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Ⅱ．シンポジウム報告編

Monitoring of Water Utilization and Water Balance on Agriculture Fields in Nganjuk, East Java, Indonesia
インドネシア、ジャワ島ナンジュック地域における農業地帯の水利用と水収支の調査

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Abstract

In the dry season, water shortage has occurred in Nganjuk, East Java, Indonesia. The northern area of Nganjuk irrigation blocks was drier than southern area, and downstream in southern area was drier than upstream area. Regardless the water shortage, the farmers of these areas would like to increase productivity, cropping intensity and farmer's income by using shallow and deep wells. In the future, the utilization of groundwater for irrigation can be impact to land subsidence and can compete with other uses of groundwater such as domestic and industrial. The estimation of groundwater uses for irrigation is required for sustainable water resource management and farmers prosperities.

Monitoring stations were installed in Nganjuk to analyze water balances. Shallow groundwater levels were monitored at four irrigation blocks. The discharge rates were monitored in river reaches of upper, middle and lower streams. The monitoring data of groundwater showed the tendency of recharge in rainy season and uptake in dry season. However, in southern area Mrican-Kiri block, the tendency was not clear. Groundwater levels in the southern area (Mrican-Kiri and Kuncir-Bodor blocks) were higher than those in northern area (Widas and Ketandan-Tretes blocks) in dry season. The rainfall and discharge rate data showed that the infiltration and percolation were high in the beginning rainy season. Base flows were increased in second month of the rainy season and peak discharge was around 6 mm d^{-1} in the upper stream and approximately 2 mm d^{-1} in whole watershed.

Key words: groundwater, water shortage, conjunctive irrigation, monitoring

要 旨

インドネシア、ジャワ島ナンジュック地域において、乾季に水不足が発生している。ナンジュックの灌漑ブロックにおいては、北部ブロックが南部ブロックより水不足がひどく、また南部ブロックにおいても下流域では上流域より水不足がひどい状況である。水不足にも関わらず、これらのブロックにおいて、各農家は地下水の汲み上げにより生産性や、作付回数、農家収入を増加しようと試みている。将来、このような灌漑のための地下水の利用は、地盤沈下や、他産業や生活用水との競合を引き起こすことが懸念される。そこで、地下水の灌漑用途に関して、持続可能な水資源管理と農業に向け水収支を求める。

そこで、水収支のためモニタリングステーションを導入した。灌漑ブロックを 4 つに分け、浅層地下水の地下水位を観測した。河川においても、上、中、下流にてモニタリングを行い、流量を求めた。地下水のデータから、雨季において地下水が涵養され、乾季において汲み上げが大きくなることが示された。しかし、南部ブロックのムリチャンキリブロックでは、明確な傾向が見られず、乾季においては、南部ブロックの地下水位は北部ブロックより高くなった。また、降雨と河川流量データから、雨季の始まる時期に損失量が増加することから浸透量が多くなることを示した。基底流出は、雨季が始まってから 2 カ月目に増加し、ピーク流量は上流側で約 6 mm・d^{-1} であり、流域全体では約 2 mm・d^{-1} であった。

キーワード:地下水、水不足、灌漑、モニタリング

1. INTRODUCTION

Grain production in dry season is still important for regional sustainable development in Indonesia. Java is the main production area for grain in Indonesia, where 53 percent of paddy and 55 percent of corn from each total production are produced (BPS, 2009). Agriculture in Java must be conserved for sustainable food security in Indonesia. For that purpose, improvements in land use and water management are needed.

The Nganjuk lies in a climatic regime characterized by the annual progress of rainy and dry seasons, and receives approximately 80% of precipitation within the 5 to 6 months of the rainy season (December-May). Nganjuk has flat area in central and eastern of Nganjuk with altitude ranging from 35 to 100 m above sea level. Mountains are located in the southern and northern area. The agricultural production in Nganjuk was increased; In 1991, average cropping intensity was 2.31 crops per year (BPS of Nganjuk, 1992), and in 2001 it was increased and stable at 2.8 crops per year. Rice production was 414 metric ton per year with productivity around 5.8 ton per hectare and harvested area was 71,893 hectare. Corn production was 204 metric ton per year with productivity around 5.8 ton per hectare and harvested area was 35,144 hectare. Soybean production was 17 metric ton per year with productivity around 1.7 ton per hectare and harvested area was 10,091 hectare (BPS of Nganjuk, 2009).

The Nganjuk lies in Brantas basin at Widas sub-basin, where is one of the three major tributaries of the Brantas River in East Java Province. In Nganjuk, there are three planting season; wet season (WS, November-February), first dry season (DS1, March-June), and second dry season (DS2, July-October). Paddy fields are cultivated in WS and DS1. Sugar cane cultivated in WS, DS1, and DS2. Secondary crops (corn, soybean, red onion, chilies, melons and vegetables) are cultivated in DS1 and DS2.

Water shortage has occurred in dry season in all irrigation blocks. The northern area of irrigation block was drier than southern area. The downstream in southern part area was drier than upstream area in dry season. Regardless of the water shortage, the farmers of these areas would like to increase productivity, cropping intensity and farmer's income by using shallow and deep wells. The cash crop is important to increase farmer's income, especially in dry season. These economic situation influences in the water balances, so it is important to analyze water balances in the Nganjuk.

In the future, the utilization of groundwater for irrigation can be impact to land subsidence and can compete with other uses of groundwater such as domestic and industrial. The estimation of groundwater uses for irrigation is required for sustainable water resource management and farmers prosperities.

An objectives of this paper is to analyze monitoring data for water balances. For further research, the data could be to develop a computer simulation model to propose a sustainable water resouce management and to increase water utilization on agriculture fields.

2. STUDY AREA

The lowland in Nganjuk is alluvial plain formed by Widas River and Brantas River. Based on hydrogeology map (Poespowardoyo, 1984), these area has aquifer with medium and high productivity. Many irrigation wells were constructed in Nganjuk. The number of wells in village was varied from 0 to 606 wells per village and total number of wells is 15,475 wells on around 200 villages.

There are four main sub-basins, Widas, Kuncir, Bodor and Warujayeng-Kertosono (**Fig.1**). There are two tributaries, the Kedungsoko River and the Widas River. the Kedungsoko River is for Kuncir and Bodor sub-basins, and the Widas River is for Widas sub-basin. Those rivers were merged into Brantas River through Warujayeng-Kertosono sub-basin that is flat and predominated by agriculture field.

In addition, irrigation area in Nganjuk was divided four irrigation blocks. The area of irrigation blocks is around 40,000 hectare. There are two main surface irrigation systems (Widas and Mrican-Kiri blocks) and two local surface irrigation systems (Kuncir-Bodor and Ketandan-Tretes blocks). Each block has characteristic depend on the water supply system and geomorphology (see **Table 1** and **Fig.2**). The main surface irrigation system has infrastructure such as canal, reservoir, and water supply. The local surface irrigation has water supply from small and seasonal rivers. Widas block lies in Widas sub-basin and supplied water from Bening Reservoir and small rivers in the block. Mrican-Kiri block is supplied water from Mrican barrage on Brantas River and lies in Warujayeng-Kertosono and Bodor sub-basins. Kuncir-Bodor block is supplied water from small rivers from Wilis Mountain without reservoir and lies in Bodor and Kuncir sub-basins. Ketandan-Tretes block is supplied water from small rivers from Kendeng Mountains with small reservoirs and lies in Widas sub-basin. All of irrigation systems in Nganjuk area are conjunction irrigation surface and groundwater irrigation and reusing drainage water from upstream area.

Fig.1 Map of study area

Table 1 The feature of irrigation block in Nganjuk area

Feature	Widas	Mrican-Kiri	Kuncir-Bodor	Ketandan-Tretes
1. Main Purpose				
• Irrigation	O	O	O	O
• Hydro power generation	O	-	-	-
• Flood control	O	O	O	O
• Recreation	O	O	-	-
2. Number of reservoir				
• Medium	1 (33 MCM)	-	-	-
• Small	2	-	-	6
3. Number of barrage	-	1	-	-
4. Number of weir	20	3	20	5
5. River	Seasonal	Annual	Seasonal	Seasonal
6. Originate of river	Kendeng Mountains, Pandan Mountain & Wilis Mountain	Flat area	Wilis Mountain	Kendeng Mountain
7. Sub-basin	Widas	Warujayeng-Kertosono & Bodor	Kuncir & Bodor	Widas
8. Retarding basin	O	O (28 MCM)	O	O
9. Irrigated command area (ha)	10,496	12,912	13,403	3,139
10. Average water supply (mm/d)	0.46 – 5.47	1.64 – 5.69	0.80 – 10.71	0.37 – 8.67

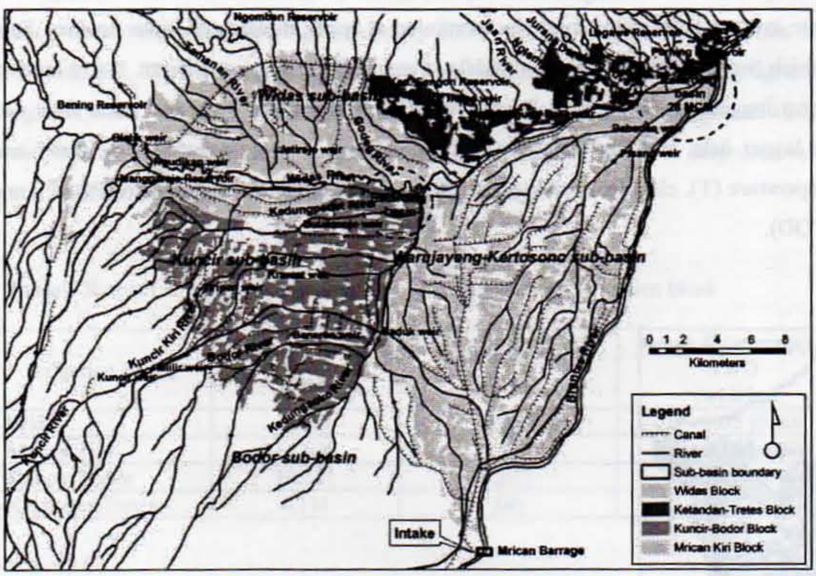


Fig.2 Irrigation Schemes in Nganjuk district

3. INVESTIGATION

Based on preliminary field survey, the monitoring data station was developed (**Fig.2**). Water quantity and water quality was monitored in those stations. The number of station was decided based on cost of construction, maintenance, and security. The shallow groundwater level was monitored at four irrigation blocks. The river water level was monitored at upper, middle and lower reaches, and observed discharge rate in those stations.

The shallow groundwater level was monitored at four irrigation blocks. Each irrigation block was installed one monitoring well. The monitoring well at Ketandan-Tretes block was already installed by province government. Depth of well was varied 6 to 15 meters, depend on shallow aquifer location and condition. Water level of groundwater was recorded by water logger every six hours. Every week (Thursday) groundwater level was manually measured to calibrate water logger data. Water sample was taken to measured pH, temperature (T), electrical conductivity (EC), nitrate (NO_3-N), phosphorus (PO_4-P), and chemical oxygen demand (COD).

Table 2 The feature of monitoring well

Irrigation block	Station name	Number of monitoring well	Well depth (m)	Casing depth (m)	Parameter
Mrican-Kiri	Sumberkepuh	1	10	8	Water level,
Kuncir-Bodor	Tanjungrejo	1	15	12	pH, T, EC,
Widas	Ngadiboyo	1	14	12	NO_3-N,
Ketandan-Tretes	Banjardowo, Pandean*	2	14**	12.5	PO_4-P, COD

Note: * one monitoring well is conducting by province government

** Monitoring was lift-up to 6 m after 6 months

To analyze discharge rate in river, river water level was monitored at upper, middle and lower reaches. Four stations were constructed, which two on upstream, one on middle stream and one on downstream. Water level of reaches was recorded by water logger every one hour. Every week (Thursday) water level and reach flow was measured to calibrate water logger data, and discharge rate and rating curve were calculated. Also, water was sampled to measure pH, temperature (T), electrical conductivity (EC), nitrate (NO_3-N), phosphorus (PO_4-P), and chemical oxygen demand (COD).

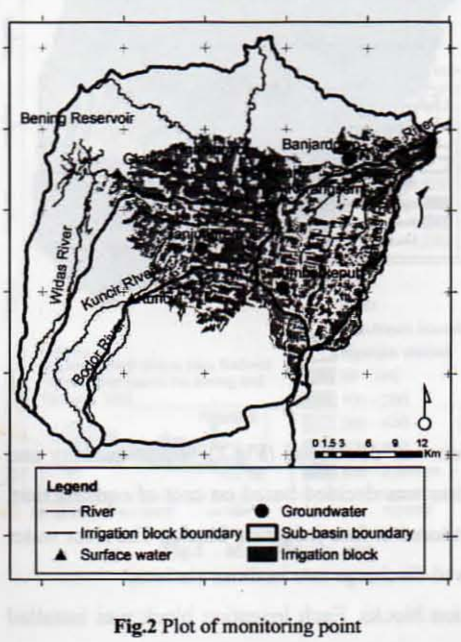


Fig.2 Plot of monitoring point

Rainfall and climate data were taken from government monitoring station. Rainfall monitoring station is scattered on 45 locations and two climate stations is located at upper and lower area.

4. RESULTS

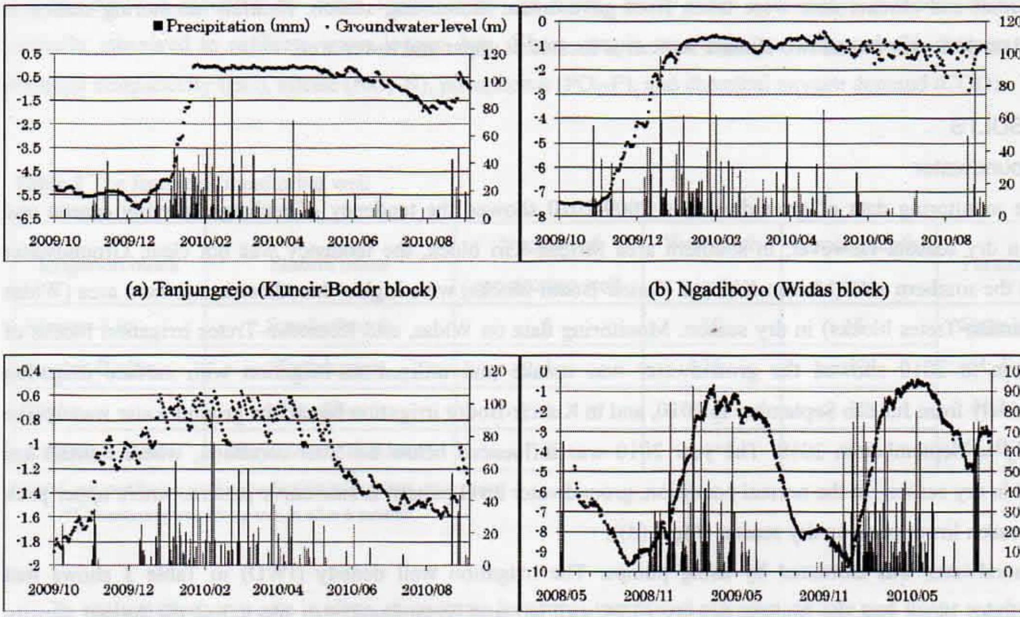
4.1 Groundwater

The monitoring data of groundwater in 2009-2010 showed the tendency of recharge in rainy season and uptake in dry season. However, in southern area Mrican-Kiri block, the tendency was not clear. Groundwater levels in the southern area (Mrican-Kiri and Kuncir-Bodor blocks) were higher than those in northern area (Widas and Ketandan-Tretes blocks) in dry season. Monitoring data on Widas, and Ketandan-Tretes irrigation blocks of dry season in 2010 showed the groundwater was uptake and utilized as irrigation with surface irrigation conjunctively from June to September in 2010, and in Kuncir-Bodor irrigation block, the ground water was uptake from July to September in 2010. The year 2010 was influenced below La-Nina condition, where rainfall has occurred in dry season. In the normal condition, groundwater level pattern is sine curve pattern, where upper peak on wet season lower peak on dry season (**Fig.3** (d)).

Groundwater was extracted by using pumps. The irrigation well density (IWD) in Table 3 shows that Kuncir-Bodor block had the highest density (0.76 well/ha) and Ketandan-Tretes block had the lowest density (0.08 well/ha). The IWD where related with water extraction was estimated by agricultural area and the number of irrigation wells. However, IWD in Mrican-Kiri block was not related to groundwater extraction, because surface water was enough for all years. Irrigation wells in Mrican-Kiri block is only used in occasional condition such as water allocation of surface irrigation was not well doing.

Table 3 Number of well and irrigation well density (IWD) per irrigation block

Irrigation Block	Area (ha)	Number of well (wells)	Range & (average) of IWD (well/ha)
Widas	9,889	2,005	0 – 1.05 (0.20)
Mrican-Kiri	14,608	5,447	0 – 2.83 (0.37)
Kuncir-Bodor	10,151	7,677	0 – 2.99 (0.76)
Ketandan-Tretes	4,131	346	0 – 3.36 (0.08)



(a) Tanjungrejo (Kuncir-Bodor block)

(b) Ngadiboyo (Widas block)

(c) Sumberkepuh (Mrican-Kiri block)

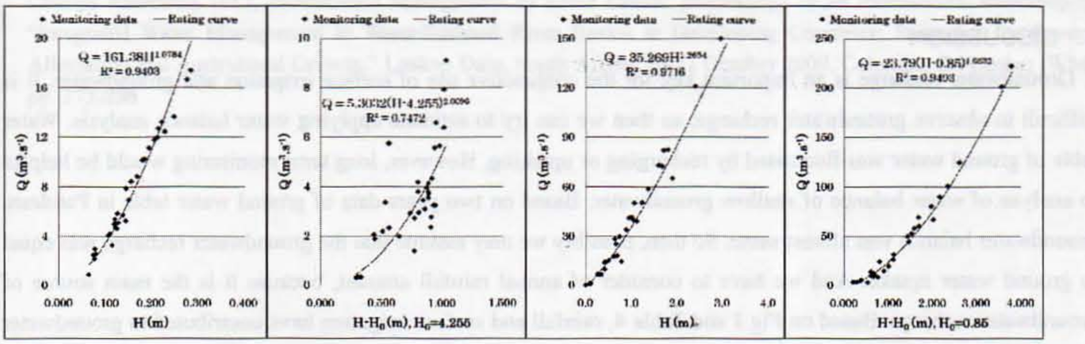
(d) Pandean (Ketandan-Tretes block)

Fig.3 Groundwater level at four blocks

4.2 Surface Water

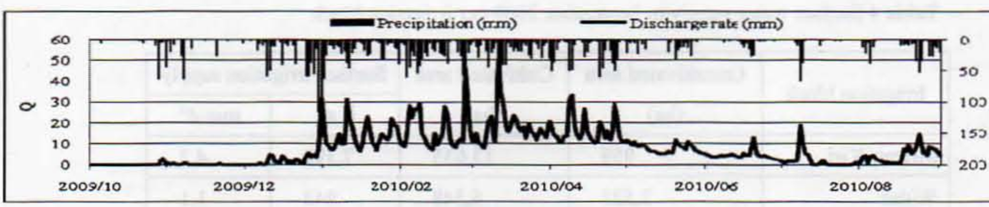
Discharge rates at four monitoring station were weekly measured. Rating curve was calculated in an exponential equation by discharge rate and continuous water level data. Exponential correlation for the rating curve of three monitoring stations was satisfied with the coefficient of determination (R^2) of more than 0.94 (**Fig.4**). Coefficient of determination for the rating curve of Glatik station was 0.74. The coefficient of determination for Glatik station was lowest, because floodgates were sometime manipulated to open after heavy rain for avoiding sedimentation on Glatik weir.

Continuous discharge rates were calculated using rating curve model and water level data on each monitoring station. The discharge rate in dry season 2009 (August and September) was almost zero. All rivers in Nganjuk are seasonal river, where quite small water is found in dry season and flooded condition is found in wet season. However, discharge rate in 2010 was comparatively higher than ordinary years in all rivers (**Fig.5**).

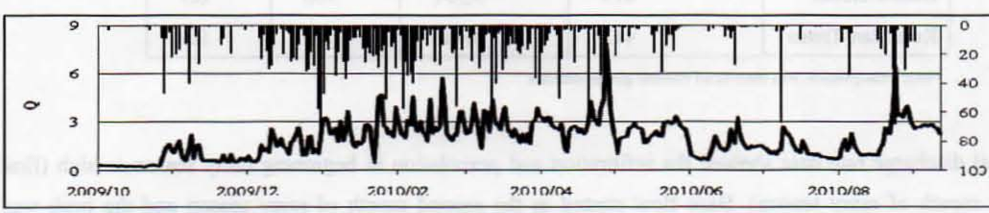


(a) Kuncir (upstream) (b) Glatik (upstream) (c) Karangsemi (middle stream) (d) Bolowono (downstream)

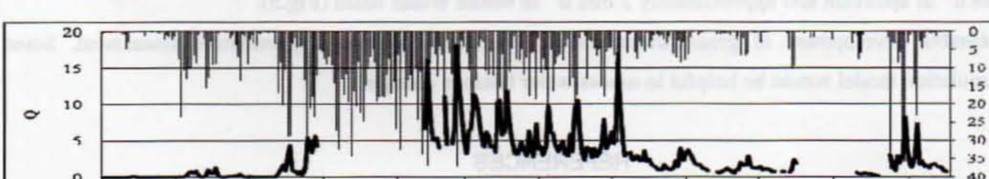
Fig.4 Rating curve at upper, middle and lower reaches



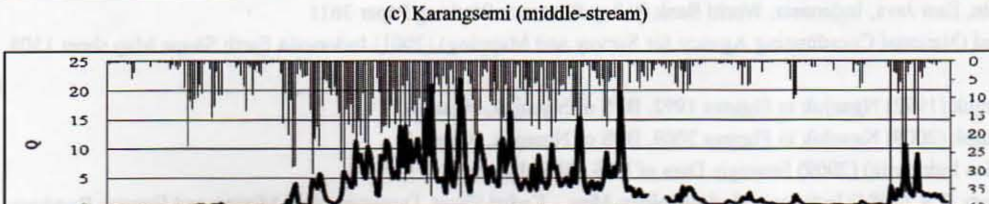
(a) Kuncir (upstream)



(b) Glatik (upstream)



(c) Karangsemi (middle-stream)



(d) Bolowono (downstream)

Fig.5 Hydrograph at upper, middle, and lower streams

5. DISCUSSION

Groundwater recharge is an important key for the conjunctive use of surface irrigation and groundwater. It is difficult to observe groundwater recharge, so then we can try to estimate applying water balance analysis. Water table of ground water was fluctuated by recharging or uptaking. However, long term monitoring would be helpful to analyze of water balance of shallow groundwater. Based on two years data of ground water table in Pandean, groundwater balance was almost same. So then, possibly we may assume that the groundwater recharge was equal to ground water uptake. And we have to consider of annual rainfall amount, because it is the main source of groundwater recharge. Based on Fig.3 and Table 4, rainfall and surface irrigation have contributed to groundwater recharge. In September, ordinary, there were no rain but some rain was available in 2010 under La Nina condition. The fluctuation of water table in Widas and Mrican-Kiri blocks in August 2010 showed that ground water table was influenced by surface irrigation.

Table 4 Surface water supply in September 2009 per irrigation block

Irrigation block	Uncultivated area (ha)	Cultivated area (ha)	Surface irrigation supply	
			$L\ s^{-1}$	$mm\ d^{-1}$
Mrican-Kiri	959	13,635	7,390	4.7
Widas	3,523	6,348	842	1.1
Kuncir-Bodor	815	9,351	300	0.3
Ketandan-Tretes	413	3,486	0	0.0

Note: precipitation was zero at all rainfall gauge stations

The actual discharge rate data showed the infiltration and percolation in beginning rainy season is high (first and second month of rainy season). Base flow started in the second month of rainy season and the peak was around 6 mm d^{-1} in upstream and approximately 2 mm d^{-1} in whole Widas basin (**Fig.5**).

The sustainable development of groundwater resource requires continuous quantitative assessment. Some computer simulation model would be helpful to assess water balance change.

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