Sains Malaysiana 42(8)(2013): 1101–1108

Performance of Shallow Tube Well on Groundwater Irrigation in Tropical Lowland Rice Cultivation Area

(Prestasi Telaga Tiub Cetek untuk Pengairan Menggunakan Air Bawah Tanah di Kawasan Penanaman Padi Tanah Rendah Tropika)

MOHD FAUZIE JUSOH*, MOHAMED AZWAN MOHAMED ZAWAWI, HASFALINA CHE MAN & SUZILAWATI KAMARUDDIN

ABSTRACT

Groundwater irrigation is one of the alternative methods to irrigate the paddy crops beside surface water. The use of shallow tube well for paddy irrigation is able to overcome water scarcity especially during dry season and off planting season in Malaysia. The performance of a shallow tube well was evaluated based on well efficiency and pump efficiency. The study was conducted at Seberang Perak Integrated Agricultural Development Area (Seberang Perak IADA). In this study, on-off automatic water controller was installed in the field and connected to the pump system which gave the command to the pump to irrigate the field during pre-saturation and normal growth plantation period. Water level inside the pumping well and cultivation plot was observed and recorded by the water level transducers. The result of the study showed that the pumping well is moderately productive with the well efficiency between 91 and 94%. The submersible pump efficiency was 87.5%. The potential yield of the pumping well was 450 $m^3 day^{-1}$ and it was enough and sufficient to irrigate 1 ha of paddy field.

Keywords: Groundwater irrigation; pump efficiency; shallow tube well; well efficiency

ABSTRAK

Pengairan dengan menggunakan air bawah tanah merupakan salah satu cara alternatif untuk mengairi tanaman padi selain menggunakan air permukaan. Penggunaan telaga tiub cetek untuk pengairan padi boleh mengatasi masalah kekurangan air terutamanya ketika musim kering atau musim penanaman luar waktu di Malaysia. Prestasi telaga tiub cetek dinilai berdasarkan kepada kecekapan telaga dan kecekapan pam. Kajian ini telah dijalankan di Kawasan Pembangunan Pertanian Bersepadu Seberang Perak (IADA Seberang Perak). Dalam kajian ini, pengawal aras air automatik buka-tutup telah dipasang di petak sawah dan disambungkan kepada sistem pam untuk memberi arahan kepada pam untuk mengairi kawasan sawah semasa peringkat pra-tepu dan pertumbuhan normal. Aras air di dalam telaga pengepaman dan kawasan sawah telah dipantau dan direkod oleh perekod aras air. Keputusan menunjukkan bahawa kecekapan telaga pengepaman berada dalam julat 91 ke 94%. Kecekapan pam selam adalah 87.5%. Potensi hasil bagi telaga pengepaman adalah 450 $m^3 day^{-1}$ dan cukup untuk mengairi 1 ha kawasan penanaman padi.

Kata kunci: Kecekapan pam; kecekapan telaga; pengairan air bawah tanah; telaga tiub cetek

INTRODUCTION

Water is important in agriculture sector for plant growth. It is estimated that 70% of fresh water worldwide is being used for agriculture where 1000 L of water are required to produce 1 kg of cereal grain (Pimentel et al. 2004). Rosegrant et al. (2002) reported that worldwide cereal demand will grow by a projected 46% between 1995 and 2025 and for developing countries; it is projected by 65%. Water is a critical element in rice cultivation and this crop need a large amount of water during pre-saturation and normal growth (Akinbile et al. 2011; Azwan et al. 2010; Lee et al. 2005a; Mahmad et al. 2000; Rosegrant et al. 2002).

Since the beginning of the Green Revolution in the 1970s, irrigation using groundwater has evolved rapidly in South Asia and this region becomes the largest user of groundwater in the world (Rosegrant et al. 2007; Scott & Sharma 2009; Shah et al. 2006) due to the development of large scale irrigation project during this period (Faures & Mukherji 2009). Nowadays, there are 301 million ha irrigated areas for agriculture in the world where 38% from those areas are irrigated by groundwater (Siebert et al. 2010). Rice is the staple food for most of the Asian country including Malaysia. More than 90% of global rice is produced and consumed in Asia (Akinbile et al. 2011; Lee et al. 2005b; Rosegrant et al. 2007). Malaysia is currently ranked 25th of the world paddy production with a production capacity of 2.4 million tonne and cultivable land of about 0.7 million ha since 1980s (Akinbile et al. 2011).

Groundwater irrigation is important in South Asia countries (India, Pakistan and Bangladesh) and North

China Plain (Shah 2007). Shallow groundwater irrigation has been practiced in Nganjuk-East Java, Indonesia since 1975 during dry season to meet the water demand for secondary crops such as corn, soybeans, onion and vegetables (Prastowo et al. 2007). Groundwater was also used to irrigate the paddy field in Maligaya, Philippines where it had increased the grain yield from 7.27 to 8.58 tonne per ha for PSB Rc28 rice cultivar and from 3.08 to 4.02 tonne per ha for New Plant Type IR66106-5-3-2-3 (Quilang et al. 2004). According to Food and Fertilizer Technology Centre, FFTC (2003), the pilot project of controlled irrigation conducted in Philippines showed significant water savings of about 11-15% in tube wells without significant reduction in rice yield. In Thailand, groundwater was used for irrigation especially during dry season in Chiangmai valley for small-scale farming (Vithijumnok 1982). Malaysia has experience in using groundwater for irrigation purpose on paddy plantation. Irrigation and Drainage Department of Malaysia had used groundwater and surface water conjunctively during off season for rice cultivation at Meranti and Pasir Mas, Kelantan in 1970s (Mohammed & Huat 2004). The utilization of groundwater in agriculture was also used in Rhu Tapai, Terengganu and Pekan, Pahang (Nazan 1998).

Malaysia receives abundant amount of rainfall each year. The average annual rainfall for Peninsular Malaysia, Sabah and Sarawak are 2400 mm, 2360 mm and 3830 mm respectively (Che-Ani et al. 2009). However, Malaysia is experiencing occasional water shortages (David 2004). The largest granary area for Malaysia which is Muda Irrigation Scheme had experienced six incidents of drought in the period of 1977 until 1992 (Mon & Chan 2008). This phenomenon has affected paddy crop and rice production in Malaysia (Keizrul 2006; Mon & Chan 2008).

Alberto et al. (2006) mentioned that groundwater irrigation is a more reliable supply, lesser vulnerability to drought and easily access for individual use compared with traditional surface water irrigation method. Llamas and Martínez-Santos (2005) expected that the utilization of groundwater irrigation has become widely use due to advances in hydrogeology and well drilling techniques as well as familiarization of submersible pump that causes the abstraction cost over time have reduced. The perspective of groundwater irrigation in Malaysia is high because most of the granary area in Malaysia is located at the river basin which is covered with alluvium deposits. Nazan (1998) supported that the most productive aquifer is alluvial aquifers which located along the coastal area of Peninsula Malaysia with the range of yield between 30 and 50 m^3h^{-1}. The aim of this study was to evaluate the performance of shallow groundwater irrigation in terms of well efficiency and pump efficiency. This study provided information on quantity of shallow groundwater that can be abstracted at this area besides it can assist water engineer for better management of groundwater resources at paddy cultivation area.

MATERIALS AND METHODS

The study was conducted at Seberang Perak Integrated Agricultural Development Area (IADA Seberang Perak) in the state of Perak, Malaysia. IADA Seberang Perak area was chosen as a pilot project for groundwater irrigation due to potentially available fresh water on it shallow aquifer (Hoong 1992) and low water table at this area where indirectly it can reduce the pumping cost. Specifically, the study was conducted at Block C with latitude and longitude 4°02' to 4°09' North and 100°56' to 101°05' East, respectively (Figure 1). Groundwater was used to irrigate the paddy field on August-December in 2009. The size of area irrigated by groundwater was 0.8 ha. The test plot was supplied by groundwater extracted from shallow tube well during pre-saturation and normal growth. Fertilizer and insecticide were applied to the study area as normally applied to the other plot by the farmer. Irrigated water was controlled by on-off automatic water level controller and control panel. Water distributions and monitoring system consist of one unit of submersible pump, two units of water level transducers, one unit of control panel and two units of flow rate meter. The water was distributed by using polyethylene pipe. The schematic diagram of water distribution system is shown in Figure 2. The volume of rainfall at the study area was recorded by weather station which located near to the study site.

WELL PERFORMANCE

The performance of the pumping well was evaluated by conducting step drawdown pumping test. In this test, the water was pumped at different discharge rate and at the same time, the water level inside the well was observed. In this study, the test was designed in three steps. The time for each step was set for 2 h. After 2 h, the rate of pumping was increased to the next steps continuously without stopping the pump. The single-three phase inverter was connected to the centrifugal pump to vary the discharge rate. The discharge rate was measured by flow rate meter. Centrifugal pump (*Leo*) two-horse power was used to pump the water from pumping well and water level was measured by water level transducer (levelogger *Solint*). The collected data were analyzed by using alternative approach of step-drawdown test proposed by Shektar (2006) by using polynomial trend line fitting on drawdown and discharge. This method is approximate to Rorabaugh's method (Rorabaugh 1953) with well loss power equal to 2 by skipping the process of plotting specific drawdown versus discharge and finding the slope. Besides that, this method avoids complex computations of Rorabough's method (Shekhar 2006). The efficiency of the well at each pumping steps was calculated by well efficiency formula:

$$Well\ efficeny = \frac{BQ}{BQ + CQ^2}, \quad (1)$$

where Q is pumping rate in m^3day^{-1}, B is linear well loss coefficient and C is non-linear well loss coefficient.

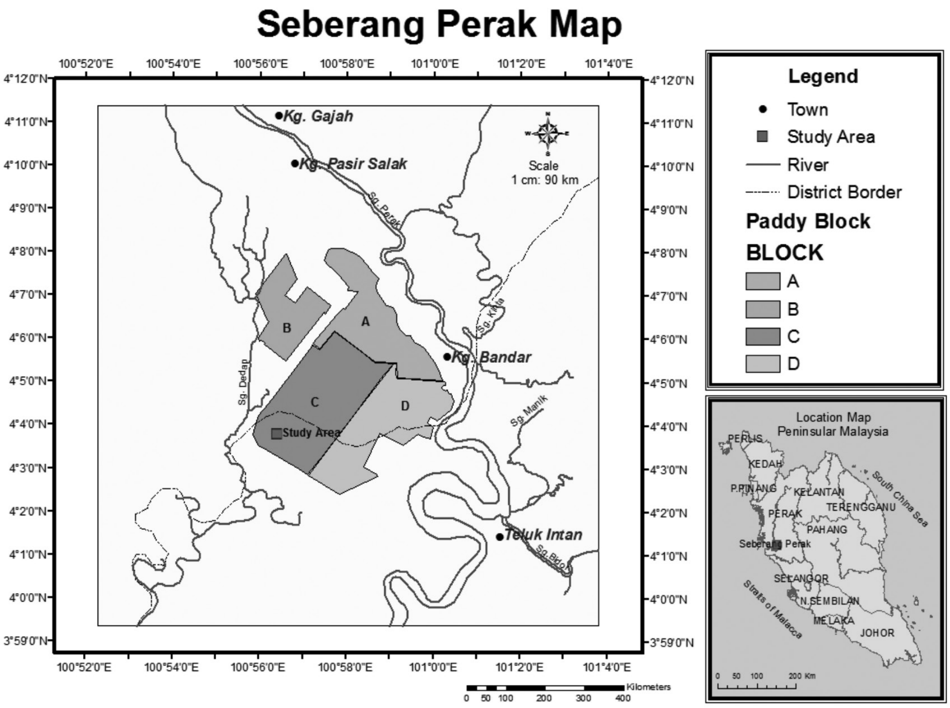

FIGURE 1. Map of Seberang Perak, Perak, Malaysia and location of the study area at Block C of Seberang Perak Integrated Agricultural Development Area

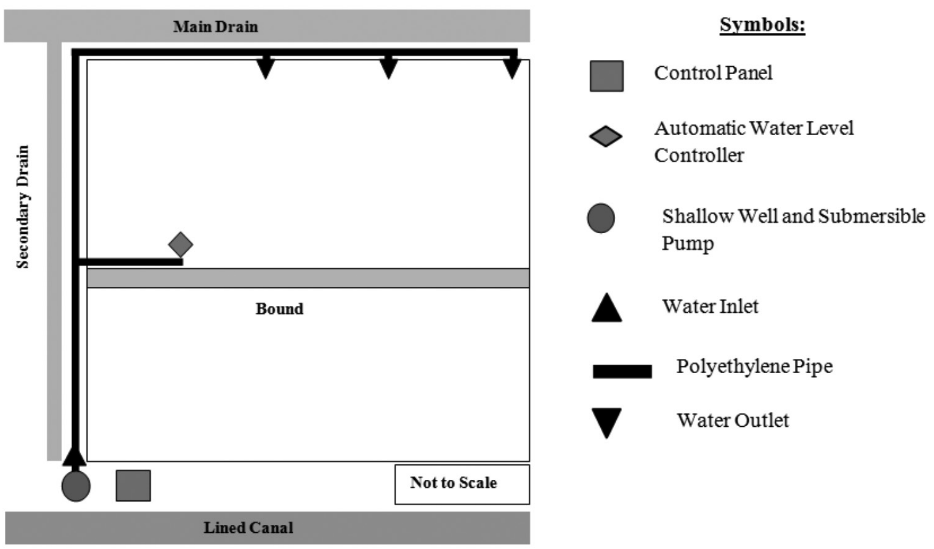

FIGURE 2. Schematic diagram of water distribution system at the study area

The coefficient of B and C is obtained from Shekhar's method. BQ is known as formation loss and CQ^2 is known as well loss.

PUMPING PERFORMANCE

The 1.16 kW submersible pump (*Grundfos*) was installed about 1 m from the top of the pumping well's screen. The depth of pumping well is 11 m from ground surface. The system was provided with flow rate meter to measure the volume of water abstracted from the shallow tube well. The ball valve was installed before flow rate meter to prevent water backflow when the pump is shut off. The water level inside the well was monitored by water level transducer (levelogger *Solint*) where it records the water level hourly and it is located 1 m below submersible pump location. The pipe loss was calculated by using Hazen-William equation (2) and a minor loss was calculated based on (3). The efficiency of the pump was considered in the term of volumetric efficiency (4),

$$Pipe\ Loss = \frac{10.7Q^{1.85}L}{C^{1.855}D^{4.87}}. \quad (2)$$

$$\text{Minor Loss} = K\frac{V^2}{2g}. \quad (3)$$

$$Volumetric\ efficiency,\ \eta_v = \frac{Q_a}{Q_t}\ x\ 100, \quad (4)$$

where Q is water flow rate in m^3s^{-1}, L is pipe length in m, C is roughness constant (Messina 2001), D is pipe diameter in m, K is coefficient loss (Cruise 2007), V is flow velocity in ms^{-1}, g is gravitational acceleration (9.81 ms^{-1}), Q_a is actual discharge in m^3h^{-1} and Q_t is the theoretical discharge in m^3h^{-1}. The actual flow rate of the pump was obtained during pumping activity. The theoretical flow rate was obtained from the submersible pump performance curve produced by manufacturer. The total head is also called total dynamic head which consist of the components of discharge head, pressure head, friction head and velocity head.

Results and Discussion

Well Efficiency

Figure 3 shows the polynomial trend line fitting of drawdown and discharge for the tested well as proposed by Shekhar (2006). After rearranging the trend line equation, the values of B and C were found to be 0.1513 hm^{-2} and 0.002 h^2m^{-5}, respectively. Table 1 shows specific capacity and well efficiency for each step. In each step, aquifer loss is always greater than well loss and this indicate that the major influence of drawdown inside the pumping well is controlled by aquifer loss component.

The well efficiency decrease when discharge rate is increased from 4.9444 to 7.3971 m^3h^{-1}. When more water is pumped, the well efficiency decreases due to obstruction near the well screen. This result is in agreement with the study conducted by Shekhar (2006) where he reported that the tube well efficiency decrease when the discharge of water increase in step pumping test on a tube well. The well efficiency of the tested well is higher than well efficiency tested by Prastowo et al. (2007) for shallow tube well which is in the range of 55 to 77%. The difference in well efficiency might be due to the tested well is the new constructed tube well.

The values of specific capacity of the tested well indicated that the developed well was classified as moderately productive well (Şen 1995). The high value of specific capacity is better because it shows the better and highly productive well. Low value of specific capacity implies low production of well and the screen of the well might be cloggy. There are two assumptions in estimating specific capacity of the well. First, the well is pumped at the constant rate until it achieves steady state condition (in this study it is 2 h for each step). Second, the drawdown within the tested well is a combination of the decrease in hydraulic head within the aquifer and head loss due to turbulent flow within the tested well.

Pump Efficiency

The discharge and water level inside the pumping well during groundwater irrigation is shown in Table 2. The actual flow rate of submersible pump was obtained from the pumping activity. The discharge values were arranged and the actual discharge was taken from 90th percentile of the discharge which was 5.2944 m^3h^{-1}. The theoretical flow rate was obtained from submersible pump performance curve produced by manufacturer based on the total dynamic head (Grundfos 2002). The suction head of submersible pump is zero because the suction region of the pump is already submerged into water. The total dynamic head component and it explanation was shown in Table 3. The total dynamic head in this study was found to be 27.63 m and by referring to pump performance curve (Grundfos 2002), the theoretical flow rate was 6.05 m^3h^{-1}. The volumetric efficiency of the submersible pump was found to be 87.5%.

Pump efficiency is very important to be considered because it shows the performance and the reliability of the pump during irrigation process. The submersible pump is suitable to be used due to it high efficiency. The pump's motor which already submerged into the water makes the water as natural cooler for the pump. Submersible pump is an economic pump due to it high efficiency and good operating condition as mention by Helweg (1982) and Durmus et al. (2008).

TABLE 1. Specific capacity and well efficiency for each steps

Step	Pumping rate (m^3h^{-1})	Drawdown (m)	Specific Drawdown (hm^{-2})	Specific Capacity (m^2h^{-1})	Aquifer Loss, BQ	Well Loss, CQ^2	Well efficiency (%)
1	4.9444	0.7834	0.1584	6.3115	0.7481	0.0489	94
2	6.0120	1.0018	0.1670	6.0012	0.9096	0.0723	93
3	7.3971	1.2218	0.1650	6.0543	1.1192	0.1094	91
Average	6.1178	1.0023	0.1635	6.1223	0.9256	0.0769	92

TABLE 2. The discharge and water level inside the pumping well during groundwater irrigation

Date	Time	Flow Rate Meter Reading, m^3	Discharge, m^3h^{-1}	Water Level, m
9/12/2009	10.35	1451.5029	-	6.9714
	11.35	1455.6101	4.1081	5.6364
	12.35	1460.9045	5.2944	5.8304
	1.35	1465.9065	5.0020	6.6941
10/3/2009	12.30	1876.7348	-	7.0064
	1.30	1881.9330	5.1982	7.0038
	2.30	1886.1129	4.1799	7.0433
	3.30	1891.3623	5.2503	7.0336
	4.30	1896.5872	5.2249	7.032
10/4/2009	9.00	1912.7070	-	7.1366
	10.00	1916.9993	4.2823	7.1347
	11.00	1921.3891	4.3998	7.1278
	12.00	1926.5923	5.2023	7.1198
	1.00	1931.6593	5.5069	7.1122
	2.00	1936.7896	5.1303	7.0992
	3.00	1941.7860	4.9964	7.0917
	4.00	1945.9361	4.1500	7.0856
	5.00	1950.7181	4.7571	7.0774
10/24/2009	10.30	2001.4232	-	7.1132
	11.30	2006.5479	5.1247	7.1025
	12.30	2011.7543	5.2064	7.1484
	1.30	2017.0235	5.2692	7.1371
11/18/2009	-	2068.8720	Pump stop	

TABLE 3. Total dynamic head and it components

Head Loss Component	Explanation	Head Loss Value, m
Discharge Head	The discharge head is the total vertical distance that the pump must lift the water. i. Distance from static water level to discharge point is equal to 2.06 m ii. Pumping water level is 6.15 m	8.21
Pressure Head	The pressure head is the water surface elevation inside the pumping well. i. The atmospheric pressure at the surface of water is 10.33 m ii. The average mean sea level of the study area is 2.30 m	12.63
Friction Head	The friction head is the losses exist due to type of pipe material, expansion and contraction i. Pipe losses is equal to 0.61 m ii. Check valve loss is equal to 6.10 m iii. Ball valve loss is equal to 8.71×10^{-3} m iv. Tee socket loss is equal to 0.03 m v. Reducer contraction loss is equal to 0.02 m vi. Enlargement loss is equal to 0.02 m	6.79
Velocity Head	The velocity head is very small and it is negligible	0
	Total Dynamic Head	27.63

WATER DEMAND AND WATER SUPPLY

The quantity of water required to irrigate the study plot was calculated based on crop water requirements studied by Azwan et al. (2010). It was estimated that crop water requirement for Seberang Perak paddy field was 775 mm per season where one planting season consist of 119 days. Thus, the estimated volume of groundwater required to irrigate the study plot is 6200 m^3 for one season (the size of groundwater irrigation area is 8000 m^2). The water demand decrease with the plantations period when the crops become mature.

In this study, the supplying of groundwater to the paddy plot is controlled by the control panel. The water level sensor is located at the paddy plot where it gives the signal to the control panel to switch-on or switch-off the pump. The farmer can adjust the standing water level at the planting plot by adjusting the scale or depth of water at the water level sensor. If the groundwater amount is achieving the required standing water level at the plotting area, the control panel will switch-off the submersible pump automatically. However, if there are rainy days, the irrigation process to the paddy plot is indirectly assisted by the rainwater. Indirectly, the amount of groundwater abstracted and pumping cost can be reduced. If there are excess water at the paddy plot, the water will flow to the overflow pipe which already installed at the early time of planting. Figure 4 shows the actual volume of groundwater abstracted and volume of rainfall at the study area during rice cultivation at the studied plot. The total actual volume of water supplied from groundwater and rainfall was 2617

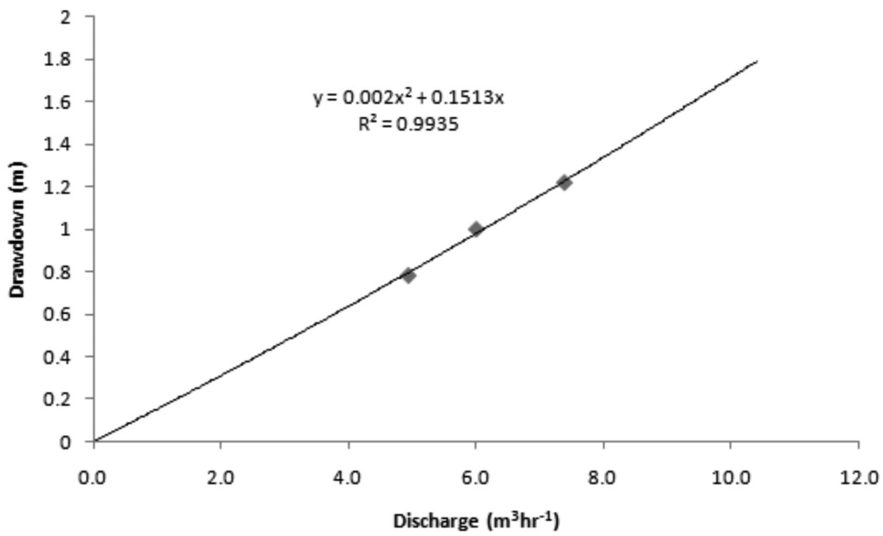

FIGURE 3. Plot of drawdown versus discharge with a polynomial trend line to estimate the value of *B* and *C*

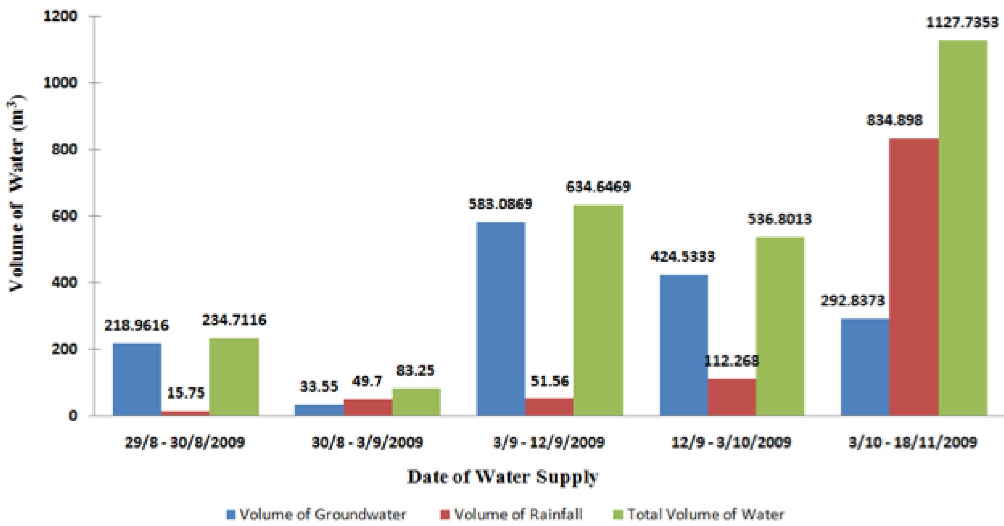

FIGURE 4. Volume of groundwater abstracted and rainfall at the study area during rice cultivation

m^3. The actual volume of water supplied is lower than estimated total volume required.

The potential yield of the well can be calculated by multiplying specific capacity by the fraction (one half to two third) of the available drawdown of the pumping well (Mohammed & Huat 2004). The available drawdown of the pumping well was 6.1484 m (the depth from static water level to pump' suction area) and the average value of specific capacity was found to be 6.1 m^3h^{-1}. The allowable drawdown was assumed as half from the available drawdown for the safety purpose. Thus, the potential yield of the pumping well was calculated as 18.75 m^3h^{-1} (450 m^3day^{-1}). Since the potential yield of the well was exceeded the average water demand for one day, single pumping well was enough and sufficient to irrigate 1 ha of paddy field.

Conclusion

The performance of groundwater irrigation in term of well efficiency and pump efficiency was studied in this paper. The well efficiency of the pumping well was varied between 91 and 94% and the pump efficiency was 87.5%. The potential well yield of shallow tube well was evaluated as 450 m^3day^{-1} and it was sufficient to irrigate 1 ha of paddy field by single well with the depth of 11 m from ground surface at Seberang Perak IADA.

REFERENCES

Akinbile, C.O., Abd El-Latif, K.M., Rozi, A. & Yusoff, M.S. 2011. Rice production and water use efficiency for self-sufficiency in Malaysia: A review. *Trends in Applied Sciences Research* 6(10): 1127-1140.

Alberto, G., Martínez-Santos, P. & Llamas, M.R. 2006. Groundwater irrigation and its implication for water policy in semiarid countries: The Spanish experience. *Hydrogeology Journal* 14: 340-349.

Azwan, M.M.Z., Sa'ari, M. & Zuzana, P. 2010. Determination of water requirement in a paddy field at Seberang Perak rice cultivation area. *Journal-The Institution of Engineers, Malaysia* 71(4): 32-41.

Che-Ani, A.I., Shaari, N., Sairi, A., Zain, M.F.M. & Tahir, M.M. 2009. Rainwater harvesting as an alternative water supply in the future. *European Journal of Scientific Research* 34(1): 132-140.

Cruise, J.F., Sherif, M.M. & Singh, V.P. 2007. *Elementary Hydraulics*. United States of America: Thomson.

David, W.P. 2004. Water resources and irrigation policy issues in Asia. *Asian Journal of Agriculture and Development* 1(1): 83-106.

Durmus, K., Yagmur, E.A., Yigit, K.S., Kilic, F.C., Eren, A.S. & Celik, C. 2008. Energy efficiency in pumps. *Energy Conversion and Management* 49: 1662-1673.

Faures, J.M. & Mukherji, A. 2009. *Trends and Divers of Asian Irrigation*. International Water Management Institute & Food and Agricultural Organization.

FFTC (Food and Fertilizer Technology Centre). 2003. *Improving Water Use Efficiency in Asian Agriculture*.Assessed November 30, 2011. http://www.agnet.org/library/ac/2003d

Grundfos, 2002. *User Manual*. L-SP-TL-017R5/06.

Helweg, O.J. 1982. Economic of improving well and pump efficiency. *Ground Water* 20(5): 556-562.

Hoong, L.H. 1992. *Quaternary Geology of the Teluk Intan Area, Perak Darul Ridzuan*. Kuala Lumpur: Geological Survey of Malaysia.

Keizrul, A. 2006. Managing water resources in Malaysia: The use of isotope technique and its potential. *Proceedings of Seminar on Water Resources and Environment, Application of Nuclear and Related Technologies*. Department of Irrigation and Drainage Malaysia & Malaysian Institute for Nuclear Technology Research (MINT).

Lee, T.A., Aminul, M.H. & Najim, M.M.M. 2005a. In-time rice irrigation water management under limited water supply. *Pertanika Journal of Science and Technology* 13(1): 97-111.

Lee, T.A., Aminul, M.H. & Najim, M.M.M. 2005b. Scheduling the cropping calendar in wet-seeded rice schemes in Malaysia. *Agricultural Water Management* 71: 71-84.

Llamas, M.R. & Martínez-Santos, P. 2005. Intensive groundwater use: Silent revolution and potential source of social conflicts. *Journal of Water Resources Planning and Management* 131: 337-341.

Mahmad, N.J., Puteh, S. & Arjunan, S.N.V. 2000. A computational model for water use efficiency in rice production. *Jurnal Teknologi Maklumat* 12(1): 1-13.

Messina, J.P. 2001. General characteristic of pumping systems and system-head curves. In *Pump Handbook*, 3rd ed., edited by Karassik, I.J., Krutzsch, W.C., Fraser, W.H. & Messina, J.P. New York: Mc-Graw Hill.

Mohammed, T.A. & Huat, B.B.K. 2004. *Groundwater Engineering and Geotechnique*. Universiti Putra Malaysia: UPM Press.

Mon, L.K. & Chang, C.M. 2008. The impact of drought and flood on paddy cultivation in Muda Irrigation Scheme. *13th Malaysia Conference on Irrigation and Drainage (13th MANCO)*, Kota Kinabalu, Sabah.

Nazan, M.A. 1998. An overview of groundwater resources potential in Malaysia. *World Day Seminar for Water 1998 - Groundwater, The Invisible Resources*, UPM, Serdang.

Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., Clark, S., Poon, E., Abbett, E. & Nandagopal, S. 2004. Water resources: Agricultural and environmental issues. *BioScience* 54 (10): 909-918.

Prostowo, S., Hardjoamidjojo, B., Pramudya, & Murtilaksono, K. 2007. Performance of shallow groundwater irrigation schemes in Nganjuk-East Java, Indonesia. *Agricultural Engineering International: CIGR Ejournal*. vol. IX.

Quilang, E.J.P., Guerra, L., Ramirez, A., Hernandez, J. & Maki, T. 2004. Effect of ground water irrigation on paddy rice yield in Maligaya, Philippines. *J. Agric. Meteorol*. 60(2): 95-104.

Rorabaugh, M.I. 1953. Graphical and theoretical analysis of step-drawdown of artesian well. *Proceeding American Society of Civil Engineers, Vol. 79*.

Rosegrant, M., Ringler, C. & Msangi, S. 2007. Agricultural research and knowledge in a changing environment. *SAT eJournal* 4(1): 1-35.

Rosegrant, M.W., Cai, X. & Cline, S.A. 2002. *World Water and Food to 2025: Dealing with Scarcity*. Washington D.C: International Food Policy Research Institute.

Scott, C. & Sharma, B. 2009. Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin. *Intl. J. River Basin Management* 17(1): 1-6.

Şen, Z. 1995. *Applied Hidrogeology for Scientists and Engineers*. United States of America: CRC Press.

Shah, T. 2007. The groundwater economy of South Asia: An assessment of size, significance and socio-ecological impacts. In *The Agricultural Groundwater Revolution: Opportunities and Threats to Development,* edited by Giordano, M. & Villholth, K.G. CAB International.

Shah, T., Singh, O.P. & Mukherji, A. 2006. Some aspects of South Asia's groundwater irrigation economy: Analysis from survey in India, Pakistan, Nepal Terai and Bangladesh. *Hydrogeology Journal* 14: 286-309.

Shekhtar, S. 2006. An approach to interpretation of step drawdown tests. *Hydrogeology Journal* 14: 1018-1027.

Siebert, S., Burke, J., Faures, J.M., Frenken, K., Hoogeveen, J., Döll, P. & Portmann, F.T. 2010. Groundwater use for irrigation – a global inventory. *Hydrol. Earth Syst. Sci.* 14: 1863-1880.

Vithijumnok, K. 1982. Using groundwater for irrigation in small-scale farming. In *Proceeding of the Regional Seminar on Water Technology towards Rural Development*, edited by Amin, M.M.S., Yan, K.W. & Rosnah, M.Y. Serdang: University of Agriculture.

Department of Biological and Agricultural Engineering
Faculty of Engineering
Universiti Putra Malaysia
43400 Serdang, Selangor D.E
Malaysia

*Corresponding author; e-email: fauzie_jsh@yahoo.com

Received: 28 June 2012
Accepted: 25 January 2013