Characterization of Groundwater Development Potential of Agusan del Norte, Philippines

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Abstract—The world’s groundwater aquifer system is suffering from stress due to the growing pressure exerted by rapid socio-economic growth and development. In order to optimize groundwater utilization to augment domestic, agricultural and industrial water demand, it is significant to understand the local hydrogeology. This paper evaluates the groundwater development potential of Agusan del Norte, Philippines using a groundwater resource potential index (GRPI). Geographic information system was utilized to manage, process and analyze existing data of well lithologic logs and to produce thematic maps of eight GRPI indicators. The provincial hydrostratigraphy confirms that the study area is characterized by a shallow aquifer and a confined aquifer located at varying depths of 38-55m below ground surface. Further analysis delineated approximately 60%, 21% and 18% of the study area to have moderate, high and low groundwater development potential respectively. This study will strengthen the provincial water management strategies in ensuring agri-industrial productivity.

Keywords—GIS, Regional development, Groundwater development potential, Hydrogeology, Local government

I. INTRODUCTION

The province of Agusan del Norte, Philippines has a growing population, increasing urbanization and emerging agri-industrial production. These development trends are the major reasons for the unprecedented increase in water demand. Regarded as an under-valued resource, groundwater is one of the means to augment the provincial water demand. Groundwater usage has becoming extensive because of its widespread occurrence, better water quality and reliability even on drought season [1].

Consequently, random well drilling and unregulated groundwater extraction to augment domestic, agricultural and industrial water demand eventually would result to unproductive wells and deterioration of aquifer characteristics. Thus, in order to optimize groundwater utilization, it is significant to understand the provincial hydrogeology, which requires the characterization of groundwater development potential.

One of the fundamental constraints of groundwater studies in developing countries is the lack of data and information of the groundwater resource [2]. Nonetheless, the introduction of geospatial information system (GIS) has allowed innovative approach in conducting hydrogeologic investigation. GIS can utilize readily available data without actual well drilling, thus conserving significant amount of time, human and financial resources. With the aid of GIS, smaller organizations with limited financial resources like local government units can conduct cost-effective hydrogeologic studies.

This study intends to develop a support mechanism that will contribute to the provincial local government units’ water management strategies by characterizing the provincial groundwater development potential.

II. CHARACTERIZATION FRAMEWORK AND METHODOLOGY

The characterization of groundwater development potential takes five steps: 1) data collection, 2) identification of groundwater resource potential index (GRPI), 3) development of well geodatabase, 4) visualization of provincial hydrostratigraphy, and 5) analysis of groundwater development potential. This study used the hydraulic conductivity (K) values of soil sample in the well lithologic log to differentiate the aquifer units [3].

Subsequently, a model was developed to evaluate the groundwater development potential of Agusan del Norte, Philippines. The GRPI model is composed of eight indicators, categorized in three sub-indices. Geographic information system (GIS) was utilized to manage, process and analyze existing data of well lithologic logs and to produce thematic maps of the eight GRPI indicators namely; 1) depth of confined aquifer, 2) thickness of confined aquifer, 3) static water level, 4) land use, 5) soil type, 6) slope, 7) effective rainfall and 8) rice consumptive use. The GRPI indicators and sub-indices were integrated using weighted multi-criteria overlay analysis to generate the groundwater development potential map [4]. The GRPI was classified into five classes to create the groundwater development potential (GDP) map. The GDP map delineated the study area as: very high, high, moderate, low and very low GDP.

A. Study Area

The study area comprises mainly of the Agusan Valley, which is part of the Agusan River Basin (Fig. 1). It is characterize by a low gradient alluvial floodplain with recent geology and lies between the longitudes from 125° 12’ 50.4” to 125° 39’ 21.6’’.
and latitudes from $8^\circ 42' 18.0''$ to $9^\circ 27' 39.6''$. The study area has a total geographical area of about 1,121 km$^2$, which occupies about 40% of the province of Agusan del Norte. This areal extent constitutes 76% of all the settlement area wherein 95% of rice is being produced.

Agusan Valley is the most important agricultural research and production center in Caraga Region. This area has increasing urbanization and is rapidly becoming an agri-industrial hub which consequently intensifying its water demand. Aside from paddy rice, other major plantation crops include banana and mango. Wood, pulp and paper, coconut and banana processing dominates the agri-industry.

The main source of potable water is surface water from Taguibo River and other lesser-known springs. Groundwater is main source of potable and irrigation water in the municipalities of Remedios T. Romualdez, Magallanes, Tubay and Cabadbaran City.

There is a growing consciousness among the residents of the province to access sufficient water while maintaining environmental sustainability.

### B. Data Collection

A fieldwork in the Philippines was conducted in December, 2009 until January, 2010. The objectives of the fieldwork were; 1) to gather existing data of well lithologic logs, 2) to revalidate gathered data, and 3) to rationalize the GRPI indicators and sub-indices.

1) Identification of Relevant Data: The researcher visited multiple national and local government agencies in Metro Manila and Agusan del Norte, Philippines to gather existing data. Relevant data collected include: lithologic logs or borehole logs of wells, geologic formations, soil type, land use, slope, rainfall, static water level, seismic faults, and rice production volume. Related groundwater studies, reports and development plans were also collected as supplemental information. The researcher had a consultation with local well professionals to discuss about the perceived location of deep confined aquifer within the province.

2) Local Seminar-Workshop: On January, 2010, the researcher organized a provincial seminar-workshop, which was participated by 40 representatives from various government agencies. Specific objectives of the local seminar-workshop were; 1) to present the research proposal, 2) to revalidate collected data, 3) to rationalize the proposed GRPI indicators and indices, and 4) to discuss sustainability issues of the research outputs. After the presentation of the research proposal, the workshop started with revalidation of the general well database by the participants coming from the municipal local government units.

### C. Groundwater Development Potential Model

A model was developed for converting the eight groundwater resource potential indicators and sub-indices into a unitary value called groundwater resource potential index (GRPI). The GRPI model (Table I) was rationalized and justified during the local seminar-workshop.

During the workshop, the proposed indicators and sub-indices were defined and their relationship relative to groundwater development potential was discussed. Then, worksheets were disseminated wherein each participant were to weight the eight indicators based on their experiences and perception of the factors affecting groundwater availability, rechargeability and consumptive use. Also, participants provided their justification behind the relative weights given to each indicator. Afterwards, all the responses were consolidated and the average of the weight of each indicator and sub-index were computed to create the GRPI model. The provincial groundwater development potential was evaluated using the GRPI model.

### Table I

<table>
<thead>
<tr>
<th>GPRI Sub-indices and Indicators</th>
<th>Weight (%)</th>
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<tbody>
<tr>
<td>A. Availability sub-index</td>
<td></td>
</tr>
<tr>
<td>1. Depth of confined aquifer</td>
<td>37</td>
</tr>
<tr>
<td>2. Thickness of confining layer</td>
<td>35</td>
</tr>
<tr>
<td>3. Static water level</td>
<td>28</td>
</tr>
<tr>
<td>B. Rechargeability sub-index</td>
<td>32</td>
</tr>
<tr>
<td>4. Land Use</td>
<td>36</td>
</tr>
<tr>
<td>5. Soil type</td>
<td>26</td>
</tr>
<tr>
<td>6. Slope</td>
<td>20</td>
</tr>
</tbody>
</table>
The GRPI sub-indices are: 1) availability, 2) rechargeability, and 3) consumptive use. The sub-index value is the summation of all indicators under each sub-index category multiplied by its respective indicator’s weight, as shown in the model. This model utilized weighted multi-criteria overlay analysis. Literature supports that this analysis has been adopted recently in groundwater availability and groundwater recharge studies [4], [5]. Similarly, GRPI was calculated by the summation of the three sub-index value multiplied by its respective sub-index weight. Clustering of indicators into categories or sub-index can be effective in analyzing the strengths and weaknesses of a certain area or municipality.

III. RESULTS OF DATA ANALYSIS

A. Provincial Hydrostratigraphy

The provincial hydrostratigraphy was visualized using three-dimensional cartography in ArcGIS ArcScene application. The provincial hydrogeology shows the following major findings. First, the entire study area is characterized by a shallow aquifer (water bearing formation of depth less than 20m). Second, the analysis found that another water bearing formation (deep confined aquifer) is located below the shallow aquifer with depths ranging from 38 to 55 meters below the ground surface (Fig. 2). This can be interpreted that the shallow aquifer could be a satisfactory source of irrigation water whereas the deep confined aquifer is the suitable source of potable water.

These findings are particularly significant on the following two contexts. Firstly, the presence of a shallow aquifer concurred with the previous reliable study of rapid assessment of water supply sources conducted by the National Water Resource Board in 1982. This study further identified larger scale of shallow aquifer. The presence of shallow aquifer in the entire study area agreed with David that most arable land in the Philippines is overlain with a shallow aquifer [6]. Secondly, there has been discussion among local professional well drillers that the area is exemplified with a deep confined aquifer. However, this study is the first to visualize its existence, supporting the argument of local professionals.

The three-dimensional cartography of the hydrostratigraphic layer was limited to a depth of 70m because most wells have lithologic log data until this depth. Although some wells have lithologic logs up to 150 meters, especially wells owned by water utility service providers, analysis results would be unreliable due to limited number of data points.

Being aware of the presence of a shallow aquifer and deep confined aquifer throughout the study area, the provincial government can promote shallow well irrigation and can assist in the establishment of municipal water districts. Development of new agricultural and industrial areas can also be pursued. Understanding the provincial hydrostratigraphy will enable stakeholders to determine the feasible location of wells, design well specifications and estimate construction cost of wells.

B. Groundwater Development Potential

Using GRPI model in the weighted overlay analysis of availability, rechargeability and consumptive use sub-indices, the GDPI map was generated. Results showed that the lowest GRPI value is 1.7979 while the highest GRPI value is 4.5768. Almost the entire area of Butuan City has relatively low GRPI value where most areas of the municipalities of Magallanes and Tubay have relatively high GRPI value.

In order to describe qualitatively the groundwater development potential of Agusan del Norte, Philippines, GRPI map was classified into five categories. This resulted to the creation of the groundwater development potential (GDP) map (Fig. 3). The GDP map delineated approximately 60%, 21% and 18% of the study area to have moderate, high and low groundwater development potential respectively (Table II).

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>GROUNDWATER DEVELOPMENT POTENTIAL RESULTS</th>
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<tbody>
<tr>
<td>JICTEE-2010 Luang Prabang, Lao PRD. Dec 21 - Dec 24, 2010</td>
<td></td>
</tr>
<tr>
<td>Effective rainfall</td>
<td>18</td>
</tr>
<tr>
<td>Consumptive use sub-index</td>
<td>13</td>
</tr>
<tr>
<td>Rice consumptive use</td>
<td>100</td>
</tr>
</tbody>
</table>
IV. INTERPRETATION AND IMPLICATIONS OF GROUNDWATER DEVELOPMENT POTENTIAL

Groundwater development potential (GDP) describes the ability of an area to support groundwater demand for domestic, agricultural and industrial use. The GRPI provides the relative magnitude of GDP of one area with respect to another area. In order to differentiate GDP description, it is particularly suggested that the users refer back to the GRPI sub-indices, to formulate the necessary groundwater management strategies.

As indicated in figure 3, areas with high and very high GDP can be interpreted that the locality is capable of supporting current and future groundwater demand for domestic, agricultural and industrial use. Nonetheless, these localities still need groundwater management strategies for sustainable groundwater utilization. Especially in zones where artesian (free flowing) wells exist, a mechanism to sustain groundwater demand is needed. In zones where low groundwater development potential are entitled to the surplus water from these areas.

Areas with moderate GDP can be inferred that the locality is capable of supporting current groundwater demand for domestic, agricultural and industrial use. However, the capability of the area to support groundwater demand in the future is uncertain. In order to ascertain that the locality can support the future groundwater demand, specific groundwater management strategies should be formulated. These strategies hinge on the analysis of groundwater availability, rechargeability and consumptive use sub-indices. For example, in the case of the municipality of Buenavista wherein most areas have moderate GDP, results showed that the municipality of Buenavista also has: 1) moderate groundwater availability, 2) low groundwater rechargeability, and 3) low consumptive use. This means the municipal local government can focus on formulating strategies on: first, how to improve groundwater rechargeability, and second, how to conserve groundwater and improve groundwater use efficiency. Possible strategies to address these concerns may be three-fold: 1) reforestation of brush and grasslands to enhance land use and productivity, 2) construction of surface-water irrigation system, and 3) regulation of number of deep well drilling for household use.

Areas with low and very low GDP can be understood that the locality has difficulty in supporting current and future groundwater demand for domestic, agricultural and industrial use. The locality may be able to support its currents groundwater demand but not to its desired level. Groundwater flow may be irregular throughout the zone and thus, groundwater can be unreliable. Therefore, groundwater management strategies are urgently needed. In the case of Butuan City where its northern part has low GDP, immediate groundwater management strategies are desired to conserve and improve efficiency of groundwater utilization like regulation of deep well pumping. This may call for temporary suspension of privately owned deep wells to buy time for the confined aquifer to recharge. This may also mean that only the local water utility service provider, in this case the Butuan City Water District (BCWD), is allowed to pump groundwater. However, in this scenario, BCWD should ensure universal coverage of potable water to all its customers.

The provincial local government’s strategy of establishing agri-industry cluster areas and special economic zones should consider the groundwater development potential of the target area. Technically, these new development areas are to be established away from settlement zones where water supply conveyance and distribution infrastructure are in place. Extending water supply conveyance system to these new agri-industrial areas may be financially unattractive to local water service providers. It may be also inefficient if investors themselves finance the water supply conveyance system. Thus, investors to these new development areas are most likely to tap the groundwater resource. In this scenario, this study would be of great help in siting areas with relatively high groundwater development potential.

V. CONCLUSION

GIS provided an opportunity for conducting hydrogeologic studies using existing data of lithologic logs and other secondary data. Thematic maps and tabular data were developed after relevant data were processed and analyzed to characterize the provincial hydrogeology. The study found significantly that the study area is characterized by a shallow confined aquifer as well as deep confined aquifer. With these findings, the provincial government can pursue water resources planning for sustainable groundwater use to achieve its socio-economic development agenda.

The GDP map, hand in hand with the provincial hydrostratigraphic map, can be a good reference to individuals in making decision on their housing location or other water demanding ventures. Likewise, academic institution can make use of this study as baseline information for groundwater-related studies. The author hopes that the government’s executive departments such as DENR, DPWH and DA can benefit from study in analyzing the technical feasibility and subsurface specifications of their infrastructure projects.

REFERENCES


