Site Suitability Analysis of Diversion Dams in Quezon, Philippines using Multi-Criteria Decision Analysis and GIS

Bryan M. Baltazar[1], Ronaldo B. Saludes[1], Moises A. Dorado[1], Pompe C. Sta. Cruz[2]

[1]Agrometeorology and Farm Structures Division, IAE, CEAT, UPLB
[2]Institute of Crop Science, CAFS, UPLB
Email: bmbaltazar1@up.edu.ph, rbsaludes@up.edu.ph, madorado@up.edu.ph, pcstacruz@up.edu.ph

KEY WORDS: GIS, MCDA, SSA, Irrigation, Dams

ABSTRACT: Philippines as an agricultural country remains as a net importer of rice due to its lack of irrigation facilities and structures. With the prevailing effects of climate change, tremendous damage to rice production sector is inevitable if not addressed properly. Development of diversion dams and other small-scale irrigation projects is one of the adaptive measures being implemented by the government to overcome negative effects of climate change on agricultural productivity. However, diversion dam development is influenced by different factors including environmental and social factors. Also, during the site selection process for diversion dam, large volumes of environmental and geospatial data sets and information must be handled and analyzed. Hence, in this study, Multi-Criteria Decision Analysis (MCDA) and GIS were used to conduct site suitability analysis of diversion dams for rice irrigation in Quezon, Philippines. MCDA was employed to facilitate the decision-making process for dam site selection involving 10 criteria that were grouped into agrometeorological, physical, and economical factors. Moreover, Analytic Hierarchy Process (AHP) and consultation with experts from academe, industry, and institutions were used to determine the weights of each factors and criteria. Open-source GIS platform was utilized to process gathered data and to generate the overall suitability map. The generated overall suitability map showed that 3.5% of total river networks in Quezon were highly suitable sites for diversion dam. These river networks could irrigate additional 7,110.33 ha of rice areas. Field validation showed that 86% of selected existing diversion dam were operational and located in highly suitable sites, while 14% were partially operational and located in moderately suitable sites. Based on the generated maps and validation results, it can be concluded that Multi-Criteria Decision Analysis (MCDA) and GIS can be effective tools in determining suitable sites for the development of diversion dam and other small-scale irrigation projects for rice production.

1. INTRODUCTION

The Philippines is the world's eighth-largest rice producer. A total of 4.4 million of rice area where harvested in 2010 and it increased to 4.8 million hectares in 2017, which produced 19.3 million MT of rice. However, this production is still very small compared with other major rice-producing countries in Asia. A major factor for increasing rice productivity is by supplying enough water through irrigation. However, as stated by David and Inocencion in an article in Development Research News of Philippine Institute for Development Studies (2014), the country's national irrigation systems have always underperformed due to overly optimistic technical and economic assumptions, inadequate water supply, inappropriate designs, and difficulties in operation and maintenance. With the prevailing effect of climate change, (e.g. increasing temperature, changes in intensity, timing, spatial distribution of rainfall) tremendous damage to rice production sector is inevitable, if not addressed properly.

In addressing these issues, one of the adaptation measures is the development of irrigation structures, such as diversion dams, that would provide supplemental irrigation to underserved irrigable and rainfed rice areas. As defined by BSWM (2017), a diversion dam is a concrete or rockfill structure constructed across a channel or river with continuous flow to raise the water level and allows diversion of water by gravity from the source to the service area.

Construction of more diversion dam units are underway as part of the government's effort for increasing rice productivity. The first step in diversion dam construction is to identify its best location. It is also the most crucial part that would determine the success or failure of the operation of the dam. Locating suitable sites for diversion dam is affected, as well as influenced, by different factors including both environmental factors and human society factors (Dai, 2016). It involves sensible decision-making process comprising of various consideration of factors and criteria (Boateng, Stemn, and Sibil, 2016). It also involves different stakeholders, with different objectives and interests which are normally diverse and conflicting. To facilitate the decision-making process, a method that allows openness, transparency and participation is needed to find a balance among the different stakeholders.

Moreover, during the site selection process, large volumes of data sets and information must be handled and analyzed, whereas most of the information are about the environment and geospatial spatial in nature. A method that can be used which accounts for the different conflicting factors and criteria, as well as, handling large volume of geospatial data could be useful and could give efficient way of locating potential sites for small diversion dam construction. Integrating Multi-Criteria Decision Analysis (MCDA) and Geographic Information Systems (GIS) would provide an efficient way of suitability analysis for diversion dam location as it is a combination of decision-making support method and tools with powerful capabilities of handling large amount of data with computation, visualization, and mapping.

Hence, in this study suitable sites for the construction of diversion dams (DD) intended for rice irrigation using integrated MCDA and GIS were evaluated. Specifically, the study focused on locating suitable sites for diversion dam construction and not on the design of dams nor its specifics and technicalities (e.g. storage capacity, years of use, serviceable area, and construction cost) because it requires more site-specific information which is not in the scope of analysis. Also, the study considered rice as the only crop planted in the area in order to simplify the analysis brought by different cropping seasons, agrometeorological requirements, and other factors. The decision-making process involved physical, agronomic, and economic factors. Social factor, such as acceptance or rejection of the dam, was not covered since it entails a wider scope of survey that is beyond the capability of the research. Remotely sensed data (e.g. rainfall, evapotranspiration) were used when primary data from agencies/institutions concerns were not available. Also, secondary processing/extraction (e.g. river network, distances, and slope) were done to produce the data needed in the analysis.

2. STUDY AREA

Quezon, which is in southern part of Luzon, is the 8th largest province in the Philippines. The topography of the province is characterized by rugged terrain with few plains, valleys and swamps with slopes ranging from 0-3% and above. Majority of the province falls under Type IV climate, which means that rainfall is evenly distributed throughout the year. On the other hand, western towns of the province fall under Type III climate. These areas experience short dry season, lasting only from one to three months and has no very pronounced maximum rainfall period.

The topography and climate of Quezon permits prime agricultural activities within the province. It is considered as the top agricultural producer of various farm products in Southern Luzon. According to the Philippine Statistics Authority (2019), the province’s share in regional rice production reaches to 42 percent. There are two rice cropping seasons in the province of Quezon which depends on rainfall distribution. In general, the dry cropping season starts from April until July while wet cropping season starts from November and ends in February. However, because of lesser amount of rainfall during dry season, lesser areas are being irrigated resulting into lesser harvested rice area than wet season.

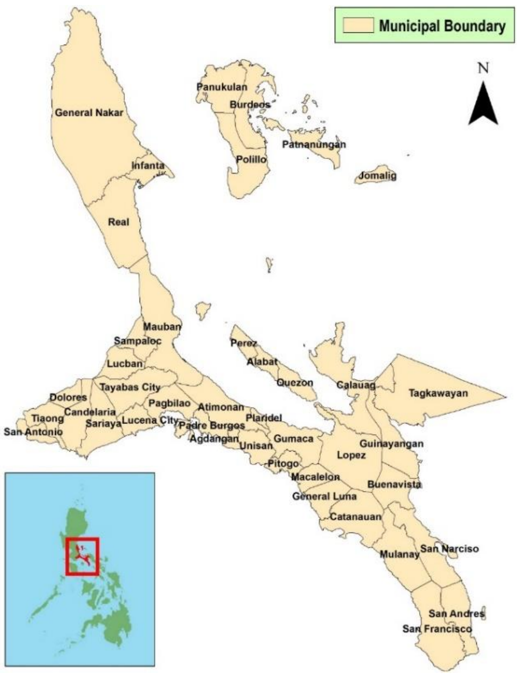

Figure 1. Quezon Province

3. METHODOLOGY

In site suitability analysis of diversion dam for rice irrigation, multi-criteria decision analysis was utilized in determining factors relevant on decision-making process while Geographic Information Systems (GIS) was used as a tool in processing spatial data necessary in the analysis. Integrating the two platforms required intertwining procedures and processes that was needed to produce a site suitability map of diversion dam. These procedures were summarized and shown in Figure 2.

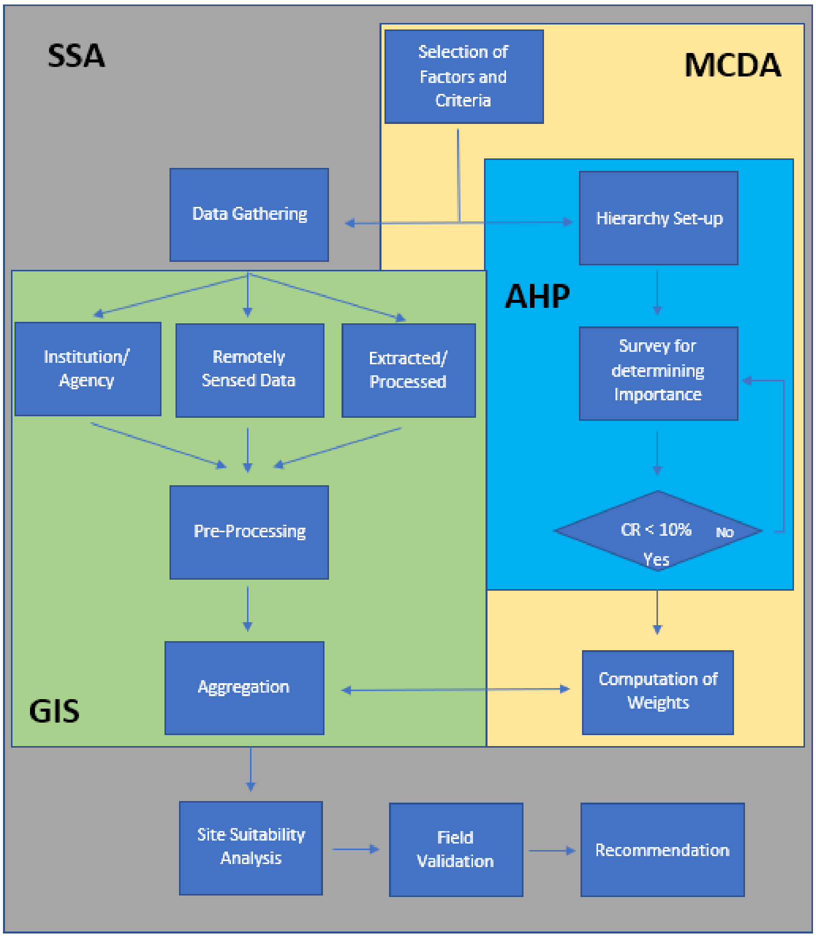

Figure 2. General workflow of site suitability analysis of Diversion dam for rice irrigation

3.1 Determination of Factors and Criteria

The site suitability analysis of diversion dam started by determining and selecting relevant factors and criteria that affect the construction, function, operation, and maintenance of the dam. Based on previous studies, consultation with experts and stakeholders involved, and considering that the dam is intended for rice irrigation, 10 criteria and two (2) constraints were considered in the analysis. Constraints or exclusionary criteria were areas that is due to environmental and hydrological concerns were rejected for purpose of siting dams (Tsiko and Haile, 2011). In this study, the constraints were river network, and protected areas.

On the other hand, the 10 factors were slope, soil type, river width, land cover, river discharge, rainfall, evapotranspiration, distance from potential service areas, distance from road networks, and distance from built-up areas. These ten (10) criteria were grouped into three main factors, namely; physical, agrometeorological, and economic.

Physical factors entail the physical aspect needed for diversion dam construction, these factors include slope, soil type, land cover, and river width. On the other hand, agrometeorological factors consider the effect of agrometeorological parameters on diversion dam that could affect its function and operation. The agrometeorological factors used were rainfall, river discharge and evapotranspiration. These criteria affect mainly amount of water that can be stored, delivered, and loss in the diversion dam. Lastly, economic factors determine the use of diversion dams and the cost of its construction and maintenance. These factors include distance from potential service areas, road networks and built-up areas. The summary of description of each factor is shown in Table 1.

Table 1. Description of Criteria for Diversion Dams Site Suitability Analysis

Criteria	Description
Slope	it is the main factor that influence safety of a dam
Soil type	it influences diversion dam function in the aspect of runoff amount and seepage
River Width	it affects the foundation of diversion dam construction and how much material will be needed
Land Cover	it affects sediment loads on diversion dams, as well as, water loss due to evapotranspiration
River Discharge	river flow ensures that there is available transport to irrigation canal
Rainfall	additional source of water for storage
Evapotranspiration	it decreases water storage for irrigation
Distance from Road	should be located near an access road for repair and maintenance
Distance from Built-up Areas	should be far from built-up areas (residential, commercial) to avoid contamination and pollution
Distance from Service Area	should be located as near as possible to its service area to minimize cost of construction

3.2 Analytical Hierarchy Process

Accompanying constraints and factors, a decision hierarchy model was constructed that was used in weighing the importance for each factor using Analytical Hierarchy Process (Saaty, 1977). From the selected factors and criteria, a three-level hierarchy was constructed. The hierarchy was constructed based on the impact the criteria affects the selection process. Afterwards, weights, that determined significance in the analysis, were assigned for each factor. Survey forms were given to experts, researchers, and practitioner that were involved in diversion dam practices.

In the survey form, the expert chose between what is more important between two factors given within a level and decide how important one factor compare to other using scale from Saaty (1977). The scales in the form were inputted in a template to compute for consistency ratio. Forms with CR value more than 10 % were given back for reevaluation until the CR is less than 10 %. When all forms had a consistency ratio less than 10 %, the scales for each pairwise comparison were consolidated by computing their geometric means. The consolidated ratings were used to compute for the final weights for each criteria and factors.

3.3 Data Acquisition

The study used various datasets. These datasets include both vector and raster data of different scales and resolutions. Data were obtained from different sources which include remotely sensed data, Government Institutions, data generated through processing of Digital Elevation Model (DEM); and data obtained through field validations. Different sources of the primary datasets used in the study were summarized in Table 2.

3.4 GIS Processing

After obtaining all the required datasets, QGIS v.2.18 was utilized to produce site suitability map of diversion dam in Quezon province. After gathering all dataset needed, GIS processing was done. The resolutions and projections of all dataset was set uniformly. Afterwards, the extent of the analysis was set by setting Quezon provincial boundary shapefile as mask during clipping process. After setting the extent, reclassification and standardization of datasets was done. And lastly, the datasets, with their respective weights, were aggregated to generate the site suitability map of diversion dams.

3.5 Field Validation

Field work was done to validate the reliability of the Suitability map. It was done to determine if the generated suitability map can be used as basis for constructing more diversion dams that could increase rice production in the province. Existing diversion dam sites and proposed location of diversion dams by LGUs were used as validation point. The status of the existing diversion dam and the suitability score for each validation sites were noted.

Table 2. Sources of primary dataset used in the study.

DATA	SOURCE
River Network	Philippine Renewable Energy Resources Survey using LiDAR Dataset (PHIL-LiDAR 2: ReMAP)
River Discharge	
River Width	
Existing Diversion Dam	Bureau of Soils and Water Management
Protected Area	PHILGIS
DEM	National Mapping and Resource Information Authority (NAMRIA)
Soil Type	Department of Agriculture-Bureau of Agricultural Research (DA-BAR)
Land Cover	National Mapping and Resource Information Authority (NAMRIA)
ET	MODIS Terra
Rainfall	Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS)
Quezon Rice Area	Philippine Rice Research Institute-Philippine Rice Information SysteM (PhilRice-PRISM)
Temperature	MODIS Terra
Road Network	Department of Public Works and Highway (DPWH)
Built-up Area	National Mapping and Resource Information Authority (NAMRIA)

4. RESULTS AND DISCUSSION

4.1 Weights of Factors and Criteria

The process of selecting suitable sites for diversion dam requires many factors, criteria and considerations that needed to be accounted for. These considerations may come from stakeholders, farmers, concerns agencies, and practitioners related to the diversion dam. Based from literatures and expert's suggestions, 10 factors and criteria were used in the study. These factors were grouped into three main factors. The 10 criteria and 3 factors constituted to a three-level hierarchy of factors and criteria (Figure 3).

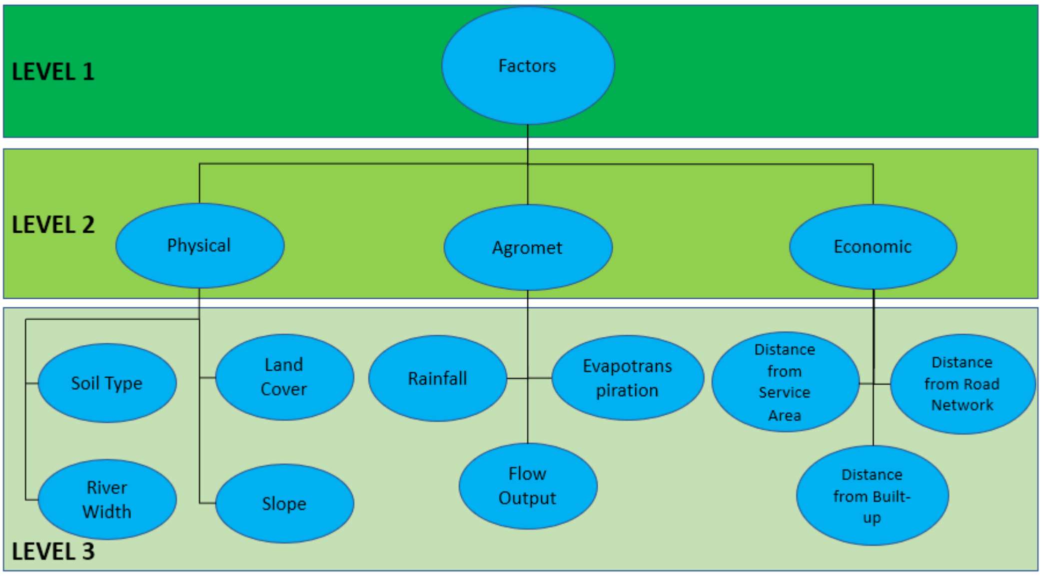

Figure 3. Three-level Hierarchy for Diversion Dams Site Selection Process

These factors and criteria had their own importance relative to each other that affects the decision-making process on selecting suitable sites for diversion dam. By utilizing Analytic Hierarch Process; five (5) experts from academe, industry, and policy-making institutions were consulted; relative importance of each factors and criteria on each level were able to be determined. As shown in Table 3, for the main factors, the physical factor had the most importance of 47%, followed closely by agrometeorological factor with weight of 43%, and lastly by economic factor with weight of 10 %. Physical factor being the most important factor can be attributed to the fact that involves criterion that could determine the effectiveness of the diversion dam. On the other hand, Agrometeorological factor importance is not that far from the physical factor, it is because criteria under this factor are responsible on the continuous operation of the dam. Also, it determines whether the diversion dam can provide needed irrigation water for the service area. The Economic factor had the lowest importance compared with Physical and Agrometeorological factors because it involves criteria that can be resolve by other means or solution either by policy control or by increasing funding for the construction

Table 3. Consolidated weights of factors and criteria from AHP.

Factors	Criteria
Physical **(47%)**	Slope **(42 %)** Soil Type **(23 %)** Land Cover **(12 %)** River Width **(23 %)**
Agrometeorological **(43%)**	Rainfall **(33 %)** Evapotranspiration **(10 %)** River Discharge **(57 %)**
Economic **(10%)**	Distance from Potential Service Area **(49 %)** Distance from Road Networks **(31 %)** Distance from Built-up areas **(20 %)**

Furthermore, dwelling on each criterion under physical factor, it shows that the slope has the highest importance of 42 %, followed by Soil type and River width, both with weight of 23 %, and lastly, land cover with weight of 12 %. For agrometeorological factor, the river discharge criterion had the highest importance of 57 %, followed by Rainfall with weight of 33 %, and Evapotranspiration with weight of 10 %. And, for the Economic factor, distance from service area had the highest importance of 49 %, while distance from road networks had 31 %, and distance from built-up had 20 %.

4.2 Suitability Map

The physical, agrometeorological, and economic factor where aggregated with the Constraints that generated the Overall Suitability Map (Figure 4). It shows suitable areas for diversion dam construction based on the consolidated datasets for the three major factors and areas excluded in the analysis.

As shown in the Overall Suitability Map (Figure 4), the northern part of Quezon province generally had low suitability areas with exception on the northern most part where a community with a large rice crop area exist. Meanwhile, the southern part and the central part of the province had many highly suitable areas. The central part of the province has major rice cropping areas, while in the southern part, it has high potential for additional rice cropping area because there are many areas that have suitable and highly suitable areas for diversion dam intended for irrigation.

Highly suitable areas are concentrated on the narrow land area of the province. It stretches from the municipality of Mauban up to municipality of San Narciso. These can be attributed to relatively flat topography in the area with high density of river network and high potential for having additional rice cropping area. The protected areas in these parts were also few and limited almost to coastal and marine sanctuaries. Also, there are few diversion dams or irrigation structures that can be found in these areas; hence, additional structures are needed. Lastly, rainfall in the area is enough that it can sustain the dam even through dry seasons.

Highly suitable areas were only 3.47% (58.5 km of river network) of the total river network in the province even though the province is favorable in terms agrometeorological factors, that had the second highest importance next to Physical factor. The economically unfavorable situation of the province greatly affected the suitable river network for diversion dam in the Quezon province. These sites are mostly located in the narrow strip of land in the central part of Quezon extending up to the Bondoc peninsula, with small areas located in the northern most municipality of General Nakar.

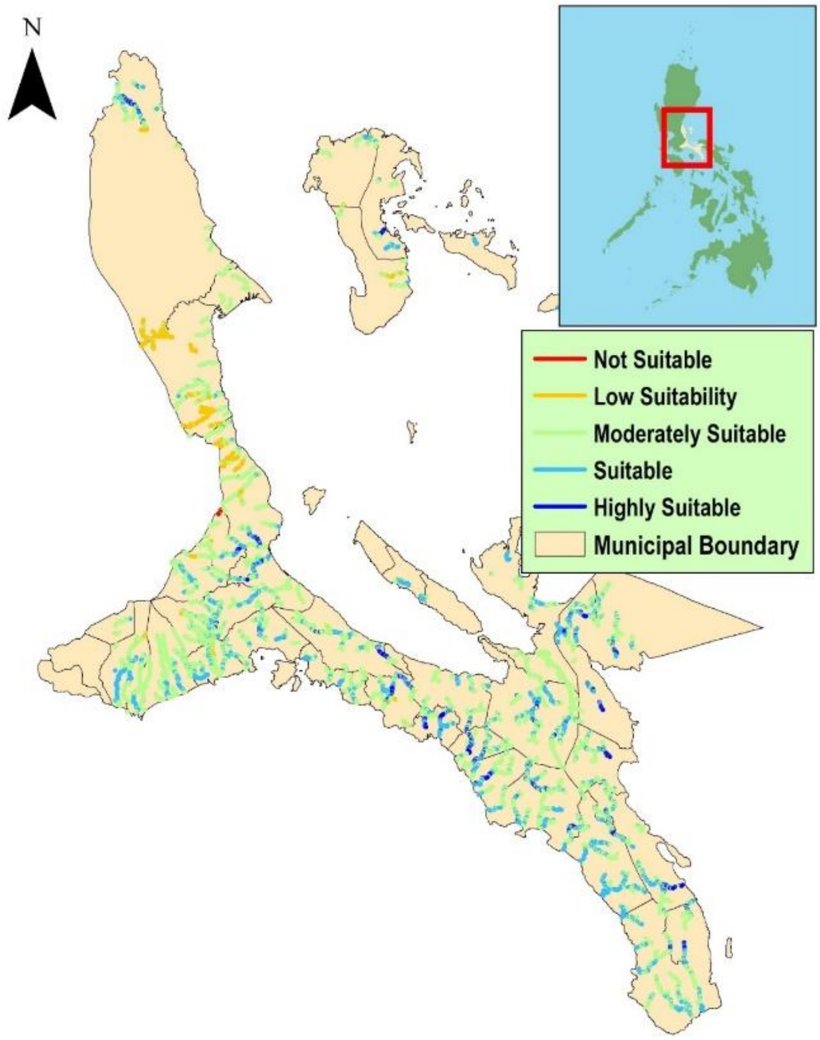

Figure 4. Overall suitability map of suitable diversion dams in Quezon province

The percentage of river network that are classified as highly suitable areas for diversion is summarized in Figure 5. It can be seen in Figure 5 that the municipality of Macalelon had the highest percentage of highly suitable areas, which is 0.39 % that is equivalent to 6.5km of river network. On the other hand, the municipality of Lucban has the lowest percentage of highly suitable areas of 0.01 % or 0.24km. In total, the percentage of highly suitable areas for diversion dam in the province of Quezon is 3.5 % or 58.5 km of river network.

Diversion dams could be installed in these spans of river network and could serve as supplemental irrigation for rice area with deficit irrigation during the dry cropping season or additional irrigation source for additional rice cropping area. In general, the total potential service area that could be an additional rice production area in the province, is 71,10.33 Ha

4.3 Field Validation

Existing diversion dam sites or proposed location of diversion dams from seven municipalities in Quezon were validated. Validations were conducted by the researchers and municipal agricultural officers. Based from the validation it was determined that the 6 diversion dams (85.7%) were still operational and 1 diversion dam (14.3 %)

was partially operational. The 6 operational diversion dams were located near river networks classified as highly suitable sites. On the other hand, the partially operational diversion dam was located near a river network classified as moderately suitable site. The status of operation and suitability classification of the locations of each validation site were supported by the actual conditions in each site.

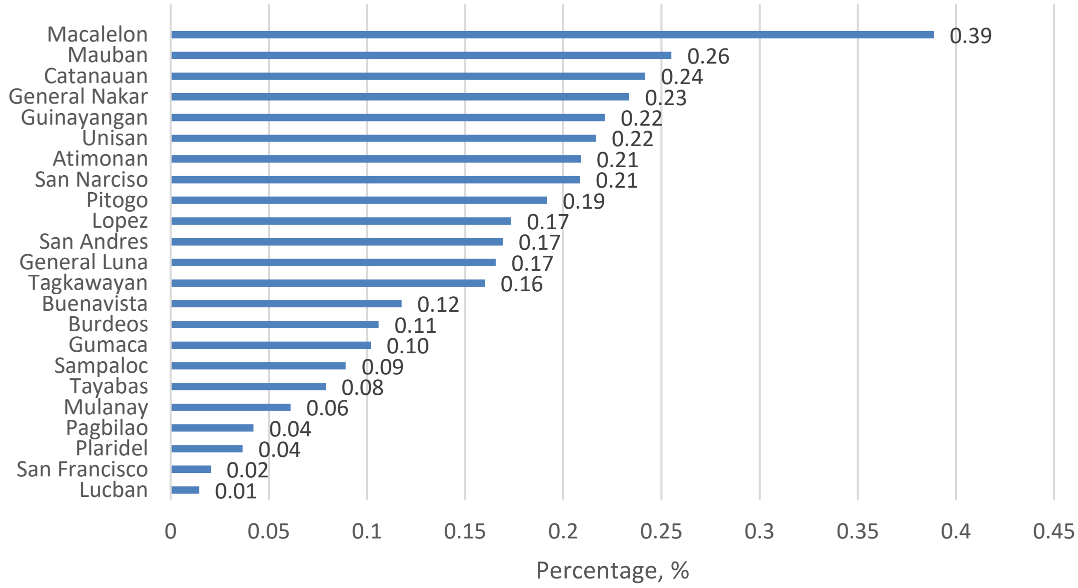

Figure 3. Percentage of highly suitable river networks in each Municipality of Quezon

5. CONCLUSION

Diversion dams and other small impounding reservoirs are being constructed to increase the number of irrigation structures that could provide continuous supply of water for crops. However, it is important to consider different factors in locating suitable sites for diversion dam because it involves environmental and social factors. Different stakeholders, with varying objectives and interests, have roles in considering suitable sites for diversion dams. Moreover, during the site selection process for diversion dam, large volumes of data sets and information must be handled and analyzed. Hence, a method that can be used which accounts different conflicting factors and criteria, as well as, handling large volume of geospatial data could be useful and could give efficient way of locating potential sites for diversion dam construction.

In this study, Multi-Criteria Decision Analysis (MCDA) and Geographic Information Systems were utilized to conduct site suitability analysis of diversion dam for rice irrigation in Quezon, Philippines. Integrating the two platforms required intertwining procedures and processes that was needed to produce a site suitability map of diversion dam. It started with selection of relevant factors and criteria. After determining these factors and criteria data gathering and weighting their importance were conducted simultaneously. After datasets were completed and weights had been determined using Analytic Hierarchy Process, an open-source GIS platform was used to consolidate the weights as the same time process the spatial information of each factors and criteria.

The final suitability map shows that river networks that are highly suitable for diversion dam are only 3.5 % of 58.5km of the total river network in Quezon province. These highly suitable sites could supply irrigation water to 7110.22 Ha of potential service areas for rice cropping. Existing diversion dam sites or proposed location of diversion dams from seven municipalities in Quezon were validated. Based from the field validation, it was determined that the six (6) existing diversion dams were still operational and located in a highly suitable river network. While, one (1) existing diversion dam was partially operational and located in moderately suitable river network. This validate that the generated suitability map represents the actual condition of possible suitable sites for diversion dam construction.

Therefore, based on the generated maps overall suitability map and field validation, it can be concluded that using multi-criteria decision analysis coupled with a GIS platform is a powerful aid in locating suitable sites for diversion dam construction. It was shown that the suitability classifications generated from the methodology were supported by the actual conditions of existing diversion dam, as well as, diversion dams still under construction. However, it is recommended to conduct site specific analysis to determine if the suggested site identified from site suitability analysis would really cater the needs of the farmers and beneficiaries.

6. ACKNOWLEDGEMENT

Special thanks to Philippine Rice Research Institute's Philippine Rice Information SysteM (PRISM) and PHIL-Lidar 2: Project ReMAP for sharing their research outputs for the completion of the datasets needed, the Department of Science and Technology (DOST)- Engineering Research and development Technology (ERDT) program for funding this study, and the "Identifying Suitable Sites for Small Scale Irrigation Projects in Region IV-A (CALABARZON) through GIS-based Water Resources Assessment" Project of the BIOMECH-UPLB.

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