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Identifying suitable sites for pump irrigation system from open source and shallow tube well in selected areas of Davao Del Sur through geographic information system-based water resources assessment

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Abstract. This paper features the Geographic Information System (GIS) in identifying suitable sites for small scale irrigation projects (SSIP) particularly pump irrigation system from open source (PISOs) and shallow tube well (STW) through water resource assessment. The development of GIS-based assessment model for SSIP and resource map in aid of SSIP planning and development is limited in some municipalities. To develop a reliable GIS-base framework, the ArcGIS tool and spatial method was used in compiling specific factors with field analysis and developing regional resource map for SSIP. The results showed that STW in Digos City and Municipality of Hagonoy is 117 units and 17 units respectively. The average water depth in existing STW is within the 6.5 meters with capacity to irrigate 3 to 5 hectares per unit, low investment with high water use efficiency and simple to operate. It was found out that most STW is provided by Department of Agriculture-Regional Field Office XI and Local Government Units. The STW is suitable for Digos City with an area of 379.32 hectares. While the PISOS were identified with different range of pump horsepower. There are 10 units of PISOS in Digos City and 15 units in Hagonoy mostly provided by National Irrigation Administration-XI. It was found out that in Digos City the 1,855.53 hectares are highly suitable and 14,377.55 hectares are not suitable for PISOS. The results of this study may assist the decision making processes for planning and development of SSIP using the developed protocol and tools for different purpose in agricultural production in Davao del Sur, Region XI and the whole country.

1. Introduction

Water is the most essential basic commodity for any living creature. It is a primary necessity for agricultural production. The available water resources are under pressure due to increasing demands. The identification of potential sites for irrigation development is an important step towards maximizing water availability and land productivity in rainfed areas.

Davao del Sur is composed of 3,934.01 square kilometres land area with 23,859 hectares of potential irrigable area. The developed service area (firmed-up service area) has a total area of 16, 742 hectares with 6,712 hectares from National Irrigation System (NIS), 9,415 hectares from Communal Irrigation System (CIS), and 615 hectares from private irrigation system. The irrigation development for Davao del Sur including Davao Occidental is at 70.17%. The primary source of water in Davao Region comes from twenty-two major river basins with an estimated length of 1,170 kilometers (NEDA-XI, 2014).

Davao Region recently was hit by El Niño phenomenon thus greatly affects the farming communities that are reliant on rainfed agriculture. Recent initiatives to address this have shifted focus to explore more efficient alternatives to water supply and the recognition of numerous opportunities to implement small scale irrigation projects (SSIP) as a means to supplement water availability even on areas not considered irrigable areas by NIA. The traditional fragmented approach of identification of potential sites for irrigation facilities is no longer viable and a more innovative approach to water resource assessment is essential to maximize meager resources and ensure the success of the project. Precise planning is necessary in identifying expansion areas for irrigation and the mode of SSIP suited for the location. This research shall develop a Geographic Information System (GIS)-based model as a decision support framework to optimize and identify locations to implement SSIP effectively and efficiently. The output of this R&D activity shall be the guide for future allocation of SSIPs nationwide.

2. Objective

The general objective of this research is to identify the suitable areas intended for small-scale irrigation projects which are limited only to shallow tube wells (STWs) and pump irrigation system for open sources (PISOs) in selected areas in the province of Davao del Sur. Specifically, the study aims the following objectives:

Specifically, the study aims the following objectives:

i. To formulate a GIS-based model to be used in identifying suitable sites for STWs and PISOs.
ii. To determine the spatial distribution of existing shallow tube wells (STWs) in selected areas in the province of Davao del Sur.
iii. To identify and determine the extent of suitable areas for shallow tube wells (STWs) in selected areas in the province of Davao del Sur.
iv. To identify and determine the extent of suitable areas for Pump Irrigation System for Open Sources (PISOs) in selected areas in the province of Davao del Sur.

3. Review of Related Literature

3.1. Geographic Information System (GIS)

A geographic Information System (GIS) is a computer system capable of capturing, storing, analysing and displaying geographically referenced information attached to a location such as latitude and longitudes of a certain spatial data in ground (Butler et.al., 2011).

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. The key word to this technology is Geography – this means that some portion of the data is spatial. In other words, data that is in some way referenced to locations on the earth. Coupled with this data is usually tabular data known as attribute data. Attribute data can be generally defined as additional information about each of the spatial features. An example of this would be schools. The actual location of the schools is the spatial data. Additional data such as the school name, level of education taught, student capacity would make up the attribute data. It is the partnership of these two data types that enables GIS to be such an effective problem solving tool through spatial analysis.

GIS is more than just software. People and methods are combined with geospatial software and tools, to enable spatial analysis, manage large datasets, and display information in a map/graphical form (Martindale, 2018).

3.2. Application of Geographic Information System in Water Resource Engineering

There are many areas in Water Resources Engineering where GIS may be successfully applied. GIS could be applied in project planning for a storage structures including calculation and estimation of watershed area, reservoir surface area and its volume. In project planning for a diversion structure, GIS

is very important. It could be used in identifying location site of the barrage, alignment of off taking canal and determination of command areas to be served by the canals (Kharagpur, 2011).
Poor Management of water is also big concern for water scarcity as well as unavailability of storages sites. Conventional water resource planning and management is mainly focused on blue water (water in streams, rivers, aquifers, lakes and reservoirs). There is a dire need to incorporate rainfall, especially in arid and semi-arid basins that infiltrates naturally into the soil and on its way back to the atmosphere in the form of evapo-transpiration. Managing non-beneficial evaporation will result in a significant reduction in water use that can be re-allocated to other users.

Remote sensing and GIS play a vital role in the conservation and utilization of country's water resources. For achieving optimum planning and operation of water resources, related projects and latest techniques of remote sensing must be combined with the traditional methods of measurement and management of ground water that will last into sustainable groundwater management (Masud, 2017).

3.3. Small Scale Irrigation Projects
Small scale irrigation project is an important aspect of irrigation development in many countries. Approximately half of the irrigated area in Sub-Saharan Africa, for example, is irrigated in this way. It involves individual or small groups of farms, organized and managed by farmers, usually independent of government resources (FAO Rome, 1992).

Small Scale Irrigation Projects (SSIPs) refer to irrigation systems like Small Water Impounding Project (SWIP), Small Diversion Dam (SDD), Shallow Tube Wells (STW) and Pumping Irrigation System for Open Sources (PISOs) and Small Farm Reservoir (SFR). These SSIPs were able to provide supplemental irrigation to about 8,100 hectares of rainfed rice area based that benefited more than 5,500 farmers (Dayo, 2001).

3.4. Irrigation and Land Productivity
With declining productivity in rainfed agriculture and with the need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture (FAO, 1994). It is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Hence, the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as intensification of cropping by producing more than one crop per year. In this regard, sustainable food production that can be expected through an optimal development of water resources, in conjunction with development of land depends on the method of irrigation considered (FAO, 2003). Continuous investments on SWIP and other SSIP is essential for country's development considering the results from different R & D studies on SWIP (Maslang, 1997; Samar, 2006, among others). Specifically, DENR has identified SWIP as a sustainable development initiative. BSWM (2006) has proven that SWIP is both El Nino and La Nina intervention.

3.5. Suitability to Irrigation Development Projects
Planning process for irrigation has to integrate information about the suitability of the land, water resources availability and water requirements of irrigable areas in time and place (FAO, 1997). Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field (Fasina et al, 2008). Since all kinds of rural land are involved by different land cover/use types, its suitability evaluation for surface irrigation also provides guidance in cases of conflict between rural land use and urban or industrial expansion, by indicating which areas of land covers /uses are most suitable for irrigation (FAO, 1993). The amount of runoff in river catchments with limited stream flow data can be determined from runoff coefficient of gauged river basin (Goldsmith, 2000; Sikka, 2005). After the amount of river discharges both gauged and un-gauged are quantified, an important part of the evaluation is the matching of water supplies and water demand (FAO, 1977b).

However, these factors should be assessed in an integrated manner, geo-referenced and mapped for surface irrigation development possibilities. With an adequate database, Geographic Information Systems (GIS) can serve as a powerful analytic and decision-making tool for irrigation development (Aguilar-Manjarrez and Ross, 1995). Large area extent of GIS as well as its ability to collect store and manipulate various types of data in a unique spatial database, helps performing various kinds of analysis and thus, extracting information about spatially distributed phenomena. In this kind of situation, the factors that are involved for irrigation potential assessment such soil, land cover/use, land slope and distance between water supply and suitable command area should be weighted and evaluated by the use of GIS according to their suitability for irrigation.

4. Conceptual Framework

The conceptual framework of the research study is presented in Figure 1 below following the INPUT – PROCESS - OUTPUT scheme. The methods were in the accordance of the objectives of the study which is to identify and determine the extent of arable, agricultural, suitable sites STWs and PISOs and agricultural-rainfed in selected areas in the province of Davao del Sur.

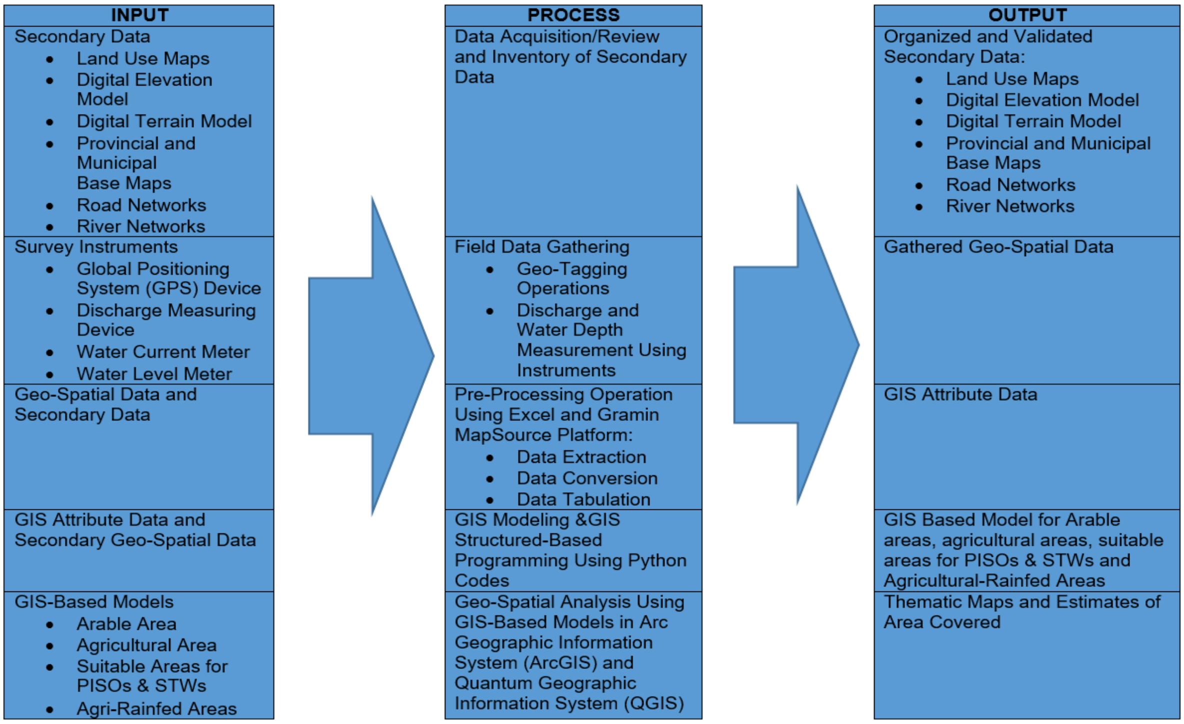

Figure 1. Conceptual Framework of the Research Study

5. Methodology

5.1. Acquisition and Validation of Secondary Data

Spatial data on irrigated areas was acquired from the regional office of the National Irrigation Administration (NIA), an agency of the Philippines administering the distribution of irrigation facilities and services in the country. An Interferometric Synthetic Aperture Radar (IFSAR) data specifically the Digital Surface Model (DSM) and the Digital Terrain Model (DTM) was obtain from the office of National Mapping and Resource Information Authority (NAMRIA), a central mapping agency of the Philippines.

Spatial data involving political boundaries like provincial, municipal and barangay boundaries were obtained from the Provincial Environment and Natural Resources in the province. A validation of secondary data was done to ensure its quality in terms of its reliability and accuracy which includes ground rooting activity and random field samplings.

5.2. Gathering of Primary Data

Primary data gathering was done to fill the gaps of the secondary data collected and validated. It involved geo-tagging of existing SSIP projects and facilities in the area including existing shallow tube wells (STWs) and pump irrigation system for open sources (PISOs). Measuring of water depth in the shallow tube wells was done with the aid of the electronic water level meter.

Geo-tagging using the Global Positioning Device (GPS) of existing potential water sources for small scale irrigation projects was performed. All field data gathering activities conducted are in accordance to the consent and aid of local officials in the research area.

5.3. Identification of Arable Areas

The agricultural areas in the selected municipalities of the province was determined by deducting the union of the secondary data including the land use plan (non-agricultural area), road networks and non-arable areas to the arable areas of the province. Below is the GIS-Based model coded to determine the agricultural area of Davao del Sur.

Extraction of road network of the province will be done using Clip geoprocessing tool around its political boundaries and buffered to 8 meters. Buffered roads, non-agricultural area including built-up, protected and commercial areas based on the LUP of each municipality of the province and areas above 10% slope will be combined using Union geoprocessing tool. A differencing analysis will be performed between the arable area of the province and combine non-agricultural areas. Dissolving and area calculation will be performed to determine and estimate the total agricultural sites in the selected area of the province.

Shown below in Figure 2 is the GIS-Based model used in identifying agricultural arable areas in selected municipalities in the province.

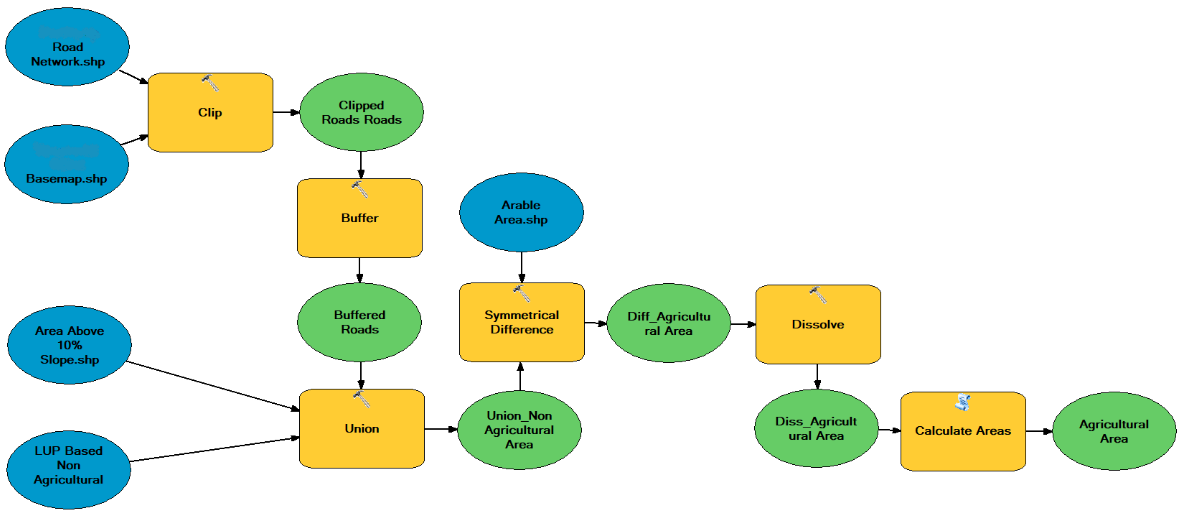

Figure 2.GIS-Based Model in Identifying and Determining Agricultural Areas in Selected Municipalities of the Province of Davao del Norte.

5.4. Identification of Suitable Areas for PISOs

The suitable areas for Pump Irrigation System for Open Sources (PISOs) was determined using the GIS-Based suitability model shown in the Figure 3 below. The suitability criteria to be considered was presented in Table 1.

The geoprocessing operation requires the use of the spatial distribution of rivers as vector data and to be buffered with three (3) different measurements (50m, 100m and 200m) as prescribed by the suitability criteria for PISOs shown in Table 1 below. Each Buffered river data set will be dissolved ready for differencing analysis from non-agricultural area data set using Symmetrical Difference spatial tool. Resulted features including highly suitable area (HS), most suitable area (MS) and suitable area (S) will undergo dissolving process to combine features and attributes. Area calculation will be done using Calculate Area geo-statistical tool to estimate the total extent of each area.

Table 1. Criteria in Suitability Mapping for PISOs in the Province of Davao del Sur (BSWM Criteria.

Suitability Description	Suitability Scale	Proximate Distance from Water Source
Highly Suitable	3	0-100m
More Suitable	2	>100m-200m
Suitable	1	>200m

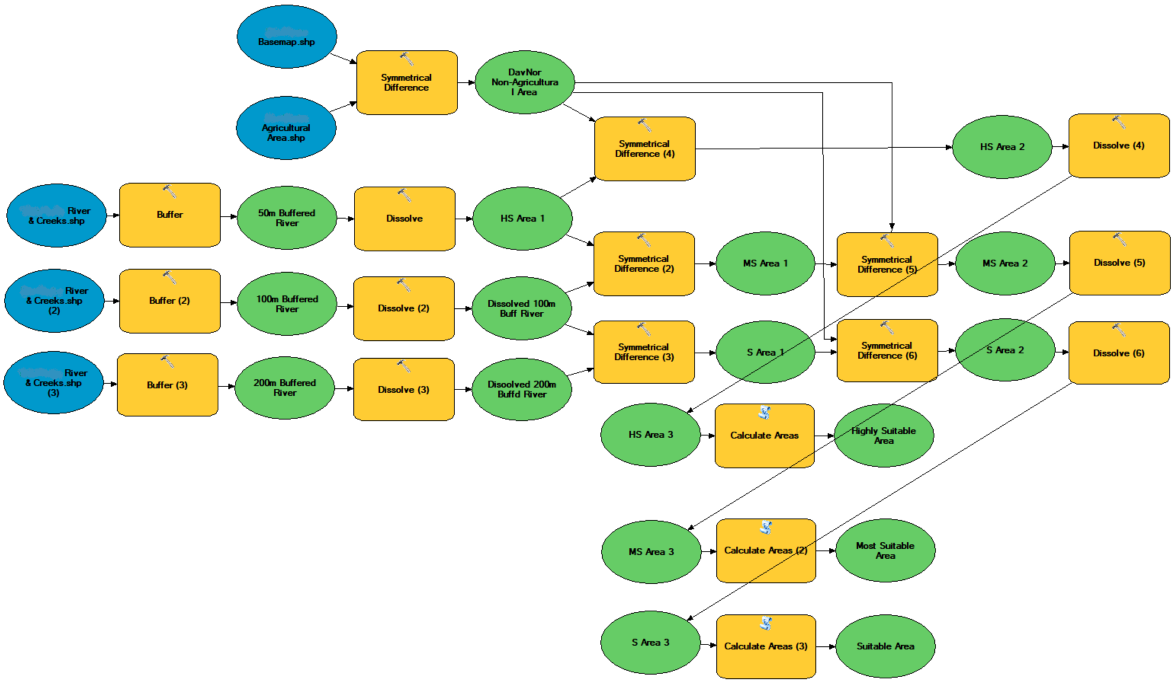

Figure 3.GIS-Based Model in Identifying and Determining Suitable Areas for PISOs in Selected Municipalities of the Province of Davao del Sur.

5.5. Identification of Suitable Areas for STWs

The identification of suitable sites for Shallow Tube Wells (STWs) was done based on the GIS-based suitability model shown in Figure 4. Table 2 shows the suitability criteria to be used in identifying suitable sites for STWs.

The geo-spatial distribution of shallow tube wells with a depth of less than 6.5m meters was used and buffered using a buffer geo-spatial analysis tool with the coverage area of 5 hectares. In parallel to the buffering process, the non-agricultural area was also generated using symmetrical difference spatial analysis tool between the identified agricultural areas and municipal base map of the selected municipalities of Davao del Sur. Another differencing operation was done between the buffered areas of STWs and no-agricultural area in order to generate the suitable area for shallow tube wells.

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Table 2. Criteria in Suitability Mapping for STWs in in the Province of Davao del Sur.

Suitability Description	Suitability Scale	Water Level form Ground Surface
Suitable	1	<6.50 m
Not Suitable	0	>6.50 m

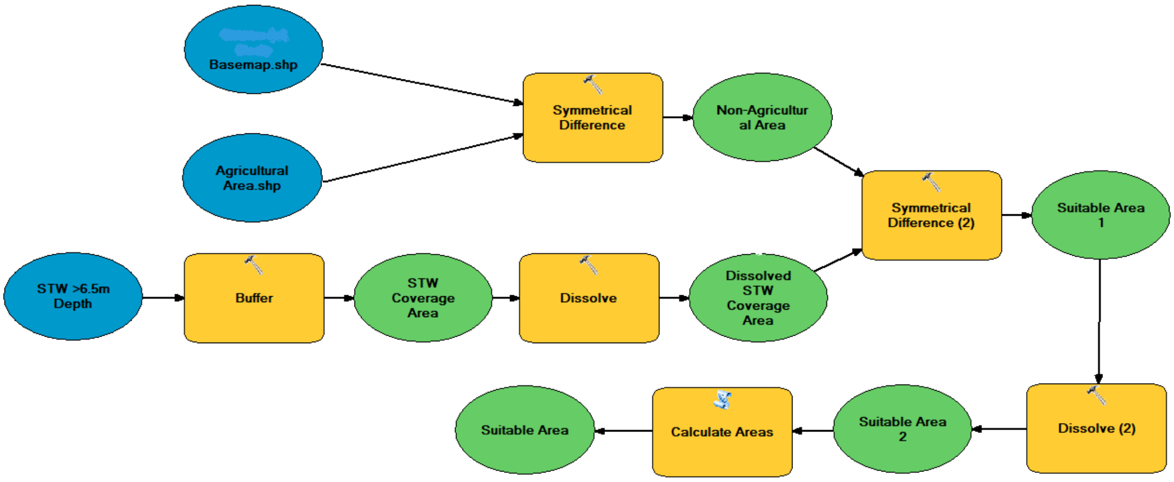

Figure 4.GIS-Based Model in Identifying and Determining Suitable Areas for STWs in Selected Municipalities of the Province of Davao del Sur.

5.6. Identification of Agricultural-Rainfed Areas

Agricultural-rainfed areas in the selected municipalities was identified using the formulated GIS-based model shown in Figure 5 below. The model was dependent on the output of the previous models including identification of arable areas, agricultural and suitable area for STWs and PISOs GIS-based models.

Using the resulted suitable areas of STWs and PISOs combined and dissolved using Union and Dissolve geo-spatial analysis tool, the agricultural-rainfed area of the province was generated through performing symmetrical differencing between the agricultural area and combined suitable areas.

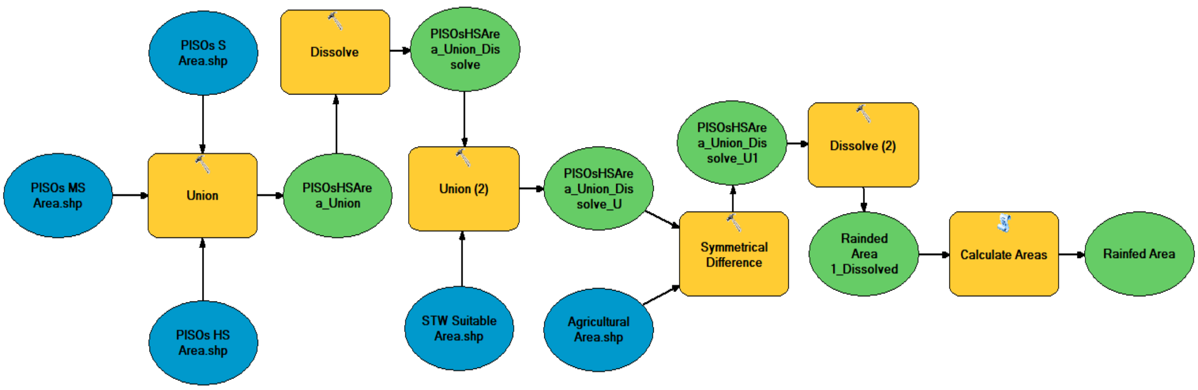

Figure 5. GIS-Based Model in Identifying and Determining Agricultural-Rainfed in Selected Municipalities of the Province of Davao del Sur.

6. Results and Discussion

6.1. Spatial Distribution of Shallow Tube Wells (STWs)

A total forty-two (42) shallow tube wells was tagged and assessed during the field data gathering conducted in the city of Digos. There are 117 units of STW gathered wherein 97.43% still function and only 2.56% were non-functional. Majority of the STWs are privately owned by farmers, association or cooperative, and public installations as shown in Table 3. These units were installed for domestic and agricultural purposes.

Figure 6 below shows the spatial distribution of existing shallow tube wells located in Digos City, Davao del Sur. Most of the shallow tube wells were located on areas with low elevation above sea level. One hundred percent of the shallow tube wells presented have a corresponding water depth of less than 6.5 meters above the natural ground surface.

Table 3. Location of STW's in Digos City, Davao del Sur.

Location (Barangay)	STW Status		Total	Source	
	Functional	Non-Functional		Government	Private
Colorado	17	0	17	1	16
Igpit	8	0	8	0	8
Matti	31	1	32	2	30
Sinawilan	16	2	18	0	18
Tiguman	42	0	42	0	42

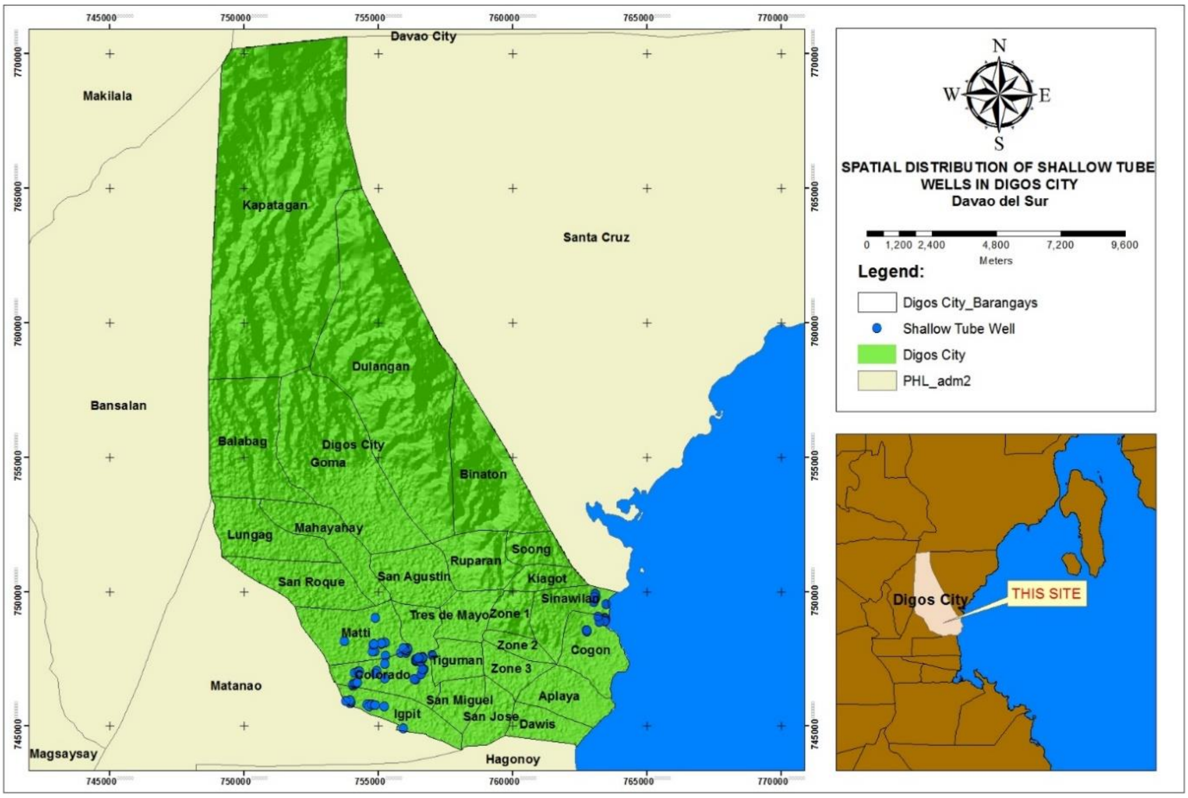

Figure 6. Spatial Distribution Map of Shallow Tube Wells in Digos City, Davao del Sur.

On the other hand, a total of seventeen (17) units were found and installed in six barangays of the municipality of Hagonoy as provided by National Irrigation Administration (NIA) in assistance to farmers as presented in Table 4 and sixteen (16) of STW units were came and subsidised by the said government agency. Barangay Sacub is said to be the highest recipient of the project.

Presented in Figure 7 is the spatial distribution of shallow tube wells in the municipality of Hagonoy.

Table 4. Location of STW's in Municipality of Hagonoy.

Location (Barangay)	STW Status		Total	Source	
	Functional	Non-Functional		Government	Private
New Quezon	2	0	2	2	0
Sacub	10	0	10	10	0
Malabang	1	0	1	1	0
San Guillermo	1	0	1	1	0
Poblacion	2	0	2	1	1
Crossing Hagonoy	1	0	1	1	0

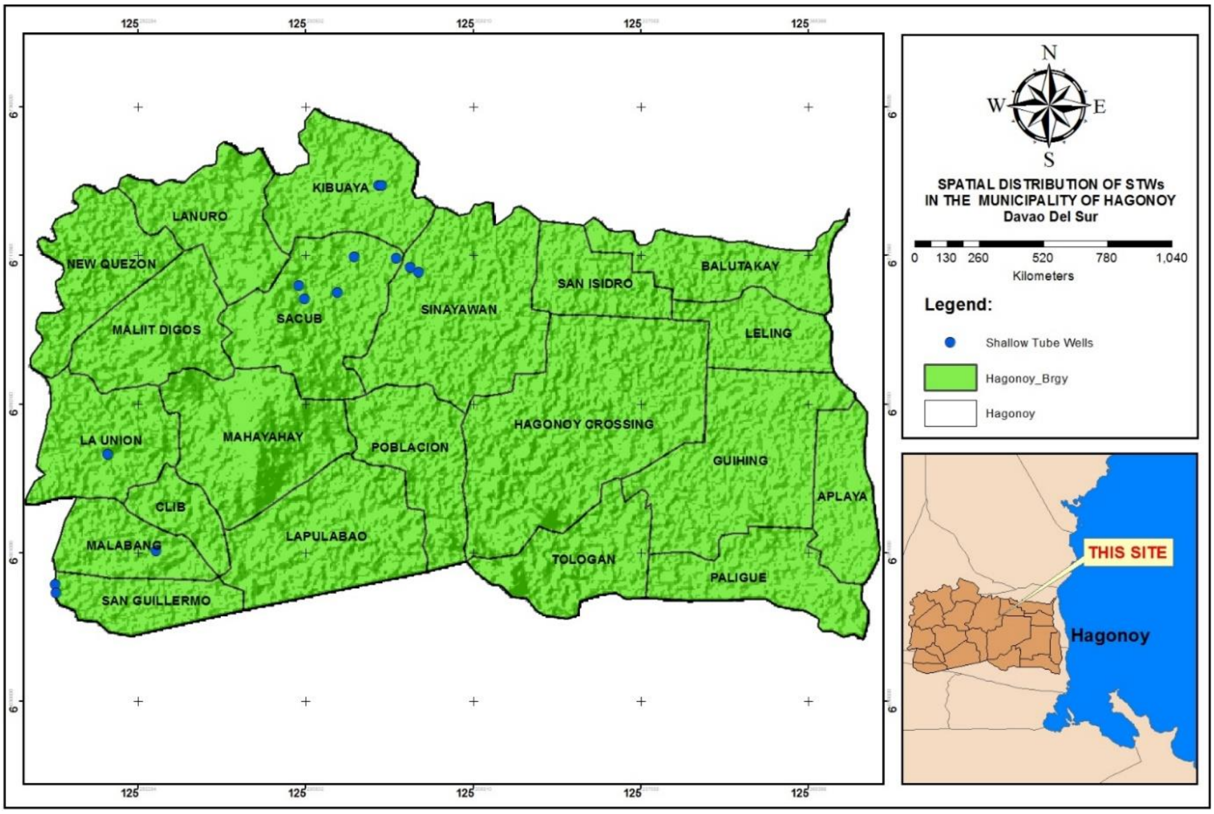

Figure 7. Spatial Distribution of Shallow Tube Wells in Municipality of Hagonoy, Davao del Sur.

6.2. Suitable Sites for Shallow Tube Wells (STWs)

The suitable areas for shallow tube wells were identified based on the spatial distribution of existing STWs in Digos City. Only STWs with less than 6.5 meters of water level from the ground surface are being included the in the geo-processing operation. Each STWs with less than 6.5 meters of water level from the natural ground surface are buffered geometrically with a coverage area of five (5) hectares radius based on the formulated GIS-based suitability model for STWs as shown in Figure 4.

Results shows that a total of 379.324 hectares were identified to be the suitable areas for shallow tube wells which is around 0.29% of the total land area of the province. A suitability map below (Figure 8) shows the spatial distribution and extent of suitable areas for shallow tube wells.

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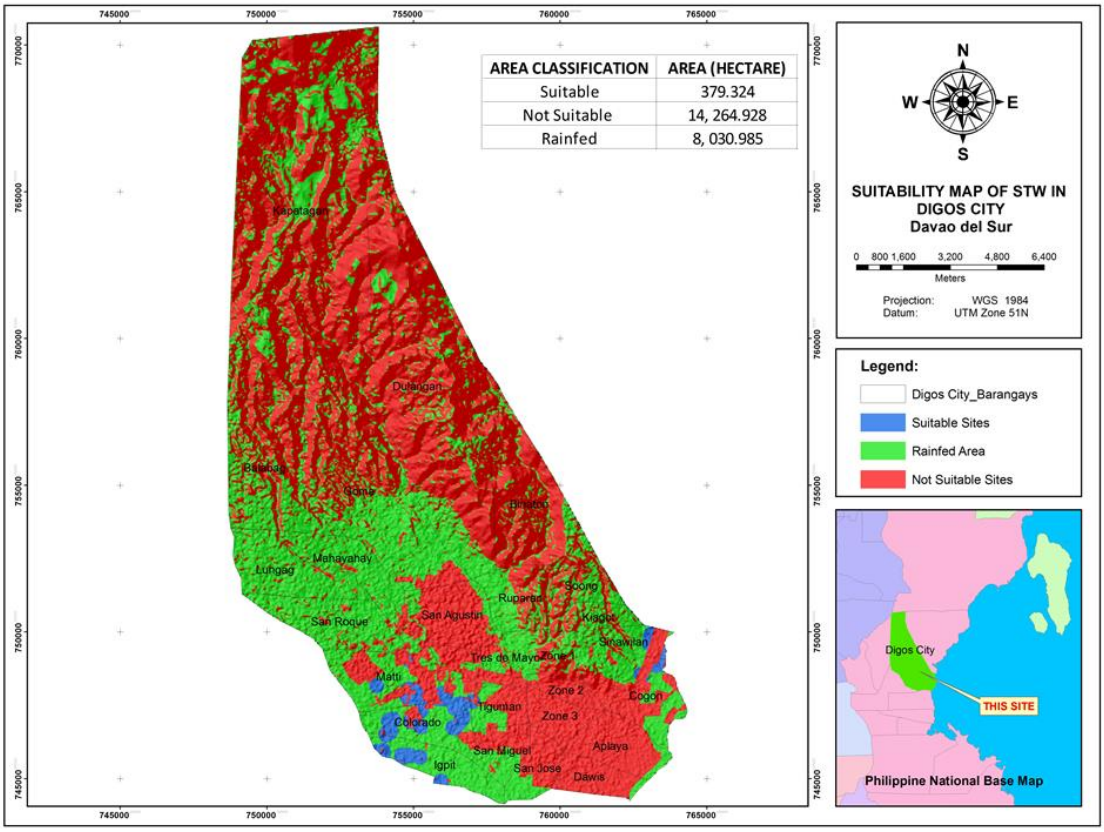

Figure 8. Suitable Sites for Shallow Tube Wells in Digos City, of Davao del Sur.

6.3. Suitable Sites for Pump Irrigation System for Open Sources (PISOs)

The GIS-Based Suitability model presented in Figure 3 was used in determining and identifying suitable areas for Pump Irrigation System for Open Sources (PISOs) in Digos City and the municipality of Hagonoy. The spatial distribution of rivers was used and buffered to create a coverage area with the distance of 100 and 200 meters from the centreline of the rivers based on the suitability criteria presented in table 1.

Based on the results of the geo-spatial analysis using the model, a total 5,035.00 hectares was determined and identified to be the suitable areas for PISOs in Digos City, 1,637.74 hectares for most suitable and 1,855.53 hectares for highly suitable areas. About 21.98%, 7.15% and 8.10% of the total land of the province are covered by the suitable, most suitable and highly suitable areas for PISOs respectively. Around 14,377.86 hectares was identified to be the not suitable area for PISOs covers around 62.77% of the total land area of the province as presented in Table 1 previously.

On the other hand, the municipality of Hagonoy has a total suitable area of 2,356.46 hectares, 1,320.34 hectares for most suitable and 1,002.54 hectares for suitable. An estimated area of 6,749.39 hectares was found to be not suitable for PISOs projects from the total land area of 11,428.73 hectares.

Figure 9 and 10 below shows the thematic map of the suitable areas of PISOs in Digos City and municipality of Hagonoy. Areas with red colours represents the not suitable areas. While areas blue, yellow and cyan colours are the highly suitable, most suitable and suitable areas for PISOs respectively.

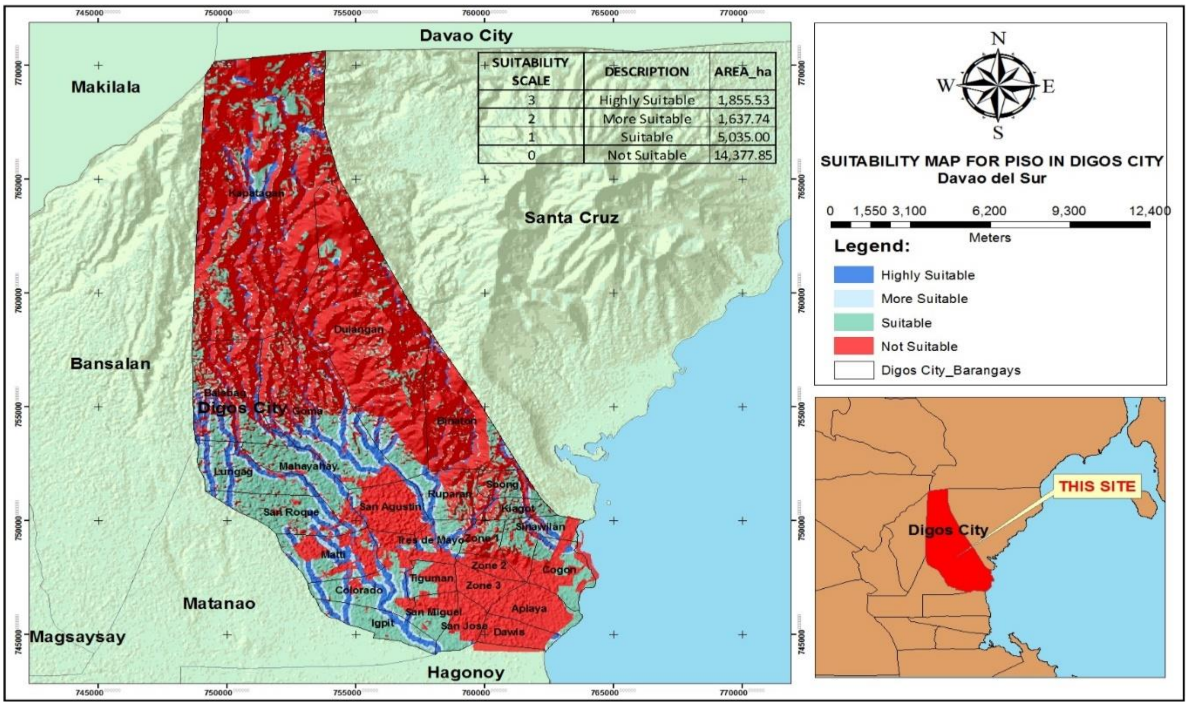

Figure 9. Suitable Sites for Pump Irrigation System for Open Sources (PISOs) in Digos City, Davao del Sur.

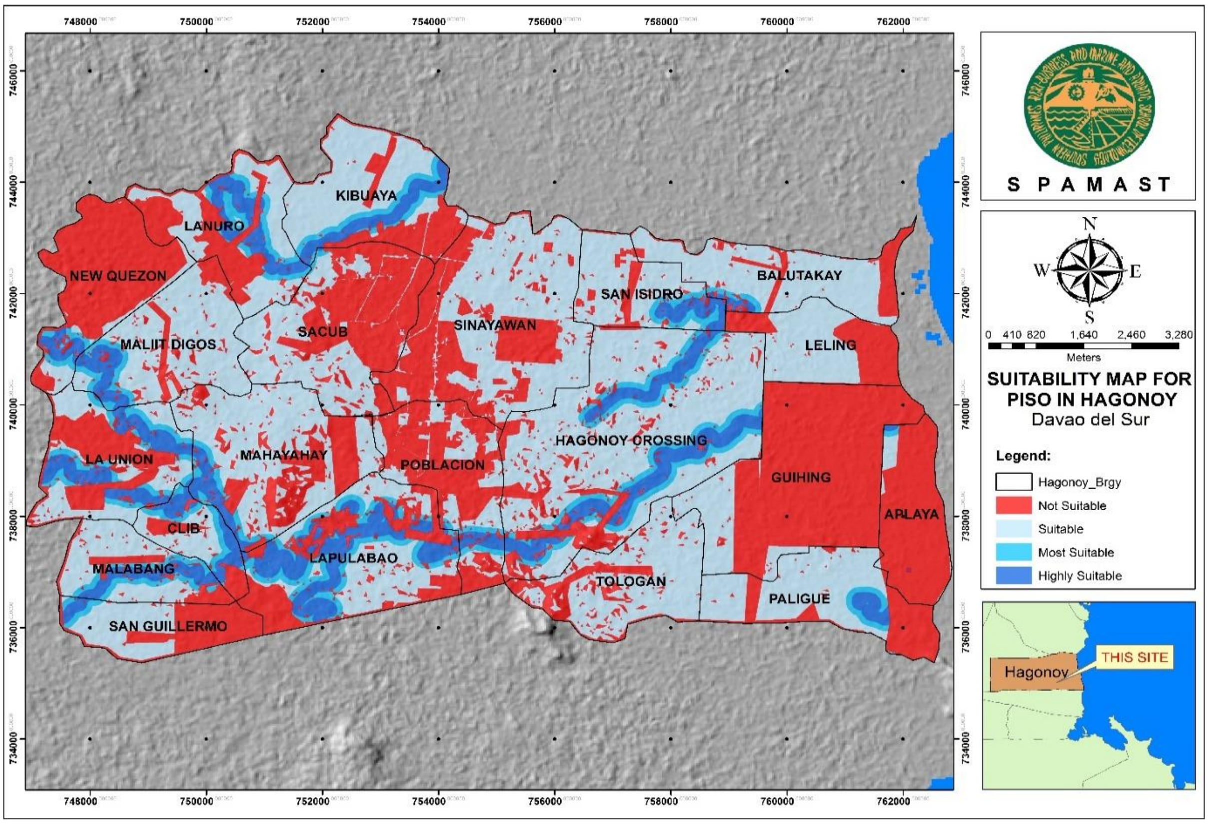

Figure 10. Suitable Sites for Pump Irrigation System for Open Sources (PISOs) in Hagonoy, Davao del Sur

7. Summary and Conclusions

The small scale irrigation project system such as shallow tube wells (STWs), Pump Irrigation System from Open Source (PISO) and springs development are important in agricultural production and domestic use. In shallow tube well development, water table depth should be located 2 – 3 meters or below ground surface at the onset of the dry season. Important features of shallow tube wells are its capacity to irrigate 3 – 5 ha per unit, low investment cost, high water use efficiency, simple to operate and maintain, sustainable development and empowerment of farmers. In PISOs development, the proximity distance between open water source and service area of agricultural production is critical and important to be factor in suitability mapping. While the data on restrictions of the discharge facility and service area were used as the factor in suitability mapping for Spring Development.

There are 117 units of STW in Digos City and 17 units in Municipality of Hagonoy which 97.76% still functional and only 2.24% were non-functional. Majority of the STWs in Digos are privately owned by farmers, association and cooperative while NIA provided the assistance in Hagonoy. Therefore concluded that STWs generally needed more in some barangays in Digos City than in Hagonoy for domestic and agricultural purposes. It can also be concluded that there are barangay areas in Digos City that are highly suitable areas covering 379.32. The suitability map for PISOS in Digos City and Municipality of Hagonoy can be use in planning and development, therefore concluded that PISOS is suitable in areas near a river network.

There are 10 units of PISOs in Digos City and 15 units in Hagonoy for agricultural production during dry spell. This could be attributed to the presence of well-established NIA irrigation agency through NIS and CIS which administered by association and cooperatives. The Municipality of Hagonoy has vast area of rice and corn thus CIS and NIS irrigation system are strategically distributed and well maintained. Larger portions of the City are not suitable for PISOS with 1,855.53 hectares are highly suitable and 14, 377.55 hectares are not suitable. Therefore, concluded that these suitable areas may be provided a government assistance provided service area is available.

There are only three (3) functional springs in Digos City and forty-five (45) functional springs in Hagonoy for agricultural and domestic purposes.

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