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OPTIMIZATION MODELS FOR SUSTAINABLE UTILIZATION OF GROUNDWATER IN WAJO DISTRICT, SOUTH SULAWESI PROVINCE OF INDONESIA©

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ABSTRACT : The groundwater in Siwa-Pompanua basin of Wajo Regency has a coverage area of 93,900 ha and a potential debit of 379 millions m^3/yr. The groundwater has been utilized since 1995 to irrigate rice fields managed by farmers themselves. Since then number of wells has been increased rapidly and randomly distributed and at the present time there are 16 units covering 232 ha of rice fields. There are still high trends that the number of wells would increase. Without well understanding and proper management of the groundwater it is easy to witness that many problems have been accumulated. These problems are not only physical but also social as well as threatening the environment that would affect the availability of the ground water. Thus, it is timely important to find a way out to solve the problems based on basic knowledge so the utilization of the groundwater is sustainable. This study aims at optimizing the utilization of groundwater for irrigating the rice fields with taking into account socio-economical and environmental aspects. Herewith, mathematical models were developed based on the water flow equations, crop water requirement and combined with socio-economical analysis and preventing degradation of the aquifers. The water flow model was compared to measured data and resulted in a good conformity. Based on the daily water requirement of 46 $m^{3/}$ha and with preventing excessive drawdown, the optimum discharge of each well differs with the others. Its values are between 279 m^3/d and 1268 m^3/d and the command areas range from 10 ha to 28 ha, respectively. A neighboring well should be in the radius of about 479 m away. In the average, farmers would gain an extra income if they manage the groundwater in this sustainable way.

KEYWORDS : Rice fields, irrigation, optimum and sustainable groundwater utilization.

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1. INTRODUCTION

In recent years, there has been a conversion or displacement of productive paddy rice fields into non agriculture lands. In between 1999-2003 alone there were about 563,150 ha of rice fields converted into other forms of land uses. On the other side, the Government of Indonesia has initiated a plan to increase production of grind-ready rice yields from 54.66 million tones in 2006 to 58.18 million tones in 2007. This will then depend on the intensification of less productive dry lands with highly rely on groundwater utilization.

Wajo Regency in South Sulawesi province (Fig.1) is an example where rice fields have been highly dependence upon the utilization of groundwater dated back to 1995. Right now, the total rice fields is 86.142 ha within a so called Siwa-Pompanua Basin of which 65,780 ha (75%) is classified as dry lands. Just below the basin there are a productive layer of aquifers which has a potential discharge 379 m3/years (Burhanul, 2004).

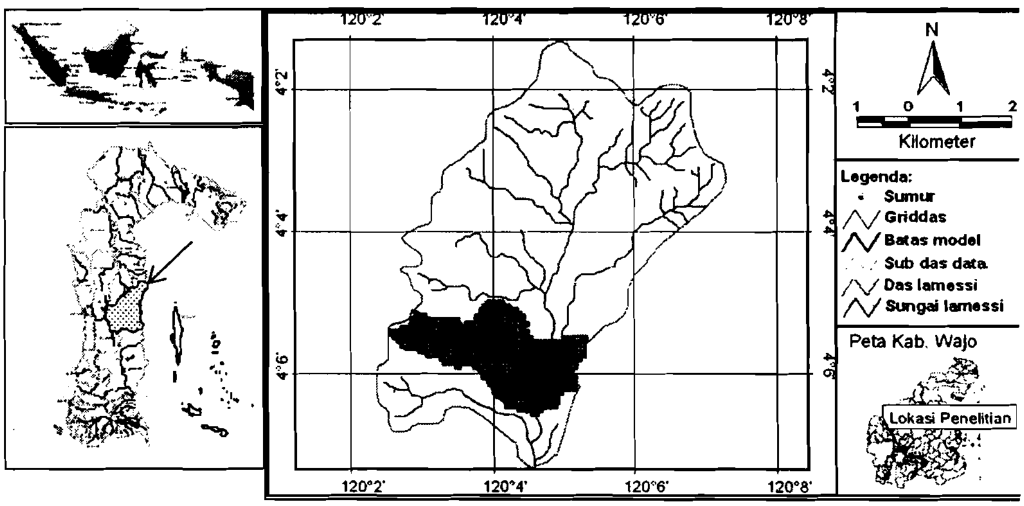

Figure 1. The upside left corner is Indonesia, downside left corner is South Sulawesi, in the middle is Siwa Pompanua Basin and shaded area is the studied site.

As seen Table 1, planted area was steady in between 2000-2003 but then declined in 2004 but then regain in the year of 2005. Yields are significantly unchanged and better than the averaged yields of rain-fed paddy field (<2 ton/ha) in Indonesia. This success in production is partly because of the intensive pumping program which later on freely managed by the farmers themselves.

Presently, rapid extraction of groundwater has drawn many parties attention on the sustainability of using this one form of vulnerable water resources. In Wajo Regency now there are 2.037 wells, and in a specific cluster alone there 16 wells covering command areas of 232 ha over this is unevenly distributed. Pumping capacity ranged from 280 to 1190 liter per minute. Until this time there was no yet complain from each farmer on how a neighboring pumping affects the productivity of his well. Although there are some indications that progressive drawdown has been noticed since wells have been extended deeper and deeper (25-50 m). What the farmers facing now is to allocate more money to buy more gasoline for their pumps to get the same amount of water as before for the same area. To put the extraction point deeper is also a kind of unwillingly competition which to some extent in the near future would exaggerate social conflict.

Table 1. Rice production in Wajo Regency

Year	Planted (ha)	Harvested (ha)	Production (ton)	Yield (ton/ha)
2000	112.129	104.800	565.087	5,392
2001	110.729	118.457	575.955	4,862
2002	102.211	100.018	434.871	4,348
2003	114.342	102.175	422.764	4,138
2004	89.658	61.393	273.076	4,448
2005	106.667	85.721	390.322	4,553

Thus, it is time to take necessary actions in order to succeed rice production whilst preventing degradation of the groundwater and social conflict in this site of interest. This study aims at optimizing the utilization of groundwater for irrigating the rice fields with taking into account socio-economical and environmental aspects. To date such attempts to integrate multi-components on dealing with the optimization of groundwater utilization are found elsewhere (Table 2). It is clear that in this study we attempt to integrate all the components as a succession of the previously studied by Waspodo (2001).

Table 2. Various integrated models (Waspodo, 2001 and Suhardi, 2008)

No	Integrated Models	Components														
		Q	h	A	C	U	T	R	S_y	r	f	h_e	p	h_j	e	s_r
1	Gorelick (1983)	√	√	-	-	-	√	√	√	-	-	-	-	-	-	-
2	Willis dan Liu 1984)	√	√	-	-	-	√	√	√	-	-	-	-	-	-	-
3	Kinzelbach (1986)	√	√	-	-	-	√	-	-	√	-	-	-	-	-	-
4	Heckele (1988)	√	√	-	-	-	√	-	√	-	-	-	-	-	-	-
5	Mays dan Tung (1986)	√	-	-	-	-	√	-	√	-	-	-	-	-	-	-
6	Finney *et al.* (1992)	√	√	-	-	-	√	√	√	-	-	-	-	-	-	-
7	Herlina et al. (1997)	√	√	-	-	-	√	-	√	-	-	-	-	-	-	-
8	Nishikawa (1998)	√	√	-	-	-	√	√	√	-	-	-	-	-	-	-
9	IRRI (1990)	√	-	-	-	√	-	-	-	-	√	√	√	√	√	-
10	Waspodo (1993)	√	-	-	-	√	-	-	-	-	√	√	√	√	√	-
11	Ardani (1997)	√	-	-	-	√	-	-	-	-	√	√	√	√	√	-
12	Waspodo *et al.* (2001)	√	√	√	-	-	√	√	√	-	√	√	√	√	√	-
13	Suhardi (2008)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Note: Q is discharge, h is water level, A is area, C is water price, U is financial benefit, T is transmissivity, R is recharge, Sy is specific yield, r is radius, f is crop water requirement, h_e is effective rainfall, p is water need for soil tillage, h_j is rainfall, e is total efficiency, and s_r *is* recharge well.

2. METHODOLOGY

As previously shown in Fig.1, the studied site (E120:2:30-120:6:46, S4:4:30- 4:7:20) was covering 760 ha of paddy fields in Wajo Regency and field works were conducted from January to August 2006. Characteristics of the aquifer have been available observed by Public Work Project of Groundwater Management (Fig.2). Thickness of the aquifer is about 15 m with a specific yield is of 0.32 (Bear and Verruijt, 1987). And in addition, pump tests with its discharge of 145 m^3/d were carried out to get hydraulic conductivity constant under a quasysteady using the inverse problem of the groundwater flow equation in a spherical coordinate system (Eq.1). The hole of well was made of PVC of 4" in diameter. The averaged value of conductivity was 16.13 m/d. This result was also in good agreement with that of Dupuit equation at the steady state.

$$S_y \frac{\partial h}{\partial t} = K \cdot \frac{h}{r} \cdot \frac{\partial}{\partial r}\left(\frac{\partial h}{\partial r^2}\right) + q \qquad (1)$$

Equation 1 was then was used to simulate drawdown (h) with the objective on maximizing pumping rate (q) within which the resulted drawdown is under tolerable limits ($h \leq h_{max}$). Herewith, the value of q should be larger than the crop water requirement (f). Maximizing pumping rate means enlarging its command area but preventing interference on the neighboring pumping operations. This can be done by setting the water level at outside boundaries remains at the initial condition during the pumping operation ($h_\infty = h_0$). This value of h_∞ can be found easily by solving Equation 1 at the steady state or the left hand side is zero. For economical review, it is assumed that enlarging the command area would give additional returns for the farmers. Indicator will be given in B/C value.

3. RESULTS AND DISCUSSION

As a result of observation taken for 60 days, once after the commence of pumping operation (145 m^3/d) water level dropped sharply from 4.7 m to 8.17 m and almost stayed around this level for the rest of the operation. Theoretically it could be said that the model has attained the steady state at 8.39 m but actually water level fluctuated somewhat in the range of 7.90-8.55 m. Regression coefficient (R2) comparing calculated and measured water level resulted in 0.85. Any deviations were partly due to unstable pumping rates and some possibilities that the pumped water percolated and finally recharged to the aquifer.

Table 3 shows the results of pumping optimization for all the existing 16 wells. Location of each well is represented by X-Y Coordinate. In this case, the tolerable drawdown was set at 15 m which was mostly acceptable recovery of less than 5 days. As influenced by distance among wells each well has different maximum discharge and command area. One well could discharge 1289 m^3/day to irrigate 28 ha and the other one could discharge 473 m^3/day for 10 ha to meet daily crop water requirement which varied in three stages of the plant growth. At present time however farmers are only affordable of using their pumps that have lower suction capacity of about 8.6 m. So, it is then good opportunity to increase pumping rate and furthermore to extend the command area.

Another optimization process was to find an optimal distance between two neighboring wells which prevent interferences. We found the optimal radius is about 479 m and capable of irrigating a command area of 23 ha with pumping rate was about 1000 m^3/d. If it is applied in the basin then more benefit would be gained especially from the effectiveness use of one well over wider areas. Under such optimal conditions, Fig.2 shows calculated equipotential and flow line in the groundwater.

Table 3. Optimal Discharge and Command Area for Each Well

No	Well (x,y)	Drawdown (m)	Transmisivity (m^2/d)	Discharge (m^3/d)	Area (ha)
1	W1(37,12)	8,64	139,33	808,43	17,58
2	W2(37,14)	8,64	139,32	463,50	10,08
3	W3(30,15)	9,85	158,91	865,97	18,83
4	W4(14,16)	9,31	150,20	1.268,33	27,58
5	W5(29,27)	10,00	161,30	868,91	18,89
6	W6(40,18)	8,79	141,75	601,47	13,08
7	W7(41,18)	8,66	139,65	750,94	16,33
8	W8(11,27)	8,91	143,72	1.095,87	23,83
9	W9(18,31)	8,14	131,32	480,75	10,45
10	W10(21,32)	8,16	131,68	342,78	7,45
11	W11(26,33)	8,98	144,85	635,97	13,83
12	W12(27,35)	8,55	137,90	532,49	11,58
13	W13(25,35)	8,37	135,06	279,54	6,08
14	W14(26,36)	8,25	133,15	406,02	8,83
15	W15(25,40)	6,54	105,54	463,50	10,08
16	W16(25,43)	5,62	90,64	808,43	17,58
	Total			10.672,90	232,07

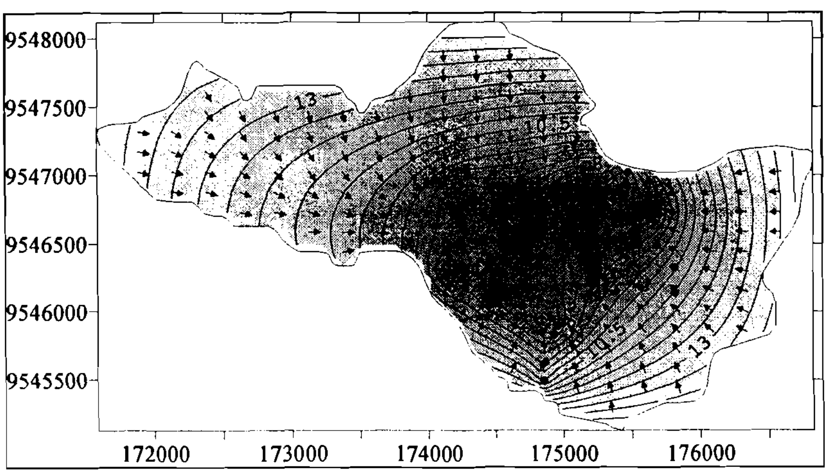

Figure 2. Equipotential profile and flow line of groundwater under the optimal discharge

Table 4 shows possible cost and income that would be incurred when the optimal discharge and size of the command area is in operation. Cost and income are different between planting season 1 and season 2 because of different weather condition which influences crop water requirement. The duration of pump operation resulted in different B/C for both planting season. It is worthy to notice that for all season, the longer pump operation than 720 hour decreases B/C. Thus, in this very case, duration of pump operation of 720 hour can be considered is the best practice.

Table 4. Cost and income at the optimal discharge and size of the command area

Planting Season	Components	Pump operation per season (hour)		
		720	1080	1440
1	Cost (Rp)	13.401.729	16.663.238	19.924.747
	Income (Rp)	190.075.592	189.009.503	189.213.699,52
	B/C	14	11	10
2	Cost (Rp)	11.765.518	15.027.027	18.288.536
	Income (Rp)	191.711.802	190.645.714	190.849.910
	B/C	16	12	10

4. CONCLUSION

This study described utilization of groundwater in Wajo Regency and found that so far farmers could earn good income from their rice fields. However, rapid increase of the number of wells is threatening their sustainability. Characteristics of the aquifer is well represented by the groundwater flow equation, and by simulation we found that the present practice is still far from effective management. Then by applying optimization process farmers can possibly gain better income if they utilize the ground water at the rate of about 1000 m3/d with the command area of 23 ha and pumping duration is 720 in each planting season without disturbing the aquifer and causing interference to the neighboring farmers. Possible B/C value amounts to 19 in the second planting season.

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