Geographic Information System-Based Suitability Analysis for Potential Shallow Tube-Well Irrigation Development

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Abstract

TThis study developed a geographic information system (GIS)-based decision support system in the spatial identification of a viable location for shallow tube-well irrigation development in the province of Isabela. Factors such as slope, soil type; land cover and groundwater depth were used as input parameters. Around 98% of the existing shallow tube-wells were within the suitable area. The developed map was validated using existing irrigated areas. Results show that more than 377,000 hectares were found potentially suitable locations for shallow tube-well irrigation development. These areas are characterized with a water table depth of <6.5 m, a slope of<18%, soil textures (sandy loam, clay loam, and sandy clay). Sufficient factors in combination with the GIS tool is a great tool to carry out spatial data in land-use analysis and the use of this as a means in identifying viable locations for shallow tube-well irrigation development in other places is reliable.

Keywords: shallow tube-well, irrigation development, geographic information system (GIS), suitability mapping, Isabela, Philippines

1.0 Introduction

To produce a kilogram of cereal grains requires a thousand liters of water and this makes agricultural applications to utilize approximately 70% of clean water worldwide (Pimentel et al., 2004).The projected cereal demand worldwide will grow by 46% between 1995 and 2025 and the projected cereal demand for developing countries is 65% (Rosegrant, Cai, & Cline, 2002). It is frequently assumed that irrigation encompasses direct and indirect effect in the reduction of poverty (Hussain&Hanjra, 2004). Thus, high cost of surface irrigation and shortage of water encouraged the utilization of groundwater in support of irrigation to intensify cropping intensity, improve crop yield and ultimately increase the income of farmers and this will make them achieve an improved quality of life (AFMA law). According to Asian Development Bank report (2012), utilization of groundwater is a feasible means to supply irrigation in areas that have adequate groundwater but present issues or challenges to the development of surface irrigation systems. Moreover, groundwater irrigation is an unconventional method to irrigate rice crops as well as surface water (Jusoh et al., 2013).

In the Philippines, irrigation development and management of water for agricultural application holds the important potential to advance yield productivity and decrease susceptibility to climatic instability. Water scarce areas in the country are subject to different hydrological restraints that can be attributed to unequal rainfall distribution, specifically within farming communities with poor resources and that are dependent on rain fed farming. To deal with these problems, current initiatives are in the direction of shifting focus towards the exploration of more efficient options to water supply and the acknowledgment of many opportunities to implement small-scale irrigation projects (SSIP) as a way to increase water availability.

As reported in the Cagayan Valley Regional Development Plan (CVRDP, 2017-2022), there are still hundreds of thousand hectares of potential irrigable areas as of December 2015. Of this area, national irrigation system (NIS), diversion dams, communal irrigation system (CIS), small water impounding projects (SWIP), and shallow tube wells (STW) are the different schemes of irrigation system used. Field assessment and studies show that only 75% of the designed service area of NIS and CIS is actually irrigated (NIA).Few irrigation systems are not operational due to the scarcity of water, destroyed structures and poor management of water. The STWs are attractive options for the utilization of groundwater is a feasible means to supply irrigation in areas that have adequate groundwater but present issues or challenges to the development of surface irrigation systems or in the absence of surface irrigation (ADB). Relative to other irrigation systems, STWs requires relatively low investment capital. This makes STWs more attractive to small- and medium scale farm holders and is more suitable for small-scale operations (Center for Engineering Research and Development, 2007). A STW is a well, lined with a metal tube, bored to extract groundwater through a pump (in this study, the STW considered is a well with a drill depth of less than 6 meters).

The identification of possible locations for STW irrigation development is an essential step towards maximizing water availability and land use efficiency in rain fed areas and in areas where scarcity of water for surface irrigation development is observed. However, the usual method of identification of suitable sites for irrigation facilities consumes more time and requires a lot of estimations on the part of the implementing agency. New and more advanced technique of identification of possible sites for STWs development is essential. Precise planning is necessary for identifying expansion areas for STW irrigation development. This calls for a need to conduct studies to assist in identifying irrigation suitability of land which is a basis of sound land management. This research shall develop a Geographic Information System (GIS)-based model as a decision support framework to optimize and identify locations to implement Shallow tube-well irrigation systems effectively and efficiently. GIS-based approach could be used to develop land suitability model for development and can be used as a policy tool in decision making for planning and development (Chandio, Talpur, &Taufique, 2016) and it offers strong facilities for groundwater resources management(Manos, Bournaris, Papathanasiou, &Moulogianni, 2007). The output of this research could be used as a decision support framework in the direction of policy making especially in identifying priority areas in establishing STW projects, particularly in the province of Isabela.

Appropriate management and proper selection of land for irrigation are the requirements used for wise consumption of an insufficient resource of water and soil. If these resources are not properly developed and wisely managed, extensive and serious environmental degradations are to be expected.

Hence, assessing the existing physical resource potential with respect to its suitability for irrigation with the help of GIS in Isabela would enable us to identify sites for sustainable irrigation development.

Generally, this study developed a water resources assessment model for identifying potential sites for the development shallow tube-well irrigation in the province of Isabela.

Specifically, it aimed to:

- Map existing and potential identified irrigable areas based on soil, slope, land use and depth of the water table
- Identify suitability criteria for the development of shallow tube-well
- Identify potential irrigable areas for shallow tube-well in Isabela
- Develop shallow tube-well irrigation land suitability map of Isabela

2.0 Design and Methodology

Location

Isabela province is located at 16° 42′ 53.9388″ N and 121° 33′ 13.3884″ E (Latitude Longitude.org). The province represents almost 40% of the Cagayan Valley region with a total land area of 12,414.93 square kilometers (4,793.43 square miles) making it the second largest province in the Philippines. Isabela is surrounded by the province of Cagayan towards the north, the province of Kalinga towards the northwest, the Mountain Province towards the central-west, the province of Ifugao and Nueva Vizcaya towards the southwest, the province of Quirino in the direction of the south, and the province of Aurora towards the south. The eastern part of the province lays the Philippine Sea, and this makes the province prone to typhoons.

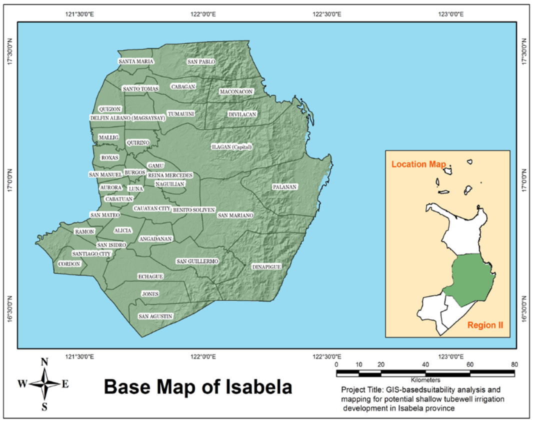

Figure 1. *Location Map of the province of Isabela*

Climate

There are two types of climates in the province. The eastern and coastal areas are experiencing type IV climate whereinmoderate rainfall there or thereabouts distributed all through the year. The western part of the province is experiencing type III climate wherein seasons are not extremely pronounced; more or less dry from the months of November to April and wet throughout the rest of the year. The normal temperature in the province is noted at 27.1 ˚C. The maximum precipitation periods in the province are not incredibly pronounced and dry period lasts only for one to three months.

Topography

The topography of the province is characterized by numerous tributaries, which frequently dissect the plains. On the western part of the area, the elevation is a complicated system of higher, lower hills bordering, interrupting the plains and gently slope towards the Midlands. The eastern area, straddled with the Sierra Madre mountain range, is rugged and densely forested. A large part is uncharted. In several locations, small hills are to be found. Generally, the land elevations vary from 68 m to 1,785 meters above sea level.

Soil

The major soil type in the province of Isabela (study area) is sandy clay loam with an effective depth of moderately deep to deep. Some areas are dominantly clay loam, sandy loam and other soil types (sand, silt loam, and mountain soil).

Land Use/Land Cover

The land use/land cover (LULC) of the study area includes cultivated lands, grassland, built-up area, river beds, and forestland. The forestland type is found in eastern and mountainous part of the province. Most of the cultivated land or agricultural land is used for the cultivation of crops mostly cereals in the central and western part of the province. The pasture type of LULC distributed in different parts of the province and the community in the province use the areas as grazing land. There are also mature trees covering >50% closed canopy. Other croplands are mixed with coconut and other plantations.

Irrigation and Agriculture

The sources of water for irrigation in the province are the Cagayan River and the Magat River. The primary irrigation system in the province is the national irrigation administration-Magat River Integrated Irrigation System (NIA-MRIIS) and its service areas are the cities of Santiago and Cauayan and towns of Ramon, San Mateo, Cabatuan, Luna, San Isidro, San Manuel, Roxas, Burgos portions of Cordon, Echague, Angadanan, Reina Mercedez, Quirino, Mallig, and Aurora. The major crop grown in these irrigated areas is rice. The total area presently served by the NIA is 144,575.91 hectares (National Irrigation Administration, 2016).

Data Requirements, Sources, and General Processes

Different types of data were utilized to attain the objectives. Soil data and well log data were taken from Department of Agriculture and at Isabela State University, Echague, Isabela. Other data were taken from NIA.

Different data were collected and derived from different sources and GIS was used for making maps. Different shape file, digital elevation model and slope of the study area were extracted from digitized elevation map (DEM).

The process of suitability analysis and mapping was totally based on evaluation criteria. Criteria were taken from available data on the basis of different related reviewed literature,(Food and Agriculture Organization, 1977; 1985; 1993; United Nations Development Program, Food and Agriculture Organization - European Commission on Agriculture, IOA and the Regional Government of Ilgray, 1994; FAO, 1997; Aguilar & Ross, 1995; Fasina, Awe, &Aruleba, 2008; Hailegebriel, 2007;Hecker, 2000 and Girma, 2015; discussions with related experts and depending on related previous works. The criterions used for shallow tube-well irrigation site suitability analysis include soil type, water table depth, and land cover/land use and slope suitability shown in table 1. The suitable site's mapping was done using multiple-criteria decision evaluation (MCDE). To carry out the MCDE, each criterion with its associated feature data is digitally encoded in GIS database. A geo-database consisting of all factor layers was created in GIS software then point and line features were changed into raster data. Each layer was subjected to undergo reclassification process and weighted. Then the overlay analysis was conducted using GIS spatial analyst extension. Finally, the shallow tube-well irrigation suitability map of the study area was produced.

Soil

The soil is one of the major factors in the suitability of land for irrigation system development. Its primary influence is in the productive capacity, but it may also influence production and development costs. For diversified crop production, the most suitable soil class for sustained irrigation includes the following; 1) a good water holding capacity that will adequately retain and provide required soil moisture for the crops between irrigation intervals; 2) a good drainage sufficient to maintain an aerated root zone and salt level acceptable to crop growth; 3) a good infiltration rate sufficient to replenish the soil moisture depleted through evapotranspiration; 4) a sufficient depth of soil for optimum crop root development; 5) an arable surface; 6) allowable quantity of exchangeable sodium; and 7) modifiable by a sufficient supply of nutrients for plants. The soil type classification considered in this study to determine the suitability of soil for irrigation development is shown in table 1.

Slope

Slope is a major factor affecting irrigation. This factor may affect the selection of the method of irrigation, development of land, design of on farm irrigation systems, hazards to erosion, drainage requirement, water use practices, crop and other management and production costs. In this study, soil slope ranging from 0-3% are considered highly suitable; slope of 3.1-8% are considered moderately suitable; slope of 8-18% are considered marginally suitable; and soil slope greater than 18% are considered not suitable for STW irrigation development.

Land use/land cover

Land cover and land use are often interchangeably. Land use refers to the actual economic activity for which the land is used i.e. food production, commercial forestry and etc. Land cover refers to the cover of the earth's surface i.e. vegetation, bare soil, urban development without reference to how that cover is used. This factor was considered to identify availability of land for irrigation agriculture. The three land cover classes shown in table 1 are used in the study to determine suitability of the area for STW development.

Water table depth

Water table depth is defined as the upper level of an underground surface in which the soil or rocks are saturated with water at all times. It changes both with the seasons and from year to year because it is disturbed by climatic differences and by the amount of precipitation used by vegetation (Trondillo et al., n.d.). Ideally, for shallow tube well development, water table should be less than 6 meters. The depth of groundwater table was the major factor considered in shallow tube-well irrigation development. It is the most important factor considered in the study because this factor defines the availability of water for the establishment of STW projects. The criteria set for the determination of suitability for STW development i shown in table 1. Water tables with a depth of less than 6 meters were considered suitable for STW development. Water tables with a depth of greater than 6 meters were considered not suitable for STW development.

Analysis and Identification of Potential Areas for Shallow Tube-well Irrigation Development

The flowchart showing the methodology adopted for STW suitability analysis is shown in figure 1. In this process, land-use map, slope map, soil map and water table depth map were selected as factors and collected from different sources. The suitability scale for each factor is shown in table 1. The weight for each factor is shown in table 2.The overall suitability was determined using weighted overlay analysis in GIS environment.

Shallow tube-well suitability (S) model was derived from combining the factors with their corresponding weights for determining the potential areas for STW. Equation 1was used in calculating the suitability value of each grid cell:

S = [(Soil texture x stf) + (slope x sf) + (land use x luf) + (water table depth x wtdf)] equation (1)

Where:

S = suitability value for shallow tube well
Soil texture = soil texture factor map
Slope = slope factor map
Water table depth = water table depth factor map
Land use= land use map
stf = soil texture weight
sf = slope weight
wtdf = water table depth weight
luf = land use factor

The suitability scale of each factor was multiplied by each respective suitability weight (shown in table 2) and came up with the suitability map. The slope map, for instance, the slope map was categorized as highly suitable, moderately suitable, marginally suitable and not suitable for suitability scale of 3, 2, 1, and 0, respectively. These suitability scales were multiplied with the suitability weight for slope which is equal to 0.15. The procedure was done for the other factors and the output map was the STW suitability map.

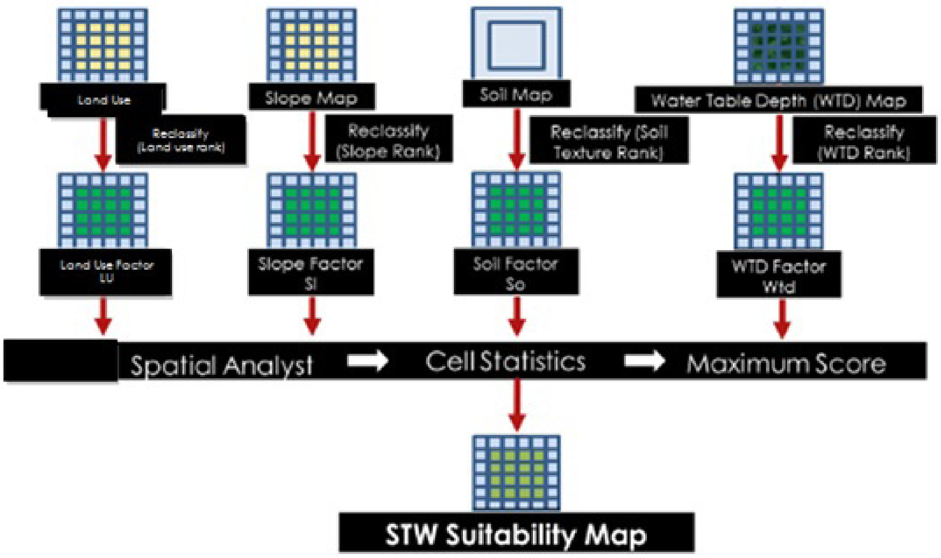

Figure 2. *Flowchart showing the methodology adopted for STW suitability map*

Table 1. Shallow tube-well suitability criteria set for the present study

Factor	Description	Suitability Scale	Suitability Class
Slope	> 18%	0	N (not suitable)
	8 – 18%	1	Marginally suitable
	3.1 – 8%	2	Moderately Suitable
	0 – 3%	3	Highly Suitable
Soil Texture	Others (sand, silt loam, silt, Mountain soil)	0	N (not suitable)
	Sandy Loam	1	Marginally suitable
	Sandy clay loam	2	Moderately Suitable
	Clay loam and siltclay loam	3	Highly Suitable
LULC	Others (Built-up, forest, etc)	0	N (not suitable)
	Grassland	0	N (not suitable)
	Cultivated	3	Highly Suitable
Water table depth	Greater than 6.5 m	0	N (not suitable)
	Less than 6.5 m	3	Highly Suitable

Table 2. STW Suitability factors and each factor weights

Factor	Suitability Scale	Suitability Weight
The depth of groundwater	0 and 3	55%
Soil texture	0 – 3	15%
Slope	0 – 3	15%
Land use/Land cover	0 and 3	15%
Total		100%

3.0 Results and Discussion

Identification of Potential Areas for Shallow Tube-well Irrigation Development

Slope Suitability

One of the factors being considered in irrigation suitability analysis is the slope. The slope of the province was evaluated and classified into four slope ranges or classes. The suitability of the province for shallow tube-well irrigation system development based on soil slope analysis is presented in figure 3 along with the areas of coverage by each suitability class are shown in table 3.

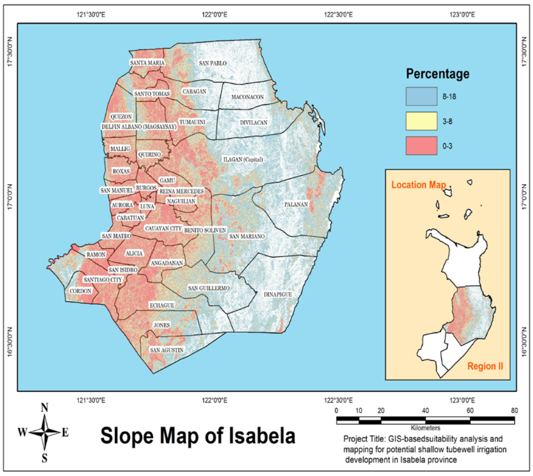

Figure 3. Suitable sites for shallow tube-well irrigation development based on soil slope analysis

Table 3. *Slope suitability range of the province of Isabela for shallow tube-well irrigation*

Slope range (%)	Area coverage (ha)	Percent (%) of the total area	Suitability classes
0 – 3	316, 958.9	31.4	Highly Suitable
3 – 8	218,067.90	21.6	Moderately Suitable
8 – 18	246,849.80	24.45	Marginally Suitable
18 – 84	227,576.90	22.54	Not suitable
Total	1,009,453.50	100	

Based on the slope classification, 77.46% of the entire area of the province (covering an area of 781,876.6 ha) was characterized as marginally suitable to highly suitable for STW irrigation development. The highly suitable areas are situated in the western part of the province. Most of the areas that categorically under the moderately to marginally suitable are situated in the eastern part of the province. Most of these areas are undulating and rolling areas. They could be used for intensive agriculture but with good planned erosion control measure. They are best suited for fruit trees and other perennial crops. The remaining area of 227,576.9 hectares or 22.54% is generally mountainous and were categorized as not suitable for shallow tube well irrigation development because of technical, practical and economic reasons. Development of irrigation system in these areas would cause severe environmental degradation. Further, these lands are best suited for forest purposes.

Soil Texture Suitability

Generally, clay is a soil mineral that is chemically active. Clay has great surface area per unit mass due to its small size particles relative to its total size. The important attribute of clay particles relative to plant nutrition and water is the ability to keep moisture, abundant positively charged ions in an exchangeable state.

According to FAO guideline (FAO, 1985) and discussions with related experts and depending on related previous works for soil evaluation, the soil texture of the province was evaluated and classified in to clay loam, sandy clay loam, sandy loam and others (sand, silt loam, silt, and Mountain soil) as presented in figure 4. The distribution of areas according to soil texture suitability analysis for shallow tube-well irrigation development in the province is given in table 4.

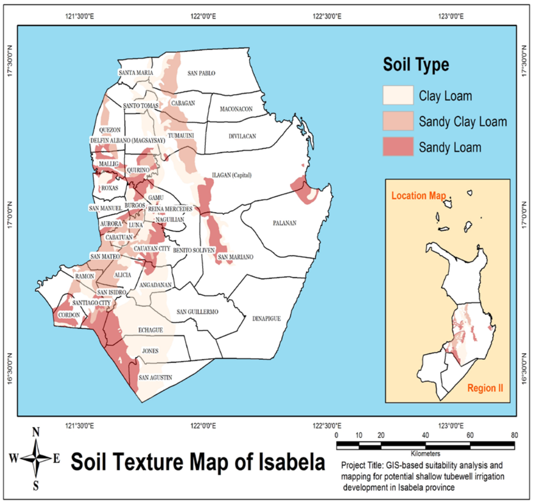

Figure 4. *Suitable sites for shallow tube-well irrigation development based on soil texture analysis*

Table 4. Distribution of Areas according to Soil Texture Suitability Analysis for shallow tube-well irrigation

Soil Texture	Area of coverage (ha)	Percent (%) of the total area	Suitability classes
Clay Loam	92,964.78	9.21	S_3 (Highly Suitable)
Sandy clay loam	86,067.22	8.53	S_2 (Moderately Suitable)
Sandy Loam	147,300.94	14.59	S_1 (Marginally Suitable)
Others	683,120.54	67.67	N (not suitable)
Total	1,009,453.48	100	

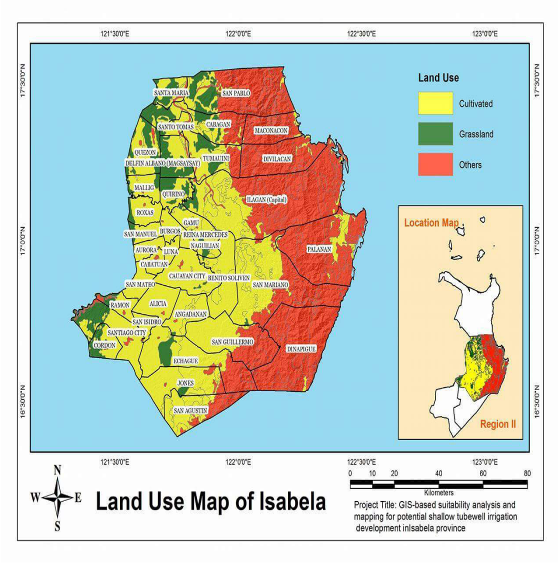

***Figure 5.** Land use map of the province of Isabela*

Based on the result of soil texture analysis and evaluation criteria only 32.33% covering an area of 326,332.94 hectares was classified as marginally suitable to highly suitable for STW irrigation development. While 67.67% was classified as not suitable for STW irrigation development because the soil texture in these areas is sand, silt mountain soil and other classes which are not suitable for irrigation development.

Land Use/Land Cover Suitability

The land use/land cover of the province was evaluated and classified into cultivated land, grassland and other land use/land cover which this includes, built-up areas, river beds, lakes, forest (mature trees covering > 50% canopy), plantation trees, mangrove vegetation and unclassified land use/land cover as shown in figure 5. Table 5, shows the distribution of areas according to land use analysis for shallow tube-well irrigation.

***Table 5.** Distribution of Areas according to land use analysis for shallow tube-well irrigation*

<table>
<tr><th>Land Use</th><th>Area of coverage (ha)</th><th>Percent (%) of the total area</th><th>Suitability classes</th></tr>
<tr><td>Cultivated</td><td>497,582.54</td><td>49.30%</td><td>S_3 (Highly Suitable)</td></tr>
<tr><td>Grassland</td><td rowspan="2">511, 870.938</td><td rowspan="2">50.70%</td><td>N (Not suitable)</td></tr>
<tr><td>Others</td><td>N (Not suitable)</td></tr>
<tr><td>Total</td><td>1,009,453.48</td><td>100</td><td></td></tr>
</table>

Based on the result of the land cover analysis, and evaluation criteria, only 49.3% is highly suitable for irrigation development while 50.7% are not suitable. These areas are grassland, forest, river, lakes and built-up areas.

Water Table Depth

The depth of groundwater table was the major factor considered in shallow tube-well irrigation development map. According to FAO guideline and discussions with related experts and depending on related previous works for groundwater evaluation, the groundwater table depth of the province was evaluated and classified into two namely; greater than 6.5m and less than 6.5m as presented in figure 6. The distribution of areas according to the depth of water table analysis for shallow tube-well irrigation development is shown in table 6.

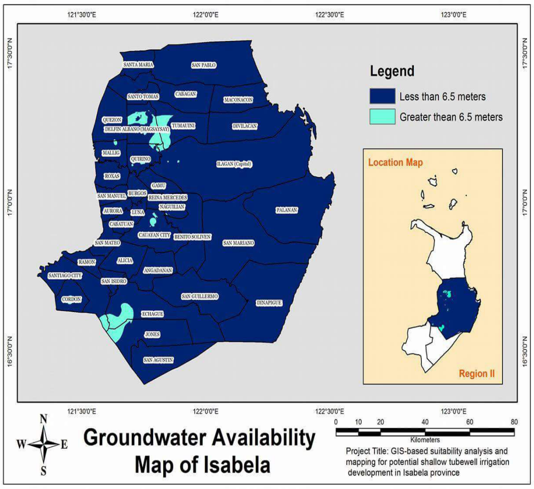

Figure 6. *Groundwater table map of the province of Isabela for shallow tube-well irrigation*

Table 6. *Distribution of Areas According to the Depth of Water Table Analysis for Shallow Tube Well Irrigation*

Water Table Depth	Area of coverage (ha)	Percent (%) of the total area	Suitability classes
Greater than 6.5 m	26,658.38	2.6	N (not suitable)
Less than 6.5 m	983,379.10	97.4	Highly Suitable
Total	1,009,453.48	100	

Based on the result of the analysis and evaluation criteria on the depth of groundwater table, 983,379.10 hectares or 97.4 percent of the area has a groundwater table depth of fewer than 6.5 meters. The area of this depth of groundwater table is highly suitable for shallow tube-well irrigation development. The remaining area of 26,658.38 hectares or 2.6 percent of the area has a groundwater table depth of greater than 6.5 meters. The area of this depth of groundwater table was classified as not suitable for shallow tube-well irrigation development.

Data Integration and Manipulation for the Generation of Shallow Tube-well Irrigation Suitability Map

The four (4) factors that were reclassified and weighted according to the result of their individual suitability assessment forms the thematic layers (slope map, soil texture map, land use, and depth of groundwater map) and that was used in the suitability analysis. Given that the raster data type was used in the entire analysis during the study, themes were superimposed using the GIS raster calculator. Simple operations from addition and multiplication to the creation of complex logical/conditional statements of raster data were performed to generate the final suitability map. Each pixel size was 20m x 20m.

Generation of Potential Irrigable Area Map for Shallow Tube-well of Isabela

The generation of potential irrigable area map for shallow tube-well of Isabela shown in figure 7, were made using the different thematic map layers. Layer 1) potential areas for irrigation based soil slope analysis; Layer 2) potential areas for irrigation based on soil texture; Layer 3) potential areas for irrigation based on water table depth and Layer 4) potential areas based on land use. The four thematic layers were assigned weights using the equation 2 and the generated potential irrigable area map for STW development is shown in figure 7. This covers an area of 512,869.73 hectares.

From this area, 28.2% (144.575.91 ha) is presently served by NIA (figure 8) leaving an area of more than 377,000 hectares (figure 9) potential for STW irrigation development.

S = [(Soil texture x 0.15) + (slope x 0.15) + (land use x 0.15) + (water table depth x 0.55)] eq. (2)

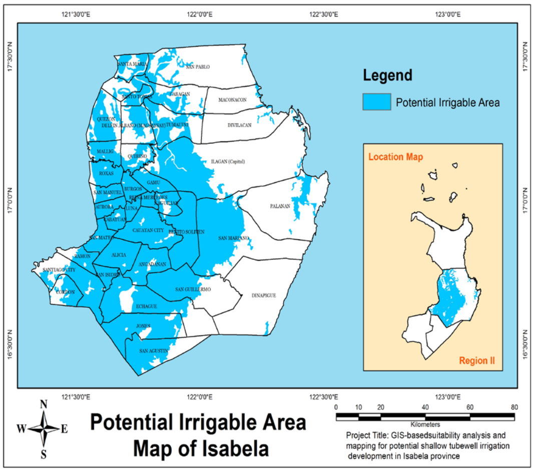

Figure 7. *Potential Irrigable Area Map of Isabela for shallow tube-well development*

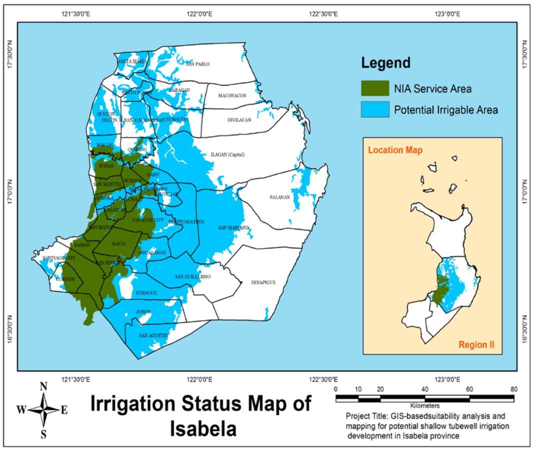

Figure 8. *Existing Irrigated Service Area of National Irrigation Administration and Potential Areas for Shallow Tube-well Irrigation Development of the Province of Isabela*

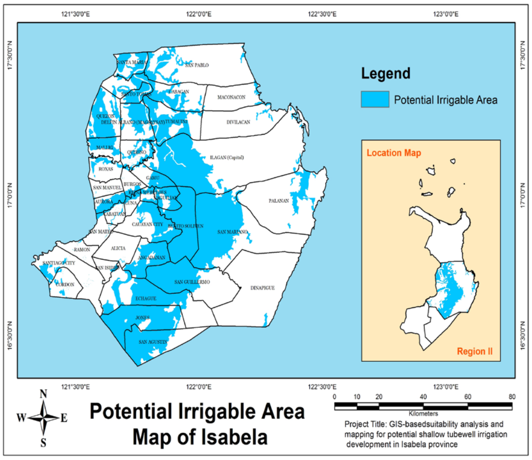

Figure 9. *Map Potential Irrigable Area for Shallow tube-well Irrigation Development*

Generation of Shallow Tube-well Irrigation Suitability Map

The final analysis for shallow tube-well irrigation suitability map excluded the areas presently served by the NIA, rivers and a 20-m river buffer. Figure 10 shows the remaining potential irrigable areas that were classified into four classes (highly suitable, suitable, moderately suitable and low suitable). Table 6As shown in table 11, 97,398.1 hectares or 25.8% of the total potential irrigable area are found to be highly suitable. Approximately 196,165.00 hectares or 51.94% of the total potential irrigable area are found to be suitable. Approximately 74,101.0 hectares or 19.62% of the total potential irrigable area are found moderately suitable and 9,977.40hectares or 2.64% of the total irrigable area are found to be moderately suitable for shallow tube-well irrigation development. This implies that if all the area considered as the potential irrigable area will be irrigated, then the irrigated rice production area in the province will increase the present irrigated rice production area (144,575.91 hectares) up to about three times. Consequently, the rice production of the province would further increase its rice sufficiency rate and increase its national contribution in supplying rice demand of the country.

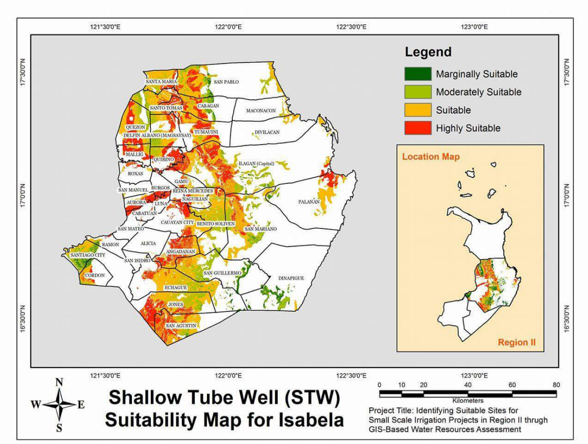

Figure 10. *Shallow Tube-well Irrigation Development Suitability Map*

Table 7. *Distribution of areas according to STW development suitability Analysis*

Level of Suitability	Area of coverage (ha)	Percent (%) of the total area	Attributes			
			The depth of the water table	Soil texture	Soil slope	Land use/ land cover
Highly Suitable	97,398.10	25.80%	< 6.5 m	Clay Loam	0 – 3%	Cultivated
Suitable	196,165.00	51.94%	< 6.5 m	Varying from sandy clay loam to clay loam	Varying 0-3% to 3 – 8%	Cultivated
Moderately Suitable	74,101.00	19.62%	< 6.5 m	Sandy clay loam	Varying from 3-8% to 8-1%	Cultivated or other land use
Marginally Suitable	9,977.40	2.64%	< 6.5 m	Sandy Loam	Varying from 8-18%	Grassland or uncultivated
Total	377,641.50	100.00%				

Validation of Results

The existing irrigated agricultural land of the study area covers 144,575.91 hectares. According to the suitability map figure 11 produced from overlay analysis, almost 100% of the existing irrigated agricultural land area fell under or within the identified potential irrigable area of the province. Further, about 98% of the existing shallow tube-well present in the study area fell under or within the identified potential irrigable area for shallow tube-well irrigation as shown in figure 12. This implies that the shallow tube-well suitability model developed in this research match-up/conform with the criteria set by the National Irrigation Administration for the existing irrigated agricultural land. Therefore, the irrigated agricultural land and production may be optimized utilizing the suitability map developed in this analysis. Therefore, shallow tube-well irrigation suitability map derived in this study could be used in optimizing irrigated agricultural land and production.

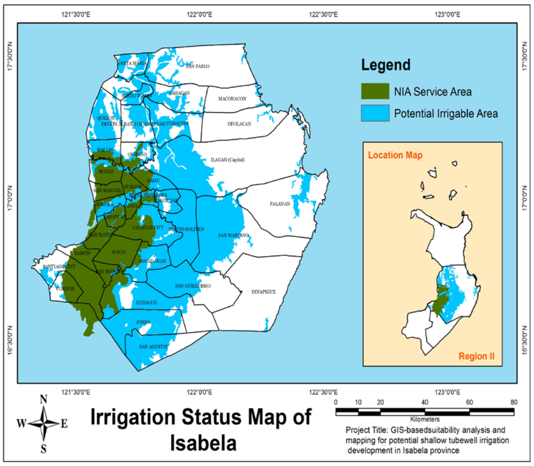

Figure 11. *Existing irrigated agricultural overlaid in derived potential irrigable areas for shallow tube-well irrigation*

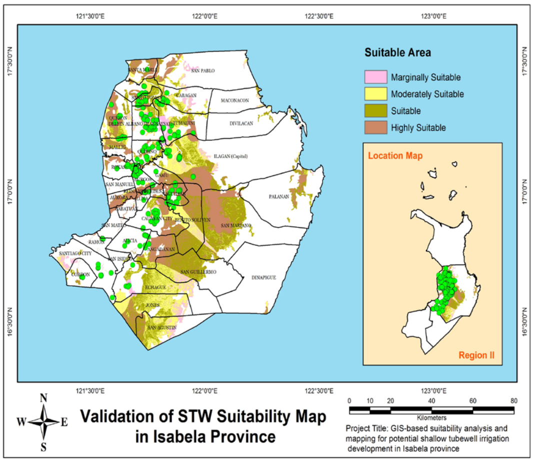

Figure 12. *Existing shallow tube-well overlaid on derived potential shallow tube-well irrigation map*

4.0 Conclusion

Based on the result of the analysis, the following conclusions were drawn;

- The depth of water table in most of the area of the province of Isabela is shallow and is within the suitable depth (<6.5m depth) for STW irrigation development.
- The potentially suitable areas identified are characterized with a water table depth of <6.5 m, a slope ranging from 0-18%, soil textures (sandy loam, clay loam, and sandy clay) and these areas are mostly cultivated lands and grasslands.
- The suitability criteria used in this study coincide with the criteria of the existing irrigation systems (both for STW and surface irrigation) such as depth of water table, land use, slope and soil texture as manifested by the validated results.
- The suitability map produced from overlay analysis indicated that almost 100% of the existing irrigated agricultural land and about 98% of existing STW in the province fell under or within the potential irrigable area for STW irrigation system. Thus, the STW irrigation suitability map derived in this study could be used as a decision support framework in the direction of policy making especially in identifying priority areas in the establishment of STW projects, particularly in the province of Isabelain optimizing irrigated agricultural land and production.

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References

Agricultural and Fisheries Modernization Act of the Philippines (AFMA law) Retrieved from https://www.lawphil.net/statutes/repacts/ra1997/ra_8435_1997.html

Aguilar-Manjarrez, J., &Ross, L. G. (1995). Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico. *Aquaculture International*, 3(2), 103-115.

Asian Development Bank Report (2012). *Shallow Tubewell Irrigation in Nepal: Impacts of the Community Groundwater Irrigation Sector Project*. Impact Evaluation Study. Retrieved from https://www.adb.org/sites/default/files/evaluation-document/35900/files/ies-nep-final.pdf

Center for Engineering Research and Development. (2007). *Development of database for irrigation development in Nepal.* Retrieved from http://www.rlarrdc.org.in/images/Development%20of%20Database%20for%20Irrigation%20Development%20in%20Nepal.pdf

Chandio, I. A., Talpur, M. A., &Taufique, A. Q. (2016, April). Integrated GIS-based site selection of hillside development for future growth of urban areas. *Mehran University Research Journal of Engineering & Technology*, 35(2), 303-308. Retrieved from https://www.researchgate.net/publication/297332606_Integrated_GIS-Based_Site_Selection_of_Hillside_Development_for_Future_Growth_of_Urban_Areas

Fasina, A. S., Awe, G. O., &Aruleba, J. O. (2008, July). Irrigation suitability evaluation and crop yield: An example with *Amaranthuscruentus* in South-western Nigeria. *African Journal of Plant Science,* 2(7), 61-66.

Jusoh, F., Zawawi, M.A.M., Man, H.C., &Kamaruddin S. (2013).Performance of Shallow Tube Well on Groundwater Irrigation in Tropical Lowland Rice Cultivation Area. *Sains Malaysia* 42(8)(2013): 1101-1108. Retrieved from https://www.researchgate.net/publication/264786840_Performance_of_Shallow_Tube_Well_on_Groundwater_Irrigation_in_Tropical_Lowland_Rice_Cultivation_Area

Food and Agriculture Organization (FAO).(1977). Crop water requirements. *FAO Irrigation and Drainage Paper,* 24. Retrieved from http://www.fao.org/3/a-f2430e.pdf

Food and Agriculture Organization (FAO). (1985). Guidelines land evaluation for irrigated agriculture. *FAO Soils Bull,* 55, 290. Retrieved from http://www.fao.org/docrep/018/t0412e/t0412e.pdf

Food and Agriculture Organization (FAO). (1993). Guidelines for land-use planning. *FOA Development Series 1*. Retrieved from https://www.mpl.ird.fr/crea/taller-colombia/FAO/AGLL/pdfdocs/guidelup.pdf

Food and Agriculture Organization (FAO). (1997). *Irrigation potential in Africa: A basin approach*. Retrieved from http://www.fao.org/docrep/W4347E/W4347E00.htm

Girma, R., Moges A., &Qurashi S. (2015).GIS Based Physical Land Suitability Evaluation for Crop Production in Eastern Ethopia: A Case Study in Jello Watershed. Agrotechnology 2015, 5:1 DOI: 10.4172/2168-9881.1000139. Retrieved from https://www.omicsonline.org/open-access/gis-based-physical-land-suitability-evaluation-for-crop-production-in-eastern-ethiopia-a-case-study-in-jello-watershed-2168-9881-1000139.pdf

Hailegebriel, S. (2007). I*rrigation potential* *evaluation and crop suitability analysis using GIS and remote sensing technique in Beles Sub-basin, BeneshangulGumez Region.* (Master's thesis). Addis Ababa University, Ethiopia. Retrieved from http://etd.aau.edu.et/handle/123456789/6736

Hecker, F. (2000). *Land classification for irrigation in Alberta.* Retrieved from https://open.alberta.ca/dataset/cff31d54-1cbd-40c2-8536-6ae0e16e54a7/resource/3d485fde-ca8f-4e31-9a11-cebf6d94854d/download/2000-560-3.pdf

Hussain I., &Hanjra, M. (2004). Irrigation and poverty alleviation: Review of the empirical evidence. *Irrigation and Drainage,* 53, 1-15.

LatitudeLongitude.org. Retrieved from https://latitudelongitude.org/ph/isabela/

Manos, B., Bournaris, T., Papathanasiou, J., & Moulogianni, C. (2007, July 24-26).A DDS for agricultural land use, water management and environmental protection. *3rd IASME/WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development.* Agios Nikolaos, Greece.

National Economic and Development Authority Regional Office 02. (2017). *Cagayan Valley Regional Development Plan (CVRDP) 2017-2022.* Retrieved from http://www.neda.gov.ph/wp-content/uploads/2018/02/2-Cagayan-Valley-RDP-2017-2022-19Jan18.pdf

National Irrigation Administration.(2016). *2016 annual report: Ang NIA at magsasaka, magkatuwangsa ginhawa!* Retrieved from http://www.nia.gov.ph/sites/default/files/newsletter/2016-annualreport.pdf

Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., Clark, S., . . .& Nandagopal, S. (2004). Water resources: Agricultural and environmental issues. *BioScience,* 54(10), 909-918.

Rosegrant, M. W., Cai, X., & Cline, S. A. (2002). *World water and food to 2025: Dealing with scarcity. Washington D. C.*: International Food Policy Research Institute. Retrieved from https://www.worldfoodprize.org/documents/filelibrary/images/borlaug_dialogue/2002/transcripts/rosegrant_transcript_F2A98817596C1.pdf

Trondillo, M. J., Generalao, I. C., Valleser, R. A., Lopez, M. T., Janson, A. Z., Bejarasco, J., Molina, R. J., . . . Mativo, A. (N.D.). *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.* Retrieved from http://www.academia.edu/36673517/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