DEVELOPMENT OF WEB-BASED SPATIAL DECISION SUPPORT SYSTEM FOR GROUNDWATER RESOURCE MANAGEMENT IN INDONESIA

(A Case Study: Banyumas Regency)

Jumadi [1] *, Sigit Widiadi[2], Priyono [1], Yuli Priyana [1], and Agus Anggoro Sigit [1]

[1)] Faculty of Geography, Muhammadiyah University of Surakarta
[*)] email: jumadi_geo@ums.ac.id
[2)] Banyumas Regency Bureau of Energy and Mineral Resource

ABSTRACT

Increasing demand of freshwater and unreliable freshwater quality are main issues that urge sustainable groundwater use. A continuous effort to maintain the sustainability of groundwater use and supply is through careful groundwater management, which takes into account diverse regional components, including physical-environmental and human-related factors. The establishment of regional database embracing wide aspect of regional components and automated administering protocol to control groundwater use serve as a tool for this management objective. This study aims at developing web-based Spatial Decision Support System (SDSS) to satisfy this database and administering necessity.

System is developed through waterfall model of life cycle procedures with steps as follows: 1) defining System Requirements; 2) proceeding System Development; 3) carrying out Test and Evaluation; and 4) implementation. Literature research and peer observation and discussion reinforce the system development.

Findings witness the usefulness of web-based Spatial Decision Support System (SDSS) in providing strategic input in decision-making process in regard with groundwater management attempt as it is capable of providing rigour data and information and simplifies administrative protocols. Practical implementation ranges widely from the monitoring to controlling stages.

This study suggests that following studies employ specific spatial analysis to model the impact of excessive groundwater exploitation and include the model as additional input for the currently developed web-based Spatial Decision Support System (SDSS) since it is regarded as effective measure in planning and controlling groundwater use. In addition to this, creation of groundwater dynamics log through recording spatiotemporal pattern of available water in wells also provides valuable input to monitoring and controlling measure.

Keywords*: web-GIS, SDSS, groundwater sustainability, groundwater management, and groundwater modelling*

INTRODUCTION

With the nature of Indonesia as a tropical country with abundant surface water, the intensity of groundwater use is supposed to be shrinkable. However, empiric situation witnesses continuing groundwater exploitation. This situation needs control because excessive exploitation leads to basin damage that can result in land subsidence and seawater intrusion (ESDM, 2009).

Consistent with Santosa & Adji (2007) and Sudarmadji (2006), data shows that freshwater demand in Banyumas Regency continuously rises along with advancement in regional development. Statistics reveal a 6.16% increase of tap water consumption in 2007 (11,383,923m^3) compared with figure in 2004. As much as 8,631,101m^3 of 2007 regional water consumption is to satisfy domestic needs (Banyumas Statistics Bureau, 2007). On the other hand, the 2007 annual required amount of freshwater supply for domestic needs is estimated to be 76,447,020m^3. As a consequence, to meet with this requirement, supply from water tap is insufficient. The use of groundwater through dug wells, pumped wells, or drilled wells then becomes inevitable.

As a preventing measure to unsustainable groundwater use, attentive groundwater management taking into account both regional physical and human-related factors is entailed. Physical factors refer to the environmental carrying capacity to groundwater supply, while human-related factors refer to method, pattern, and intensity of human activities that influence the preservation effort. In detail, physical factors include rainfall, geology, geomorphology, geohydrology, the presence of groundwater basin, and land use. Human-related factors include the excessive groundwater use, human-induced environment degradation in recharge area, pollution, and inappropriate groundwater sampling procedures.

As an attempt of providing strategic input to tactical decision-making within the groundwater management objective, the establishment of administering protocol through the provision of regional groundwater database with spatial orientation is involved. In accordance with this, the

development of Spatial Decision Support System (SDSS), as said by Malczewski (1999) to be the advancement of Geographic Information System (GIS), is needed.

RESEARCH METHOD

Malczewski (1999) mentions Spatial Decision Support System (SDSS) to be an interactive, computer-based system designed to support a user or a group of users in achieving higher effectiveness in decision-making process while solving a semi-structured spatial decision problem. Compared to Geographic Information System (GIS), which can be described as a piece of software that can perform generic spatial analysis and geo-processing methods towards sets of geographic data and requires an analyst or expert as operator, Spatial Decision Support System (SDSS) is a domain or an industry-specific software with no necessity of operator presence. As the name suggests, Spatial Decision Support System (SDSS) enables support for decision-making, but to do so, the presence of domain expert made of spatial analysis, geo-statistics, geo-processing or other tools from spatial information science is required. To start with, Spatial Decision Support System (SDSS) must be designed to address specific questions with geographic elements. Therefore, relevant up-to-date spatial data along with algorithms from spatial information science, domain-specific models to answer domain-specific questions, and a method of visualisation must be accessible (http://www.geospatial.nomad-labs.com), Furthermore, Malczewski (1999) details Spatial Decision Support System (SDSS) in three major activities, namely: Database Management System (DBMS) and geographic database; a Model Based Management System (MBMS) and model based; and Dialogue Generation and Management System (DGMS).

Literature Review

This stage is carried out to explore diversity of related data and information from books, journals, research, and the Internet, serving as background for this study.

Peer Observation and Discussion

This phase aims at discussing data, information and procedures needed in the development of Spatial Decision Support System (SDSS). Personnel from multi-disciplinary background (geology, geography, information technology and management) take part in the discussion.

Geodatabase Management System (DBMS) Development

The Geodatabase Development method adopts Artur & Zeiler (2004) procedure that consists of three main phases, i.e. conceptual, logical, and physical design.

Model Based Management System (MBMS) Development

This phase develops procedures and methods to support decision-making in groundwater exploration management. Procedures and methods are developed from common practice of groundwater management in Banyumas Regency. The common practice is regarded as conceptual model. Spatial data is involved to establish an integrated system.

System Development

System development procedures employ waterfall model as suggested in Demers (1997). The waterfall model is constructed from four main stages: 1) defining System Requirements; 2) proceeding System Development; 3) carrying out Test and Evaluation; and 4) implementation. Being called so as the model requires sequential process, meaning that one phase cannot be implemented before the completion of initial stage.

RESULT AND DISCUSSION

Study Area

The study area is Banyumas Regency, which lies within Central Java Province, Indonesia (see Figure 1) and measures 1,327.60km^2 (132,759.56ha). The centre lies between mainland and mountains, through Serayu River valley that is used mainly for agricultural purpose. Most of the highland is allocated for settlements, while the mountainous area is for plantations and tropical forests.

Banyumas Regency is an area with high potential of natural resources as it is situated within the vincinity of active volcano (Mt. Slamet) with its fertile vulcanic soils and vast forest. The weather is influenced by wet tropical climate. Local temperature ranges from 21.4°C to 30.9°C. Being situated between the slopes of mountains far away from coast, sea breeze effect is not apparent. With the low-lying southern coast, the wind seems to cross the mountain, headed to valley with 1001mbs averaged pressure (http://www.wikipedia.org).

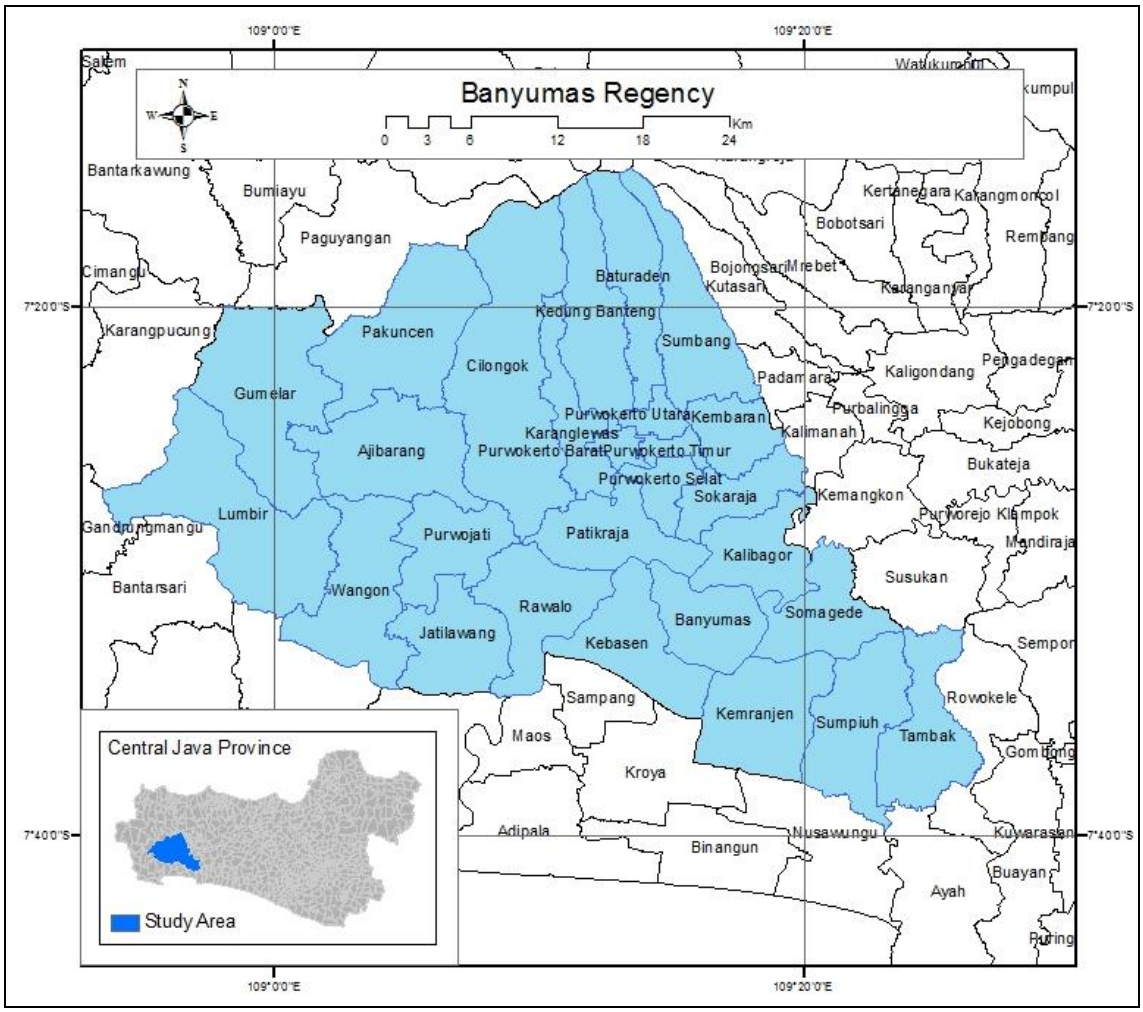

Figure 1. Study Area

Result of Geodatabase Development

Database used in this application is spatial database originated from primary and secondary data source, with the inclusion of some non-spatial data. The primary source is field survey to

locate the existing wells, industrial areas, and other groundwater users, while the secondary data source is project and research documentation, and digital map (see Table 1).

Table 1. Data and Sources Used for Geodatabase Development

Data	Scale	Type	Source
(Map of) Geology	1:25.000	Spatial	Digital Map (RBI)
(Map of) Groundwater Basin	1:25.000	Spatial	Digital Map (RBI)
(Map of) Topography	1:25.000	Spatial	Digital Map (RBI)
(Map of) Aquifer Productivity	1:25.000	Spatial	Field Work
(Map of) Groundwater Potential Area	1:25.000	Spatial	Field Work
(Map of) Conservation Plan	1:25.000	Spatial	Policy
(Map of) Administration	1:25.000	Spatial	Digital Map (RBI)
(Map of) Industrial Area	1:10.000	Spatial	Field Work
(Map of) Wells Location	1:10.000	Spatial	Field Work
Additional Map (road networks, bridges)	1:25.000	Spatial	Digital Map (RBI)
Groundwater User	-	Non-spatial	Registration
Wells Administration Data	-	Non-spatial	Registration and Survey
Groundwater Laboratory Analysis	-	Non-spatial	Survey and Laboratory Analysis
Pumping Test data	-	Non-spatial	Survey
Groundwater Level Observation data	-	Non-spatial	Survey
Exploration Permit	-	Non-spatial	Registration
Drilling Company Data	-	Non-spatial	Registration
Hydro-geomorphology Surveying Company	-	Non-spatial	Registration

Photograph	-	Non-spatial	Survey

Sources: Modified from ESDM (2004)

Data is stored in a database system in a MySQL table. The GEOMETRY data type from MySQL Spatial is used to enable storing spatial data in point, line or polygon format. Spatial extension in MySQL allows storage of geographic objects that are usable in Geographic Information System (GIS) applications. Based on the specifications of the OGC, every MySQL Spatial object/layer is saved in separated table within the database, with one record in the table of each spatial feature (MicroImages, 2006)

Result of Model Based Management System (MBMS) Development

This system uses several maps bearing physical factors information as input, being: map of geology; map of geohydrology; map of precipitation; map of geomorphology; map of wells location; map of groundwater conservation plan; map of groundwater basin; and map of potential groundwater source. This input data is stored within a RDBMS database aimed at serving as basis for implementing the managerial procedures in groundwater conservation. With inclusion of existing and potential wells location data, all before-mentioned data supports the decision-making whether or not consent for groundwater exploration at specific site will be issued.

The issue of consent follows some procedures. When applicants lodge their proposal, system will ask for the coordinates of parcel site where the well to be situated and the specific coordinates of the drilling plan (obtainable through the use of Global Positioning System apparatus). In practice, locating coordinates will be carried out by appointed officer acting as surveying person within the management body. Coordinates will then be used by system to perform spatial query referring to the intersection of MySQL Spatial analysis in order to extract environmental information (as so called ‘physical factors’ information: geology; geohydrology;

precipitation; geomorphology; groundwater basin; and potential groundwater source) about the proposed well location. As assessment criteria, the proposed plan is to satisfy the conservation zoning plan, water quality requirement, groundwater potential criteria, and exploration ownership criteria. Conservation zoning is developed based on local policy; groundwater potential is analysed based on environmental condition and pumping test; and water quality is assessed through laboratory test. This dataset is to generate recommendation for consent (see Figure 2). If, based on suitability criteria having been applied, the proposal is permissible, the system user will perform technical analysis to make recommendation for issuing groundwater exploration consent. If, within the groundwater conservation plan, the proposed location does not comply with the zoning, system will refuse to issue consent.

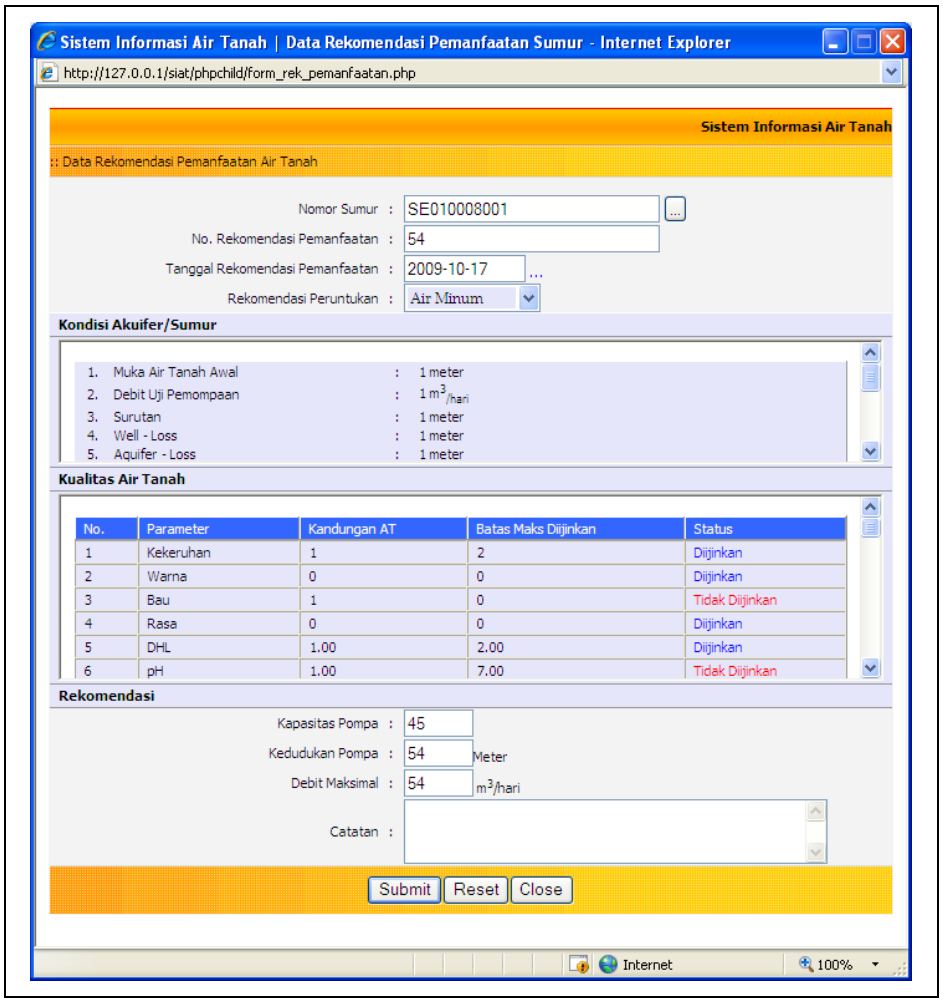

Figure 2. Groundwater Exploration Recomendation Form

For approved applications, when drilling completed, system will request information in accordance with existing rock bedding at drilling site. This information will then be used to publish recommendation of well construction. The construction blueprint is automatically provided by system (see Figure 3). This recommendation is given with taking into consideration

type of utilisation and environment-friendly discharge procedure alternative. Other considerations include pumping test to determine the amount of groundwater permissible to be explored and laboratory test to confirm water quality.

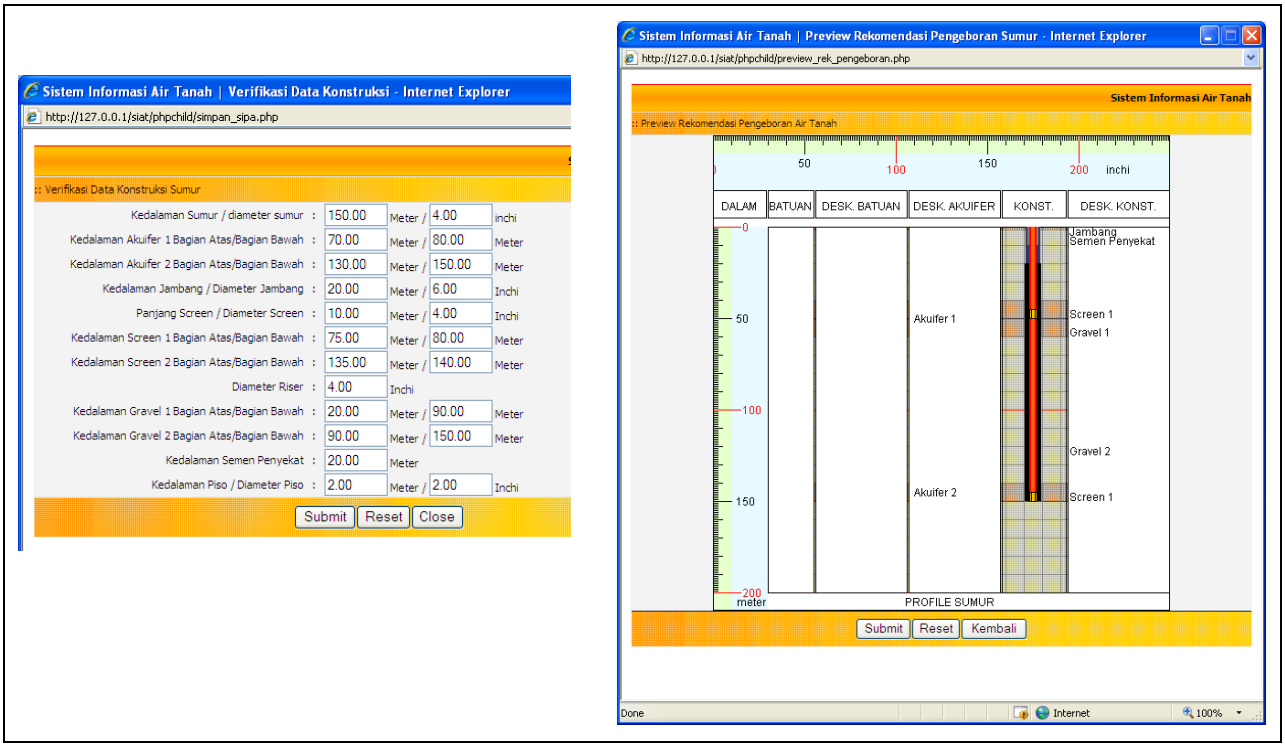

Figure 3. Well Profile Modeling

Once information in regard with an application is obtained, next procedure to be done by authorities is field check to verify information provided by system and to attain documentation for supporting the issue of Water Use Permit (SIPA). The Water Use Permit (SIPA) is to be issued for certain time period and renewable after expiry through resubmitted application. Through this procedure, continuous monitoring of groundwater use is enabled, and deterrent

consequence can apply for groundwater users when non-complying use is proven. Information resulted from monitoring measure is then used as basis for decision-making in determining subsequent use of the groundwater source. Decisions are to satisfy the optimisation of groundwater use and conservation.

Dialog Generation (DGMS) Development

The user interface adopts common desktop Geographic Information System (GIS) application design in order to create user-friendly environment (see Figure 4). The main page includes a set of toolbar representing spatial and non spatial features, menus, navigation, and geographic analysis tools. These tools can be classified into 9 categories, being: 1) Header and Title; 2) Main Menu, 3) Sub Menu; 4) Map Navigation Tool; 5) control layer, legend, and data retrieval; 6) Layer Control; 7) Space Map; 8) inset map; and 9) panel pointer.

Controlling of input and output data is built in such way that enables users to operate applications. Combo box optimization and utilisation of AJAX technology to display standard data fields provide users with an interactive display that enhances the possibility of reducing human error in input data process.

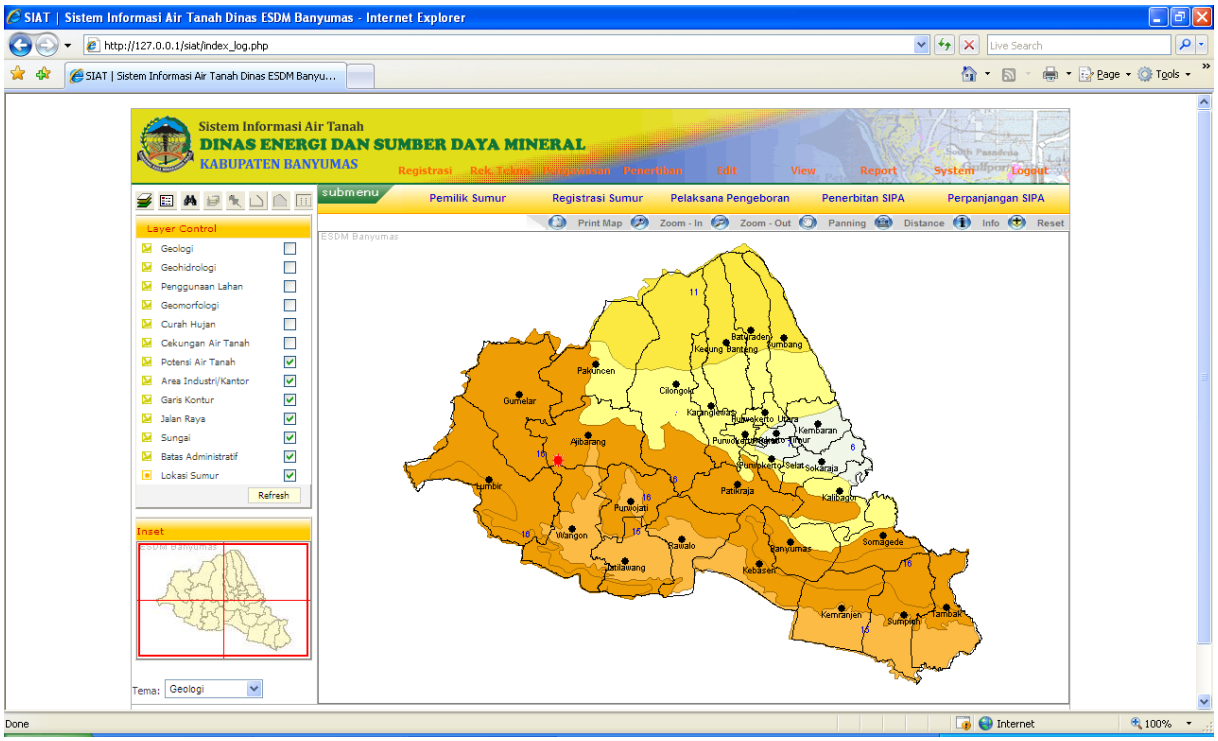

Figure 4. Application User Interface

System Implementation

System developed through this study is highly applicable in some stages of groundwater management practice and expected to nurture practical benefits such as: 1) providing information about site setting (both physical and human-related setting) of proposed groundwater use; 2) serving as a tool for rock layers data inventory; 3) simplifying the protocols needed for the issue of consent and recommendation in groundwater use; 4) serving as a tool for monitoring amount and quality of groundwater supply; 5) serving as a tool for controlling groundwater use; 6) simplifying administrative reporting task in groundwater management

practice; 7) enabling spatial suitability model of well locations; 8) enabling rock bedding modelling; and 9) monitoring and controlling well development and distribution.

CONCLUSION

As performed through this study, MySQL database is employed to establish geodatabase compiling both spatial and non-spatial data. Visualised and managed with customised user interface and enabling spatial modelling practice using PHP and Java applet, system developed through this study supplies effective decision support system for groundwater use management.

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Name of the Presenter: Jumadi

Author(s) Affiliation: Faculty of Geography, Muhammadiyah University of Surakarta

Mailing Address: Jl. A. Yani Tromol Pos 1 Pabelan Surakarta, Indonesia

Email Address: jumadi_geo@ums.ac.id

Telephone number(s): +62271-717417 ext 151

Fax number(s):

Author(s) Photograph:

Brief Biography (100 words):

Jumadi was born in Sragen, Indonesia, on 26 August 1980. He completed his undergraduate study from the Faculty of Geography, Muhammadiyah University of Surakarta in 2004. His recent main activity is working as Junior Lecturer at the faculty from where he attained his

Bachelor's degree. He currently holds fellowship from Competitive Scholarship Programme, provided by the Bureau of Planning and International Cooperation, Indonesian Ministry of National Education. This programme provides him with an opportunity to take part in a double-degree M.Sc. programme between Graduate School of Gadjah Mada University and the University of Twente (Faculty of ITC) majoring Geo-information for Spatial Planning and Risk Management.

HP: +6285293050010