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Groundwater potential in the Jaffna Peninsula and impacts of climate change

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Abstract

Excessive pumping and over-abstraction in Jaffna Peninsula, in Sri Lanka, has decreased the ground water levels in the last years. The total area of the Peninsula is 1017 km^2 and includes two internal lagoons with an area of 87 km^2 and 35 km^2 respectively. Climate in the Peninsula is characterised by wet and dry seasons. The recharge to the groundwater in the Peninsula is almost entirely from rainfall percolation, which occurs mainly on the wet season. During the wet season, most of the rainfall percolation is lost into the sea through the openings on the lagoons and as a groundwater outflow. Therefore, any water management scheme should be based on the effective control of the excess rainfall that is lost to the sea. Barrages/regulators were built in the fifties but the objectives of these schemes never materialised. Currently these control/regulator structures are in a state of disrepair. Two scenarios studied the groundwater levels in the Peninsula, the first by using the existing conditions and the second by controlling the barrages for letting seawater into the lagoons during dry periods and capturing surface runoff from land during the monsoon. In addition, climate change impacts on the groundwater system were considered. All the scenarios were examined by applying a three-dimensional groundwater flow model. Results showed that an excess of 10 Mm^3 could be added on the available water in the Peninsula, by controlling the barrages and that climate change could have a positive impact in the region. It can be concluded that lagoons playing a key role on the groundwater storage and could be used effectively as a management option to control the groundwater levels in the Peninsula.

Introduction

Jaffna Peninsula forms the northern part of Sri Lanka with an area of approximately 1017 km^2 (Figure 1). The peninsula is about 70 km long and 10 to 36 km wide. It is delimited by the Palk Strait on its western and northern side, by the Bay of Bengal on the east and by mainland Sri Lanka on the south. Jaffna includes two internal lagoons, namely the Vadamarachy lagoon or Thondamanaru lagoon and the Upparu lagoon, with an area of 87.1 km^2 and 34.7 km^2 respectively. The peninsula is separated from the mainland by two external lagoons, the Jaffna lagoon and the Elephant Pass lagoon.

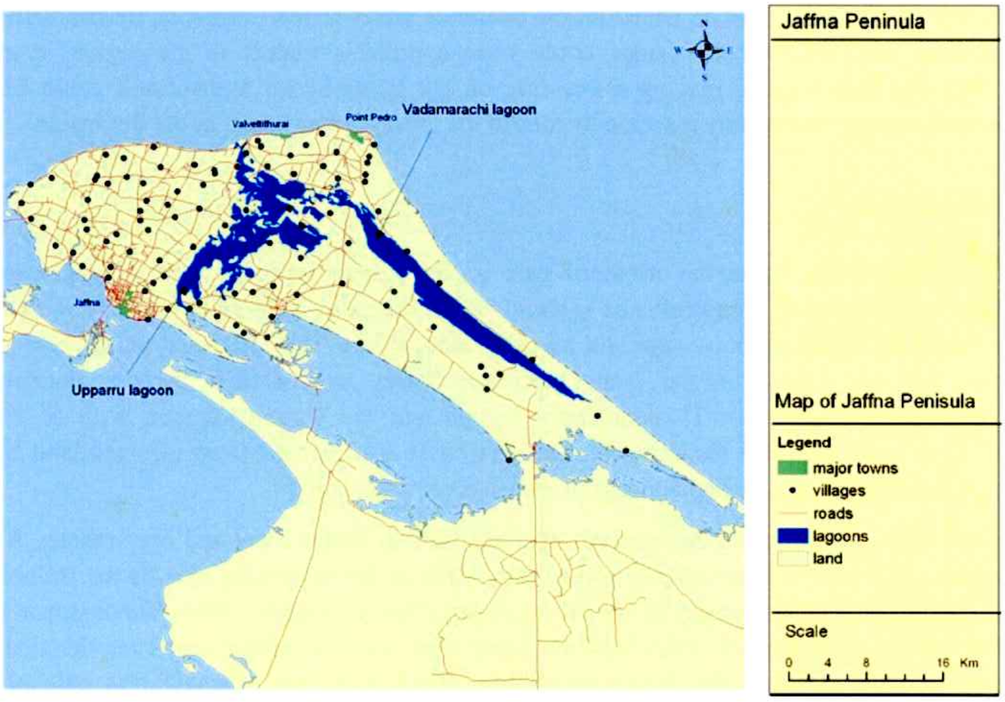
The climate in the Jaffna Peninsula is characterised by distinct wet and dry seasons. A rainy season occurs from September to December, while in the remaining months the influence of the monsoon is characterised by very low rainfall (Nakagawa et al. 1994; Nandakumar 1984). 80% of the precipitation falls between September and December, however the peninsula receives most of the rainfall during November. This leads to heavy runoff. It is estimated that 10-15% of the annual rainfall is lost as runoff (Nandakumar 1984).

According to Fernado (1973), while the rainfall follows a periodic pattern, there is a significant variation from year to year. It is approximated that the annual rainfall is 1300 mm. Records for the period between 1975 and 1994 show an annual rainfall of 1266 mm while for the period 1999 to 2004 it was calculated to be 1490 mm. It is noticeable that for 2003 it was 1328 mm and for 2004 the annual rainfall was 1868 mm, indicating the high fluctuations on the rainfall pattern.

Jaffna peninsula is mainly composed of Miocene limestones, which are exposed at the north central part (Balendran et al. 1968; Cooray 1984), extending in a NNW to SSE direction. The limestone is underlain by a thick sandstone formation, known as Mannar Sandstone Formation. Bordering with the limestone on the western part are patches of red bed formations, encompassing the brown sand formation which occupies a large area on the peninsula (Moorman 1961). Enclosing these along the western coast are lagoon deposits. The area east of the lagoon is occupied mainly by brown sandy loams in the south and sand dunes in the north along the eastern coast of the peninsula.

The hydro-geological system of Jaffna Peninsula consists of three aquifers separated by the lagoons, which worked as hydraulic barriers. The first aquifer occupies the west part of the peninsula and is called Chunnakam aquifer, the Point Pedro aquifer lies on the east part of the peninsula and the third aquifer is located on the southwestern part of the peninsula and is called Chavakachcheri aquifer. Fresh water is mainly located in limestone but on the Point Pedro and Chavakachcheri aquifers it can be found in sand deposits. All aquifers are unconfined and the core of fresh water lenses has a maximum thickness of 15-24 m as measured from the water table to the top of the transition zone (Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) 2002)

Figure 1: Geographical location of the Jaffna Peninsula, Sri Lanka.



Groundwater measurements of 40 wells between 1965 and 1968 presented that the maximum groundwater level happened on January 1968 and is equal to 3.82 mAOD, while the minimum water level occurred the August 1965 with a value equal to –1.80 mAOD (Balendran et al. 1968).

During 1972, groundwater levels were measured in 411 monitoring wells (Nandakumar 1984). Results showed that during December 1972, 50% of the area had levels over 1.5 m above MSL, with 80% of the wells having levels between 0 to 1.8 m above MSL and 10-15% above 1.8 m above MSL. On the other hand, during August 1972, 50% of the water table was below MSL, 35% from MSL up to 0.6 m above MSL, 10% from 0.6m to 1.2m above MSL and 8% between 1.2m to 2 m above MSL.

Data from monitoring wells from the period between 1978 and 1980 showed that groundwater levels during August were very close or just below MSL with few exceptions, while November water levels range from 0.6 m to 1.2 m above MSL and rarely more than 1.5 m (Engineering Sciences 1984).

The latest report involves monitoring of 176 wells during 1999 (Rajasooriyar 1999). Results showed that the minimum water levels during the August was –4.98 m AOD and the maximum 4.75 m AOD, while for December the minimum was equal to –3.42 m AOD and the maximum equal to 5.18 m AOD.

Results from the monitoring wells showed that the water table is lowered through the years, especially during the dry season. This is a result of the over-abstraction from the aquifer to cover the increased agriculture demands.

Numerical modelling

A three-dimensional groundwater flow and quality model has been used to simulate the groundwater levels. The groundwater model for the region has been developed by using the software HYDRO-3D (Guganesharajah 2001), which simulates spatial and temporal distribution of water levels, velocities and several water quality parameters. The model cells are tetrahedral and the model uses the finite integral element numerical method to predict flows and water levels in the system.

The modeled area covers 1019 km^2 and consists of the entire peninsula, including the two lagoons. The model boundaries of the hydro-geological system are constant head (0.43 mAOD) along the coastline, which is the mean sea level. The top of the layer represents the water level of the unconfined aquifer and the bottom layer corresponds to the base of the limestone, which is represented by the no flow boundary.

The domain of the study is discretised with normal triangular elements, which vary from 350 m on the land to 200 m on the lagoons. The elements are well adapted to precisely describe the aquifers and the lagoons and also to manage the model with short computer running time. The grid consists of eight faces and seven layers extending to a depth of 94 m, with 13 865 nodes for each face and 552 510 tetrahedrals in total.

The first layer represents limestone, lagoonal and estuarine deposits, dune sands and yellow and brown sands. The base of the first layer varies from 5-15 m. The remaining layers are part of the limestone formation and their thickness has been chosen wisely to simulate the water quality of the aquifer.

The values of the hydraulic conductivity for the limestone have been estimated by calibrating the model until the simulated piezometry is adjusted to the observed piezometry during the period between 1999 and 2004. Porosity (n) and storativity (S) of the aquifers and the hydraulic conductivity for Point Pedro and Chavakachcheri aquifers have been estimated from the aquifer tests (Engineering Sciences 1984) and presented in Table 1.

The calibrated model for the period 1999 to 2004 used the CropWat code (Clarke 1998) to estimate the evapo-transpiration of the area. The CropWat code uses the Penman-Monteith method. Runoff was assumed to be 20% of the total rainfall and using monthly time steps ran the model.

Table 1: Hydraulic properties of the model

Formation	n	S	Kx (m/d)	Ky (m/d)	Kz (m/d)
Sand	0.28	0.1	3	3	3
Dune sand	0.25	0.15	28	28	28
Deposits	0.3	0.1	2	2	2
Limestone	0.2	0.05	112 - 280	112 - 280	112 - 280

The calibrated groundwater model was used to simulate the groundwater levels proposed management strategies and to predict the groundwater levels under two different climate change scenarios.

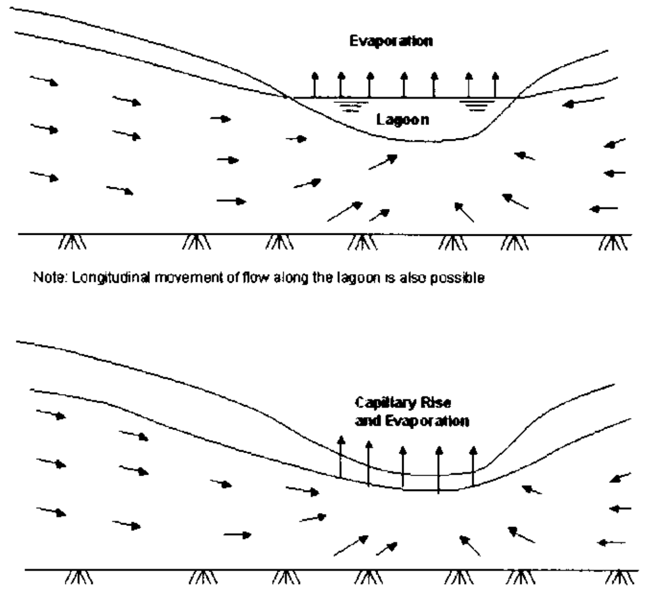
Groundwater management

The purpose of the model was to maximise the groundwater potential in the region. The model runs mainly focus on minimising the surface and subsurface losses to the sea by selecting appropriate design measures. Any excess water that is available from these measures will be utilised to supplement the water supply and to satisfy the demand from agriculture.

The existence of the damaged barrages/regulators on the openings of the lagoons can be used as a viable option to retain water in the lagoons with the barriers maximizes the retention levels. Control mechanisms on the barriers can allow seawater to enter into the lagoons during dry periods and capturing surface runoff from land during the monsoon. In conclusion, the lagoons can be used as a hydraulic barrier to reduce the subsurface runoff entering into them laterally.

If the lagoons are to be converted into freshwater lagoons it is also essential to address the possible implications of movement of more groundwater into them particularly during dry periods. When the lagoon beds become dry they can act as a sink, drawing groundwater and then losing it by evaporation due to capillary action (Figure 2).

Figure 2: Flow regime in the lagoon region (Tyriakidis et al. 2006)



An evaluation of the above option was undertaken using the HYDRO-3D model developed for the Jaffna peninsula. The base case scenario represents the "do-nothing" approach where applied the same conditions similar with the calibrated model. The second scenario assumes that the lagoon openings at Upparu and Vadamarachchi lagoons have been closed with a barrage with a height equal to 0.3 m above the mean sea level (0.43 m). The barrage remains close if the water level in the lagoon is above 0.73 mAOD and opens if it is lower to retain the water levels in the lagoons. The scenario focuses on the effects on the water levels in the lagoons and the aquifer by closing the lagoons openings. In addition, it is concentrated on the consequences of interactions between sea and lagoons compared by the base case scenario. Both of the scenarios assumed that the rainfall follows the same pattern with the 1999-2004 period. The period of simulation was for five years, covering the years between 2005 and 2010.

The total average rainfall was assumed equal to 1508 Mm^3, which includes 1331 Mm^3 in the land, and 177 Mm^3 of rainfall in the open water (lagoons). Moreover, 1057 Mm^3 of the average rainfall falls during the wet season of September up to December with November to be the wettest month with 457 Mm^3 of rainfall.

Results showed that the average annual groundwater outflow for the management scenario is 84.43 Mm^3 (79.91 Mm^3 in the base case) and the groundwater inflow is 26.88 Mm^3 (28.97 Mm^3 in base case). Thus the total excess water in the second scenario is 6.5 Mm^3. In addition, the net flow in lagoons for the first scenario is 23.69 Mm^3, while for the second is 28.76 Mm^3, indicating that there is an excess of 5 Mm^3 that ending into the sea. Table 2 summarises the groundwater/lagoon inflows and outflows for both scenarios.

Table 2: Summary of the groundwater and lagoons inflows and outflows*

Scenarios	Groundwater		Lagoons		NET	
	Inflows (MCM)	Ouflows (MCM)	Inflows (MCM)	Ouflows (MCM)	Groundwater (MCM)	Lagoons (MCM)
First scenario - base case	28.97	-79.91	33.83	-57.52	-50.94	-23.69
Second scenario – control the barrages	26.88	-84.43	60.16	-88.92	-57.55	-28.76

*positive values means flow from the sea to the system (aquifer+lagoons)

It can be concluded that controlling the barrage in lagoons openings can improve the water levels in the aquifer. The higher hydraulic gradient between the aquifer levels and the lagoon water, will cause a feed into the lagoon with fresh water, which will balance with the 5 Mm^3 of extra sea water into the aquifer, providing 10.5 Mm^3 of extra water available for use in the Peninsula.

Climate change impacts on groundwater

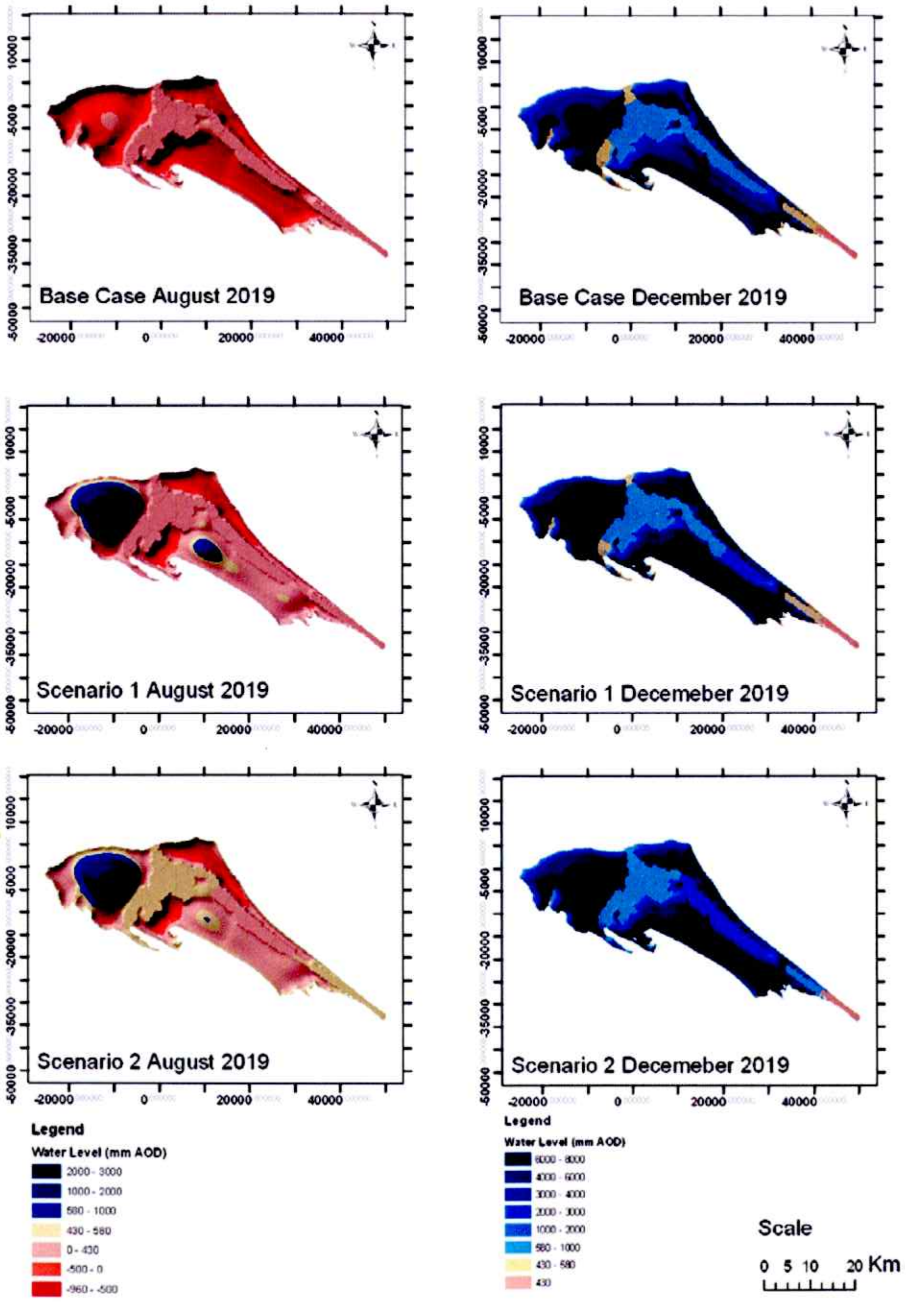
Climate change can significantly affect groundwater resources and thus influence the availability of fresh groundwater. The Intergovernmental Panel on Climate Change (IPCC) developed long-term emission scenarios referred to as Special Report on Emission Scenarios (SRES), which have been widely used to analyse possible climate change, its impact and mitigation strategies. Climate change projections have been developed for each scenario based on expected changes in population, carbon dioxide concentration, global mean annual temperature and mean sea level rise (IPCC 2007). Droggers (2004) studied the climate change impacts in Walawe, Sri Lanka, by using climate projections from the Hadley General Circulation Model (HadCM3) and the climate change scenario (A2). He stated that precipitation and temperature would both increase in the future with high variations in climate. In addition, he showed that the number of consecutive years when precipitation is severe and the number of years with extreme temperatures is expected to be higher in the future. Overall, the impact of climate change in Walawe was shown to have more positive than negative effects.

Climate projections from the Hadley general circulation model have been used to predict climate change for all the SRES emission scenarios. The lowest emission scenario gives a global-mean temperature rise of about 1°C by year 2030 (Johns et al. 2003). Sea level will change owing to expansion of the oceans, melting of glaciers, snow and ice. Global sea level is predicted to have risen by about 0.1 m by 2030 as calculated by the Hadley model (Gregory et al. 2000). Finally, maximum annual five-day rainfall events have changed significantly over the last decades and showed an increase of 10% in northern mid-latitudes (Met Office 2005).

The climate change impacts have been studied by using the numerical model HYDRO-3D (Tyriakidis et al. 2009). The study examined two different scenarios to show changes in groundwater in Jaffna Peninsula and compared with a base case scenario with no influence by the climate. The simulation used the calibrated values for the rainfall, temperature and evapo-transpiration to predict the situation by the year 2019. The first scenario assumed an increase in rainfall and runoff by 10% and 20% respectively and rises in temperature by 1° C. The second scenario considered an additional increase in sea level by 0.15 m and an increase in run-off by 24%. All the scenarios were simulated for 18 years, covering the period between 2005 and 2022.

The results showed that during the dry season, water levels increased in the middle of the aquifers but were almost the same in the coastal areas (Figure 3). On the other hand, during the wet season, there was a significant increase in water levels. Simulated water levels for the dry period reaches up to 2.8 m for the first scenario and 2.18 m for the second scenario, whereas the base case scenario showed that the simulated water levels in the dry season of 2019 would reach up to 0.43 m. In addition, groundwater outflows increased by 33% and 30% for scenarios one and two respectively during 2019 in contrast with the groundwater inflows that have been reduced by 37% and 32% for the first and second scenario respectively.

Figure 3: Simulated water levels for the base case and climate change scenarios (Tyriakidis et al. 2009).



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The study concluded that groundwater outflows are increased for the climate change scenarios while groundwater inflows are reduced. However, differences for the second scenario have less influence on the water resources, excluding the flow from the lagoon to the sea, owing to an increase in runoff. In addition, sea level rise can have negative impacts on the system, but it is mainly controlled by changes in rainfall. Therefore, rainfall and temperature rises are the predominant factors, with changes in rainfall and runoff to play a secondary role on the changes in groundwater resources.

Conclusions

Conclusions based on controlling the barrages on the lagoons to retain the levels in the lagoons 0.3 m AOD, showed that it could be an excess of 10 Mm^3 of fresh water available to the Peninsula.

In addition, results showed that climate change could have a positive impact in the region. Changes in rainfall and temperature are the predominant factors, followed by the sea level rise and runoff. Although there is a significant improvement on the groundwater resources, fresh water in the wet season moves from the lagoons to the sea.

In both cases, the excess water can be used efficiently under a capable water management, to provide a cost-effective and valuable solution for the water problems encountered in the Jaffna Peninsula.

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