Suitability Evaluation of Existing Agrometeorological Network in Luzon, Philippines Using GIS-based Analytical Hierarchy Process (AHP)

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Suitability Evaluation of Existing Agrometeorological Network in Luzon, Philippines using GIS-based Analytical Hierarchy Process (AHP)

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Abstract: *Weather and climate data are among the most valuable information for agricultural operations. The dearth of existing agrometeorological stations is not a new issue, particularly for developing countries. This study evaluated the suitability of the agrometeorological stations based on different expert-consulted criteria and was subjected to Analytic Hierarchy Process (AHP) Analysis. The results suggest that most (10 out of 13) of the existing agrometeorological stations are between marginal to moderate suitability levels and none has reached the highly suitable mark which implies possible inaccuracies in observed data due to their inherent location. Further evaluation reveals that only 26.47% of the land area over Luzon has the potential to be a suitable site for future stations with a maximum possible suitability level of 3.4. This study aids in a sound strategic site selection for agrometeorological stations which serve a crucial role in elevating agricultural practices in different agroclimatic zones over Luzon.*

Keywords: AHP Analysis, GIS, agrometeorological network, suitability, decision-making.

1. INTRODUCTION

The agricultural sector is at the front seat of climate change and its corresponding impacts. It is highly dependent upon climatic and weather parameters which define the overall agricultural operations. The prevailing climate and weather conditions are also intricately connected to the utilization of natural resources, such as the amount and schedule of irrigation. The driving variables for plant growth e.g., photosynthetically active radiation, radiation use efficiency, rainfall, and even humidity that can induce favorable conditions for pests and diseases, and management practices such as cropping calendar, optimum date of harvest, and application of fertilizer, were also weather-related such as the availability of [1, 2, 3, 4].

Weather and climate information have long been recognized to be among the most important parameters in agricultural services that directly dictate farming activities through forecasts and bulletins regarding mitigation measures in preparation for seasonal climatic variations such as the occurrence of El Niño and La Niña phenomena [5]. Other microclimatic variables are also important in mainstreaming global warming impacts. By and large, the measurement of agrometeorological parameters is primarily concerned with crop production. Phenological stages of crops can be expressed in simple degree-day concept to an ensemble of agrometeorological indices [6, 7]. Farmers are the most vulnerable to climatic extremes and disasters. Reliable agrometeorological data provides appropriate, accurate, and timely, information not only enables them to modify cropping practices to survive meteorological extremes but also, good agrometeorological data can serve as auxiliary data in the allocation of adequate government subsidy and crop insurance claims. All of which revolve around the availability of an agrometeorological station.

While the main purpose of agrometeorology as a discipline involves the collective application of biometeorological and hydrological principles for agricultural production [8]. Many of the parameters being measured are also important for environmental and other engineering disciplines. The design of irrigation structures highly depends on the computation of crop water requirement which serves as the demand for water in growing crops, and the availability of water supply [9]. Crop water use or evapotranspiration can be estimated using variables derived from agrometeorological observations, from simple temperature-based equations up to more complex aerodynamic and energy balance relationships such as the Penman-Menteith Equation [10]. Agrometeorology, in essence, collects biosphere information essential to support crops, livestock, and even human lifestyle. WMO [11] presented such a description more technically, mainstreaming the role of agrometeorological stations in observing the biophysical and environmental variables. This is highly beneficial for agricultural-intensive countries like the Philippines.

Staple crops such as rice and corn are largely produced in Luzon. However, there are only a few existing agrometeorological stations that serve the previously mentioned services. This is not unusual since it was already reported by various accounts which presents the challenge due to the scarce network of agrometeorological stations, especially in developing countries [12]. Lack of financial support is among the leading causes of inadequate numbers of agrometeorological stations which translates to discrepancies in weather forecasts which prompt trust issues from farmers' point of view [13]. However, agrometeorological services are recognized to be a cornerstone in both agricultural productivity and environmental concerns [1]. For climate-vulnerable countries like the Philippines, agrometeorological stations are of high value.
Currently, there are very limited studies that explore possible selection criteria in selecting suitable sites for agrometeorological stations [12] which uses a geographic information system (GIS)-based framework in deriving

optimum locations mainly based on WMO guidelines. So far, none has attempted to evaluate the existing agrometeorological station settings regarding its suitability based on recommended site selection criteria. This study was conducted to evaluate the existing agrometeorological stations over Luzon in the Philippines concerning their current level of suitability and to recommend sites for future installation of stations in improving the agrometeorological network in Luzon. Saaty's Analytic Hierarchy Process (AHP) [14] coupled with GIS techniques was employed to estimate the corresponding weights of suitability indicators. This was carried out to capture the importance of each criterion relative to another.

2. METHODOLOGY

2.1. Study Area

This study was conducted over Luzon in the Philippines where 45.5% of the national value of the production in agriculture and fisheries is attributed [15]. Luzon has the major production of staple crops of rice and corn particularly in the vast agricultural landscapes of Central Luzon and the Cagayan Valley Region.

2.2. Framework of the Study

Fig. 1. presents the process framework observed in the study. The different criteria were selected based on WMO guidelines [11] and existing related literature. The pre-assessment and analysis including raster conversion, reclassification, and raster calculation were conducted in a GIS environment.

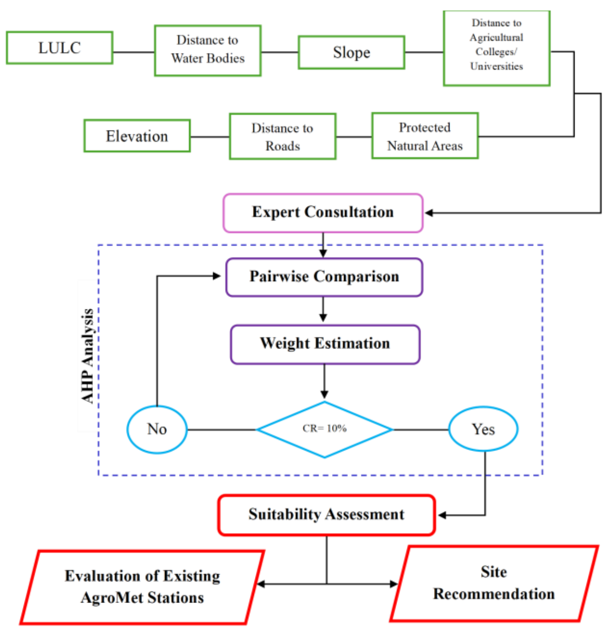

Fig. 1. Framework of the Study

2.3. Selection of Suitability Criteria

The main literature for this study was the general guidelines for selecting agrometeorological station sites provided by the WMO [11]. These guidelines were initially used by Alejo [12] in the Philippines to identify agrometeorological location sites in the Visayas region using a direct-indices consolidation. The criteria of Rojas Briceño [17] in selecting weather stations using AHP were also adopted in this study with emphasis on those that are relevant for identifying the most feasible locations for agrometeorological stations that differ from other weather stations.

2.4. Data Acquisition

2.4.1. Land Use/ Land Cover (LULC)

The latest 2020 LULC map was acquired from the GeoPortal website, an open-access platform for geospatial information in the Philippines, maintained by the National Mapping and Resource Information Authority (NAMRIA).

2.4.2. Slope and Elevation

The slope and elevation data were derived from the open-sourced Shuttle Radar Topography Mission (SRTM) DEM data with a spatial resolution of 30 meters.

2.4.3. Protected Natural Areas

The data for protected natural areas was acquired from the World Database on Protected Areas (WDPA) [, a collaboration of the United Nations Environment Programme (UNEP) and the International Union of Conservation of Nature (IUIC) which is also an open-access platform that provides spatial data for marine and terrestrial protected areas.

2.4.4. Water Bodies

The water body features from the LULC data were utilized to derive the distance from water bodies.

2.4.5. Road Networks

The main road networks over Luzon were sourced from the DIVA-GIS website and the available road network shapefiles from GeoPortal website.

2.4.6. Agricultural Colleges/Universities

The locations of different agricultural/state colleges and universities across Luzon were initially extracted manually using Google Earth and BatchGeo website.

2.4.7. Agrometeorological Stations

The list of existing agrometeorological stations in Luzon was requested from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), particularly from the Climatology and Agrometeorology Division,

2.4.8 Generation of the Thematic Maps

The different criteria were subjected to reclassification analysis to group the respective values according to the criteria scoring (Table 1) adopted from the AHP study of Rojas-Briceño [17], 4 being the most preferred values and 1 being the least.

Table 1. Suitability Criteria Scoring [17]

Criteria	(4)	(3)	(2)	(1)
Elevation (m.a.s.l.)	2200-4900	1090-2200	120-1090	-
Terrain Slope	≤5%	5-15%	15-25%	≥25%
LULC	40	20,30,60	>100	0, 50, 80, 90
Distance to Water Bodies	≥1km	0.5-1km	0.25-0.5km	≤0.25 km

Criteria	(4)	(3)	(2)	(1)
Distance to Roads	0.3-0.7km	0.7-1.2km	1.2-2.2km	≤0.3 /≥
Distance to SUC	≤10km	10-50 km	50-100 km	≥100km
Protected natural areas	Inside	Outside	-	-

Criteria:
4 = Highly Suitable;
3 = Moderately Suitable;
2 = Marginally Suitable;
1 = Not Suitable

For LULC:
0 = No Data; 20 = Shrubs, 30 Herbaceaous Vegetation; 40 = Cropland; 50 = Built-up areas; 60-Barren/sparse vegetation; 80 = Water bodies; 90 = Wetland; >100 = all forests

2.5. Analytic Hierarchy Process (AHP) Analysis

The AHP method is a multi-criteria decision analysis that has been widely employed coupled with GIS to establish sound estimates of weights for each suitability criterion. A thorough consultation among professionals and experts in agrometeorology and related fields was conducted to professionally guide the pairwise comparison of the different criteria. The pool of experts consulted includes professors, doctorate and master's degree holders, weather bureau personnel, and agricultural and hydrological researchers.

Table 2 shows the scale for pairwise comparison among the different suitability criteria. The comparison matrix will be normalized to compute the corresponding weights of the criteria.

Here, the pairwise comparison matrix *A* is represented by a_{ij} or the ratio that shows that criteria *i* has higher or lesser importance than criteria *j*.

$$A = [a_{ij}], i, j = 1, 2, 3, \ldots\ldots, n \quad (1)$$

The weighting coefficient vector was acquired using the maximum eigenvalue (λmax) of matrix *A*.

Table 2. Scale of Relative Importance [14].

Intensity of Importance	Definition
1	Equal Importance
2	Weak or Slight
3	Moderate Importance
4	Moderate Plus
5	Strong Importance
6	Strong Plus
7	Very Strong or Demonstrated Importance
8	Very, Very Strong
9	Extreme Importance
Reciprocals	If criteria *i* has one of the above non-zero numbers assigned to it when compared to criteria *j*, then *j* has the reciprocal value when compared to *i*
1.1-1.9	If the activities are very close

Similarly, the λ_{max} is also utilized to compute for the consistency index (CI):

$$CI = (\lambda max - n)/(n - 1) \quad (2)$$

where n is the total number of suitability criteria in the pairwise matrix.
The reliability of the pairwise comparison matrix was evaluated using the consistency ratio (CR) concept which is simply the ratio of the CI and the random index (RI) based on the structure of the created pairwise matrix *A*. If the CR value is greater than 10%,

$$CR = CI/ RI \quad (3)$$

As a standard, CR ratio should be less than less than or equal to 0.1 (10%)

3. RESULTS AND DISCUSSION

In this study, the resulting CR-value of 6.7% implies an acceptable pairwise comparison among criteria. Hence, the generated weights of the different criteria can be considered reliable. The corresponding rank and weight of the suitability criteria are presented in Table 3.

Table 3. Generated Weights of Suitability Criteria

Suitability Criteria	Priority
LULC	30.80%
Distance to Water Bodies	20.10%
Slope	19.00%
Distance to Agricultural Colleges/Universities	10.40%
Elevation	8.60%
Distance to Roads	6.20%
Protected Natural Areas	4.80%

LULC is by far the most important criterion that heavily influences the suitability of agrometeorological stations. This is reasonable since agrometeorological stations should be strategically placed in agricultural production areas. LULC is also a good initial indicator of what surface features should be discarded immediately during site selection since the variability in land cover features influences hydrological processes [18] that can also induce weather and climate variability. The distance to water bodies and slope criteria were almost identical at about 20% having farther from water bodies to be more favorable so that the data to be acquired is largely a representative of the production or plantation areas and not a water body which may induce large variability in measurements since it does not reflect the general land-vegetation-atmosphere continuum. The resulting suitability map is presented in Fig. 2.

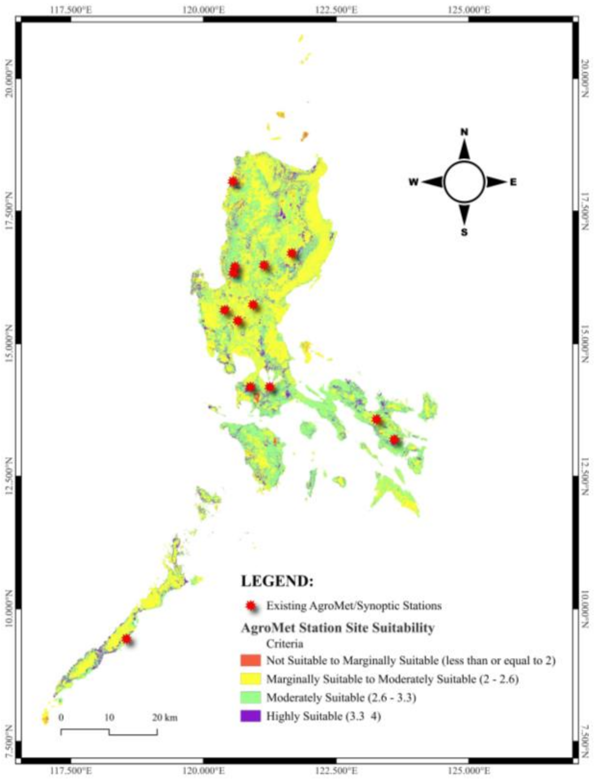

Fig. 2. Suitability Map for Agrometeorological Stations.

The WMO manual [11] recommended locating agrometeorological stations within the vicinity of an agricultural and allied college/universities if they represent important agricultural, plantation forests, and other production areas. The results of the study only place the criteria in the middle. The other criteria were found to be smaller when taken into separate accounts but still contribute to the overall weight of suitability indicators.
A thorough inspection of the figure points out the large weight attributed to both slope and LULC. While beyond the buffer distance of water, bodies indicate more favorable conditions. WMO [11] also highlights the need for more careful considerations when silviculture and forest covers are to be included since agrometeorological measurements are often associated with forest meteorology but with completely different physical features that widely vary from more agricultural-intensive landscapes. Furthermore, suitable agrometeorological stations can also give way for related practices that can also be adapted in agricultural endeavors such as the provision for water harvesting which can be investigated using weather variables such as dry bulb temperature, relative humidity, etc. [19].
This study put more significance on agricultural production areas. Depending on the proximity of the stations, deriving meteorological data can lead to misrepresentation of actual prevailing conditions such as soil temperature, albedo, air temperature, humidity, wind speed, and a lot more. When dealing with forested areas, separate and detailed consideration of weather station suitability is needed to address the specific parameters to be observed.

A thorough inspection of the figure points out the large weight attributed to both slope and LULC. While beyond the buffer distance of water bodies indicate more suitable conditions since water bodies does not represent agricultural areas well such as in terms of evapotranspiration which may be mainly attributed to continuous evaporation due to non-limiting water supply compared to agricultural areas with varying water application. Regarding the distance to roads which is rated with 6.20% level of importance, having an easy access road result to more frequent quality check-ups and maintenance of agrometeorological stations, particularly the instruments installed. The criteria, however, is not a direct measure whether the location is representative of agricultural landscapes or not Hence, its level of importance is somehow reasonably acceptable. Most of the marginally suitable and unsuitable areas were situated on the mountain ranges and related steep-slope geographical locations with non-agricultural land cover. The suitability class does not indicate production differences when it comes to agricultural landscapes, it simply displays the areas where agrometeorological stations can be more suitable to provide more reliable measurements. While the results of this study are believed to be sounder than the research that came before it from the Philippines, it is highly encouraged to consider more indicators than the ones initially presented in this study (Fig. 3.) to capture distinct features that can further improve the resulting suitability classes.
The resulting AHP-suitability values correspond to the location of the existing agrometeorological stations as shown in Table 4.

Table 4. Suitability Values of Existing Agrometeorological Stations in Luzon.

WEATHER STATION	**AHP Values**
MMSU, Batac, Ilocos Norte	2.4
ISU, Echague, Isabela	2.6
NVISIT, Bayombong, Nueva Viscaya (NVSU)	2.9
BSU (MSAC) La Trinidad, Benguet	3.4
Sto. Tomas, Baguio City	3.2
CLSU, Munoz, Nueva Ecija	2.6
TCA Camiling, Tarlac (TAU)	2.7
Hacienda Luisita, San Miguel, Tarlac	2.6
CAVSU, Indang Cavite	3.1
NAS, UPLB, Los Banos, Laguna	2.5
CSAC, Pili, Camarines Sur (CBSUA)	2.7
BUCAF, Guinobatan, Albay	3.2
PNAC, Aborlan, Palawan (PSPC)	2.8

It was revealed that based on the defined criteria in this study, 46% of the stations have moderate suitability, and similarly, 46% fall between marginal and moderate suitability classes. The station in La Trinidad Benguet is the only station that has moderate to high suitability. The moderately suitable areas with a suitability level of 3 to 3.4 summed up to only 26.47% of the total land area in Luzon at 3, 887,656 ha. And 73.53% of the total land area is classified below moderate level, with 177, 367 ha considered to be not suitable. According to the criteria considered in this study, there has been no place that reaches a suitability level of more than 3.4 meaning there are no Highly suitable areas that would perfectly satisfy

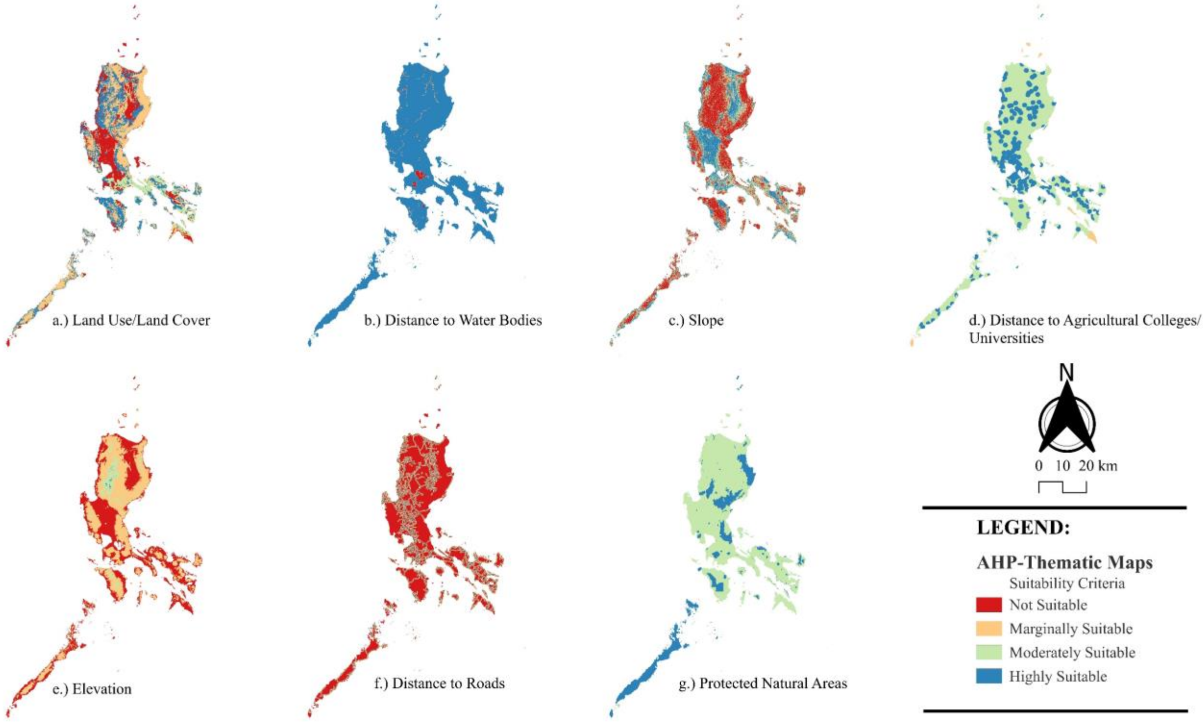

Fig. 3. Thematic Maps of Suitability Criteria

the presented criteria. Nevertheless, further evaluation of the moderately suitable areas should be done to designate future agrometeorological network locations. The station density based on the WMO guidelines [12] where each station should have an effective radius of 9km, may not be instantly achieved. However, strategic planning of such locations can be done by different distancing methods to encompass the relatively important areas.

The results of this study suggest that the agrometeorological stations, mostly found in academic institutions, do not necessarily translate to be optimum location for agrometeorological networks. Other considerations must have been included but the establishment of agrometeorological networks is suitable enough to represent actual agricultural and biological settings, which is the main purpose of such networks.
The main aim of this study is to evaluate the existing agrometeorological network in Luzon based on the presented multi-criteria decision approach, the resulting suitability maps can serve a greater purpose in terms of presenting a more concrete basis for locating suitable locations where suitability criteria follow a hierarchy where relatively low impact criteria would not be treated to have the same effect as criteria which has a reasonably larger effect. While it may be true that some stations have low suitability scores, it is not advisable to infer relocation of such stations since it is practically impossible. The information that can be deduced in this study, however, is the proper selection of future sites for agrometeorological projects and stations that will add to the existing network.

This approach provides an avenue to further enhance the selection process by considering other variables in the process using a much wider and more inclusive expert consultation.

4. CONCLUSION

Based on the criteria used in this study, almost half of the existing agrometeorological stations in Luzon are within the marginal and moderately suitable range. Since none of the existing stations reach the 4-suitability class (Highly suitable), this implies that the agrometeorological network consisting of 13 stations across Luzon may have considerable inaccuracies which may arise due to its current setting since only 4 stations were classified to be under moderately suitability level. In addition, the suitable areas in Luzon only account for 26.47% of the total area, or more than 70% is not suitable enough for agrometeorological networks. The major parameters defining the suitability of stations were LULC (30.8%), distance to water bodies (20.1%), and Slope (19%). While this AHP-based study has effectively narrowed down the potential locations of future agrometeorological stations, funding and budget allocation are still big factors to consider as it may take so long before the appropriate density of agrometeorological stations will be met. Nevertheless, studies such as this serve as a sound foundation for decision-making and policy promulgation.

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6. REFENCES

[1] K. Sivakumar, "Operational Agrometeorological Strategies in Different Regions of the World," Springer eBooks, pp. 551–571, Jan. 2011, doi: https://doi.org/10.1007/978-3-642-19360-6_43.

[2] K. A. Garrett et al., "The effects of climate variability and the color of weather time series on agricultural diseases and pests, and on decisions for their management," Agricultural and Forest Meteorology, vol. 170, pp. 216–227, Mar. 2013, doi: https://doi.org/10.1016/j.agrformet.2012.04.018.

[3] H. Punia et al., "Solar Radiation and Nitrogen Use Efficiency for Sustainable Agriculture," Resources Use Efficiency in Agriculture, pp. 177–212, 2020, doi: https://doi.org/10.1007/978-981-15-6953-1_6.

[4] M. K. Beck and H. V. Puranik, "Studied Over Rice Crops for Radiation Interception, Extinction Coefficient and Radiation use Efficiency in Two Growing Seasons in Odisha, India," Environment and Ecology, vol. 41, no. 1B, pp. 416–420, Mar. 2023, Available: https://doc.article-environmentandecology.com/external/file/lt463c802b06188394d399d8977112fc245b2

[5] G. Hoogenboom, "Contribution of agrometeorology to the simulation of crop production and its applications," Agricultural and Forest Meteorology, vol. 103, no. 1, pp. 137–157, Jun. 2000, doi: https://doi.org/10.1016/S0168-1923(00)00108-8.

[6] N. R. Dalezios, A. Loukas, and Dimitrios Bampzelis, "The role of agrometeorological and agrohydrological indices in the phenology of wheat in central Greece," Physics and chemistry of the earth/Physics and chemistry of the earth. Parts A/B/C, vol. 27, no. 23–24, pp. 1019–1023, Jan. 2002, doi: https://doi.org/10.1016/s1474-7065(02)00136-5.

[7] A. Anandhi, "Growing degree days – Ecosystem indicator for changing diurnal temperatures and their impact on corn growth stages in Kansas," Ecological Indicators, vol. 61, pp. 149–158, Feb. 2016, doi: https://doi.org/10.1016/j.ecolind.2015.08.023.

[8] D. Lal, Establishment of Agro-Meteorological Observatory and their Importance in Agriculture, in: R.K. Naresh (Ed.), Advances in Agriculture Sciences, AkiNik Publications, Delhi, India, 2023 pp. 29-38.

[9] T. K. Gates and A. A. Alshaikh, "Stochastic Design of Hydraulic Structures in Irrigation Canal Networks," Journal of Irrigation and Drainage Engineering, vol. 119, no. 2, pp. 346–363, Mar. 1993, doi: https://doi.org/10.1061/(asce)0733-9437(1993)119:2(346).

[10] S.-H. Yoo, J.-Y. Choi, and M.-W. Jang, "Estimation of design water requirement using FAO Penman–Monteith and optimal probability distribution function in South Korea," Jul. 2008, doi: https://doi.org/10.1016/j.agwat.2008.02.010.

[11] World Meteorological Organization, Guide to Agricultural Meteorological Practices. 2010. https://library.wmo.int/records/item/35689-guide-to-agricultural-meteorological-practices

[12] L.A. Alejo, "Suitability analysis for optimum network of agrometeorological stations: A case study of Visayas region, Philippines," Journal of Agrometeorology, vol. 20, no. 4, pp. 269–274, Dec. 2018, doi: https://doi.org/10.54386/jam.v20i4.564.

[13] S. S. Jagtap and A. K. Chan, "Agrometeorological aspects of agriculture in the sub-humid and humid zones of Africa and Asia," Agricultural and Forest Meteorology, vol. 103, no. 1–2, pp. 59–72, Jun. 2000, doi: https://doi.org/10.1016/s0168-1923(00)00117-9.

[14] T. L. Saaty, "Decision making with the analytic hierarchy process," International Journal of Services Sciences, vol. 1, no. 1, p. 83, 2018, doi: https://doi.org/10.1504/ijssci.2008.017590.

[15] "Regional | Philippine Statistics Authority | Republic of the Philippines," psa.gov.ph. https://psa.gov.ph/statistics/ppa-main/regional

[16] H. Bingham et al., "User Manual for the World Database on Protected Areas and world database on other effective area-based conservation measures: 1.6 User Manual for the World Database on Protected Areas and world database on other effective area-based conservation measures: 1.6." Accessed: Dec. 31, 2023. [Online]. Available: http://wcmc.io/WDPA_Manual

[17] B. Rojas et al., "Site Selection for a Network of Weather Stations Using AHP and Near Analysis in a GIS Environment in Amazonas, NW Peru," Climate, vol. 9, no. 12, pp. 169–169, Nov. 2021, doi: https://doi.org/10.3390/cli9120169.

[18] None Juven G. Luzorata, None Aljon E. Bocobo, None Liahona M. Detera, None Neki Jel B. Pocong, and None Anamarie P. Sajonia, "Assessment of Land Use Land Cover Classification using Support Vector Machine and Random Forest Techniques in the Agusan River Basin through Geospatial Techniques," Proceedings of international exchange and innovation conference on engineering & sciences, IEICES, vol. 9, pp. 240–246, Oct. 2023, doi: https://doi.org/10.5109/7157978.

[19] M. Bilal, M. Sultan, and T. Miyazaki, "Spatiotemporal Investigation of Atmospheric Water Harvesting Potential Using Response Surface Methodology for Multan (Pakistan) and Fukuoka (Japan)," Proceedings of international exchange and innovation conference on engineering & sciences, IEICES, vol. 6, pp. 128–133, Oct. 2020, doi: https://doi.org/10.5109/4102477.