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TECHNICAL ARTICLE

Delineation of Recharge Area and Artificial Recharge Studies in the Neyveli Hydrogeological Basin

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Abstract In Neyveli, Tamilnadu, India, a deep-seated multi-layered confined aquifer is being continuously pumped to permit safe mining of lignite. This paper highlights the various ground water recharge studies undertaken to quantify the potential of recharging the Neyveli hydrogeological basin to maintain the regional ground water balance. GIS studies were used to analyze artificial recharge in the Neyveli basin, commencing from the deep water table zone (recharge area) in the western upland part, the confined aquifer zone closer to the active mining area, and the confined zone further away in the east, down-dip and closer to the coast.

Keywords Artificial recharge · Confined aquifer · Dewatering · Lignite mining · Neyveli hydrogeological basin · Recharge area

Introduction

The lignite resources of the state of Tamilnadu in India accounts for more than 80% of India's known lignite reserves of 39 billion tonnes (*t*) (as of 1st April, 2009). The Geological Survey of India (GSI) conducted exploratory drilling across the entire hydrogeological basin to study the structure of the lignite deposits and its ground water aspects (Subramaniam 1969). Based on the test results, the GSI opined that lignite mining in this area would certainly be influenced by the artesian pressure in the confined aquifer beneath the lignite, but that this pressure could be controlled by dewatering. Between May 1955 and June 1956, a detailed investigation of the geology and hydraulic characteristics of the aquifers underlying the deposit was undertaken by the southern wing of the GSI and, based on the results, a comprehensive proposal for ground water control for opencast mining was sanctioned and implemented by the Government of India. Accordingly, a lignite mining company, The Neyveli Lignite Corporation (NLC) was formed on 14th November 1956. Since then, NLC has continued the exploration and exploitation of lignite and has played a key role in regional developmental activities. As a result of concerted efforts by NLC, the GSI, and Mineral Exploration Corporation Ltd (MECL), approximately 4,150 million t of lignite reserves have been identified and confirmed in a 480 km^2 area of the Neyveli basin.

The Neyveli Basin

The Neyveli hydrogeological basin is traversed with multiple aquifers and covers an area of about 3,500 km^2. It is bounded by the Ponnaiyar River in the north, the Coleroon River in the south, and the Bay of Bengal in the East; Cretaceous formations cover the Western boundary. There are three identifiable aquifers in the basin: the water table aquifer, a semi-confined aquifer above the lignite seam, and a deep confined aquifer below the lignite seam. The confined aquifer is further classified i.e. an upper confined aquifer and a lower confined aquifer, which are separated by a clay horizon of varying thickness. The basin configuration is depicted in Fig. 2 in Anandan et al. (2009) in this issue.

In the western part of the basin, large areas of Tertiary rocks are exposed; these are the main recharge conduits to the Neyveli basin, particularly the deep aquifers. The GSI first systematically studied this recharge area during the

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1950s. The recharge area extends from the Vellar River (near Virudhachalam) to the Gadilam River (near Panruti) in a southwest to northeast direction (541.8 km^2) (Fig. 1).

The recharge area of the Neyveli ground water basin extends up to Cuddalore in the east and beneath the alluvium of Ponnaiyar and Pondicherry in the northeast. Physiographically, most of the region is above mean sea level. The flat topography in the area slopes gently to the south, southeast, and east. Much of this flat country is covered by thick sandy soils, supporting thin scrub vegetation. In this area and the wasteland area that exists to the west, northwest, and north of the recharge area, are exposed sandstones that are hydraulically connected with the confined aquifers in the lignite field. The soils there have a high infiltration capacity, and precipitation that lands on the flat ground sinks down rapidly, though there is ample evidence of swift sheet flow associated with storm events. The amount of precipitation over this recharge area at Neyveli has been computed and it was initially estimated that 15% of the rainfall infiltrates into the system (GSI 1969).

Demarcation of the Recharge Area by Different Agencies (1960–2006)

The recharge area was studied in detail by various agencies to demarcate its extent and refine the computed rate of infiltration:

(1) NLC's early studies
(2) Tritium tagging method by NLC and National Geophysical Research Institute (NGRI), Hyderabad
(3) Radioisotope study by NLC and NGRI
(4) GIS based estimates

NLC's early studies (1960–67) indicated that the recharge to the Neyveli ground water basin was from:

(a) Infiltration in the intake area during rainy months when conditions are favorable;
(b) Influent seepage in certain areas from the Vellar, Manimuktha Nadhi, and Gadilam Rivers during high water episodes;

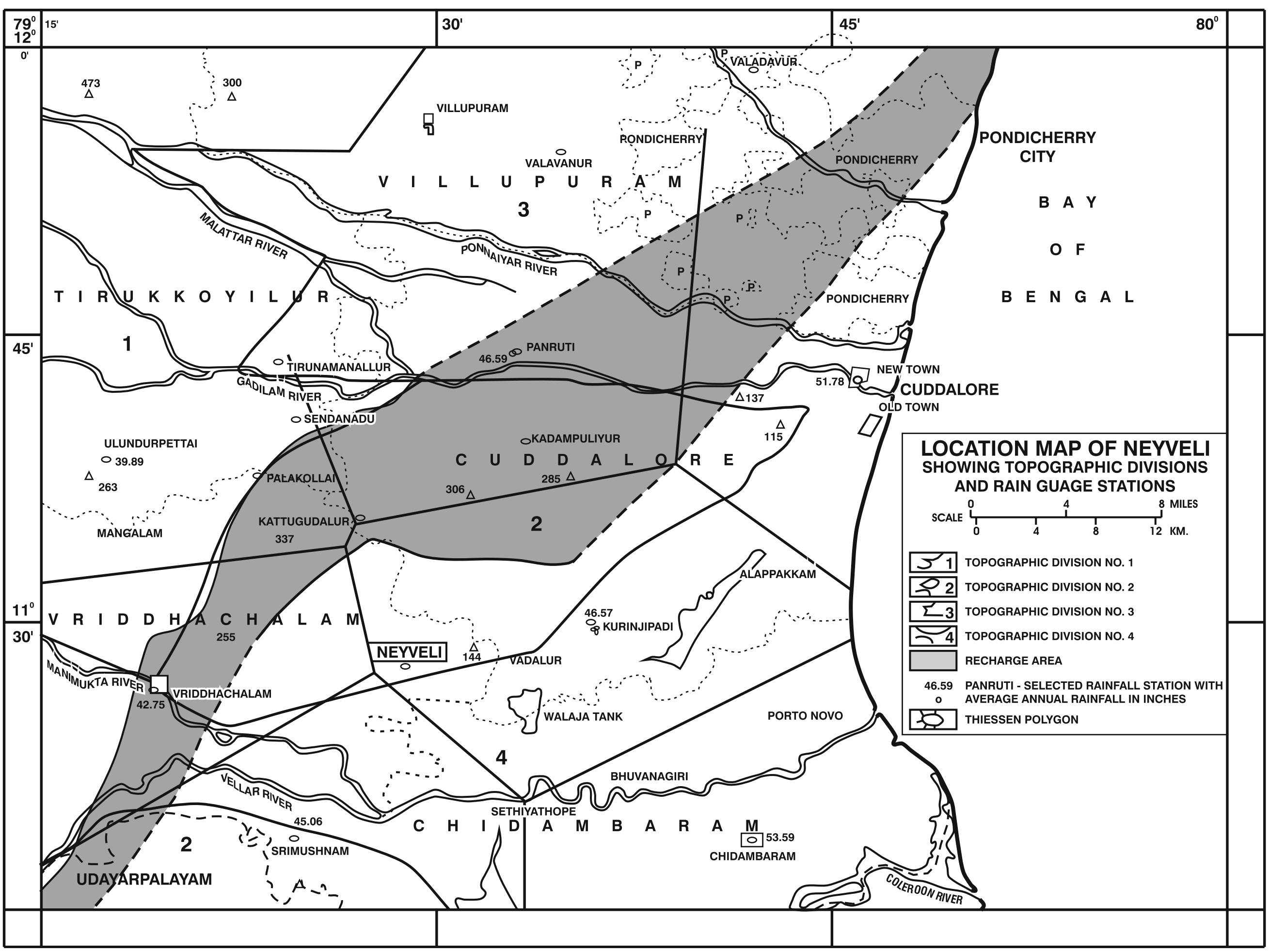

Fig. 1 Recharge area of Neyveli identified by the Geological Survey of India; [Source: Geological Survey of India (GSI) 1969]

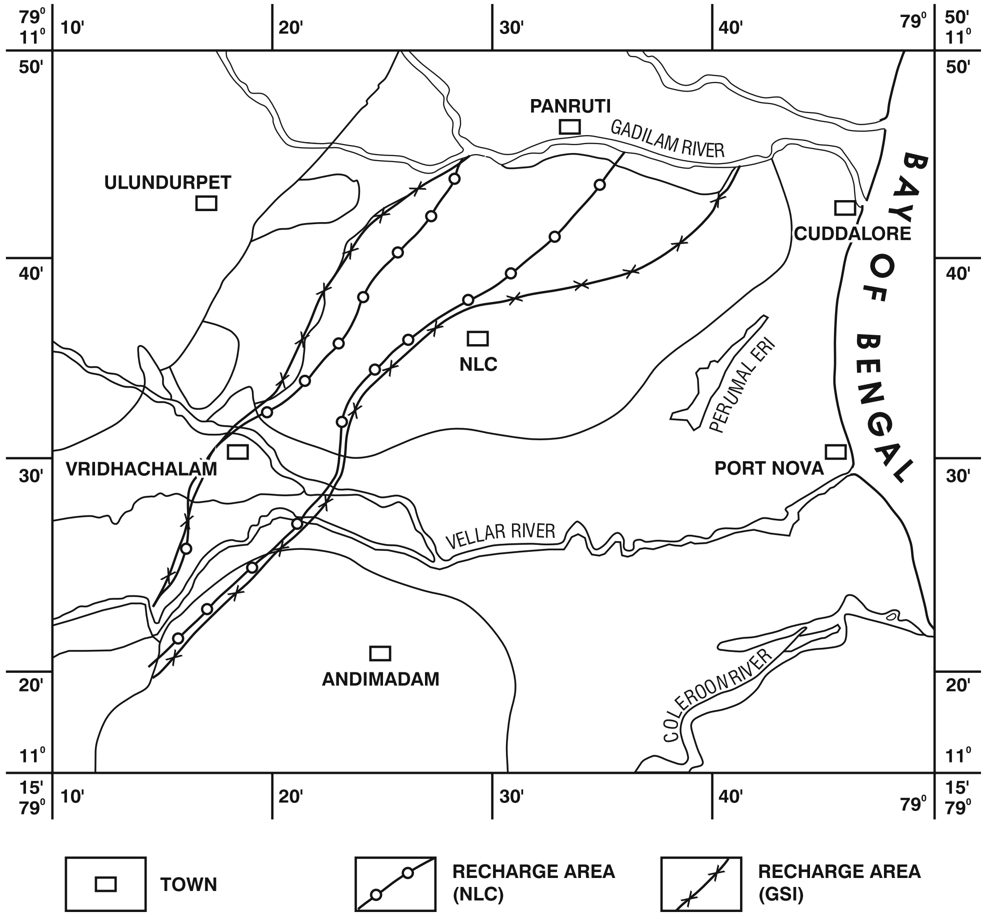

Fig. 2 Recharge area demarcated by Neyveli Lignite Corporation (NLC)

(c) Infiltration of run-off water during and immediately after rains;
(d) Infiltration from tanks and from stagnant water in and near the intake area; and
(e) Slow downward movement of unconfined water through the confining beds in areas where the head is favorable for such movement (Baratan and Subramanian 1967).

The approximate limits of these infiltration areas are shown in Fig. 2.

These studies indicated that the intake area was 350 km^2. The recharge rate appeared to total about 0.94 million m^3/cm of rainfall, of which $\approx$ 19 million m^3/year were found to flow away from the reservoir as underflow, mostly towards the northeast. In addition, $\approx$18 million m^3/year of recharge contributed to the confined zone by downward flow from the unconfined zone above (Subramanian et al. 1970).

Recharge measurements by NLC and NGRI, conducted during 1985–87 using injected tritium as a tracer, led to the following important inferences:

(a) The annual inputs to shallow aquifers of the Tertiary formation bounded between the Gadilam and Vellar rivers were determined by tritium tagging during two monsoons to be 160 and 90 million m^3, respectively. This is approximately equivalent to 13.4 and 16.1% of the causative rainfall of 1,425 and 746 mm, respectively.
(b) This study was conducted for two hydrological years that had above normal and subnormal precipitation, respectively, suggesting that annual recharge strongly depends on the amount of corresponding precipitation (Rangarajan et al. 1989).

A subsequent radioisotope study conducted by NLC and NGRI in 1993 indicated that the recharge area was 420 km^2. Input to the confined aquifer system was calculated based on the recharge area demarcated by the isotopic and hydro-chemical evidences; the recharge rates were estimated by the injected tracer method. Fractional recharge from local rainfall indicated that the average recharge was 15.5%. Based on the average annual rainfall of the study area (1,200 mm), the annual recharge was calculated to be about 111 MCM. It was also concluded from this study that the northwest belt was the principal recharge area. Ground water samples had been rainfall less than 50 years before, the chloride content was very low, and the carbon-13 concentration were low. The movement

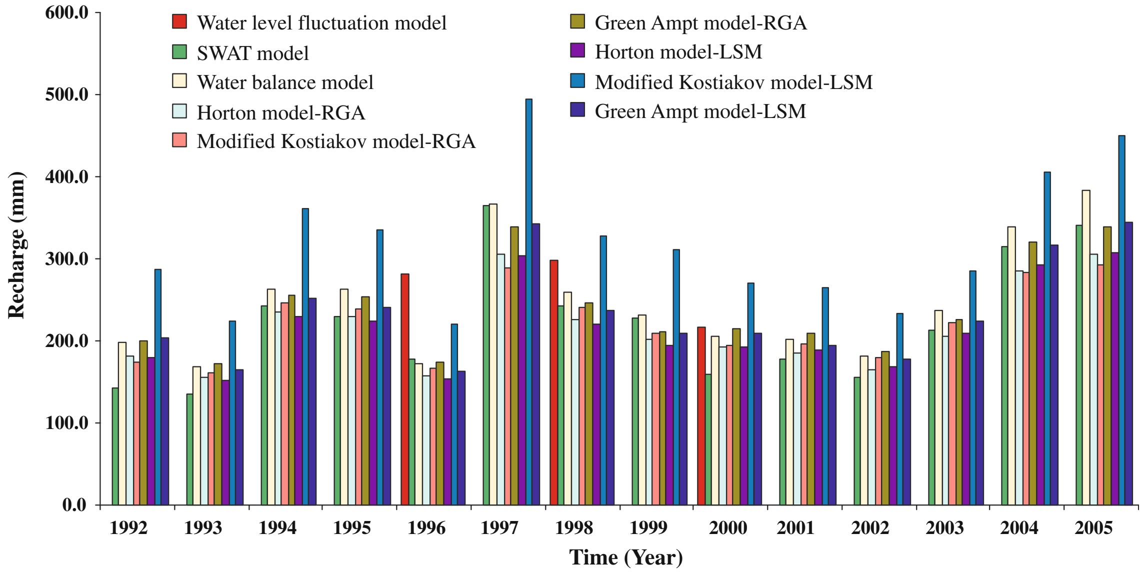

Fig. 3 Comparison of recharge areas estimated by different methods

of ground water from this area is towards the confined aquifers in the southeast (Sukhija 1986, 1993).

Using GIS packages and different modeling techniques (listed below), an extensive comparative evaluation was conducted in 2006 to estimate the recharge area of the aquifer system (Mohan et al. 2006).

- SWAT model (Soil and water assessment tool)
- Infiltration models
  - Green Ampt model
  - Modified Kostiakov model
  - Horton model
- Water level fluctuation model
- Water balance model

The previous study had indicated that the recharge area was 420 km^2, these models provided different values. The recharge area estimates for each are compared in Fig. 3.

Discussion and Analysis

Theoretically, recharge could be either natural or man-made and is greatly influenced by geological features (i.e. rock structures present, stratigraphy, and lithological sequence) and by upward, downward, or lateral movement of water through vertical inter-connections between the different aquifers. After considering the various technical studies and recharge related parameters of the Neyveli basin, the recharge area was demarcated. Based on the stratigraphy, lithology, and the configuration of the top of the water-bearing unit (selecting points where it is nearest to the surface), the area was estimated to be 420 km^2. Given the aerial continuity of the deep aquifer and its thickening down-dip in the region where it is confined below the lignite, the sandstones in the recharge area are able to transmit water laterally and down-dip a great distance with little loss of head. To some extent, major streams like the Vellar and the Gadilam add to the recharge. The recharge quantum assumed to balance the ground water computations was 16.8% of the annual rainfall.

It was observed that the ground water flow regime in the Neyveli hydrogeological basin is influenced by ground water withdrawals from the wells in the lignite mine area and from a number of pumping wells established by different agencies for various purposes such as irrigation, drinking water, and industry. Proper management of the ground water system was felt to be essential to maintain a proper hydrological balance between the water discharged and recharged into the aquifer. At present, ground water extraction tends to exceed the average recharge, causing a decline in water levels in the region. Balancing the water discharged and recharged requires optimizing the effectiveness of the pumping, minimizing the amount of pumping, and increasing the rate of recharge. Additional efforts could be made to achieve water balance using artificial recharge and by allowing a slight positive pressure along the lignite deep cuts in the mines. NLC has adopted all of these techniques to reduce ground water extraction.

Recharging the Neyveli Basin: Artificial Methods Attempted by the NLC

Induced Artificial Recharge

Ground water modeling carried out by NLC suggested that artificial recharge could be achieved using injection wells at different locations around the lignite-bearing area. Since not many proven techniques are available for recharging a deep-seated confined aquifer, NLC undertook an experiment to inject against an upward pressure of 500–800 kN/m^2. In accordance with the results of the model studies, NLC first induced artificial recharge by injection wells north of the lignite boundary (5 km north of Mine I.). Site selection and injection well design mainly depended on the configuration of the aquifer, the results of a hydrological evaluation, and the location of the excess water source. To evaluate the parameters, periodic pump tests were carried out and the recharge was quantitatively estimated (Fig. 4).

Pump tests were conducted to evaluate various aquifer parameters such as transmissivity, the storage coefficient, and leakage. The aquifer parameters were estimated based on the water levels in the observation and pumping wells with respect to pumping time, drawdown, and distances. Two different flow conditions, viz. steady state and unsteady state, were assumed for the numerical model. A natural flow rate of 2.6 m/day flow was determined in the Neyveli aquifer for a pumping rate of 535 l/min. The front of the injected water body is moving outward from the injection well in the direction of natural flow over time. From the analytical model study, the water front flowed 13 m in one day (Fig. 5).

The long duration induced artificial recharge tests conducted in Neyveli (5 km north of Mine I) indicated that artificial recharge of ground water in the confined aquifer is a viable and effective means of maintaining the balance in the aquifer. It was found that 535 l/min could be recharged

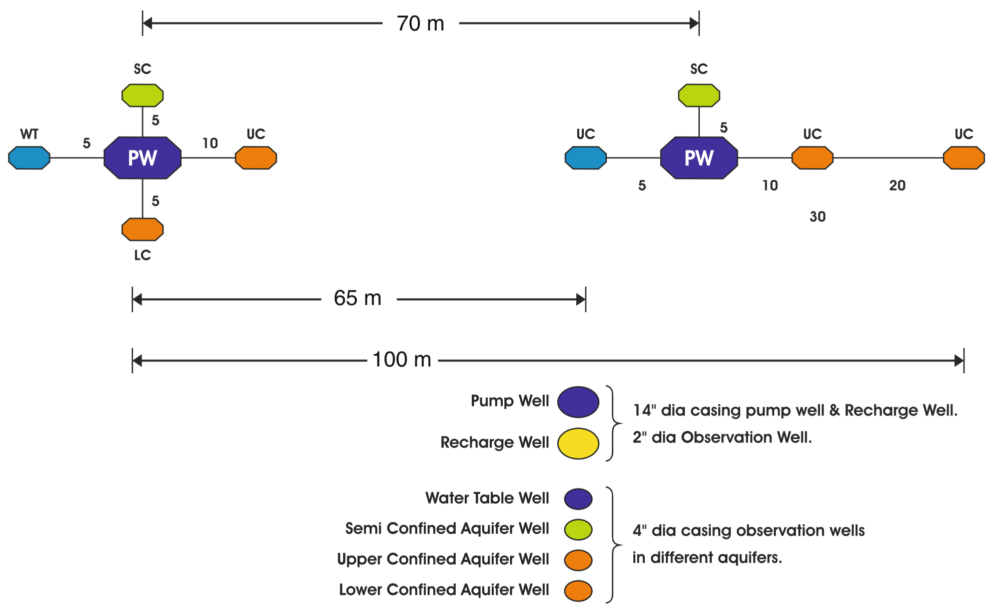

Fig. 4 Site plan showing wells for the induced artificial recharge tests

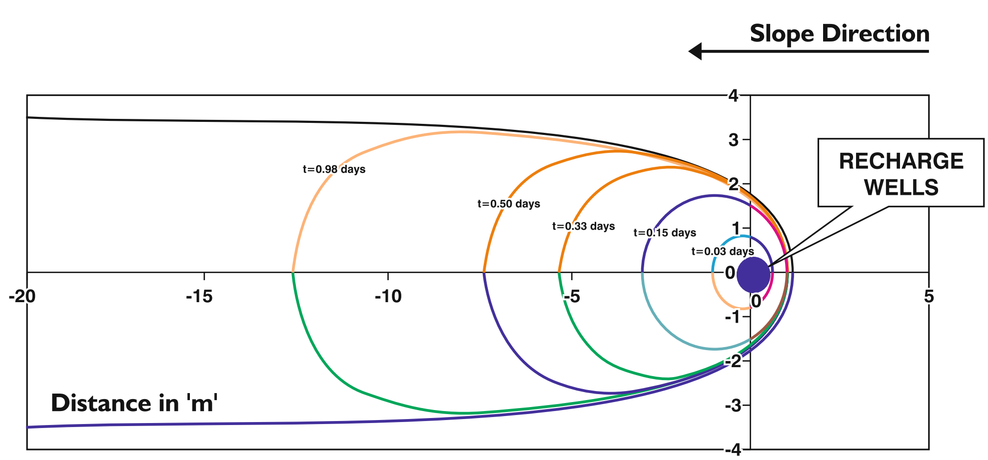

Fig. 5 Movement of the injected water front

through the injection well technique without any problem for a period for 72 hrs. Almost 75% of the injected water was recharged into the aquifer. The numerical model predicted that the recharge water would reach the pumping well after 3.13 days (Mohan et al. 2006). The water quality was not affected by the continuous artificial recharge and it was determined that the confined aquifer could be used for recharge without any preliminary treatment. However, to avoid clogging, certain preventive measures were taken, such as re-pumping the recharge well, letting out the initially pumped water, and redevelopment of the recharge wells.

As an outcome of this study, it was felt that artificial recharge also had to be tried beyond the area of active mine pumping towards the coast in the down-dip direction of the basin, where the hydrostatic pressure would be much higher. In 2005, the NLC carried out artificial recharge studies with technical assistance from RE-Germany and the Indian Institute of Technology (IIT)-Madras. This experiment was carried out about 20 km away from the zone of influence of the mine pumping, where the aquifers are 200 to 250 m below the ground surface. A numerical infiltration model for the proposed area was developed and sites have been identified as per the results.

In the proposed test field, two injection wells are planned, 100–150 m apart, supported by an array of 5 observation wells along the natural flow direction of the ground water. Surplus surface water available in a nearby lake is proposed to be injected, after suitable precautions are taken. This experiment is the first of its type in India, and the results could be useful for other studies where similar hydrogeological and geo-environmental conditions exist. Successful implementation of this experimental study would also allow NLC to better maintain the ground water balance in the region besides checking for potential seawater intrusion.

Artificial Recharge Through Gravity

NLC undertook a scientific study on enhancement of recharge potential in the recharge area of the Neyveli deep seated aquifers, working with researchers from the IIT-Madras (Mohan et al. 2006). This study was able to develop a hydrological model using GIS and remote sensing data to carry out micro-level assessments, monitoring, and quantification of recharge in the Neyveli Basin. In addition, infiltration experiments were carried out at 57 locations in the defined recharge area for Neyveli basin and two sites, the villages of Nadiyapattu and Maligampattu, were identified for artificial recharge using the gravity recharge method (Figs. 6 and 7). Figures 8, 9, 10 illustrate the types of recharge structures that were found to be relevant for the studied region and accordingly constructed.

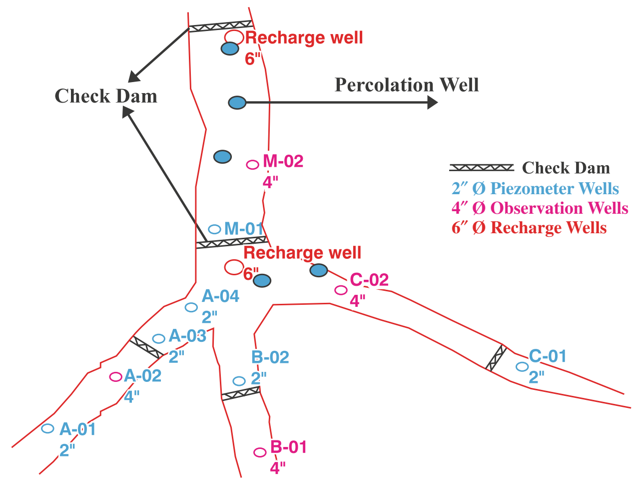

Fig. 6 Layout of recharge structures in Maligampattu Odai

Design and Construction of Recharge Structures

Check Dams

A suitable site for check dams was identified based on the geological and geomorphologic conditions, and check dams were constructed (Fig. 8). Three observation wells were also established at each site and the effect of the check dams were studied by observing the water levels in these wells for four seasons.

Percolation Pond with Percolation Wells

(Percolation ponds were constructed with percolation bore wells inside the area shown in Fig. 9. The bore wells in the pond were filled with gravel and coarse sand to enable the recharge to take place faster. A percolation well is very similar to a soak pit with its top covered and the bottom opening into permeable strata that contains little or no water. The water coming into the well will dissipate into the permeable formation (aquifer) through percolation/infiltration from the large surface area of the aquifer that the well intercepts.

Recharge Wells

A recharge well is a well that admits water from the surface to the underground formation or aquifer. Recharge wells are suitable only in areas where a thick impervious layer exists between the surface of the soil and the aquifer to be replenished. A relatively high rate of recharge can be attained by this method. Observation wells were constructed and the effects of recharge wells were studied by observing the water levels in these wells over a period of time (Fig. 10).

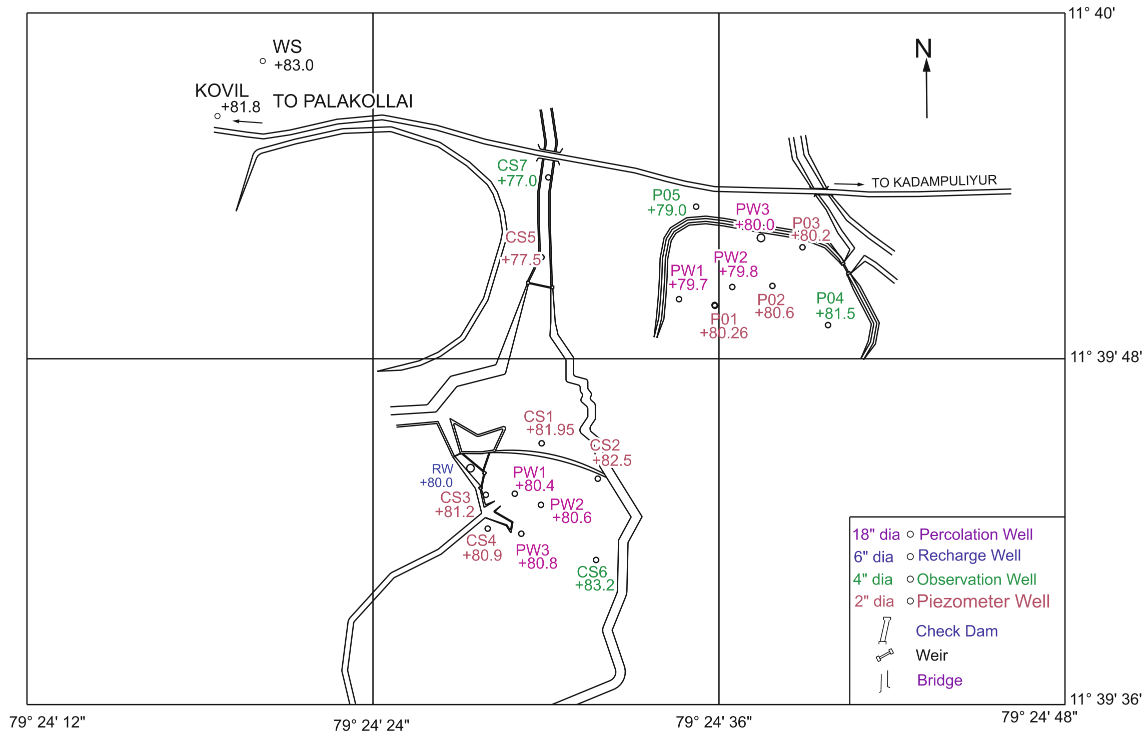

Fig. 7 Layout of recharge structures in Nadiyapattu Odai

Fig. 8 Check dam at Nadiyapattu Nadu Odai

Different sensitivity analysis model studies were attempted to assess the effectiveness of the recharge structures. From this analysis, it was found that:

- The maximum available water content and rooting depth are major influencing factors for natural recharge of Neyveli aquifer.
- Among the different artificial recharge structures studied, percolation ponds with recharge wells were found to be more effective in recharging surface water into the aquifer than other structures.
- Water quality in the aquifer has been improved due to artificial recharge.
- The observed and predicted (simulations) heads match well. An average increase in water level of 2 to 3 m has been noticed after artificial recharge in most of the places in Nadiyapattu.
- The optimum values of hydraulic conductivity for different locations in the Nadiyapattu study area range from 1.95 to 17.65 m/day.
- Water levels were projected for a period of 5 years from 2006 and the water level pattern varied little.

Fig. 9 Percolation wells in a pond along with observation wells in Nadiyapattu

Fig. 10 Recharge wells in pond along with observation wells

- The influence area of the percolation pond with percolation wells recharges (500 m parabolically, towards the dip of the aquifer) has a radial influence area of 125 m.
- The recharge (basin scale) study showed that, on average, 80–90% of the change in volume in the percolation pond was due to aquifer recharge rather than evaporation loss. This shows that the structure is efficiently recharging the aquifer.

Conclusions

From the studies carried out, it can be concluded that artificial recharge is a viable solution for sustainable development of water resources of Neyveli area and in particular for both shallow and deep confined aquifers. At the same time, proper planning and optimum resource utilization and management of the available ground water resources are of paramount importance to conserve it for the future.

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