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# Sustainability of Agrowell Irrigation on Hardrock Aquifers of Sri Lanka

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*ABSTRACT. Water shortage is the major problem for agricultural activity in the intermediate and dry zones of Sri Lanka. More than 90% of these zones are on hardrock aquifers, where agrowells are being introduced for supplementary irrigation. Present agrowell systems are without proper guidance on hydrogeological properties of the aquifer and safe yield, which may cause severe implications on groundwater resources. Therefore, a case study has been conducted in a representative agrowell system in North-Western province to determine the well dimensions and the irrigated land area to achieve sustainable irrigation.*

*Two computer models are used in this study. First is an existing model based on soil moisture balance method to estimate the actual recharge and irrigation water requirement. Second is a radial flow model which was developed to predict the drawdowns in the well and aquifer during short term and long term pumping.*

*Results confirm that the water yield per well increases with increased well radius, well spacing and well depth. But recharge is the major limiting factor; for sustainable irrigation average abstraction must be less than average recharge. The sustainable irrigated land area per well may be limited by recharge or by the ability for the well to abstract water. There is an optimum well radius for different aquifer depths and well spacing. Increasing the well radius more than the optimum will not help to increase the sustainable irrigated land area. Well construction cost analysis proved that the optimum well radius is the cheapest per sustainable irrigated land area.*

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## INTRODUCTION

A substantial proportion of Sri Lanka's peasant agriculture is confined to the intermediate and dry zones. Intensive cultivation in these areas depends mainly on adequate water supply. In most years precipitation is insufficient to meet the crop water requirements from February to August. Therefore, farmers in these zones depend on seasonal rainfall and storage in several thousands of small and medium village tanks to sustain their traditional way of cultivation including rainfed paddy.

Even though there are number of irrigation schemes, more than 50% of the irrigable land cannot be cultivated in the dry zone due to scarcity of water. Therefore, it is imperative that supplementary sources of irrigation water be found. Except in the Jaffna peninsula in the extreme North of the island, where the rich aquifers are associated with Miocene Limestones, groundwater has never been used on a large scale in the dry zones (Abhayaratne, 1994). Ground water potential in much of these zones is limited due to low storage and transmissivity of the underlying crystalline hard rock formations.

Large diameter wells (Agrowells) are ideally suited for the regolith above the hard rock aquifer which have low transmissivities (Sathivadivel and Rushton, 1989) because they act as a short-term storage reservoir as well as a groundwater abstraction point. Generally the conventional boreholes and small diameter wells in low transmissivity aquifer produce very small yields (Rushton and Barker, 1983). The Government of Sri Lanka realised the importance of agrowells as a water source for supplementary irrigation in areas with hard rock aquifers, and commissioned the Agricultural Development Authority (ADA) to implement a nation-wide agrowell programme. Currently agrowells are used intensively by many farmers in the area, and the construction of wells in these areas has increased. There are now more than 6500 agrowells in operation.

### Present problem

The development of agrowells has taken place in a rather haphazard way without a general assessment of the hydrogeological properties of the aquifer, the possible yield and a rational siting of wells. There is nothing to stop a farmer on private land from exploiting at his will, what are in fact national groundwater resources. Government agencies are unable to give technical advice and only provide the financial grant of 20,000 to 25,000 Sri Lankan rupees per agrowell.

The National Water Supply and Drainage Board of Sri Lanka, with financial and consultancy (COWIconsult, 1993) assistance from DANIDA, carried out a study and the preliminary results showed that there is an urgent need to bring the situation under control in order to avoid a situation, such as in Tamil Nadu, India where indiscriminate sinking of agrowells has caused a permanent depletion of the groundwater resources.

The sustainability of a system of lift irrigation using agrowells as the source, depends on the recharging of the groundwater resources and the variation in recharge over the years. Indiscriminate opening of new wells by individual farmers will lead to serious problems in future with regard to availability and quality of groundwater. Therefore, supplementary irrigation using agrowells in the dry and intermediate zones of Sri Lanka should be carefully planned with respect to recharge, well dimensions and the safe yield. The objective of this study is to identify Agrowell dimensions and the extent of irrigated land area per well for sustainable irrigation.

## METHODOLOGY

The case study areas were selected in the farming villages of Kurunegala district, under the North-Western Province of Sri Lanka where agrowells are used intensively for irrigation. A typical agrowell in Sri Lanka is 6.0 m in diameter, dug by hand and/or mechanical excavator. The walls of the well are lined with bricks and the top 1 to 2 m are plastered with cement. Farmers typically irrigate using a 50 mm pump with 50 mm diameter portable hose pipes leading directly to the crops. The well storage allows the pump to be used at its optimum rate. After pumping the well is then left to refill slowly before next irrigation. The spacing between the wells varies between 50 m to 500 m.

A typical farm used for the case study covers 2-3 ha. During the *Maha* season paddy is grown in the lowlands and if there is sufficient water, vegetables in the uplands. During the dry season, without agrowells, paddy must be left fallow and vegetable crops grown over a small area in the uplands with irrigation from small diameter domestic wells. In contrast, farmers with agrowells have started intensive vegetable cultivation in both lowland and upland. For more detailed investigation of the behaviour of the well, 25 agrowells were selected and among these six were selected for instrumentation, daily monitoring and pumping tests. Land around these wells is almost flat with a slight fall (less than 2%) across the main site. More than fifteen observation boreholes were installed around the six wells at different radial

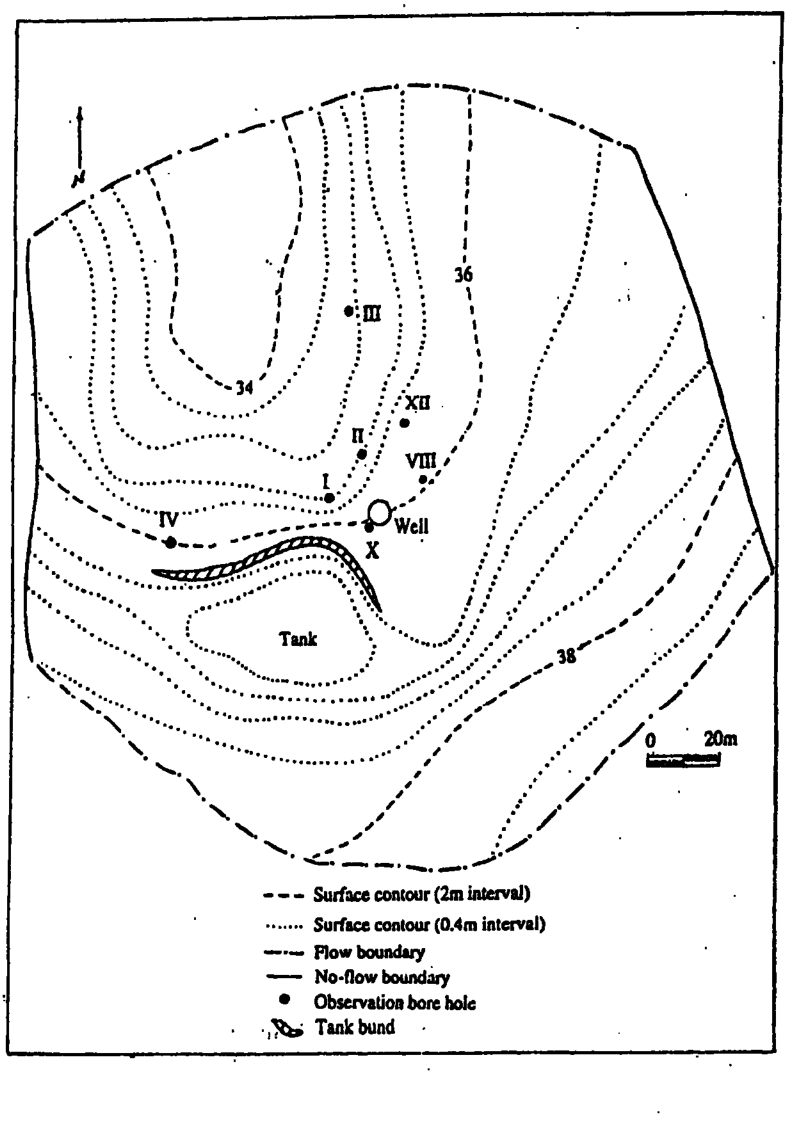



**Figure 1.** Study area with the large diameter well No.1

distances and the daily groundwater levels and changes in groundwater levels due to pumping were monitored. Study area associated with the large diameter well No. 1 is shown in Figure 1. Several pumping tests were conducted in the selected six wells during the early and late dry seasons to study the aquifer parameters. Daily rainfall and evaporation at the study site were also measured by recording raingauge and Class A evaporation pan, respectively. Complete crop and soil information were also collected during the study period. Whole monitoring processes were done in the case study areas for 20 months from March 1993 to December 1994 covering almost two dry seasons and two wet seasons.

## RESULTS AND DISCUSSION

### Soil moisture balance

A soil moisture balance model, IWR (Irrigation Water Requirement) (Hess, 1992) which runs on historic weather, crop and soil data was used to estimate the actual recharge and irrigation water requirement for a typical cropping pattern in the study area. The typical cropping pattern was decided after a careful survey of the land area under each crop in the study site, which consists of 20% of Aubergine and Chillie, 40% of Long bean, Cucumber and paddy and the rest 40% is permanent grass. The IWR model simulates a soil moisture balance to estimate the changes in the water content on daily basis taking into account rainfall (and irrigation) and outputs of evapotranspiration (modified for the crop cover and soil water status) and deep drainage (recharge). It also assumes that the water can pass through the soil zone to the aquifer only when the soil moisture deficit is zero (*i.e.* there is no preferential flow through cracks).

The model combines information on the type of crop grown (dates of planting, emergence, 20% cover, maturity and harvesting), soil characteristics (saturation, field capacity and permanent wilting point), and crop evapotranspiration at the sites to estimate the daily water use. This is combined with daily effective rainfall in a water balance to calculate a daily soil moisture deficit. The irrigation decisions are based on given irrigation plans. The irrigation can be initiated by an allowable soil water deficit (mm) or an allowable depletion of available soil water (%).

Due to lack of facilities, direct runoff measurements could not be made. Therefore, different percentages of the total rainfall were considered as runoff in the IWR model. The actual recharge estimated by the IWR model was compared with the observed recharge (groundwater table rises monitored during the study period multiplied by the specific yield) of the study site. Allowing 25% direct runoff gave the closest agreement. The average annual actual recharge was also calculated over 10 years for the typical cropping pattern with the daily weather data available. Ten year average actual recharge of the study area under the typical cropping pattern was 250 mm.

## Aquifer parameters

Due to the inability of the conventional pumping test analysis method (Papadopulos and Cooper, 1967) to include all the features of the large diameter wells such as well storage, the seepage face, the variable saturated depth of the aquifer, varying recharge and differing conditions on the outer boundary in a single equation, numerical methods have to be used.

In order to estimate the aquifer parameters, the radial flow finite difference model of Rathod and Rushton (1989) was modified to the study site conditions and used. The modified model includes features such as well storage, seepage face, effective outer boundary and variable saturated depth. Another important parameter is the lateral extent of the aquifer. The existence of a number of agrowells means that an area of aquifer is associated with each well. The average spacing between adjacent wells in the study site was 180 m, assuming that the wells are in 180 m array each well having an average area of 32400 $m^2$ associated with it. This can be represented as an equivalent outer radius of 101 m on which a condition of no-flow crossing the boundary is enforced (Rushton and Redshaw, 1979). The modified model used in this study is fully explained by De Silva (1995).

Pumping tests were analysed using the radial flow model. The model results were compared with the drawdown and the discharge from the aquifer in the pumped well and also with the observation borehole drawdowns at 13 m and 43 m from the well center, respectively. A range of parameter values were tried. Initial values for hydraulic conductivity and storage coefficient were obtained by using the type curves of Papadopulus and Cooper (1967) for the pumping phase. Modifications were then made to the hydraulic conductivity, storage coefficient and seepage face as a well loss factor until an adequate agreement was obtained between the field and modelled results for pumping and recovery. The estimated parameter values of hydraulic conductivity and specific yield are 6 m/day and 0.07, respectively (De Silva and Rushton, 1996).

## Long term behaviour of the agrowell

Although the estimation of the aquifer transmissivity and storativity from the test using agrowells is of interest, an understanding of the long term response to pumping is of far greater importance when considering the sustainability of these agrowells. The pumping test analysis examines the short term responses of the well and highlights the interaction between the well storage and the aquifer. However in the long term, the yield of the whole of the region that is associated with the well becomes particularly important. Therefore, it is essential to study the performance of the same radial flow model, which was used to estimate the aquifer parameters, in representing the long term operation of the study area for a growing season.

A detailed monthly groundwater balance analysis was conducted for the study area. An agrowell and the area of aquifer associated with it was considered as a single well unit for detail analysis. The groundwater balance analysis of this single well unit indicated that the boundary inflows and outflows were prominent only during the wet season (October to January). The inflows and outflows during the dry season (February to September) were negligible when compared with the wet season flows, with the groundwater table almost flat. Therefore, the radial flow model was used for dry season simulation.

Datum for the water level is taken as the position of the water table at the end of the rainy season in February; and the saturated depth was 6 m. The growing season is assumed to be 240 days from February. The maximum pumped drawdown in the model was set as 90% of the saturated depth so that there will always be 0.6 m of water in the bottom of the well. When this drawdown was reached in the simulation the pump was automatically switched off and the well supply was regarded as having failed.

The simulations were carried out by the radial flow model to study the sustainability of the well with different well radius, well depth and well spacing. In total 84 options were tried with 7 well radii, 4 well spacing and 3 well depths. In all options, irrigation water requirement for the typical cropping pattern (abstraction) was given throughout the growing period by a schedule of pumping rates, hours and irrigation interval. Total abstraction was increased by factors until the well reaches failure during the growing season. The total abstraction which could be abstracted from the well without well failure within the growing season was compared with the total volume of average recharge per well for a particular well spacing to ensure that the abstractions are always less than the average recharge for sustainable yield. Maximum abstraction

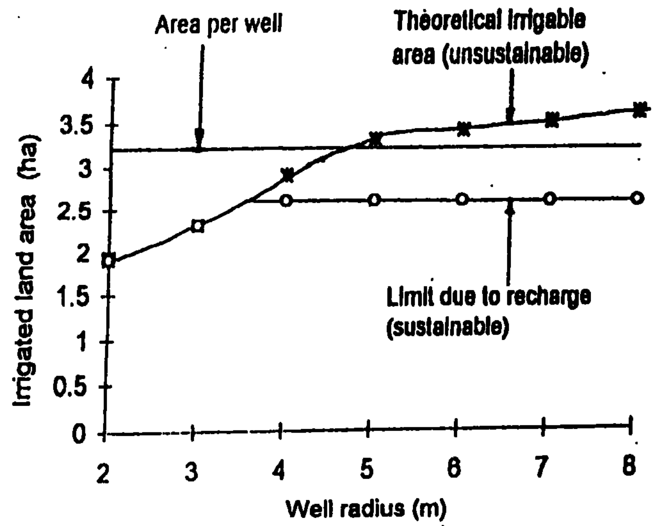



**Figure 2.** **Effect of well radius on irrigated land area with an aquifer depth of 6 m and well spacing of 180 m.**

below or equal to the volume of average recharge was converted to sustainable irrigated area.

Initially the influence of different well radii alone was examined. Well radii considered were 2 m, 3 m, 4 m, 5 m, 6 m, 7 m and 8 m. Aquifer depth (6 m) and the well spacing (180 m) were held constant. The effect of increased well radius on irrigable land area before the well drawdown exceeds the maximum permissible pumped drawdown (0.9 times initial saturated depth) is presented in Figure 2.

The results clearly indicated that increasing well radius increases the total water yield per well and therefore, the irrigable land area increases. However the maximum area associated with one well spaced at 180 m is only 3.2 ha. The recharge over that area can only irrigate 2.6 ha by a 3.15 m radius well, *i.e* 81% of the land per well. But increased water yield due to increased well radius above 3.15 m is not useful as it exceeds the recharge limit. Any

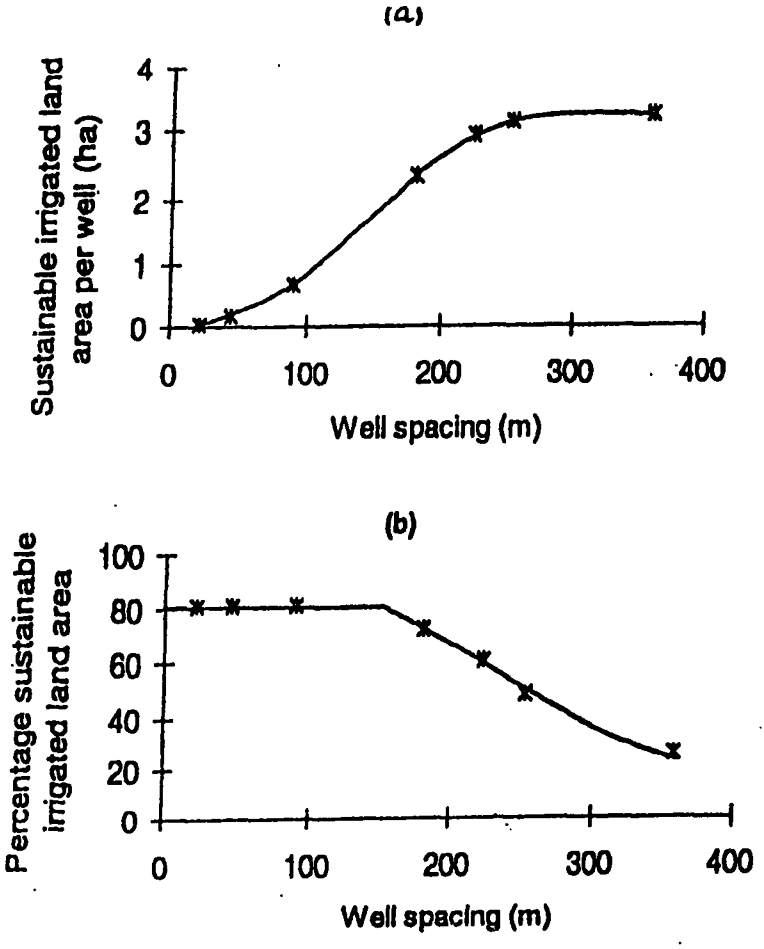
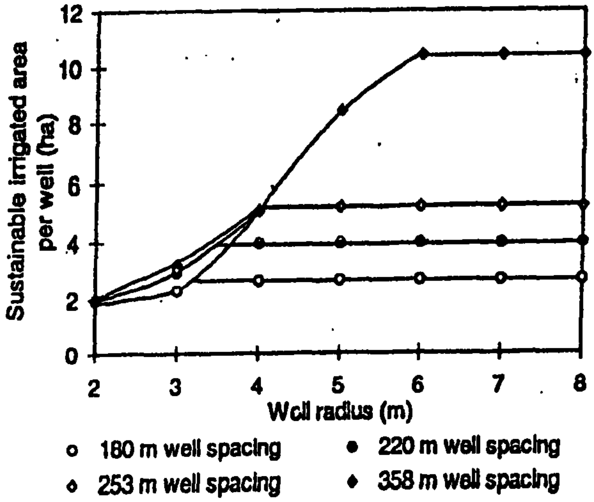



Figure 3. Effect of well spacing on (a) sustainable irrigated land area per well and (b) percentage sustainable irrigated land area for a well of 3 m radius and 6 m depth.




(b)

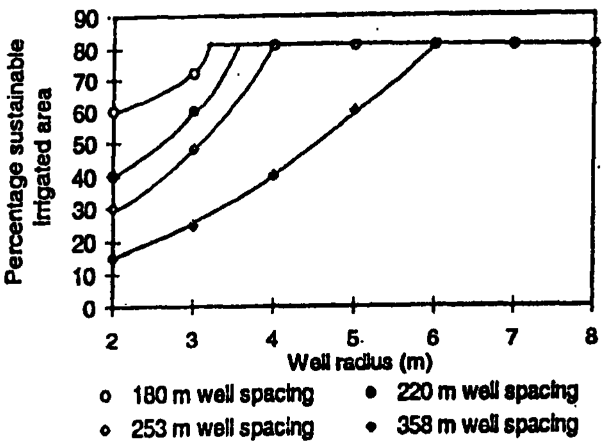



**Figure 4.** **Effect of well radius and well spacing on (a) sustainable irrigated land area per well and (b) percentage sustainable irrigated land area with the aquifer depth of 6 m.**

situation where the abstraction exceeds the recharge limit is not sustainable as this will lead to over-exploitation of the groundwater resources and interference with the neighbouring wells.

Subsequently the effect of well spacing alone was examined. In this analysis well radius and aquifer depth were held constant as 3 m and 6 m, respectively. The spacing between two nearby wells considered were 180 m, 220 m, 253 m and 358 m. The sustainable irrigated land area per well increases with increased well spacing as shown in Figure 3a for the typical well of 3 m radius and 6 m depth. Figure 3b shows the percentage of land that can be sustainably irrigated which decreases beyond about 160 m well spacing. At closer spacing it is limited by recharge to 81% sustainable irrigated land area. At larger spacings the sustainable irrigated land area is limited by the ability of the well to draw water from distant parts of the aquifer, which is underutilisation of available groundwater resources.

Figure 4 shows the combined effect of both well radii and well spacing again for the aquifer depth of 6 m.

The optimum radius (defining optimum radius here as minimum radius which achieves the maximum sustainable irrigated land area) for various spacings can be seen from the Figure 4. For example, for the well spacing of 180 m, the optimum well radius is 3.15 m; as shown previously. A larger radius will not increase the sustainable irrigated land area per well or the percentage sustainable irrigated land area. When the well spacing is reduced to 90 m (not shown), the percentage sustainable irrigated land area is 81% for all radii. Aquifer depths of 7 m and 8 m also showed the similar results.

The effect of well construction cost on increased well radius was also analysed as the well construction cost is the major and important investment in the farm budget. Crop production cost and profits were not analysed at this stage as there were not enough data. The well construction cost analysis indicated that the optimum well radius is the cheapest per sustainable irrigated land area. The effects of varying cropping patterns, pumping schedule consisting different pumping rates and intervals were also investigated using the radial flow model and interesting results were obtained (De Silva, 1995).

## CONCLUSION

Study results confirmed that the optimum well dimensions are essential for sustainable irrigation using agrowells. This methodology could be adapted to achieve sustainability in new agrowell system by finding optimum well dimensions, or in an existing agrowell system by finding the sustainable irrigated land area. The results obtained in this study on well dimensions including the well spacing and sustainable irrigated land area under each well could be used as regulations or legislations in National Agrowell Programme in Sri Lanka.

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