International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:10, No:5, 2016

# Water Budget in High Drought-Borne Area in Jaffna District, Sri Lanka during Dry Season

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***Abstract*****—**In Sri Lanka, the Jaffna area is a high drought affected area and depends mainly on groundwater aquifers for water needs. Water for daily activities is extracted from wells. As households manually extract water from the wells, it is not drawn from mid evening to early morning. The water inflow at night provides the maximum water level that decreases during the daytime due to extraction. The storage volume of water in wells is limited or at its lowest level during the dry season. This study analyzes the domestic water budget during the dry season in the Jaffna area. In order to evaluate the water inflow rate into wells, storage volume and extraction volume from wells over time, water pressure is measured at the bottom of three wells, which are located in coastal area denoted as well A, in nonspecific area denoted as well B, and agricultural area denoted as well C. The water quality at the wells A, B, and C, are mostly fresh, modest fresh, and saline respectively. From the monitoring, we can find that the daily inflow amount of water into the wells and daily water extraction depend on each other, that is, higher extraction yields higher inflow. And, in the dry season, the daily inflow volume and the daily extraction volume of each well are almost in balance.

***Keywords*****—**Domestic water, water balance, water budget, ground water, shallow well.

## I. Introduction

SRI LANKA is located between latitudes 5$^{o}$ and 10$^{o}$ N and longitudes 79$^{o}$ and 82$^{o}$ E in the tropical climate region with an average temperature of 27$^{o}$C. It receives about 2000 mm mean-annual rainfall with a range of less than 900 mm in dry areas to over 5000 mm in wet areas from two monsoon seasons, hurricanes and interim rainfall. Sri Lanka has diverse geology and landforms including 103 river basins [1]. It is divided into three climatic zones as wet, intermediate and dry as shown in Fig. 1 (a) [2].

Jaffna is located in the dry zone in the northern part of the country and has no river. It has only small ponds and seasonal water bodies on sedimentary rocks of Miocene age [3]. It receives 935-1800 mm rainfall mainly from the North-East monsoon [4]. This rainfall water is collected in the karstic aquifers, and shallow aquifers in coastal sands [5]. People mostly depend on this ground water from wells for their domestic needs and livelihoods.

According to the statistical data in 2014 by District Secretariat, Jaffna [6], 141,113 families use ground water directly from 103,777 wells including shallow wells (80.64%) and tube wells (19.36%), 14,498 families have access to 1,865 pipelines which are connected to wells, and 31,070 families use other sources like bowser, ponds. The households directly using wells extract water from morning to early evening, mainly using manpower.

In dry season, the water level of wells decreases to the lowest levels leading to drought conditions. Though, historically, meteorological and hydrological droughts have occurred in these areas the water level in wells now decreases to low levels more rapidly than in the past. This stress condition challenges people and led to severe water scarcity. At this severe condition, it is significant to find out the basis of water scarcity in the drought area by studying the factors connects with scarcity like water use, consumption.

Jonathan and Munir [7] introduced the water scarcity indicators to explain the basis of scarcity, which are "(i) water supply to water demand, (ii) water use to water supply, and (iii) human water demand to human water access". Among these indicators, indicator (ii) "water use to water supply" can be treated objectively and the water scarcity can be described as 'shortage of water supply compared to the water use' using the indicator. Therefore, we focus on the relationship between water use and water supply, and at the first step, we try to find the domestic water balance. To do it, we monitored temporal change of water depth in the several wells.

### A. Concept of Water Balance

The water balance can be determined by the balance of all of water movements that is water inflows and outflows in a defined period. It is further explained as the changes in storage for a definite area which is the difference between inflow amount and outflow amount. In general, precipitation ($P$) is the inflow; Evaporation ($E$) and Evapotranspiration ($ET$) are the outflows; and the Groundwater Flow ($GF$) and Surface Runoff ($SRO$) have the characteristics both of inflow and part of outflow. The water balance, the changes in storage $\Delta S$, can be written as [8]:

$$\Delta S = P - E - ET \pm SRO \pm GF \quad (1)$$

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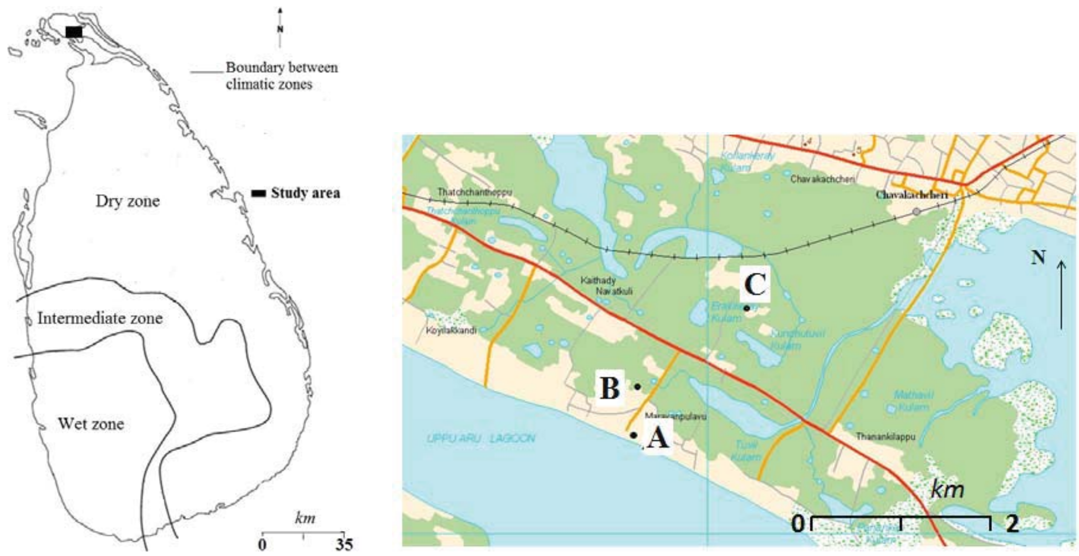


(a) Main Climatic Zones of Sri Lanka [2] (b) Topographic map of the study area and location of wells A, B, and C

Fig. 1 The study site for monitoring wells A, B, C at Maravanpulo, Jaffna, Sri Lanka

### *B. Application of the Concept of Water Balance to Well*

For well, when we denote $V_t$ for the volume of the water stored in a well, $\Delta S$ in (1) is considered as change in the volume ($\Delta V_t$); $P$ is to be rainfall amount on the open well surface ($V_r$); $E$ and $ET$ also correspond to Evaporation amount ($V_e$) and Evapotranspiration amount ($V_{et}$) from open water surface of well; *SRO* does not exist due to lack of direct interaction between water on ground surface and water inside of the well; and *GF* can be divided into the flow ($V_{if}$ ) which comes from ground water aquifer to the well and extraction ($V_{ext.}$) from the well. Therefore, (1) can be

$$\Delta V_t = V_r - V_e - V_{et} + V_{if} - V_{ext} \tag{2}$$

In addition, Evaporation ($V_e$), and Evapotranspiration ($V_{et}$) could not evaluated directly and groundwater flow would be somehow affected by the existence of $V_e$ and $V_{et}$. Therefore, both of $V_e$ and $V_{et}$ would be included into groundwater inflow. Then, (2) can be rewritten as

$$\Delta V_t = V_r - V_{ext} + V_{if} \tag{3}$$

In dry season, especially in night, we could assume that it would be no rain, that is $V_r = 0$. Then, (3) can be modified as

$$\Delta V_t = V_{if} - V_{ext} \tag{4}$$

Moreover, during night, we could also assume no extraction, (4) can be developed as

$$\Delta V_t = V_{if} \tag{5}$$

$\Delta V_t$ can be defined as the difference of the volumes at starting ($t$) and ending ($t$+$\Delta t$) of defined period ($\Delta t$) that is

$$\Delta V_t = V_{t(t+\Delta t)} - V_{t(t)} \tag{6}$$

The volume of stored water ($V_t$) in the well with cross sectional area ($A$) is obtained as

$$V_t = A\,h \tag{7}$$

In which, $h$ is the water depth in the well. The water depth can be calculated using the monitored water pressure $p$ at bottom of well by:

$$h = p/\rho g \tag{8}$$

In which $\rho$ is density of water and $g$ is gravity. Substituting (6)-(8) into (5) yields

$$V_{if} = \Delta V_t = A\left[p_{t(t+\Delta t)} - p_{t(t)}\right]/\rho g \tag{9}$$

## II. Site Selection and Monitoring

### *A. Study Area and Location of Wells*

Maravanpulo in the Thenmaradchy Divisional Secretariat area is one of the highest drought affected areas in Jaffna district, and is selected based on its drought history in recent years [9]. More than seventy percentages (70%) of households have their own wells. We choose three domestic wells with different water uses for monitoring. The location of the wells is shown in Fig. 1 (b).

Well A

It is located nearby coastal area of Jaffna lagoon. This well has fresh water and it is used for domestic needs, animal husbandry, and home gardening.

Well B

It is found in the boundary of residential area. The water of this well is modest fresh water.

Well C

It is located by ponds which are small surface water bodies. The water is saline water in dry season and modest fresh in rainy season.

*B. Shallow Wells*

The wells are commonly shallow and have free surface, and constructed with cemented sidewall and non-concreted basement to flow the water. The pressure gauge is kept at the bottom of the well as shown in Fig. 2. The well does not have plants or trees on its water surface.

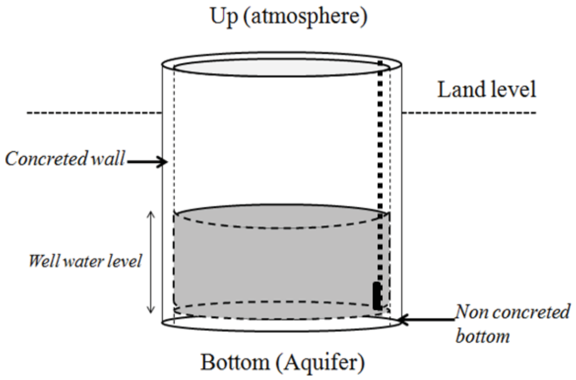


Fig. 2 Structure of typical shallow well in the study area

*C. Monitoring*

Three pressure gauges (HOBO® U20 Water Level Logger) which fixed on the bottom of the each well A, B, and C are used to monitor the water pressure and another one is kept in atmosphere at site B to measure atmospheric pressure to correct the bottom pressures. The pressures were monitored in 10 minutes interval from August 24, 2015 until December 06, 2015 during the dry and rainy seasons.

## III. Results and Discussion

*A. Water Balance to Study Area*

The water depth ($h$) is calculated from the water pressure observed at bottom of wells A, B and C using (8). Fig. 3 is the typical changes of water depths, $h_A$, $h_B$, and $h_C$, during three continuous days in dry season from 26th August to 28th August, 2015.

Fig. 3 shows that the water depth increases constantly at night and decreases quickly in several times during the daytime. It means that water recovers at night and it is used in daytime. And the daily maximum water depth is mostly found at from 5.00am to 10.00am. The water depth change of well C is smallest one compared to wells A and B in dry season. Therefore, we calculated the daily inflow volume ($V_{if\,(24)}$) using the inflow volume for the period from 1.10am to 5.00am (230 min). The inflow volume for the period from 1.10am to 5.00am is obtained by using (9). The relationship between the inflow volume for the period from 1.10am to 5.00am, $V_{if}$, and daily inflow volume $V_{if\,(24)}$, is,

$$V_{if_{(24)}} = 24(\text{hours})/(230\text{min.}/60\text{min.})V_{if} \qquad (10)$$

The daily water balance can be expressed based on (3) as,

$$\Delta V_{t(24)} = V_{r(24)} - V_{ext(24)} + V_{if(24)} \qquad (11)$$

In this equation, $V_{r(24)}$ is obtained by monitoring as daily precipitation, and $\Delta V_{if(24)}$ can be evaluated by (10). $\Delta V_{t(24)}$ in (11) means the daily change of the volume of the water in the well. Therefore, it can be evaluated by (9) using two pressure data, which are obtained at 24 hours difference. When we used the pressure at 0.00am every day, $\Delta V_{t(24)}$ can be evaluated by,

$$\Delta V_{t(24)} = V_{t(24)} - V_{t(0)} = A\,[p_{(24)} - p_{(0)}]/\rho g \qquad (12)$$

In which, $p_{(24)}$ and $p_{(0)}$ are the pressures at 0.00am in tomorrow and today morning, respectively.

$\Delta V_{t(24)}$, $V_{r(24)}$, and $V_{if(24)}$ in (11) are known by above discussion, then we can evaluate the daily extraction volume, $V_{ext(24)}$, from (11), as

$$V_{ext(24)} = V_{r(24)} - \Delta V_{t(24)} + V_{if(24)} \qquad (13)$$

In case that rain fall can be neglected, (13) is

$$V_{ext(24)} = V_{if(24)} - \Delta V_{t(24)} \qquad (14)$$

*B. Results and Discussion*

Fig. 4 shows the daily rainfall, $V_{r(24)}$, and cumulative rainfall in the monitoring period of 104 days [10].

We could recognize that the rainy season would start on 27 September 2015, and we could divide the rainy season into three periods, pre-intensive rain period, from 27th September to 26th October, intensive rain period, from 27th October to 15th November, and post-intensive rain period, from 16th November to end of the monitoring period.

Fig. 5 shows the daily inflow rate, $V_{if(24)}/A$, daily extraction rate, $V_{ext(24)}/A$, and water depth observed at 09.00am, $h_{(9)}/A$ of each well A, B and C.

Table I denotes the average values of inflow rate, inflow volume and extraction volume in dry and rainy seasons. And Table II also denotes them in every period of *pre-*, *mid-*, and *post*-intensive rainy period.

Table I shows that the average daily inflow volume and extraction volume at each well are almost same in both of dry and rainy seasons. The inflow and extraction volumes of well A are the highest among three wells in both seasons. This means that well A is the most actively used in the three wells.

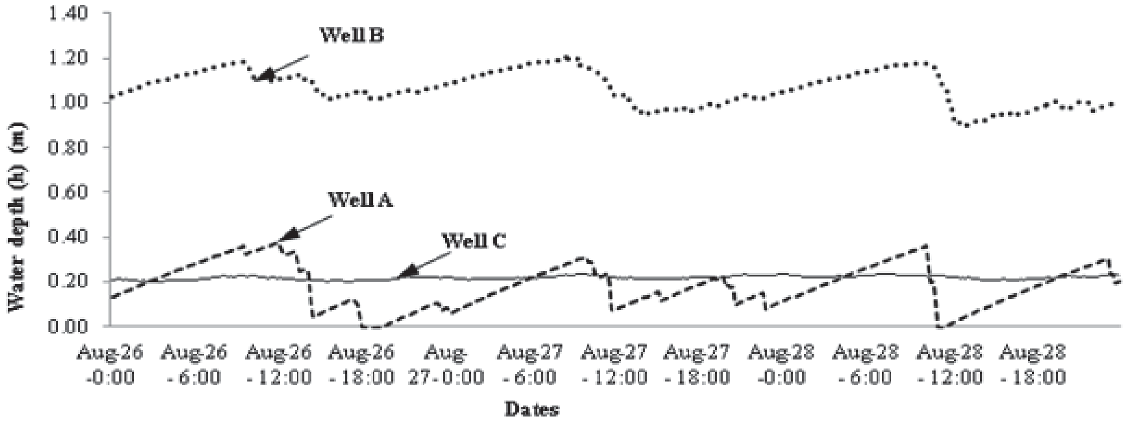


Fig. 3 Changing in water depths of wells A, B, and C in dry season from 26.08.2015 to 28.08.2015

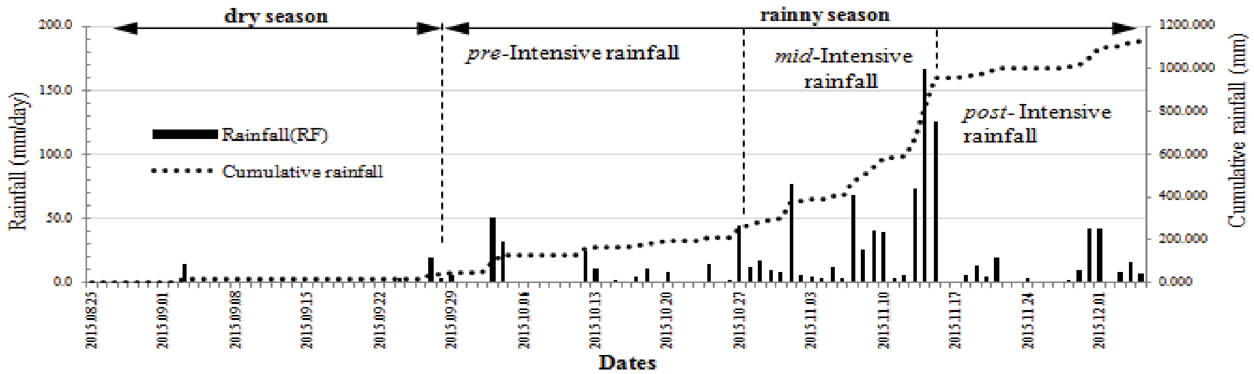


Fig. 4 Rainfall of the study area from 2015.08.25 to 2015.12.05

TABLE I
INFLOW RATE AND EXTRACTION VOLUME OF WELLS A, B, AND C IN DRY AND RAINY SEASONS

| | Unit | **Dry season:** August 24 - September 26, 2015 | | | **Rainy season:** September 27- December 06, 2015 | | |
|---|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **A** | **B** | **C** |
| Average inflow rate ($V_{if(24)}/A$) | ($x10^{-6}$) m/sec | 6.0 | 4.3 | -0. 1 | 6.7 | 4.3 | 0.4 |
| Average inflow rate ($V_{if(24)}/A$) | m/day | 0.518 | 0.374 | -0.006 | 0.580 | 0.374 | 0.035 |
| Average inflow volume ($V_{if(24)}$) | $m^3$/day | 1.176 | 0.849 | -0.015 | 1.318 | 0.851 | 0.071 |
| Average extraction volume ($V_{ext(24)}$) | $m^3$/day | 1.041 | 0.829 | -0.031 | 1.209 | 0.811 | 0.014 |

TABLE II
INFLOW RATE AND EXTRACTION VOLUME OF WELLS A, B, AND C IN *PRE-*, *MID-*, AND *POST-*INTENSIVE RAINY PERIODS

| | Unit | **Pre-Intensive rainy period:** Sep 27- Oct 26, 2015 | | | **Mid-Intensive rainy period:** Oct 27- Nov 15, 2015 | | | **Post-Intensive rainy period:** Nov 16 -Dec 05, 2015 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **A** | **B** | **C** | **A** | **B** | **C** |
| Inflow rate ($V_{if(24)}/A$) | ($x10^{-6}$) m/sec | 6.2 | 4.2 | 0.1 | 6.9 | 5.2 | 0.5 | 7.3 | 3.7 | 0.5 |
| Inflow rate ($V_{if(24)}/A$) | m/day | 0.537 | 0.363 | 0.006 | 0.594 | 0.450 | 0.046 | 0.631 | 0.318 | 0.047 |
| Average inflow volume ($V_{if(24)}$) | $m^3$/day | 1.220 | 0.776 | 0.009 | 1.350 | 0.963 | 0.065 | 1.432 | 0.680 | 0.066 |
| Average extraction volume ($V_{ext(24)}$) | $m^3$/day | 1.149 | 0.741 | -0.025 | 0.986 | 0.818 | -0.021 | 1.521 | 0.743 | 0.086 |

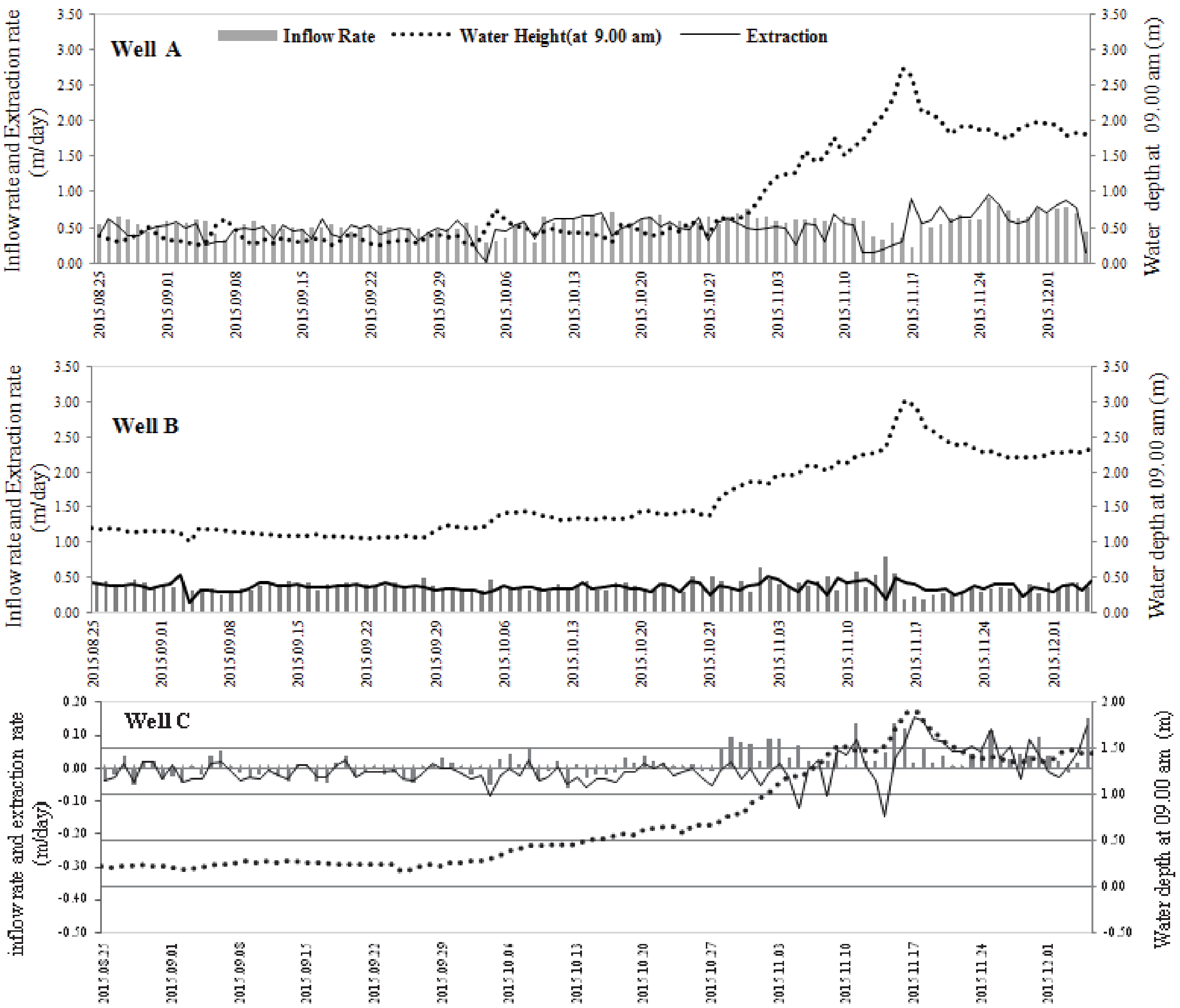


Fig. 5 Comparison of wells A, B, and C during dry and rainy seasons from 2015.08.25 to 2015.12.05

From Figs. 4, 5, and Tables I and II, we can explain the water balance status of each well as follows.

Well A

The household of five persons using well A draws an average of 1,041 liters of water, which is correspond to almost 200 liters per one person a day, in dry season and 1,209 liters, correspond to 240 liters per person a day, in rainy season for daily needs from the well according to Table I.

In dry season, from Fig. 3, the household extracts almost all of water from well every day.

According to Table II and Fig. 5, the daily inflow volume is gradually increasing from pre-intensive rainfall period to post-intensive rainfall period. However, the daily extraction volume in mid-intensive rainfall period is decreasing, and it causes the increasing of water depth in the well in this period. The highest depth is recorded at end of the mid-intensive rainfall period as 2.75 m. In the post-intensive rainfall period, the average daily inflow rate takes highest value. Further, the average extraction rate takes also highest value and is higher than the average daily inflow rate in this period. This yields the reduction of water depth. The extra extraction of water in this period may be used for the watering to home gardening. The gardening perhaps starts in the middle of October. And they may face water shortage for gardening at this period due to relatively small rainfall compared with intensive rain period.

Well B

Table I and Fig. 5 show that it is not found any considerable difference in daily inflow and extraction rates/volumes in both of dry and rainy seasons. However, from Table II, the highest inflow and extraction rate/volume are found in the intensive rainy period.

From Table I, we find household B with six members extracts 829 liters of water from the well, which is correspond to 140 liters a person a day, in dry season, and 811 liters, correspond to 135 liters a person a day, in rainy season for domestic needs.

Well C

Fig. 5 shows almost no extraction and no inflow at well C, especially in dry season. It means that the water in the well and the water in the aquifer outside of well are not exchanged because of the static equilibrium state between the well and aquifer.

The reason why they don't extract water in the dry season is high saline. They actually use common well, ditch and pond nearby to them.

In rainy season, the positive value of inflow rate is observed according to Tables I and II. Fig. 5 also shows that the water depth increases to its maximum value due to the positive inflow rate. The Household C starts to extract the water in well C because its salinity may become small in post intensive period.

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