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RESEARCH ARTICLE

Role of Remote sensing and GIS in Finding Suitable Artificial Recharge Zones in and around Neyveli Basin, Cuddalore District, Tamil Nadu, India

R. Kamaraj[1]*, N. Gunalan[2], M. Krishnan[3] and R.R. Krishnamurthy[4]
[1,3]Chief Manager/Geology; [2]Additional Chief Manager/Geology, Neyveli Lignite Corporation Ltd., Neyveli;
[4]Assoc. Prof., Dept. of Applied geology, School of Earth Science, University of Madras, Chennai
kamaraj_r@nclindia.com*, gunalan.n@nclindia.com, Krishnan.m@nlcindia.com, r.r.krishnamurthy@gmail.com; +91 9443988546*

Abstract

An attempt has been made to identify the favorable zone and locations for artificial recharge structures from weighted overlay analysis using spatial analyst tool in Arc GIS application. The input data for this analysis are different layers like geology, geomorphology, soil, rainfall, land use-land cover layer and drainage order. Overlay analysis in ‘spatial analyst’ is a group of methodologies applied in optimal site selection or suitability modeling. It is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. The factors in this analysis may not be equally important, even within a single raster; the values are to be prioritized. In this analysis, it is desirable to establish the relationship of all the input factors together to identify the desirable locations for the recharge structures. The excellent and very good zones for potential artificial recharge structures are falling in the northwest of the study area. The existing artificial structures are also falling in the excellent and very good zones. Additional recharge structures are also proposed based on the resultant map, water table contour map of dug wells present in the study area and drainage map.

Keywords: Artificial recharge structures, spatial analyst, GIS application, water table contour map.

Introduction

Groundwater is the basic element of social and economic infrastructure and is essential for healthy society and sustainable development. Due to rapid increase in density of population, fast urbanization, industrialization and agriculture use, the demand of water is increasing day by day. The aquifer replenishment through artificial recharge is necessary to sustain the area groundwater resources on a long-term basis. Process-based techniques, like numerical modeling of groundwater systems (flow and/or transport) demand lots of spatio-temporal field data, which are unfortunately not readily available for the study area or will require lot of time and efforts to collect it. In view of this, a simple approach of overlay analysis in GIS has been proposed using parameters affecting groundwater in this study.

Materials and methods

Study area: The study area extends from $11^0$20’N to $11^0$46’N latitudes and $79^0$12’E to $79^0$46’E longitudes (Fig. 1). The area falls in the Survey of India Toposheets 58, M7 and M10 & 14 and part of Toposheets 58 M10 and 14, M 6, M 7 and M 11 (Fig. 1). The rivers that flow in the study area are the Gadilam in the North, Vellar River in the South. These rivers are not perennial in nature, though flow during summer months are very low. Perumal Eri and Walaja Tank are the three major lakes in the alluvial plains of Vellar River. The eastern side is bounded by Bay of Bengal about 30 km from the lignite mines. The western side is bounded by recharge area for the Neyveli confined aquifers. Most part of the study area is a flat plain, slopping very gently towards the sea on the east. The uplands are only on the north western border, Palakollai with an elevation of <125 m above M.S.L., forming part of “Cuddalore Sand Stones”. The area has a tropical climate with the highest and lowest temperatures recorded in May and January respectively. The precipitation of this study area mainly depends upon north-east monsoon, which is cyclonic in nature and attributed to the development of low pressure in the Bay of Bengal. This area receives an annual rainfall of 1,200 mm.

Fig. 1. Study area.

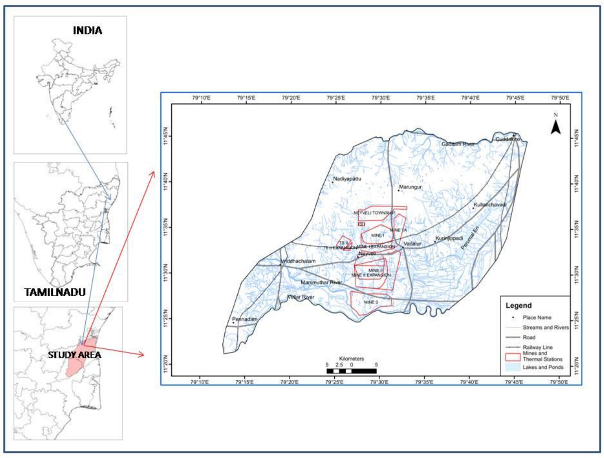
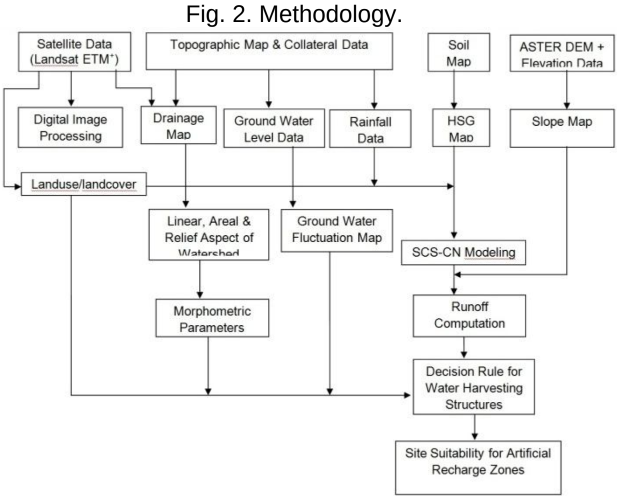


Table 1. Geology.

Era	Period	Stage	Lithology
Cainozoic	Quaternary	Pleistocene to Recent	Alluvial clay & sands, laterite with reddish brown ferruginous clayey soil.
	Tertiary	Cuddalore Formation Mio-Pliocene (Early Neogene)	Mottled, fine to coarse grained yellowish to brownish grey ferruginous sandstone, pebbly sandstone, hard compact claystone, greenish grey clay with bands of limestones.
		Neyveli Formation-Eocene	Sandstone, clay, carbonaceous clay, lignite beds, aquifer sand & clay
		Niniyur Formation-Palaeocene (Palaeogene)	Limestone, calcareous shale/mud, clay and sandstone
Mesozoic	Cretaceous	Ariyalur Group	Argillaceous and micaceous sandstone with bands and lenses of limestone's, clay sandy clay and siltstone with fine grained argillaceous sandstone
Palaeozoic	Lower Permian	Lower Gondwana	Boulder bed, conglomerates, olive green to khaki coloured shale with pink sandstones
Archean		Gneissic Group	Pink migmatite granitoid gneiss

Fig. 2. Methodology.



Methodology: Inputting the spatial database generated from various sources is the first step of GIS analysis. In the present study, the following layers are used to identify the favorable zone for artificial structures namely 1)Geology, 2)Geomorphology, 3)Soil, 4)Land use-Land cover Layer, 5)Drainage oder, 6)Rainfall layer. The drainage and canal layers are generated from Survey of India toposheets at 1:50,000 scale. Subsequently, the drainage and canal layers are updated with the geo coded merged satellite images of Mono chrome CartoSat 1 mt resolution data with LANDSAT 5 mts Resolution LISS IV data. The soil map of the area prepared from the data downloaded from the National Bureau of soil survey and land use planning. The raster map was digitized and made vector for analysis. Further, stream order, as suggested by Strahler (1964), was carried out, as it is very important parameter for undertaking soil and water conservation measures (Pandey *et al.* 2010). The stream order in the watershed is found up to 2nd order. Digital Elevation Model (DEM) derived from ASTER image of 90 mts data is used for the elevation of the study area and to match with drainage pattern of this area. All these layers are digitized and density maps are prepared. The density maps are assigned weightage according to their order of importance to the study.

Again the components of layers are assigned ranks to match with the study area. Using weighted overlay analysis tool in Arc GIS application resultant map on potential zone of artificial recharge is prepared (Fig. 2). Based on the resultant map, the drainage layer and water levels of the dug wells present in the study area are used to identify the additional recharge structures in the study area.

Results and discussion

Weighted overlay analysis: Overlay analysis in spatial analyst is a group of methodologies applied in optimal site selection or suitability modeling. It is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. The factors in this analysis may not be equally important, even within a single raster, the values are to prioritize. In this analysis, it is desirable to establish the relationship of all the input factors together to identify the desirable locations for the recharge structures. The input layers, once weighted appropriately, can be added together in an additive weighted overlay model. In this combination approach, it is assumed that the more favorable the factors, the more desirable the location will be. Thus, the higher the value on the resulting output raster, the more desirable the location will be.

Geology: The basement consists of rocks of Archean age. The Archean is exposed outside the Neyveli region in the west and northwest. The Ariyalur formations comprise calcareous sand stones; siliceous limestone, fossiliferous limestone etc. are found around Patti and Parur villages. Eocene exposures are also seen at few locations in the northeast of Vridhachalam (Table 1). However, in some of the boreholes drilled by the Neyveli Lignite Corporation Ltd. for recharge studies as well as for water supply, these (Eocene) formations were encountered at varying depths. Overlying them and exposed further east are the Tertiary consisting of the Cuddalore formation (Fig. 3). The youngest sediments in the area are various types of soils, kankar, laterites and lateritic gravels and river Alluvium of pleistocene to recent stage.

Fig. 3. Geology.

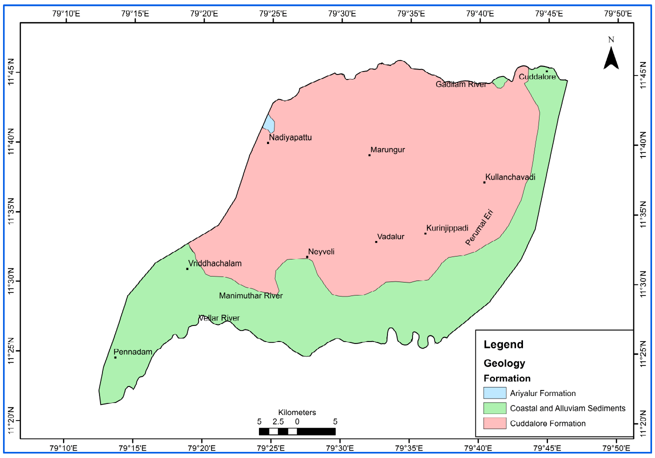


Fig. 4. Geomorphology.

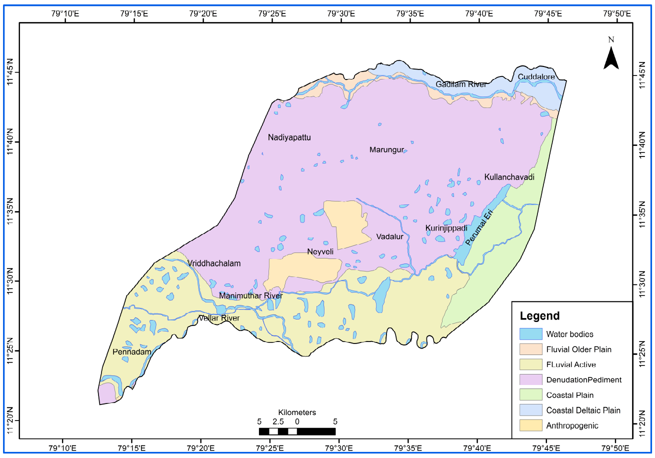
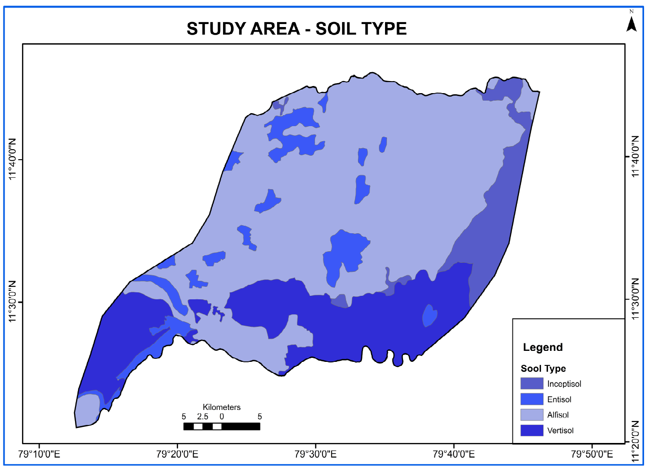


Fig. 5. Soil map of the study area.



The Alluvium of Manimuktha Nadhi and Vellar River are mostly sands and sandy clays. Laterites and lateritic gravels overlie a large part of the study area underlain by the Cuddalore sandstones. The upper 1 m to max. 4 m are developed as topsoil.

Geomorphology: Geomorphology is the science of landforms and it is inter-relative description of relief features of the earth. Landforms develop through the combined influence of exogenous and endogenous process. Geomorphology of study area show gentle slopes towards southeast and east and rivers passes through is Gadilam, Manimukthar and Vellar. The Paravanar River flowing from west to east carries mine water, industrial effluents with natural water and discharge into the Walaja and Perumal Lake east of lignite mines. In the study area, denudation pediment type of land form comprises major portion of the study area. Pediments are bedrock surfaces that are gently sloping, 0.5-7o, though typically 3-4o are smooth and gently dissected, with few stream lines. In longitudinal section, many are slightly concave, though they are often rectilinear and occasionally convex (Fig. 4). Other important geomorphic feature is Fluvial Active which is related to rivers and streams. The flowing water found here is important in shaping the landscape in two ways. First, the power of the water moving across a landscape cuts and erodes its channel. As it does this, the river shapes its landscape by growing in size, meandering across the landscape and sometimes merging with other rivers forming a network of braided rivers.

Soil: Direct surface recharge techniques are among the simplest and most widely applied methods. In this method, water moves from the land surface to the aquifer by means of percolation through the soil. Most of the existing large scale artificial recharge schemes in many areas make use of this technique which typically employs infiltration basins to enhance the natural percolation of water into the sub-surface (Mohamed *et al.,* 1983). The soil map (Fig. 5) of the area prepared from the data was downloaded from the National Bureau of soil survey and land use planning. The raster map was digitized and made vector for analysis. The major soil groups of the study area are as follows. Alfisols soils results from weathering process that leach clay minerals and other constituents out of surface layer and in to the sub-soil where they can hold and supply moisture and nutrients to plants. They formed primarily under forest or mixed vegetative cover and are productive for most crops. This soil is favorable for prospecting artificial recharge structures as they have good permeability. Vertisols are soils of semi arid humid environment that generally exhibit only moderate degree of soil weathering and development. Entisols type occurs in the area of recently deposited parent materials or in area where erosion or deposition rates are faster than the rate of soil development such as dunes, steep slopes and flood plains. They occur in many environments. Inceptosols are soils of semi arid humid environment that generally exhibit only moderate degree of soil weathering and development. Inceptisols have wide range characteristics and occur in wide range of climates.

Fig. 6. Drainage order of the study area.

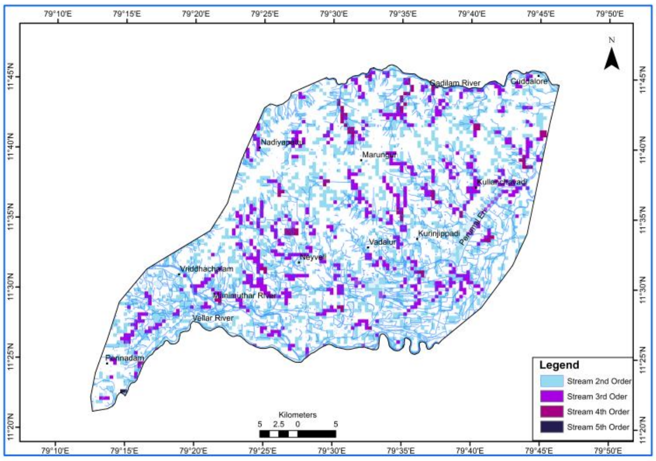


Fig. 7. Thiessan map.

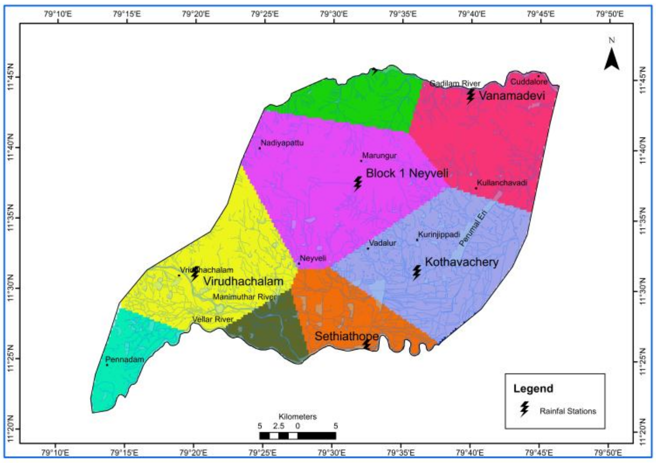
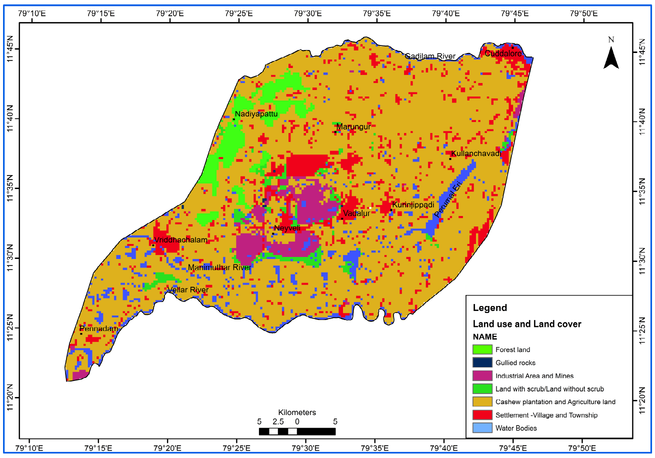


Fig. 8. Land use and Land cover map.



Drainage: The 90 mts elevation data was clipped and reprojected with coordinate system of WGS 94 and zone 44 is assigned. This layer is overlaid with stream and water body features from SOI Digital toposheets of the study area. Stream order map was prepared from the drainage map. The majority of the stream order falling in the study area is stream 2nd order. This layer is very much helpful in choosing the suitable site for artificial recharge structures. The drainage map (Fig. 6) was overlaid over SRTM elevation data and with the spatial analyst tool the stream order was arrived.

Rainfall: As precipitation is the major source of recharge directly and indirectly to the ground water reservoir, a detailed study on its intensity and variations is carried out. Thiessan map (Fig. 7) is prepared for the preparation rainfall density map of the study area. Neyveli area gets rainfall in both southwest as well as northeast monsoons. The climate of the area is of tropical characterized by long and severe summer, moderate monsoon and mild winter and March, April, and May are summer months. This is followed by the South-west monsoon (June to August). However, the real monsoon months are September, October, November and December when the area is influenced by northeast monsoon which followed by winter months. Maximum rainfall occurs in northeast monsoon i.e. 70% of the average annual rainfall is brought by the northeast monsoon, highest rainfall being in the month of November with a monthly rainfall of 268.5 mm and minimum rainfall occurs in the month of February with a monthly rainfall value of 10.70 mm.

Land use and land cover: Economic development and population growth have triggered rapid changes to Earth's land cover over the last two centuries and there is every indication that the pace of these changes will accelerate in the future. These rapid changes are superposed on long-term dynamics associated with climate variability. Land cover change can affect the ability of the land to sustain human activities through the provision of multiple ecosystem services and because the resultant economic activities cause feedbacks affecting climate and other facets of global change. Accordingly, systematic assessments of Earth's land cover must be repeated, at a frequency that permits monitoring of both long-term trends as well as inter annual variability and at a level of spatial detail to allow the study of human-induced changes. In the study area, majority of the land was covered by cashew plantation and other agricultural products. Reserve forests cover the north west of the study area (Fig. 8).

Overlay analysis: Density maps for all the layers were prepared for the weighted overlay analysis. Each thematic map was assigned a weightage and rank for its fields (Table 2) depending on its influence on the movement and storage of groundwater (Dinesh Kumar *et al.,* 2007; Avtar *et al.,* 2010; Nag and Lahiri, 2011). Relative ranking of each thematic unit in a theme were assigned as knowledge based hierarchy using spatial analyst tool of Arc GIS. The resultant map (Fig. 9) is classified into excellent, very good, good, moderate and poor groundwater prospective zones (5, 4, 3, 2 and 1). The results were validated by using groundwater level data.

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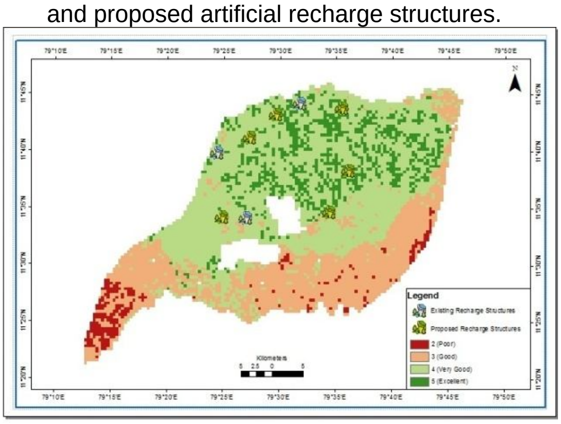
Table 2. Weightage analysis.

Thematic layer	Feature/Category	Rank	Weightages
Geomorphology	Fluvial older Plain	4	20
	Fluvial active Plain	1	
	Denudational pediment	5	
	Coastal Plain	1	
	Coastal deltaic Plain	1	
	Anthropogenic	0	
	Water bodies	5	
Geology	Cuddalore formation	5	15
	Coastal sediments	3	
	Ariyalur formation	1	
Soil	Alfisols	5	15
	Reserve forest	0	
	Vertisols	2	
Land use and Land cover	Agriculture land and cashew plantation	5	20
	Water bodies	5	
	City township settlement and new layout	0	
	Village settlement	4	
	Forest land	0	
	Gulliable rock, vacant land, land with and without scrub	5	
	Mines, thermal and industrial area	1	
Drainage order	First order	1	10
	Second order	5	
	Third order	5	
	Fourth order	5	
	Fifth order	1	
Rain fall	Vanamadevi	5	20
	Srimushnam	5	
	Block 1 Neyveli	5	
	Sethiathope	1	
	Panruti	3	
	Pelandurai	5	
	Kothavacherry	1	
	Vridhachalam	5	

Fig. 9. Weightage analysis map with existing and proposed artificial recharge structures.



The integration of various thematic maps describing favorable groundwater zones was brought out as a single groundwater potential zone map with the application of GIS by Prasad *et al.* (2008). Spatial data analysis is an analytical technique associated with the study of locations of geographic phenomena together with their spatial dimension and their associated attributes (like table analysis, classification, polygon classification and weight classification).

The various thematic maps as described have been converted into raster form considering the cell width to achieve considerable accuracy. These were then reclassified and assigned suitable weightage following the methods used by Krishnamurthy *et al.* (1996), Srinivasa Rao and Jugran (2003) and Aravindan *et al*. (2006). The occurrence and movement of groundwater in an area is controlled by various factors. The influence of all factors need not be the same in an area. Therefore, each parameter (Table 2) is assigned a weightage depending on its influence on the movement and storage of groundwater. For instance, the area being underlain by sedimentary rocks, the lithological control is less compared to the topographical control. Therefore, higher weightages are given to geomorphology and geology and land use-land cover layer. On the other hand, the influence of drainage density in the area is comparatively less, lower weightage is given to this theme. In this method, the total weights of the final integrated map were derived as sum or product of the weights assigned to the different layers according to their suitability (Fig. 9). Further, different units of each theme were assigned knowledge-based hierarchy of ranking from 1 to 5.

On the basis of their significance with reference to groundwater prospects, where 1 denotes poor prospects and 5 denotes excellent prospect of groundwater. The technical guidelines prepared by National Remote Sensing Agency (NRSA, 1995, 2000) were made use for the preparation of various thematic maps and final ground water potential zone map. Their field verification and with Google map also shows all artificial recharge structures are falling in the zones of 5 and 4.

Conclusion

Based on the overlay analysis, the northwest of the study area shows the highly potential zone for the recharge of the groundwater under excellent and very good category. The existing recharge structures established in the study area are also falling in the excellent and very good category of the analyzed area. Further to enhance the groundwater potential, additional six number of recharge structures are also identified using the resultant map, drainage system of the area and water levels of the dug wells present in this area. The impact will be maximum during post-monsoon period and a distinct rise in ground water level will be observed in the recharge area as compared to area not receiving the additional recharge. There will be rise in water level locally and mound will be formed around the recharge structures temporarily and ground water will flow in all the directions, which will dissipate afterwards. This will result in saving of energy, due to reduction in pumping lift.

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