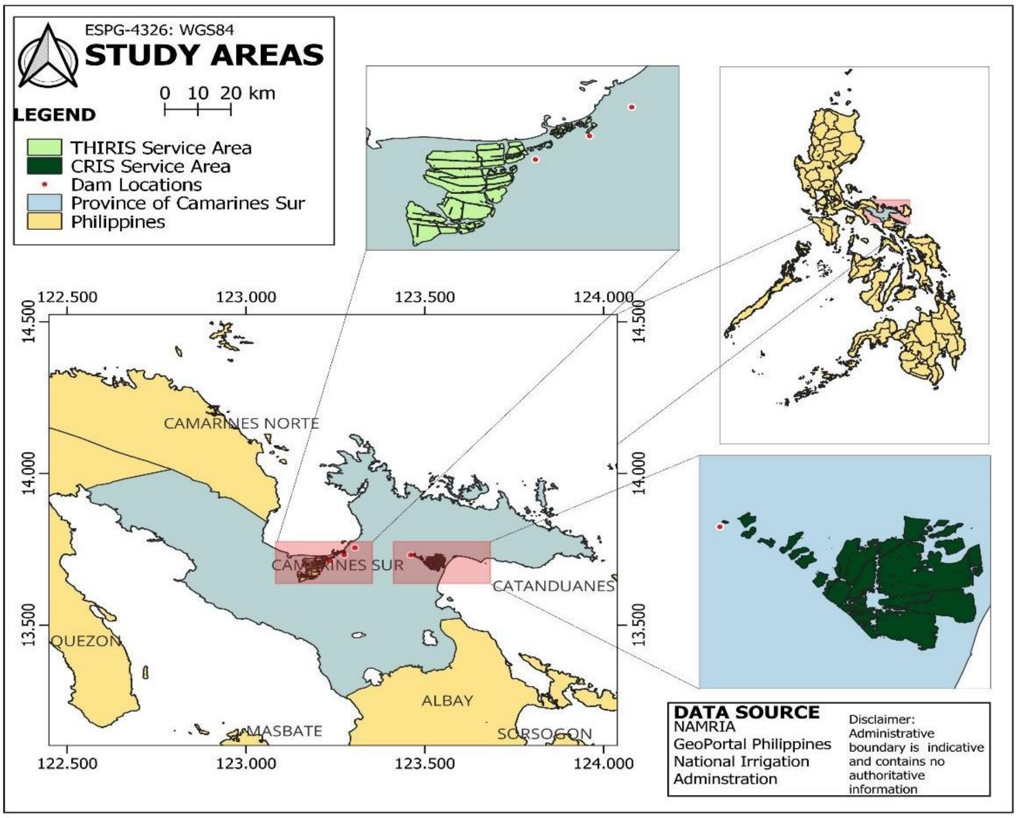

Fig 1. Location of study areas showing the service areas and dam locations.

The study areas are among the largest run-of-the-river irrigation systems in the province: the Tigman-Hinagyagan-Inarihan River Irrigation System (THIRIS) and the Cagaycay River Irrigation System (CRIS). The study assessed the baseline irrigability index in the two sites and evaluated the impact of climate change on CRIS as a representative site (see Figure 1).

2.2. Data and Pre-Processing

Geospatial data were used for hydrologic modeling and delineating potential irrigable areas. The Digital Elevation Model (DEM) was sourced from the National Mapping and Resource Information Authority (NAMRIA). Vector data were obtained from Geoportal Philippines, including soil maps, 2020 land cover maps, built-up areas, protected areas, areas with Certificate of Ancestral Domain Title (CADT), road and river networks, and administrative boundaries. Additional information, such as project briefs, technical descriptions, dam locations, service areas, parcel maps, and inventory of existing irrigation projects, were requested from the National Irrigation Administration (NIA).

In hydrologic modeling, data included rainfall, minimum and maximum air temperatures, relative humidity, net solar radiation, and streamflow records. Daily river discharge data from the Department of Public Works and Highways (DPWH) monitoring stations were used for model calibration and validation. However, the study faced challenges with the quality and reliability of streamflow records. In past modeling studies, outputs are often compared to observed data, assuming that observed values are error-free. Modeling evaluation statistics also recognized but did not provide recommendations on dealing with errors in measurement data, possibly due to the lack of literature on measurement uncertainty [16]. Such a case also applies to the modeling studies conducted here in the Philippines based on the literature reviewed for this research. In this study, a 20% expected measurement error was assumed for the calibration of the model. It is based on the visual checking and inspection of streamflow data and available information in related literature, such as [17] establishing an estimate for data uncertainty for streamflow measurement at 6-19% and [16] performance rating, modeled streamflow may be rated "good" if it is within 10-15% measured streamflow data of typical quality.

Weather data, including rainfall, air temperature, relative humidity, and wind speed, were sourced from the DOST-PAGASA agrometeorological station in CBSUA, Pili, Camarines Sur. While rainfall data were complete, other parameters had significant gaps, and net solar radiation was not measured in the weather station. Rainfall in the province also varies spatially, prompting the use of weather data from sources like Climate Hazards Group InfraRed Precipitation and Stations (CHIRPS) for rainfall, National Centers for Environmental Prediction - Climate Forecast System Reanalysis (NCEP-CSFR) for net solar radiation, and National Aeronautics and Space Administration (NASA-POWER) for air temperature, relative humidity, wind speed). These datasets were chosen for their accessibility, proven reliability in previous studies, and validation performed using the observed data from the agrometeorological station to enhance model performance.

2.3 SWAT Modeling

This study utilized the Soil and Water Assessment Tool (SWAT) to simulate streamflow using weather, soil characteristics, land cover, and topography of the area.

CRIS requires one watershed model, while THIRIS, supported by three dams, requires the development of three separate watershed models (see Table 1). The generated SWAT watershed reports from the final default models used in the study are presented in Table 2.

Table 1. Watershed models for each study area.

IRRIGATION SYSTEM/	WATERSHED MODEL
CRIS	Cagaycay
THIRIS	Hinagyagan, Inarihan, and Tigman

Model auto-calibration was carried out in the SWAT Calibration and Uncertainty Program (SWAT-CUP) using the Sequential Uncertainty Fitting (SUFI-2) algorithm, following the protocol outlined by [18], [19].

Table 2. Watershed reports for the final SWAT models.

PROPER-TY	WATERSHED			
	Cagay-cay	Hinagya-gan	Inari-han	Tigman
Size, has	4707	2019	3314	3308
Mean Elev, m	449	247	335	374
Slope Range (%)				
0-8	25.48	33.96	48.9	21.76
8-18, %	28.72	25.51	19.3	23.85
>18, %	45.81	40.53	31.81	54.39
Land use, (%)				
Forest	33.95	4.39	21.91	19.35
Agricultural land	51.18	84.35	72.55	74.60
Grassland	3.80	1.58	-	1.31
Shrubs	9.13	8.22	3.05	3.40
Urban	1.66	1.45	2.24	0.44
Water	0.28	-	0.24	0.90
Soil type, (%)				
Clay	-	20.3	95.3	18.35
Clay loam	56.6	79.7	4.7	81.65
Sandy loam	43.4	-	-	-

Only the Cagaycay and Hinagyagan rivers had gauging stations among the four watersheds studied. For ungauged rivers, the SWAT parameters regionalization was employed based on watershed characteristics derived from SWAT watershed reports. This regionalization or parameter transfer approach is supported by findings from various studies, which suggest that proximity and similar watershed characteristics are influential criteria for successful SWAT parameter regionalization. For instance, [20] highlighted the importance of geographic proximity and watershed similarity in parameter transferability. Watershed characteristics such as land use, soil type, and topography are critical in successfully regionalizing SWAT parameters [21]. [22] further documented these findings, demonstrating that regions with similar climatic and hydrological conditions can share calibrated parameters with minimal loss of accuracy.

2.4 Model Evaluation

The Nash–Sutcliffe model efficiency (NSE), RMSE-observations standard deviation ratio (RSR), Percent Bias (PBIAS), and statistical indices for stochastic models, P-factor and R-factor, were used to assess model performance.

SWAT calibrations involved optimizing the P-factor and R-factor while considering changes in NSE as the objective function. The P-factor represents the percentage of observed data within the 95PPU band, while the R-factor indicates the width of this band. It is recommended to achieve a P-factor ≥ 0.7 and R-factor ≤ 1.5 for river discharge [23], aiming to envelop observed data with minimal uncertainty [23].

2.5 Derivation of Water Resources Based Potential Irrigable Area

The WR-based PIA was determined by dividing the monthly dependable flow (by performing a Hydrologic Frequency Analysis in HEC-SSP) by the diversion water requirement. The diversion water requirement was computed based on criteria, recommendations, and guidelines from the NIA and the Philippine Agricultural Engineering Standards (PAES) [24].

2.6 Derivation of Slope and Soil Based Potential Irrigable Area

QGIS software was used to extract the SS-based PIA from the irrigation system's geodatabase, using the method adopted from [8] and [5] (see Figure 2).

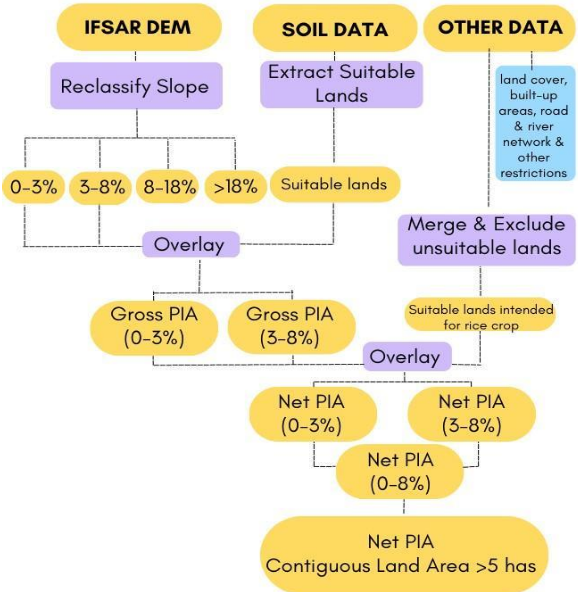

Fig 2. Methodological framework for processing the gross and net land-based potential irrigable area.

2.7 Climate Change Scenario Analysis

This study evaluated the impact of climate change on the irrigability index by focusing on the WR-based PIA in the Cagaycay River Irrigation System. The projected changes in rainfall and temperature for 2036-2050 under the RCP4.5 scenario from DOST-PAGASA were used relative to the baseline climate (1971-2000). According to PAGASA, the Philippines is already experiencing some of these projected changes, making this scenario a realistic comparison with the baseline and depicting an optimistic future with mitigated emissions [25].

3 RESULTS AND DISCUSSION

3.1 SWAT Initial Model

Initial models for the Cagaycay and Hinagyagan watersheds were evaluated using graphical analysis, NSE, and coefficient of determination (R^2) based on available river discharge measurements. Time series plots indicated that both models captured observed flow data trends and temporal behavior. However, they struggled to estimate the base flow, tending to overestimate peak flows and underestimate extremely high flows.

The uncalibrated models exhibited NSE values greater than 0, indicating better predictions than mean observed values. Both models showed similar R^2 values: 0.39 for Hinagyagan and 0.40 for Cagaycay, suggesting that approximately 40% of the observed data variability is explained by the models.

The promising performance of the initial models for Cagaycay and Hinagyagan underlines the effectiveness of applying the same dataset and modeling approach to two ungauged watersheds, providing valuable insights into their hydrological behavior.

3.2 SWAT Calibration and Validation

Calibration was conducted on the gauged Cagaycay and Hinagyagan watersheds. The outcomes of these calibrations were subsequently used as a reference for the Tigman and Inarihan Rivers. Table 3 presents the calibration and validation results, including P-factor, R-factor, NSE, PBIAS, and RSR. Figures 3-4 illustrate the 95PPU plots for calibrating each watershed.

Table 3. Statistical indices during performance evaluation of the SWAT calibrated models

	Cagaycay	**Hinagyagan**
Calibration		
P-factor	0.74	0.72
R-factor	0.77	0.75
NSE	0.45	0.45
PBIAS	10	-0.5
RSR	0.75	0.74
Validation		
P-factor	0.77	0.77
R-factor	0.91	0.99
NSE	0.53	0.32
PBIAS	-0.5	15
RSR	0.69	0.82

The final SWAT calibrated models yielded NSE below 0.5 and RSR above 0.70, while PBIAS values from -1.7% to 10%. The Cagaycay model improved significantly from 0.01 to 0.45, indicating substantial improvement of watershed parameters in model performance. Initially, the Hinagyagan River model already showed adequate performance with an NSE of 0.39, which improved to 0.45 post-calibration. However, both NSE and RSR values fell outside the "satisfactory" calibrated model thresholds (NSE > 0.50, RSR < 0.70) defined by [16].

This suggests that factors beyond the physical watershed parameters included in the model may affect the fit between simulated and observed data. Such factors could include point sources like springs that consistently recharge streams or the presence of upstream reservoirs and dams. It's important to note that many SWAT modeling studies, including those reviewed in this research, often operate with minimum required datasets due to data limitations in the Philippines. Faced with similar constraints, the decision was made to accept the model rather than adjusting parameters to meet subjective satisfactory criteria that may not account for missing components in the physical model.

Furthermore, NSE values can be subjective and influenced by data characteristics such as magnitude, number of points, outliers, and repetitions [26]. These considerations are critical for interpreting results, as both high and low flows are included in the study's calibration and validation datasets. Issues may arise when optimizing and comparing NSE across basins with diverse seasonal and dynamic characteristics [27]. Also, despite [16] defining thresholds for NSE and RSR, these indices are interrelated as NSE is the same as $1\text{-}RSR^2$ [27].

With accelerated land use changes and disturbances, the deterministic approach in modeling—focused on comparing observed and simulated values—has become increasingly challenging. Goodness-of-fit criteria like NSE, RSR, and PBIAS may not fully capture complexities introduced by these changes and uncertainties in input data (e.g., rainfall, weather, land use, soil) and measurement errors (e.g., sediment and river discharge) [23].

To assess model performance, P-factor and R-factor were used to describe the simulation results. The calibration and validation process successfully enclosed at least 70% of observed data within the 95PPU band. Average P-factor and R-factor values achieved were within the recommended thresholds (>0.70 and <1.15, respectively).

Despite the models' limitations, they showed significant improvement compared to the initial model, considering inherent uncertainties. This improvement reflects meaningful calibration and enhances their ability to simulate hydrological processes, thereby rendering them valuable for subsequent analyses in this study.

Table 4 presents the calibrated parameter ranges for the watersheds modeled in this study. Parameters from the Cagaycay and Hinagyagan watersheds were applied to the Tigman and Inarihan watersheds, respectively, due to their proximity and similar watershed characteristics (see Table 2).

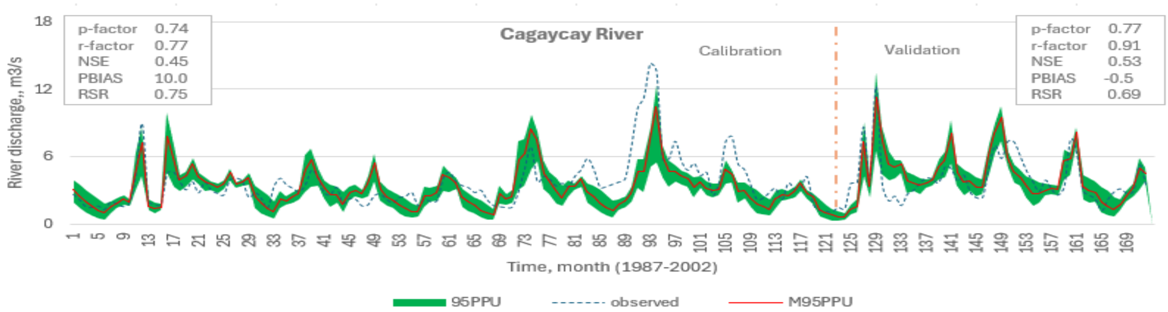

Fig 3. 95PPU plot of observed and simulated streamflow from calibrated Cagaycay watershed model

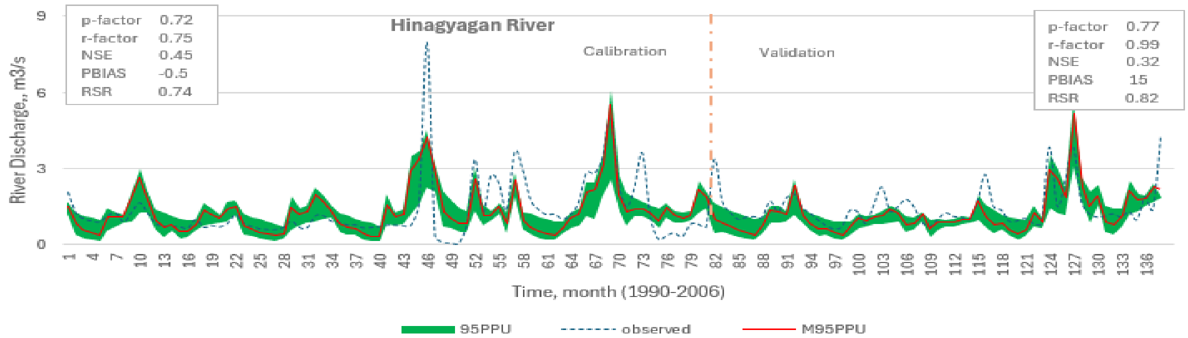

Fig 4. 95PPU plot of observed and simulated streamflow from the calibrated Hinagyagan watershed model

Table 4. Calibrated SWAT parameters

Parameter	Cagaycay		Hinagyagan	
	Min	Max	Min	Max
*CN2.mgt	-0.25	0.01	-0.13	0.008
**GWQMN.gw	180	760	317	1038
**REVAPMN.gw	810	1550	425	808
**GW_DELAYgw	5	95	22	141
**ALPHA_BF.gw	0.59	0.78	0.53	0.84
**RCHRG_DP.gw	0.7	1	0.65	1
**ESCO.hru	0.61	1	0.68	1
*OV_N.hru	0.08	0.22	0.02	0.2
*SLSUBBSN.hru	-0.08	0.15	-0.09	0.15
*HRU_SLP.hru	-0.1	0.13	-0.46	-0.13
**LAT_TTIMEhru	38	72	38	71
*SOL_AWC().sol	-0.1	0.3	-0.32	-0.05
*SOL_K().sol	-0.1	0.3	-0.4	-0.1
*SOL_BD().sol	-0.23	0.07	-0.23	0.07
**CH_N2.rte	0.15	0.3	0.15	0.29
**CH_K2.rte	60	100	59	100
**ALPHA_BNKrte	0	0.5	0	0.44
**SURLAG.bsn	10	22	9.94	21.84
**EPCO.bsn	0.61	1	0.6	1

Type of change: * relative, **replace.

Moreover, Global Sensitivity Analysis revealed that CN2 (SCS Runoff Curve Number), GW_DELAY (Groundwater Delay, days), SOL_BD (Moist Bulk Density), and RCHRG_DP (Deep Aquifer Percolation Fraction) are the most sensitive parameters at a 5% level of significance for both calibrated models for the Cagaycay and Hinagyagan watersheds.

3.3 Water Resources Based Potential Irrigable Area

The potential irrigable area was determined using the monthly dependable river flow and calculated irrigation water requirements; the provincial average varies from 1.39 to 1.57 lps/ha under various cropping calendars. Cropping calendar optimization revealed that both irrigation systems can cater to larger service areas if planting for the wet season starts in the 1st week of June and the harvesting period starts in the 3rd week of September. Meanwhile, for the dry season, planting should begin during the 1st week of December, and the harvesting period should start in the 3rd week of March. Table 5 shows the WR-based PIA under the optimum cropping calendar for each irrigation system.

Table 5. WR-based PIA for each irrigation system considering the optimum cropping calendar.

Irrigation System	Wet season, has	Dry season, has
THIRIS	2985	2274
CRIS	1915	1873

3.4 Slope-Soil Based Potential Irrigable Area

Based on the suitable slope and soil for a rice-based cropping system, the net potential irrigable of THIRIS and CRIS stands at 4,246 and 2,270 hectares, respectively.

Table 6 compares the recorded firmed-up and the derived net potential irrigable area with at least 5 hectares of contiguous area for each irrigation system. The derived net potential irrigable area exceeds the recorded firmed-up service areas.

Table 6. Comparison of firmed-up service area and derived net potential irrigable area for each irrigation system.

Irrigation System/Project	Firmed-Up Service Area	Derived Net PIA using System's Boundary
THIRIS	3,604.0	4,246.0
CRIS	2,010.0	2,270.0

This suggests that areas within the vicinity of the irrigation systems meet the criteria for potential development but have not yet been utilized for rice cropping, are not yet irrigated, or are not yet covered by the irrigation systems' service area. The higher net potential irrigable area indicates a broader potential for irrigation development beyond the current service area.

3.5 Baseline Irrigability Index

The ratio of the WR-based PIA to the SS-based PIA (using the firmed-up service area) for each site was used to express these components as an irrigability index (see Table 7). The higher the value, the more technically feasible the site is based on water availability and land suitability, assuming a rice-based cropping system and continuous flooding irrigation scheme.

Table 7. Calculated irrigability Index

Irrigation System	Wet Season	Dry Season
THIRIS	0.83	0.63
CRIS	0.95	0.93

Both irrigation systems registered an irrigability index of less than 1, indicating that the water resources available are insufficient to irrigate the designed firmed-up service area under continuous submergence conditions. Irrigability indices also exhibited a decline during the dry season, indicating the vulnerability of irrigation systems to variations in water availability. Similar situations have been documented in recent studies of other national irrigation systems in the country [28], [29].

The high irrigation water requirements for land preparation, particularly at the start of the wet season, prompt the adoption of asynchronous cropping calendars. Controlled irrigation through rotational water delivery is also practiced during the dry season. However, the impacts of these practices on irrigation system performance and yield response have not yet been optimized or fully determined.

Furthermore, the indices obtained are only based on the designed firmed-up service area. Therefore, expansion is not recommended despite the high land suitability evidenced by higher SS-based PIA. These issues on water sufficiency were proven to continue under climate change scenario analysis conducted in this study.

3.6 Irrigability Index Under Climate Change Scenario

The average irrigability index in the Cagaycay River Irrigation System is projected to decline from 0.94 to 0.79 (Table 7). This reduction is attributed to decreased rainfall and streamflow and increased evapotranspiration due to rising mean temperatures. The monthly dependable flow derived from SWAT-simulated streamflow generally reflects the trend of projected changes in rainfall and the effect of rising mean temperatures.

Table 7. Comparison of baseline and climate change scenario irrigability index of CRIS

Scenario	WR Based PIA, has		Irrigability Index	
	Wet Season	Dry Season	Wet Season	Dry Season
Baseline	1915	1873	0.95	0.93
RCP4.5	1498	1680	0.75	0.84

Figure 5 compares monthly dependable flow for the baseline and climate change scenario in Cagaycay River and the monthly effective rainfall and potential evapotranspiration in the service area of the irrigation system.

Dependable flow for the June-July-August (JJA) and September-October-November (SON) seasons is projected to decrease from 5.5 to 5.1 m^3/s and 9.6 to 9.5 m^3/s, respectively. The JJA season is projected to be the driest, with a 17.6% decrease in seasonal rainfall and the highest temperature increase of 1.2°C. This is the primary reason for a larger decline in the irrigability index during the wet season compared to the dry season. The 2.5% decrease in rainfall will also cause a minimal reduction in streamflow during the SON season.

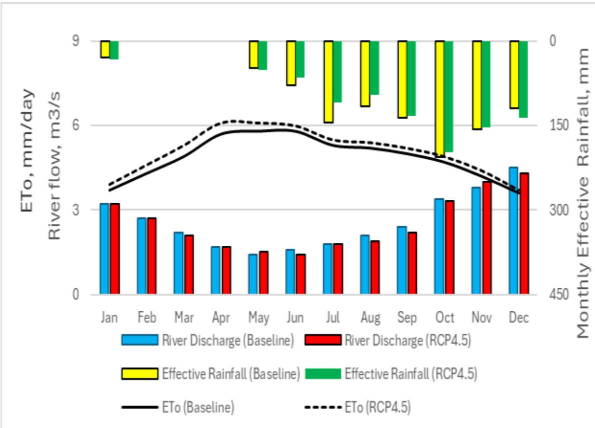

Fig 5. Comparison of baseline and climate change scenario monthly dependable, and ETo and Effective Rainfall flow in Cagaycay River Irrigation System

Almost no change is observed in the March-April-May (MAM) season streamflow. However, rainfall is projected to increase by 5.5%. Despite a 13.3% projected increase in rainfall for the December-January-February (DJF) season, the dependable flow is expected to decrease slightly from 10.4 m^3/s to 10.2 m^3/s. It should be noted that the projected increase in rainfall is primarily due to extreme events by the end of the year, with rising temperatures potentially influencing this behavior. These conditions, coupled with a projected increase in diversion water requirements from 1.25 to 1.38 (lps/ha), resulted in a lower water resources-based potential irrigable area, reflected in the irrigability index of the irrigation system.

4. SUMMARY, CONCLUSION AND RECOMMENDATIONS

The study assessed the irrigability index of selected irrigation systems in Camarines Sur, Philippines, namely the Tigman-Hinagyagan-Inarihan River Irrigation System (THIRIS) and the Cagaycay River Irrigation System (CRIS). The irrigability index is a criterion used to assess the technical feasibility of irrigation projects, considering the available water resources and land suitability. It is the ratio of the water resources-based potential irrigable area (WR-based PIA) to the slope and soil-based potential irrigable area (SS-based PIA). The higher the value, the more technically feasible the project is.

Considering the recorded firmed-up service areas, both sites registered irrigability indices of less than 1 and further declined during the dry season. This indicates that the water resources available for irrigation are insufficient to support the service area under a continuous flooding irrigation scheme. The low irrigability indices also further limit irrigation development despite the high land suitability evidenced by the higher derived SS-based PIA compared to the actual service areas.

In the case of limited water resources, efficient water utilization is crucial. The study recommends adopting the optimum cropping calendar presented in this study, enhancing farm practices and precise irrigation scheduling by evaluating the effectiveness of the irrigation systems' water delivery schedule, particularly on yield response. Irrigation program implementers should also consider the appropriateness of Alternate Wetting and Drying (AWD), dry seeding, and other water-saving technologies to increase water productivity. These technologies are well documented as effective ways to increase water productivity, especially given the case of excessive water use in irrigation and coping with water scarcity applicable to varied environmental conditions and rice cultivars [30]–[33]

Such issues with water sufficiency are projected to worsen under a climate change scenario, as the average irrigability index of the Cagaycay River Irrigation System is projected to drop by 15.8%. This reduction is attributed to decreased rainfall and streamflow and increased evapotranspiration due to rising mean temperature.

Furthermore, other regions may adopt the methodology of the study in the conduct of irrigability assessments, and weather data from sources such as CHIRPS, NCEP-CSFR, and NASA-POWER may be used as an alternative in case of lack of measured weather data. Regionalization or transfer of SWAT parameters may be employed to calibrate ungauged watersheds; however, studies with focus and in-depth analysis on calibration protocols and regionalization of SWAT parameters are recommended as a research area, as hydrologic modeling in the region is constrained by the availability and reliability of data, particularly streamflow data. The irrigation program implementers should improve the geodatabase of irrigation projects, including mapping service areas, and establish a collaborative information system for effective planning implementation and utilization of available resources across multiple projects.

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