Model Performance Index of Ground Water Irrigation Systems in the Karst Mountain Region: Case Study in Gunung Kidul Regency, Yogyakarta

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Abstract. Ground Water Irrigation Network (GWIN) make a major contribution to agricultural production in karst mountainous areas, especially in the dry season. A performance index model would be developed to measure the level of success in developing groundwater irrigation systems. Performance evaluation of groundwater irrigation systems was a value called the Groundwater Irrigation Performance Index. This study aims to obtain determinants of the parameters of the index performance of groundwater irrigation that based on technical and non-technical aspects by analyzing the variables that give effect to the both aspects. Technical variables were physical infrastructure, supporting facilities, geological conditions, vegetation conditions, water recharge area conditions, direction of spatial planning, documentation, and crop productivity. Non-technical aspects were personnel organizations, P3A (Association of Water User Farmers'), and economic-socio-cultural. The locus of research was in the Karst Mountains area of Gunung Kidul Regency, Yogyakarta. The method used in collecting data was direct measurement of site visit and secondary data from the field. The non-technical aspects of using questionnaire data as qualitative data were converted into quantitative data. Smart Partial Least Squares was used for filtering variables. GRG- Generalized Reduced Gradient method was used to solve the non-linear equation with the objective- objective assumption and constraints. The model calibration test was calibrated and simulated on the parameters used. The results were a performance index model to measure the level of success in developing groundwater irrigation systems. The performance index evaluation of the developed groundwater irrigation system was an accumulation of technical indexes and non-technical indices involving influential variables.

1. Introduction

One of the potentials that could be utilized in meeting the needs of water for humans, in addition to surface water was ground water. According to Bisri (2012), ground water wassosil underneath water that occupies cavities in the geological layer in a saturated state with sufficient quantities (identical to aquifers). Soil water was the amount of water below the surface of the earth that could be collected with wells-gold, tunnel or drainage system or by pumping.

The potential availability of ground water in Indonesia plays an important role in increasing crop productivity. The use of ground water for basic human needs was the fulfillment of irrigation water demand. Utilization of ground water for irrigation consists of two types of water provision, i.e. the main
source of water and supply in the event of water shortages. In general, in rainfed and dry land agriculture, the use of ground water as a supplement is carried out at the beginning of the dry season at the time water shortages occur (Rengganis, 2016). Irrigation networks attributed to groundwater as a water source or known as the Ground Water Irrigation Network (GWIN) make a major contribution to agricultural production, particularly in the dry season.

Karst area was identical with arid environmental conditions. Its surface was indeed dry with signature of fractured soils. However beneath it all there was high potential for groundwater sources. Groundwater in the karst region was concentrated within underground tunnels or gaps. One of the advantages of karstic springs was the long delay between deposited rain to spill out. This properties creating karst spring owning a large storage so it would have a large discharge during the dry season. This karstic areas are wellknown as"giant freshwater tanks" that could be bennefitted for the needs of human life (Haryono, 2001).

Karst area in the Gunungkidul region was first introduced by Danes (1910) and Lehmann (1936) and then it better known in the world by the name of Gunungsewu. This area was characterized by the development of the karst dome (kegelkarst), a positive landform better known as the sinuousoidal dome. Furthermore Gunungsewu can be categorized as an open karst (bare/nackter karst) in the form of conical hills that were unique and can not be found in anywhere else throughout the world.

This research would focus on the use of ground water only for the fulfillment of agricultural irrigation needs in karstic mountainous areas. It purposed to built performance index model in order to measure the actual performance of the groundwater irrigation system. Its performing evaluation was a value called the Groundwater Irrigation Performance Index. With this index model the real conditions can be represented, so it always be monitorable continuously. In the future the index collecting data comparison can be used as an evaluation for the system. With this approach the value of the function and usefulness always be traceable.

2. Material and Method

2.1. Research Area

The irrigation area studied was the groundwater irrigation area in the Gunung Kidul Mountains region of Yogyakarta. The study location was a technical irrigation area that has been carried out an performance evaluation audit by a government agency and was a groundwater irrigation location that fallsunder the authority of the Central Government.

Gunung kidul Regency was an area that experiences hydrological drought every year, so that it has limited access to clean water (Gunungkidul District Development Planning Agency, 2007). Based on the hydrogeological character, not all regions in this region experience water shortages, especially in the Wonosari and surrounding areas. According to Sir Mac Donald and Partners (1979), the Wonosari and surrounding areas have aquifers that were locally quite productive. The high quantity of ground water in the Wonosari and surrounding areas could be seen from the number of wells that have been built since the 1970s to the present. The drilled wells were partly for groundwater irrigation and others were used to meet the domestic needs of the population, both managed by the Regional Drinking Water Company (RDWC) or by the community collectively.

Gunungsewu was located in the central part of the southern part of Java Administratively, the Karst Gunungsewu area was located in four districts, namely Bantul Regency and Gunungkidul Regency (Special Region of Yogyakarta), Wonogiri Regency (Central Java Province), and Pacitan Regency (East Java). Gunungsewu Karst area has an area of about 1,300 km2, stretching as far as 85 km (west to east) with a width of 10 km to 29 km (north-south direction). The elevation of the area starts from 0
m above sea level on the southern coast of Java, up to about 512.5 m above sea level. The image of the Gunungsewu karst area could be seen in Figure 1. The northern part of the Gunungsewu karst area was bounded by the Wanosari and Baturetno basins (Figure 2.) which were composed of limestone material, but have a non-intensive karstification level. These two basins separate the Karst area of Gunungsewu with volcanic-clastic sedimentary mountains, better known as the Baturung Mountains.

![Figure 1. Image of the Gunungsewu Karst Area (Haryono, 2011)](image1)

![Figure 2. Morphological Sketch of Gunungsewu Karst Area Image(Haryono, 2011)](image2)

2.2. Data Collection

The data used in this study were secondary data on the operation and maintenance of existing groundwater irrigation and primary inventory data in the field. In general, the data needed in determining the performance index of groundwater irrigation systems was grouped into technical and non-technical aspects. The two aspects were:

1. Physical infrastructure
2. Supporting Facilities
3. Geological Conditions
4. Vegetation Conditions
5. Conditions of the Water Feed Area
6. Spatial Planning Direction
7. Documentation
8. Plant Productivity
9. Personnel Organization
10. Water User Farmers Association
11. Social, Culture and Economy

From references including journals, several parameters that could be used to support and have a dominant influence on the condition of the groundwater irrigation system could be collected to be used as a basis for determining the groundwater irrigation system index variables. The concept of this research was to collect field data to create models and graphical equations for changes in the performance of the groundwater irrigation system as shown in Figure 3.

![Figure 3. Research Concepts](image-url)

3. Result and Discussion

Determination of performance index of groundwater irrigation systems in karst mountainous areas (case study in Gunung Kidul district) was determined based on technical and non-technical aspects. Each aspect would be supported by various appropriate studies.

3.1. Technical Aspect

The technical aspects to be assessed were:
1. Physical infrastructure: the assessment was carried out on the physical infrastructure of the existing groundwater irrigation system including energy sources, pump conditions, pump houses, wells, shared buildings, outlets and carrying channels. The condition of the physical infrastructure of groundwater irrigation in the location greatly affects the performance of the ground water irrigation system.
2. Supporting facilities: assessment of supporting facilities in the ground water irrigation system, not only includes the assessment of physical infrastructure but also supporting facilities such as watervalves, inspection roads, safety fences, operator transportation, operator communication equipment, O&M offices and O&M equipment.

3. Geological conditions: to assess geological conditions, among others, determine the level of soil permeability with rock type elevation and land slope.

4. Vegetation conditions: Vegetation conditions could be seen from the vegetation density and the types of vegetation contained in the data that has been evaluated.

5. Condition of water recharge area: The water recharge area could be seen in the das status data available in the water recharge area and groundwater estimation data so that it could determine the amount of precipitation in the upper reaches of the river.

6. Spatial planning directives: the research must be in accordance with the scope of RT/RW conservation and meet RT/RW licensing requirements in accordance with the provisions.

7. Documentation: In the Development of documentation between planning and implementation was needed in connection with the work relationship so that the results of development in accordance with the plan.

8. Plant Productivity: assessment of crop productivity was determined from the realization of plants, determining the types of plants so that they could determine water needs and know the method of providing water in the needs of food plants.

3.2. Non-Technical Aspect

Non-technical aspects to be assessed were:

1. Personnel organization: the existence of an active personnel organization with adequate human resource support and a clear legal entity would provide support for the performance of the ground water irrigation system.

2. P3A: Water user farmer association that has a legal entity and organizational completeness capacity and has personal competency to support the performance of farmers in the irrigation system.

3. Social, cultural and economic: the importance of community education knowledge that would grow the community's economy in order to overcome the land irrigation system from the dry zone.

3.3. Determination of Performance Index of Groundwater Irrigation Systems

1. In determining the performance index of groundwater irrigation systems, variables or parameters would be assessed in each aspect according to conditions at the study site. Relationships between aspects and parameters would be examined linearly with the equation: \[ y = ax_1 + bx_2 + cx_3 + \ldots \] and so on. Parameters that have little effect on the groundwater irrigation index would have a small gradient coefficient. And vice versa, the influential parameters would have a gradient coefficient that was larger.

2. Data were analyzed (validation) then recapitulated for each aspect, variable and variable. However, the dimensions of each variable were still different, so to score the dimensions the scoring system was used. While the score itself was obtained from the reference results and opinion surveys of experts which were the primary data from the questionnaire.

| Table 1. Tabulation of Required Data |
|--------------------------------------|

| Required Data | Information |
|---------------|-------------|

5
| Hydro-climatology | Rain station data  |
|-------------------|--------------------|
|                   | Rainfall data at the rain station (with a span of the last 10 years) |
| Watershed, Land and Groundwater, Agriculture | DAS data  |
|                   | CAT map  |
|                   | RT / RW map  |
|                   | Basin data and groundwater exploitation  |
|                   | Geological Data and Soil Mechanics  |
|                   | Vegetation data  |
|                   | Agricultural Data  |
| Groundwater irrigation infrastructure | GWIN technical data (wells, pump housings, pumps, energy sources, and other buildings) |
| Geological | Land permeability data  |
| Policy and Institutional | Institutional condition and profile data  |
|                   | P3A institutional data  |
|                   | Data on legal aspects.  |
| Social, Culture and Economy | Population data  |
|                   | Data on the condition of community behavior  |
|                   | Data on community economic conditions,  |

3.4. Model of Performance Index of Groundwater Irrigation Systems in Gunungsewu

The condition of the groundwater irrigation network system was a unified system in which the value of function and usefulness becomes the reference parameter of evaluation. The value of functions and benefits becomes important because the conditions in the field were also found that the construction of the GWIN was carried out in stages, for example the construction of wells without being equipped with pumps, energy sources and other buildings, so that the value of functions and benefits has not been achieved.

The data that has been obtained was secondary data in the form of technical data from BBWS Serayu Opak, which were 234 groundwater wells spread in Gunung Kidul district. Filtering of variables was done with the smart PLS-Partial Least Squares tool. Then an analysis was carried out using the GRG-Generalized Reduced Gradient method to solve the non-linear equation with objective-objective assumptions and constraint assumptions. The model calibration test was calibrated and simulated on the parameters used.

Of all the technical and non-technical aspects each variable has a different dimension, so to make one dimension (dimensionless) classification and assessment scores were needed from the Performance Index of the Groundwater Irrigation System in the Karst Mountains. Scoring assessments were obtained from references and questionnaire surveys from experts, activists, academics, managers, and the public.

3.4.1. Technical Index of groundwater irrigation systems

The Technical Index of the groundwater irrigation system was calculated based on the following equation:

\[ IL_{\text{technical}} = a_1.T_1 + a_2.T_2 + a_3.T_3 + a_4.T_4 + a_5.T_5 + a_6.T_6 + a_7.T_7 + a_8.T_8 \]

with:

- \( T_1 \): Technical infrastructure index
Table 2. Classification of Performance Index of Groundwater Irrigation Systems in the Karst Mountains

| Skor | Klasifikasi |
|------|-------------|
| 1 < 2 | Bad         |
| 2 < 3 | Lacking     |
| 3 < 4 | Moderate    |
| 4 < 5 | Good        |
| 5    | Very Good   |

From all technical and non-technical variables would be tested statistically, so that it could be distinguished which variables were significant and which variables were not significant. Only significant variables would determine the model that would be used to determine the Groundwater Irrigation System Performance Index in a particular area. For one particular area such as the Gunungsewu karst mountains in Gunungkidul, a significant variable would not be the same as another area, so the model obtained would also be different from other regions. From the model that has been obtained would be determined Performance Index of Groundwater Irrigation Systems in the Karst Mountains. Furthermore, this information could be used as a reference in making decisions and following actions, whether in the form of repairs, rehabilitation, periodic maintenance or just routine maintenance.
4. Conclusions
The conclusions that could be drawn were as follows:
1. An initial model has been obtained as a tool to determine the Performance Index of the Groundwater Irrigation System, especially in the Karst Mountain region.
2. The actual model was highly dependent on local variables that have a significant effect.
3. The Groundwater Irrigation System Performance Index was very much needed as a reference in making decisions and following actions.

5. References
[1] BAPPEDA Gunungkidul Regency, (2007). Preparation of Water Resources Balance in Gunungkidul Regency. Final Report, Yogyakarta.
[2] Bisri, M. (2012). Ground Water. Brawijaya University Press, Malang.
[3] Danes, J.V., (1910). Die Karstphanomene in Goenoeng Sewoe auf Java, Tjdschrift van het kon. Ned. Aardrijksk. Gen.Tweede Serie, deel XXVII, 247-260.
[4] Haryono, E. (2011). Introduction to Gunungsewu Karst. Field Guide of Asian Trans-Disciplinary Karst Conference. Yogyakarta: Karst Research Group, Faculty of Geography, Gadjah Mada University.
[5] Haryono, E. (2001). Hydrological Value of Karst Hill. Paper at the National Seminar, Eco-Hydraulics. March 28-29 2001. Department of Civil Engineering, UGM.
[6] Lehmann, H., 1936. Morfologiche Studien auf Java, Gohr, Abh, 3, Stuttgart.
[7] MacDonald & Partners. (1984). Greater Yogyakarta - Groundwater Resources Study. Vol 3 : Main Report. Directorate General of Water Resources Development Project (P2AT), Yogyakarta.
[8] Rennganis, Heni. (2017). Potential and Efforts to Use Groundwater for Dry Land Irrigation in Nusa Tenggara.