Application of Groundwater Sustainable Infrastructure Index on Water Management in Yogyakarta City, Indonesia

I Putu Santikayasa*, Perdinan, Chusnul Arif and Yon Sugiarto

***Abstract*— Water as well as groundwater is considered as one of essential natural resources shaping the regional landscapes and vital for ecosystem functioning and services to support people livelihoods. However, there are a need for the sustainable management for fulfilling the need for the current and future generation. The Groundwater Sustainability Infrastructure Index is able to assess the status of current groundwater management. The index was applied in Yogyakarta City Indonesia. The result shown that the water management especially groundwater in Yogyakarta is rated as "good" and sustain the water availability for the future. However, the environmental issues especially in groundwater are not being the priority of the development planning. There are the issues related to the integration of groundwater management policy and regulation among the government institution. Therefore, to achieve the sustainability several tasks including increasing groundwater monitoring, increasing initiative and collaboration among stakeholders and increasing public participant must be implemented**

***Keywords*—groundwater, water resources management, sustainability index**

I. INTRODUCTION

Water is considered as one of essential natural resources shaping the regional landscapes and vital for ecosystem functioning and services to support the livelihoods of human being. However, the overuse of water resources, primarily for agriculture, and the contamination of freshwater due to domestic, agriculture, and/or industrial pollution stresses the available water resources [1]. Consequently, the ecological functions of water bodies, soils and groundwater are hampered [2].

Manuscript received June 21, 2017. This work was supported in part by UNESCO under Contract No. 4500298558

I Putu Santikayasa, Ph.D. Author is with Department of Geophisic and Meteorology, Bogor Agricultural University Indonesia (corresponding author e-mail: psantika@gmail.com).

Perdinan, Ph.D. Author is with Department of Geophisic and Meteorology, Bogor Agricultural University Indonesia (e-mail: perdinan@gmail.com).

Dr. Chusnul Arif. Author is with Department of Civil and Environmental Technology, Bogor Agricultural University Indonesia (e-mail: chusnul@gmail.com).

Yon Sugiarto, M.Sc. Author is with Department of Geophisic and Meteorology, Bogor Agricultural University Indonesia (e-mail: iyons@gmail.com).

Concerning the challenges, any innovation in water sustainable management is a necessity in order to plan for managing water supply to meet the current and future demand [3].

The Yogyakarta City is the capital of Special Region of Yogyakarta, Indonesia. The water demand is pressured by the urban population growth (urbanization) and visitors considering the city status as one of tourist destination. The number of visitors is growing about 34 – 35% annually for the period of 2008 to 2012 [4]. The population growth demands uprising in infrastructure development such as roads, settlements, buildings and the other public services. As a result the use of groundwater is utilized to provide the needs for freshwater on the area. Therefore, the pressure on water supply to meet the water demand should be addressed thoughtfully. This condition may challenge the overuse and over-extraction of groundwater resources. The over utilization of groundwater impact on the sustainable of groundwater resources in the area

For this concern, there are a need to assess the water management especially groundwater. There are several tools are used to assess the water management development including the use of sustainability indices. These indices are fundamental to the sustainable management of the resource [5]. The groundwater sustainability infrastructure index (GSII) was defined by Pandey et al [6] as the tools to assess the groundwater sustainability in order to evaluate the progress in achieving the sustainability. The GSII consist of five components and sixteen indicators. The final index is calculated as aggregation of overall indicators.

II. CASE STUDY AREA

Yogyakarta city is located between 110º24'19 "- 110º28'53" E and between 07º49'26 "- 07º15'24" S, the area is about 32.5 km^2, consisting of 14 Districts and 45 Sub-districts (Fig. 1). The population of Yogyakarta City (2014) was about 400.467 people (194.828 of male and 205.639 of female). The population density is about 12.322 people/km^2. The highest population is in Umbulharjo district (about 83.031 people), while the lowest is in Pakualaman district (about 9.164 people). Based on BPS data (2015), the district of Ngampilan has the highest population density (20.035 people/km^2), while the district of Umbulharjo has the lowest population density (10.225 people/km^2) [4].

Land cover of the Yogyakarta City is dominated by residential area (65%) while agricultural area is only about 3%

of the total area.

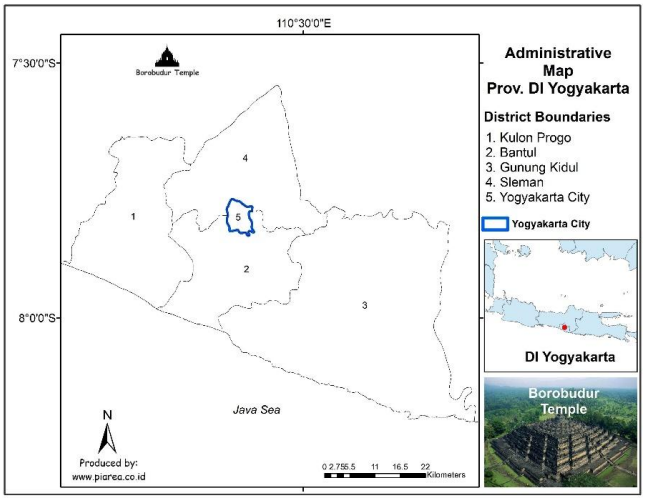

Fig. 1. Yogyakarta Province area in Indonesia

The topographical slope of Yogyakarta city varies in the range of about zero to two percents (0-2%) with mean elevation about 114 meters above sea level (a.s.l). The area is dominated by low lying areas with elevation less than 100 meters a.s.l (about 1,657 hectares) and elevation of about 100 -200 meters a.s.l (about 1,593 hectares). Soil type of the area varies and is dominated by regosol (BPS 2015). The Yogyakarta City is classified to C3 climate type based on the Oldeman climate classification. The C3 means about 5-6 months are wet (monthly precipitation > 200mm) and about 4 months are dry (monthly precipitation < 100 mm). The C3 climate type is suitable for growing rice with palawija on the dry season. The annual precipitation is about 1500 - 2500 mm, and the average temperature is about 26.3 ^{0}C

III. MATERIAL AND METHODS

The methodology presented in this paper is based on the Groundwater Sustainability Infrastructure Index (GSII) proposed by Pandey et al in 2011 [6]. The Groundwater Sustainability Infrastructure Index (GSII) is a framework for measuring groundwater sustainability in order to evaluate the progress in achieving the sustainability. The "infrastructure" term uses in the GSII refer not to the physical infrastructures (e.g engineering construction) but to knowledge, practices and institutions in which adequate strengthening may help to achieve the sustainable groundwater management.

The GSII framework is based on the conceptualization of the sustainability which is address the social, environmental, economic and institutional dimensions. To translate those component on the groundwater management component, the GSII component includes: public participation for social component, groundwater monitoring for environmental component, regulatory interventions for the economic component and institutional responsibility for the institutional component. In addition, the GSII includes a component of knowledge generation and disseminations because that the appropriate groundwater management requires a significant degree of trust among stakeholders. This mutual trust can be achieved by strengthening the data/information/knowledge generation and disseminations in transparent way to the stakeholders.

The Groundwater Sustainability Infrastructure Index (GSII) is composed by five components which disaggregates into 16 indicators (Table 1). The components are the broad categories of 'groundwater sustainability infrastructures' and are calculated as an aggregated score of the indicators representing the component. Pandey et al [6] mentioned that the indicators are flexible and can be modified (add/remove) to best suit the study area(s). As mentioned that the GSII consist of five components such as groundwater monitoring (GwM), Knowledge generation and dissemination (KgD), Regulatory interventions (ReI), Public participations (PuP) and institutional responsibility (InR).

TABLE I: GSII COMPONENTS AND INDICATORS

Components	Indicators
1. Groundwater monitoring	1.1 Groundwater level
	1.2 Groundwater extraction
	1.3 Groundwater quality
	1.4 Land subsidence
2. Knowledge generation and dissemination	2.1 Knowledge generation
	2.2 Knowledge/data compilation, storage and management
	2.3 Provision for knowledge integration and dissemination
3. Regulatory Interventions	3.1 Groundwater right
	3.2 Groundwater licensing
	3.3 Economic instrument
4. Public participations	4.1 Awareness
	4.2 Interest to participate
	4.3 Availability mechanism
5. Institutional responsibility	5.1 Availability of authority
	5.2 Legal framework
	5.3 Institutional capacity

All of the indictors are evaluated to provide scores on each indictor. In this study, each of the indicators was classified into five classes in a scale 0 – 1 as the Table 2.

TABLE I: GSII RATING AND SCORE

Rating	Score
Excellent	1.00
Good	0.75
Acceptable	0.50
Poor	0.25
Very poor	0.00

IV. RESULTS AND DISCUSSION

The methodology described above has been applied to evaluate the groundwater resources management in Yogyakarta City. Since the GSII is formed by five components, each of them will be presented separately and the overall sustainability index is computed in the end as the aggregate of overall indicators.

A. Groundwater Monitoring (GwM)

The aggregated score of the component is 0.38 and it can be rated as 'Acceptable'. The score was computed based on the field survey and data collection of the groundwater level,

groundwater extraction, groundwater quality and land subsidence. The groundwater level survey result shows that Yogyakarta has about three wells monitoring were installed and have regular water monitoring. However, inadequate coverage (space and time), inadequacy in storage and dissemination of data reflect the need of further strengthening the infrastructure. The groundwater extraction was one option to fulfil the water demand in Yogyakarta and become major part of the water supply system. However, information about groundwater extraction were not documented well. The situation of this indicator can be rated as 'acceptable'. The water quality of shallow and deep groundwater in is shown that almost 100% from the respondents mentioned that the groundwater quality is good. Despite the survey was not able to capture whole area, however, the survey was design to capture the location as the sample for the study area. However, for several location spatial and temporal coverage, data quality, data storage and dissemination aspects are inadequate. The field survey also shown no land subsiding evident caused by groundwater extraction in the study area.

B. Knowledge generation and dissemination (KgD)

The aggregated score of this component is 0.45, and it can be rated as 'Acceptable'. In Yogyakarta, there are several information was distributed to the communities related to the information of the groundwater. However, as the survey also gain the information from the communities, some respondents mentioned that they are do not know about the mentioned information. Based on this situation, the knowledge generation is can be considered as acceptable, except, the issues related to the coverage (spatial and temporal), and also access and implementation. The overall situation of this indicator can be rated as 'Acceptable'. Some of available data and study reports are available from the government and also the authorities. Moreover, the information from the assessment is available from the universities and also can be accessed by public. The overall situation of this indicator can be rated as 'Acceptable'. Integration and collective interpretation of available knowledge and scientific findings, translation in easy-to-understand form (using charts, 2D or 3D visualization, etc.) and making them accessible to all the stakeholders from a single-window (e.g., public outreach office) would enable the stakeholders to understand the latest situation of groundwater environment. This helps build mutual trust between stakeholders and ignites the feeling for preserving groundwater environment through wise use of the precious resource. In the study area, the tools as mentioned still not adequate and need to be improved. However, there are available knowledge dissemination tools used to disseminate the groundwater to the publics. This indicator has the score as 'Acceptable'.

C. Regulatory interventions (ReI)

This component is evaluated based on discussion followed by rating of three indicators. Despite several recommendations in the past, groundwater management policy and plans, which meant regulatory interventions, are not yet coming into effect. The aggregated score of this component is 0.67 and it can be rated as 'good'. On the Groundwater rights component, in Indonesia, The Water Resources Act in 2014 declares the state ownership of water resources and links groundwater directly to surface water. In reality, however, it appears that the practical right to groundwater is related to right to land. The land owner has their own right on using the groundwater for water less than mm meters deep. However, there are some policy to regulate the use of deep groundwater. Therefore, as the indicator in this study can be rated as 'Good'. Moreover, Groundwater licensing

Though, the Water Resources Act has provision for license need to utilize water resources (except non-commercial users); as well as the groundwater, especially the deep groundwater. The registration of groundwater extraction wells and licensing is mandatory for who will use groundwater for their activity especially for the commercial uses. Therefore, the current situation of this indicator can be rated as 'Good'. On the other hands, the economic instruments for groundwater extraction regulation and quality protection are available in the study area. This indicator can be rated as 'good'.

D. Public participation (PuP)

This component is evaluated based on discussion followed by rating of three indicators named awareness, interest to participate and availability of mechanism. The aggregated score of this component is 0.47 and it can be rated as 'acceptable". The awareness component shows that the public are quite aware that excessive groundwater extraction has decreased groundwater level and that has led to drying of many 'dug wells' and 'stone spouts' in the study area. But, they are not made aware about potential areas, depths and extraction rates for groundwater pumping because of lack of knowledge dissemination. There are also several activities related to organizing national symposiums/meetings, groundwater expert meeting and awareness raising programs. However, more efforts are needed in that direction to achieve the goal. On the other hands, based on encouraging public participation in other participatory environment management activities in the area, interest of public to participate in groundwater management activities can be anticipated if the institutional leadership is effective. Based on the expert judgment and also information from the stakeholders during the survey and interview, it can be summarized that this indicator can be rated as 'acceptable'. The legal/social provision/mechanism for public participation is still on development. However, the result from the interview and survey rated as 'Acceptable' for the availability of mechanism component.

E. Institutional responsibility (InR)

This component is evaluated based on discussion followed by rating (and corresponding scoring) of three indicators. The indicators named availability of the authority, legal framework and institutional capacity. The aggregated score of this component is 0.61 and it can be rated as 'good'. On the availability of authority indicator shows that a number of government agencies (ministries and departments) are available with some groundwater-related responsibilities. However, the responsibilities are clearly overlapping. The Water resources agency performs water resources policy and planning functions, but only at a very general level and do not include resource data basing, licensing or registration of water

use nor water quality aspects. The effectiveness is limited to the groundwater development for irrigation area, and monitoring of water level and quality in the study area is still limited. It is required the agency who will be responsible for groundwater data collection/processing, groundwater development planning, monitoring, regulation and research. Therefore, for this indicator can be rated as 'good' On the legal framework, there are several policies were applicable on water resources management in the area. Moreover, there are also several frameworks to regulate the groundwater extraction which is consist of several task and registration to get the certified activities of groundwater extraction. Based on the mentioned situation, it can be summarized that this indicator can be rated as "good". The institutional capacity in terms of resource (human and economic) availability for daily business and research activities, policies, and means to apply and enforce them are need to be improved. However, the respondent output shows the result that the current situation of this indicator can be rated as 'good'

F. Groundwater sustainability infrastructure index

The GSII value was calculated with equal weights to each component and result the value of 0.52. This suggests that overall situation of 'groundwater sustainability infrastructure' in Yogyakarta City can be rated as 'acceptable to good' (Fig.2), and therefore, several attentions are needed to strengthen the 'groundwater sustainability infrastructures' and subsequently achieve the goal of 'groundwater sustainability'. The scores of all the components of the index lie on the lower side of the sustainability scale (0–1, 1 representing the highest degree of sustainability); however, the situation of the regulatory intervention is relatively good (score = 0.67), the groundwater monitoring score is the worst (score = 0.38) and the others are acceptable to good ranges.

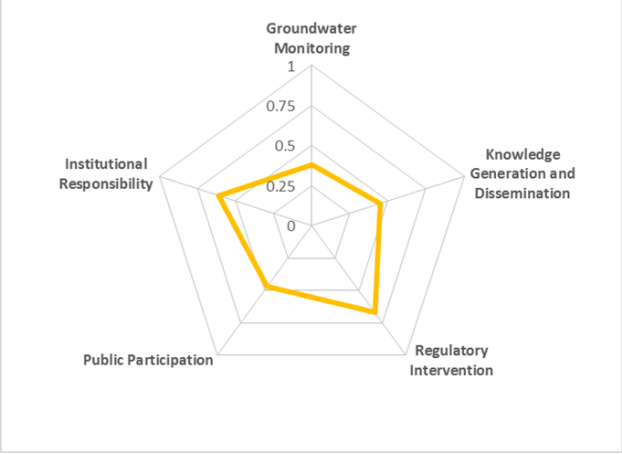

Fig. 2. Yogyakarta GSII index (Author 2016)

V. CONCLUSIONS

Groundwater is main water resource for the Yogyakarta City. The integrated water resources management can be applied to utilize sustainable groundwater. Technologies has important function in providing water supply, distribution and access for optimal both quantity and quality. There are many tools in utilization sustainable groundwater that can be adopted in those areas such as for exploration, exploitation, water treatment, water distribution and access. Getting, potential assessment study through pre-survey and survey activities is required. For future planning, study on the characteristic and potential of groundwater in Yogyakarta City is urgent particularly for obtaining optimal water supply in those areas. To achieve the sustainability, there are several tasks must be implemented in Yogyakarta water management especially on Groundwater:

- Increasing the groundwater monitoring through the implementation of the policy and regulation to manage the groundwater extraction and its environmental impacts
- Increasing the initiative and collaboration among stakeholders and interlink the water issues with the Sustainable Development Goals
- Increasing public participation on water management especially in groundwater by increasing the stakeholder's engagement to involve more participation of the multi-sectors stakeholders to achieve the development goal

ACKNOWLEDGMENT

This works was supported by UNESCO office Jakarta under contract number 4500298558

REFERENCES

[1] Bayart, Jean-Baptiste, et al. "A framework for assessing off-stream freshwater use in LCA." The International Journal of Life Cycle Assessment 15.5 (2010): 439-453.
[2] Taylor, Richard G., et al. "Ground water and climate change." Nature Climate Change 3.4 (2013): 322-329.
[3] Ghaffour, Noreddine, Thomas M. Missimer, and Gary L. Amy. "Technical review and evaluation of the economics of water desalination: current and future challenges for better water supply sustainability." Desalination 309 (2013): 197-207.
[4] BPS Statistics of Yogyakarta City. Kota Yogyakarta dalam angka. Yogyakarta: BPS Statistics of Yogyakarta City. 2015
[5] Mays, L.W. Groundwater Resources Sustainability: Past, Present, and Future. Water Resour. Manag. 2013, 27, 4409–4424
[6] Pandey, Vishnu P., et al. "A framework for measuring groundwater sustainability." Environmental Science & Policy 14.4 (2011): 396-407.

I Putu Santikayasa, Ph.D was born in Bali Indonesia on February, 24 1979. He was graduated from Ph.D program on water engineering and management from Asian Institute of Technology, Thailand in 2015.

He works as the Researcher in Bogor Agricultural University, Indonesia since 2005. During his carrier in Bogor Agricultural University, he published several peer-reviewed articles and contributing to the book chapter of "Managing Water Resources under Climate Uncertainty". Currently he is working on the field but not limited to the water resource management, climate change and agriculture, mostly for the South-east Asia region.