Mapping of hydrodynamic changes around radial arms of collector well by streaming potential survey

Groundwater plays an important role in agricultural stability in deltaic regions as during successive monsoon failure seasons, agriculture activities are forced to depend more on groundwater in these regions. This leads to over-exploitation and endangering the limited and volatile freshwater regimes by saline incursion. The shallow aquifer is tapped through manually dug-out conical pits, locally called 'doruvus' or 'ooranis'. However, with ever increasing demand for water sources and advancement of technology, the exploitation of shallow aquifer through tube wells and infiltration gallery, necessitated the study on flow regime. Instead of developing a number of observation wells for monitoring the hydrodynamic changes, which is an expensive proposition, application of geophysical methods in studying the transient changes occurring due to pumping was attempted for suggesting measures for improving the harnessing potential of collector well with radial arms without endangering the hydrodynamic conditions of fragile freshwater regime in saline coastal tract.

Radial collector or skimming well is essentially an open shallow well with radial drains, which captures groundwater from the shallow aquifer and makes harvested water flow into the well. In other words, the effective radius of the well increases manyfold. Generally, skimming wells are of shallow depth of around 3–4 m, tapping the freshwater-bearing aquifers near the coast. The placement of radial arms with a slope of 2–3% at a particular depth is essentially controlled by the water table fluctuation, coarse sand-occurring horizon and economic feasible depth. The radial arms are made of either baked slotted mud-pipes or slotted PVC pipes. Adequate care is taken to prevent entry of sand through slots by winding a nylon mesh over the pipe. Skimming wells are preferably placed near the source of recharge like canal, stream/river, sandy area, etc.

The transient changes that are induced in the vicinity of radial arms due to withdrawal of water from the collector well, can be mapped by having a number of observation wells or piezometers of various depths in the entire area of influence of collector arms; however, this is expensive. An economically viable approach is the measurement of natural fields by means of a geophysical technique called self potential (SP) method. This is considered to be more suitable, as it reflects the potential field changes due to flow of water in the interstices. For effectively monitoring the transient changes in hydrodynamic conditions, the SP fields are to be measured at regular intervals of time covering the total/part of radial arm length and adjoining areas during pumping and recuperation of skimming well.

As water fluxes are highly variable in space and time, the classical hydraulic method requires numerous and repetitive measurements. Inducement of electrical fields due to water movement through a porous medium and its study were known since a long time[1]. The natural electrical field induced is called SP, which is developed due to movement of ions between different concentrated solutions (diffusion potential), clay acting as a membrane for anions (membrane potential) and movement of electrolyte in porous media (electrokinetic potential). SP anomalies are predominantly due to the electrokinetic potential gradient that exists in the aquifer. Contributions from the other two are insignificant under natural field conditions[2,3]. A quantitative relationship between circulating water and electrical potential difference was established when saturated samples were subjected to high pressure[4]. A linear relationship between water flux and electrical field was established through field experiments by measuring the electrical potential difference between the electrodes placed at depths of 0.3 and 0.5 m and at distance of 0.2 m between them in soil resting over glacial deposits[5]. Application of this potential tool for various objectives has been evidenced through studies over active volcanic and tectonic regions, leakage studies in dams and lakes and earthquake studies[6–11]. We have studied the SP behaviour while the aquifer is excited through pumping and also the resultant inducement of flow around groundwater capture lines.

The skimming well in paddy fields of A.N. Ranga Agricultural University campus at Bapatla, Andhra Pradesh was selected for the present study, as it has been developed during 1997 with mud pipes and groundwater capturing is through pipe joints[12]. It has been reported that coconut fibres have been used to prevent sand entering into the radial arms at the time of installation. Two radial arms, each of 35 m length, have been placed along N–S on either side of the well cutting across the general groundwater flow direction of W–E. The depth to the inlet point of the radial arm is 2.88 m below the parapet wall of the well. The water level was at 2.23 m below the measuring point, while the total depth of the well was 3.5 m from the point of measurement. The arm on the northern side was considered for conducting the SP survey for mapping the changes occurring in the aquifer zone nearer to the radial arm due to pumping and excitation of the aquifer. The experiment design is shown schematically in Figure 1.

For conducting the experiment, a profile length of 10 m across the radial arm at the centre, with station interval of 1 m was made at every 5 m from the collector well. We could start and lay the profiles only at 10 m distance from the collector well till 35 m (total length of radial arm), as the ground conditions were not favourable near the well. Three methods of conducting the SP survey are: point potential (PP), where one of the potential electrodes is kept at infinite distance from the survey area and the other is moved along a profile line laid with pre-determined station interval; potential gradient (PG), where measurements are made by observing the voltage between two potential electrodes positioned on the ground with a separation of a chosen interval and observation is made by moving simultaneously both the electrodes along a profile line with same interval of spacing and in the same direction, and potential drop (PD), where measurement of potential is made between two potential electrodes of which one is fixed at the starting point of the profile line and the other moves away from the fixed electrode at regular distance in the same profile line and the drop in potential with respect to the fixed electrode is measured. The PG technique was adopted for the field experiment at the first instance. Two non-polarized electrodes (NP) with copper rod as sensors placed in copper sulphate solution in a porous cup and a high impedance multimeter for measuring the voltage, were used for the survey.

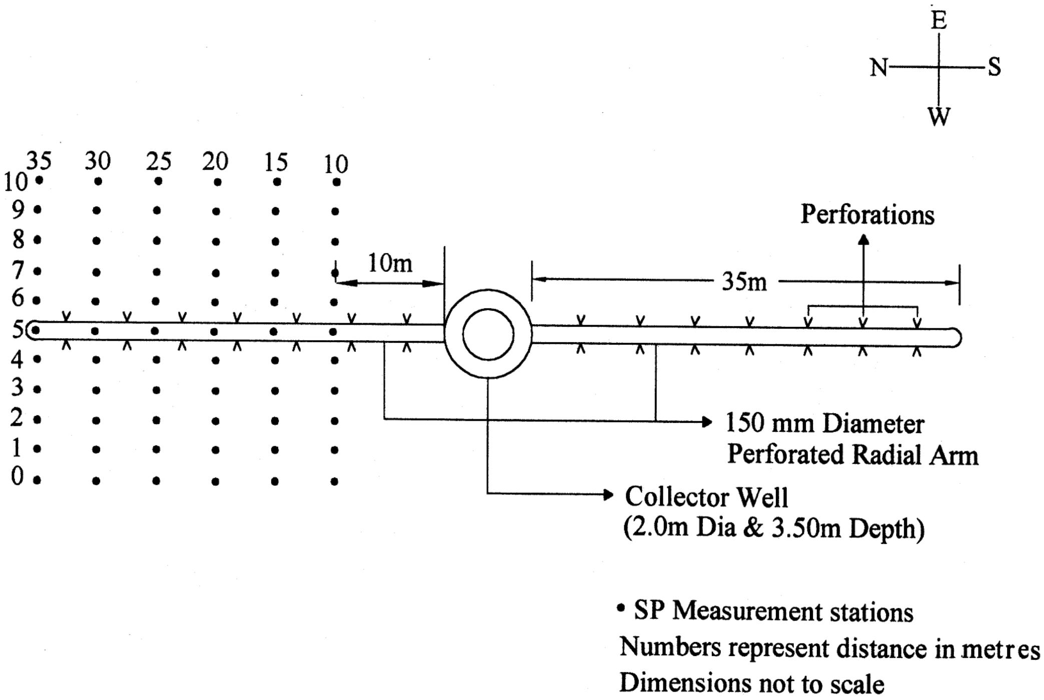

Figure 1. Bapatla two-arms collector well (near paddy field).

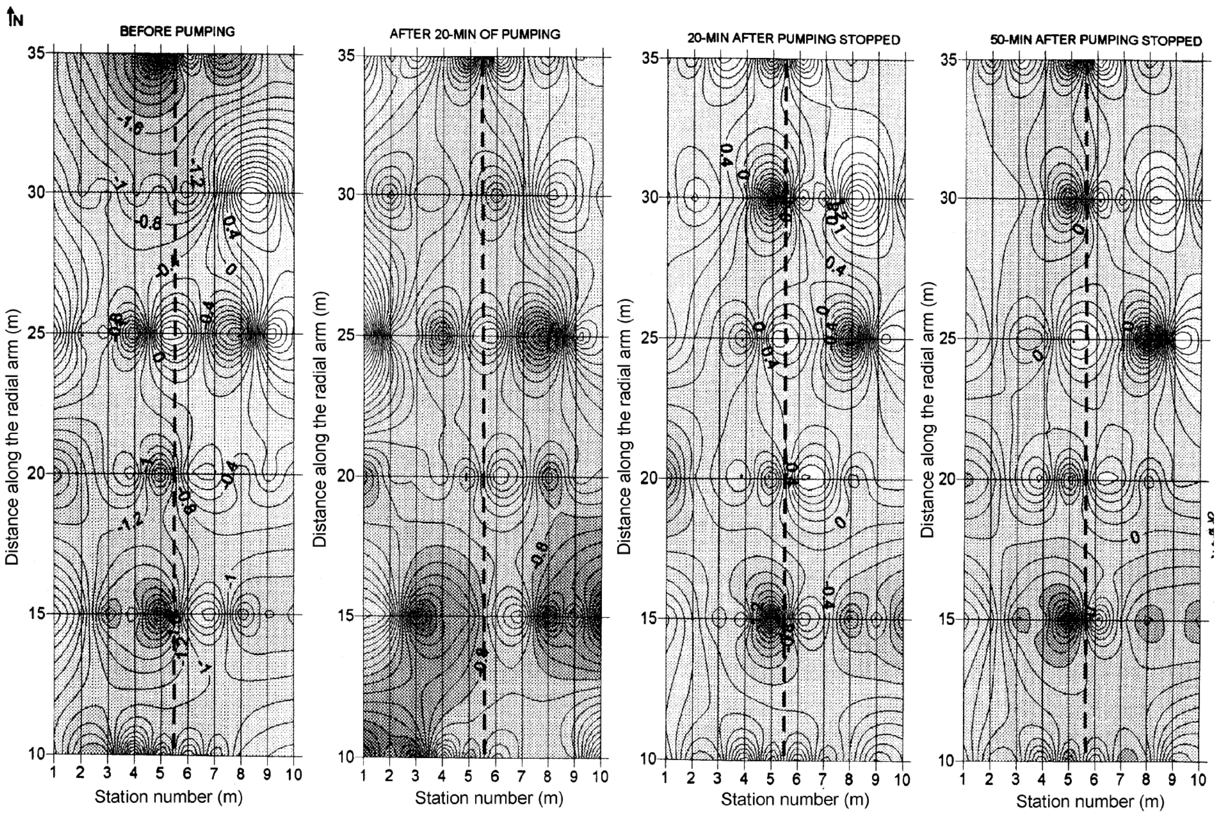

Figure 2. Contour map representing potential difference at different stages of the experiment. - - - - , Buried radial arm alignment.

Potential difference between stations along each profile at various stages of pumping and at recovery stages was measured. The observed potential difference at different stages of the experiment was plotted as contours (Figure 2). Four sets of measurements were taken during the experiment. The first one was taken before the pumping of the collector well and is expected

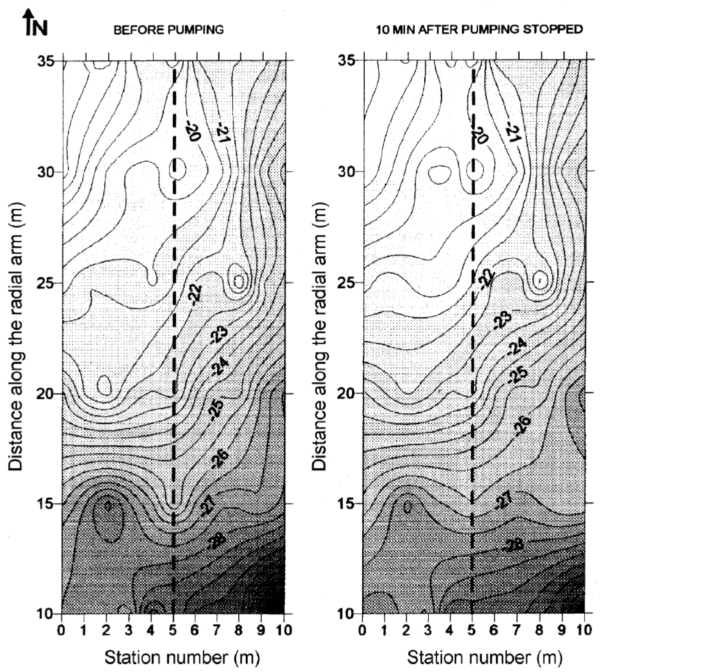

Figure 3. Contour map prepared on the basis of data collected before and during recovery period of the well. - - - - , Buried radial arm alignment.

to represent the static condition of the aquifer around the radial arm. The second set of measurements was taken at the 20th minute of pumping stage, when the water level in the collector well went below the radial arm and is expected to represent the full active mode of the radial arm. The third set of measurements was taken 20 min after stopping the working of the pump to map the signal at the time of recuperation of the well. The final set of measurements was taken at the 50th minute of the recuperation process, when the water level had nearly reached the initial water level.

The signals of potential difference are low since the topsoil is clayey in nature and also the measurement represents only difference in potential between the two electrodes placed at 1 m apart. However, adequate care was taken by observing two to three measurements at each station to ensure better accuracy. The potential difference varied from + 2.7 to – 4.2 mV. The contour map before pumping showed distinct anomaly clusters in areas adjoining the radial arm beyond 30 m and below 20 m from the collector well. Probably these parts of the aquifer are made up of coarse/medium sand sediments with high saturation. Anomaly below the 20 m profile line shows a lenticular shape, extending southwards. The PG contour map at the stage of 20 min of pumping shows clear evidence of flow inducement around the radial arm and the area up to 20 m from the well shows significant anomaly. At the time of PG measurements, the water level (2.95 m) in the collector well was below the collector arm depth (2.88 m), harnessing maximum flow through the radial arm. The significant changes in contour pattern all along the radial arm show groundwater flow from north to south, indicating the entry of water into the radial arm facilitated by the mud pipe joints (collar) aligned towards north. The influence width from the contour is inferred to be about 4 m on either side of the pipe.

Since the PG survey is indicative of shallow features (depending on the distance between electrode – station), an attempt was made using the PP method for better understanding and to reassess the inferences drawn. The PP survey was conducted with plugging of radial arms to evaluate the general aquifer condition during pumping and recuperation processes. As we were unable to plug for longer time, the pumping operation was designed for shorter time intervals. Before the beginning of the pumping operation, PP measurement was made at all the nodal points. As soon as the water level reached a depth of 3.09 m in 10 min of pumping, i.e. going below the radial arm inlet, pumping was stopped and the well was allowed to recuperate. PP survey was again conducted at the 10th minute after stopping the working of the pump. The contour map prepared on the basis of data collected before and during the well recovery period is shown in Figure 3. As in both the cases, the radial arms have been made non-active, and the SP signatures in both experiments were almost similar, indicating sensitivity of the SP method. However, the anomaly is strong in areas less than 20 m distance, indicating the potential aquifer zone. To verify the inference, we have extended the static pumping water level towards north correcting to the ground elevation and found that the extended water table probably cuts the radial arm at about 18–20 m distance and goes below the radial arm. It is expected that when the water level goes down during continuous pumping, it will lower much more in areas beyond 18–20 m. This means that at the prevailing condition (pre-monsoon), the entire length of the radial arm is not effective to capture the fresh groundwater. However, groundwater movement takes place towards the well, and is captured by the active part of the radial arm.

The pilot scale experiment demonstrated the utility of streaming potential in mapping the induced changes due to groundwater flow near the radial arms and demarcating the effective part of the radial arms in capturing groundwater from regions beyond the area of influence of the well. The survey has also brought out the following salient features: (i) Entire length of the radial arm is not in active position for capturing groundwater at the time of survey (pre-monsoon). (ii) Active part of the radial arm in capturing groundwater can be easily detected using streaming potential geophysical tools. (iii) Strength of the potential field may be a parameter/indicator for knowing the permeable strata and may help in selection of skimming well sites. (iv) Design of the radial arm, especially the diameter could be deciphered through SP survey prior to the development of the skimming well. In the present case, a telescopic arrangement of larger diameter slotted pipe near the well and reducing the diameter further away would have benefitted more in harnessing the groundwater than having a uniform diameter throughout.

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