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Ground Water Quality Improvement of Jaffna Penensula of Sri Lanka by Regulating Water Flow in the Lagoon Mouths

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Abstract— Within Jaffna peninsula there are three lagoons, Thondamanaru lagoon, Upparu lagoon and the Valukiaru lagoon with water spread area of 78, 26 and 14 squar killo meteres respectly. These three shallow lagoons cover around 11.8% of the penensola's land area of 1036 square killo meter. These lagoons are having sea mouths at Thondamanaru, Ariyali and Arali in the vicinity of Indian Ocean which covers the penebsula by 160 km of coastline and no location of penensula is more than 10 km away from the coast. Hence it is very much susceptible to the salt water intrusion in to the land area. The water resource mainly the underground water in Jaffna Peninsula is totally polluted due to prolonged negligence and improper management of existing barrages at the logoon mouths and the salt water intrusion was taken place. In addition to these garbage and soakage pit pollution and increased usage of fertilizer chemicals also affected the quality of ground water. As a result, people are facing problem in getting good quality water in their wells. Due to the salt water intrusion, hundreds of acres of lands, hundreds of wells are in abandon stage. There is a positive relationship between the level of salt water intrusion in Jaffna peninsula and the operation of the gates of Thondamanaru, Ariyali and Arali barrages. There is strong evdince from a survey conducted recently that a good correlation can be found for the entire lagoon system operation with the level of salt water intrusion effect of Jaffna peninsula. This paper outlines the research methodology and its direction towards the problem accreditation of an on going research to address the problem and to find a solution to this long standing crucial issue of the people of Jaffna peninsula of Sri Lanka.

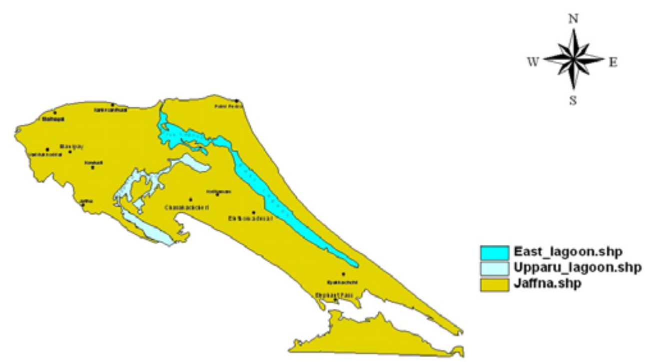
Index Terms— Coastline, Jaffna penensula, Lagoon mouths, Prolonged, Solt water intrution,

1 INTRODUCTION

THE Jaffna Peninsula is located in the north of Sri Lanka. The area of the Peninsula is 1036 km² and includes three internal lagoons, namely Thondamanaru lagoon, Upparu lagoon and the Valukiaru lagoon (insignificant). The first two lagoons comprise an area of 77.6 km² and 25.9 km² respectively. These two lagoons have exit to the sea and drain an area of 518 km². The Peninsula has predominantly been inhabited by the Sri Lankan Tamils of Dravidian origin for over several thousand years. Agriculture and fishing contribute to the livelihood of the majority of the local communities.

The main link between the Peninsula and the mainland is the Jaffna-Kandy Road. There is also a road and a 308m spill cum bridge at Chundikulam to the east of the Kandy-Jaffna Road, which are in a state of disrepair due to the long neglegent due to the peolonged unrest previlled in the region for more than three decades. It is a matter of dispute, whether to classify the Jaffna region as a peninsula or an island.

The administrative regions of the Jaffna Peninsula include the islands Mandativu, Karainagar, Kayts, Eluvaitivu, Analaitivu, Punkudutivu, Nainativu and Delft, which lie to the west of the Peninsula. Similarities between parts of the coastline of the islands and parts of the coastline of the Peninsula confirm that they existed as a single landmass. These islands are drifting away from the Peninsula at a micro-level. Similarly the Peninsula drifts away from the Mainland and the Island of Sri Lanka away from the Indian continent. The hypothesis of drifting continents was originally put forward by Wegner [1]to explain the geological and physical similarities that exist between continents which were believed to have been a single large land mass.



Jaffna Peninsula - Study Area

1.1 Geology of Jaffna Peninsula

Jaffna Peninsula is mainly underlain by Miocene limestone that outcrops in the north central and the surrounding regions. The surface stratum consists of red earth formation, sandy loams and sand dunes. There are coralline reefs on the north coast of the peninsula. A more descriptive detail of the

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geology of the peninsula is given in several publications[2],[3],[4],[5].

The Jaffna limestone is flat bedded and its vertical thickness is over 100 m. Samples from a borehole at Pallai showed that the limestone layer extended to a depth of 98 m, which was followed by thick sandstone formation to a depth of over 137 m above the Precambrian basement. Some parts of the limestone layers are richly fossiliferous and are much more porous than other zones due to their susceptibility to weathering. The porous layers with fractures and the formation of solution caverns due to dissolution of limestone form an excellent aquifer. The porosity of the aquifer was estimated to vary from 4.5 to 27% with a mean value of 15%[4].

1.2 Water Resource of Jaffna Peninsula

The main source of recharge to the aquifer is the North East Monsoon rainfall. Analysis of measured levels of water table and rainfall indicated that the estimated capacity of the stored water in the aquifer varied from 62 million m^3 to 218 million m^3 corresponding to annual rainfalls of 559 mm to 1575 mm respectively[1]. Depending on the rainfall distribution, approximately 12% of the annual rainfall accounts for recharging the aquifer[6] and over 25% contribute to surface runoff that enters the sea via the lagoons and watercourses. The quantity of rainfall lost due to interception and evaporation from bare lands is relatively small. However, the rain fed crops rely on a substantial quantity of rainfall, with supplementary irrigation from ground water.

2. THE PROBLEM OF WATER RESOURCE IN JAFFNA PENINSULA

The water resource mainly the underground water in Jaffna Peninsula is polluted due to

- prolonged negligence and improper management of existing barrages at Thondamanaru, Ariyali and Ariyali
- Unplanned usage of ground water resources implemented during the past few decades.
- Planned recharging process also was not implemented during the past.

As a result salt water intrusion taken place, people are facing problem in getting good quality water from their wells. Further due to the salt water intrusion, hundreds of acres of lands, hundreds of wells are in abandon stage.

3. RESEARCH METHODOLOGY

Groundwater moves from levels of higher energy to levels of lower energy, its energy being essentially the result of elevation and pressure, the velocity heads being neglected. The flow may be defined in various forms according to the dimensional character of the flow, its time dependency, and the boundaries of the flow region or domain.

All groundwater flow is mostly three dimensional and time dependants. Mathematically the transient condition yields a nonlinear equation to which no direct or exact analytical solution exists. Invariably, researchers have attempted to circumvent the complexity by introducing simplifying assumptions that furnish solutions of sufficient accuracy for practical problems.

During the last few decades, numerous attempts have been made to investigate the flow of water in coastal aquifers under various conditions such as steady, transient, confined and unconfined states. A vast reservoir of knowledge has been accumulated in books and journals. Severe restrictions imposed on the flow conditions and the boundary conditions have necessitated someresearchers to use numerical means for solving the equations which define groundwater flow in coastal aquifers.

3.1 Seawater Intrusion Problems and Solution

When a coastal aquifer discharges freshwater to sea, a dispersion zone occurs where the freshwater and saltwater come into contact. The location, shape and extent of dispersion zone depend upon several factors including the relative densities of the two fluids, discharge of groundwater and dispersion parameters of the aquifer.

In general, the methods used for solving saltwater movement can be broadly classified into

- Immiscible fluid method
- Miscible fluid method

The first method neglects the thickness of the transition zonebetween saltwater and freshwater in comparison with thethickness of the aquifer, thereby considering the transitionzone as sharp or abrupt one and the fluids as immiscible. This method is popularly known as sharp or abrupt interface method. The miscible fluid analysis treats the fluid as non-homogeneous and the solution technique consists of solving the convective dispersion equation.

Various methods have been in use for solving the problem of seawater movement and each one has its merit and demerit.The methods available for solving the problems of saltwater intrusion are classified as analytical methods and as follows

- Physical models
- Analogy models
- Numerical models.

Analytical solutions are the most accurate and desirable means of treating the saltwater intrusion problems. But due to the complexity of the equations governing the flow, analytical solutions cannot be obtained in many cases. Models are attempts to circumvent some of the difficulties encountered in analytical solution. The advent of digital computers made it possible to treat many complex problems satisfactorily and to obtain acceptable solution which could not be solved before.

In certain cases involving very simple geometries, analytical solutions can be obtained by direct integration of the differential equations. But inpractical saltwater problems the thickness of the aquifer and the properties of the porous media may vary from point to point. The natural recharge that enters the aquifer along its length may vary both in space and time. Wells placed along the length of the aquifer may follow any prescribed method of pumping and recharge. The freshwater discharge to the sea from inland may vary with time. Under these general conditions there seems little chance of obtaining even an approximate analytical solution for transient flow conditions. Most of the analytical solutions available are for the steady state of flow.

The first known published reference in history may be that of Braithwaite in 1865 as reported by Kashef[7]. Braithwaite illustrated salinity problems caused by well-pumping in London. Beginning with Badan-Ghyben and Herzberg, the investigations of the coastal interface have been aimed at determining the relationship between its shape and position and the various hydrological components *o*f a groundwater balance in the region near the coast. The Ghyben-Herzberg principle states that when salt water *is* stationary, the freshwater floating upon it adjusts in elevation until the depth of its lower surface, measured below sea level datum, is approximately forty times the height of its upper surface above this datum.

Muskat in 1937 as reported by Kashef [7] used a relatively simple approach to a specific problem in immiscible flow that relates to up coning problems. Assuming stationary lower liquid, he determined interface shape by determining the potential distribution along an idealized horizontal plane rather than the nonlinear up coned interface.

Hubbert in 1940 as reported by Kashef [7] in his theoretical analysis of the two fluid flow system in porous media concluded that continuous flow of freshwater to the ocean must be balanced by sufficient recharge to maintain an equilibrium. His analysis on dynamic equilibrium conditions at a stationary interface lead to the following conclusions

- Elevations of the interface increases in the direction of flow of freshwater. This occurs for example as the coast is approached.
- When there is simultaneous flow of freshwater and seawater and if the rates of flow are equal then the interface is horizontal
- The difference between the components, along the interface, of their piezometric head gradient cannot exceed a certain critical value. When it happens, a stationary interface cannot continue to exist but starts moving until a new equilibrium are reached.

Colombus as reported by Sivakumar [4] developed equations to find the length of seawater intrusion and height of phreatic surface under steady state flow in an unconfined aquifer and employed a viscous model to verify the equations. The validity of the equations was checked with experimental results and he concluded that the equations were valid even if Dupuit assumption was no longer valid.

Dagan and Bear as reported by Sivakumar[4] employed the method of small perturbations often used in the theory of surface waves, to linearise the interface equation and determined the rising interface in connection with the withdrawal of freshwater by coastal collector wells.

Strack [8] used an analytical technique for solving three dimensional steady state problems based upon the use of asingle potential which isdefined throughout all zones of the aquifer. The potential introduced by him is single valued and continuous throughout the multiple zoned aquifers. His analysis applies to both confined and unconfined aquifers and allows for variations due to accretion or well interference.

Van Der Veer developed expression for the position of interface and phreatic surface in a phreatic coastal aquifer under steady state flow inthe form of a nonlinear algebraic equation with complex potential. He inserted boundary correlations, simplified and presented expressions for determining the positions of the interface and phreatic surface and for the width of outflow face. He showed that if the total discharges of freshwater is intercepted by evaporation. The profiles of phreatic surface and interface are straight lines. He further studied that effect of movement of saline water and showed that saltwater flow has a greater effect on the interface position.

Rushton [9] indicated from investigation of field observation boreholes in the vicinity of abstraction boreholes that the saline interfaces in both boreholes do not remain at the same elevation. He explained that the interface position in an observation well *is* controlled by laws of hydrostatics whereas that an aquifer depends on the laws of groundwater flow together with too complex moving boundary conditions. He indicated that observation boreholes with limited open hole area may reduce the variation considerably.

3.2 Prevoius Studies on Seawater Intrusion Problems in Jaffna Peninsula

The idea of converting the Lagoons to a freshwater lake and reclaiming the lands in the fringe for cultivation was initiated in 1879 by Twyneham, the then Government Agent (GA) of the Northern Province. However, a catastrophic flood in the Peninsula in 1884 resulted in abandoning the project. The scheme was reconsidered in 1913 by Fesling, the then GA of the Northern Province, but in the subsequent year the scheme was abandoned by the GA without giving any reasons.

The idea resurfaced in 1916, while Horseburg was the GA of the Northern Province. But once again the scheme was rejected on the grounds that it would affect the revenue from the salt industry in the region.

In 1942, Webb, a Divisional Irrigation Engineer, was able to promote the scheme by producing a comprehensive report titled 'Jaffna Peninsula Lagoon Scheme'. His report was based on detailed analysis of relevant data and engineering solutions to harness the surface runoff entering the lagoons. He estimated that over 148 Mm^3 (120 000 acre ft) of water was lost via the lagoons to sea in an average rainfall year. In order to harness the excess runoff drained through the lagoons, Webb proposed 99 m and 122 m barrages upstream of the mouth of the North and the South Lagoons respectively. These barrages would only be able to store 65% of the average runoff at the designed retention level of 0.91 m above MSL. The main drawback of this scheme is that about 220 km^2 of land would be inundated at a retention level of 0.91 m above MSL and a substantial quantity of stored water would be lost due to evaporation before the month of May. However, the retained water can form a hydraulic barrier to prevent ingress into the land region.

The barrage across the Thondamanru lagoon was commissioned in 1953 while the barrage across the Uppuaru Lagoon was completed two years later. Currently both barrages are repared and in operational condition since 2011.

4. Objectives of Study

The broad objective of proposed Hydrogeological study is to identify and recommend the measures to develop, manage, allocate and conserve available surface and groundwater resources in a rational, systematic manner so as to achieve the maximum benefits without harming the environment.

Therefore the specific objectives of the study will be the;
1. Identification of different aquifers and their aquifer basin geometry, groundwater potentials and water quality in adequate detail.
2. Quantification of recharge to the aquifers by using of existing data sets and to set limits of extraction from different aquifers within the Northern Province.
3. Design of groundwater monitoring programme to assess environmental impact of groundwater extraction and impact of present activities upon the quality of the water and its sustainability for required use.
4. Development of database on surface and groundwater, setting out guidelines, norms and criteria for future water resources development.

5. Method

In order to carry out a comprehensive Hydrogeological assessment, it is necessary to study the available data on existing deep and shallow wells, surface drainage, water quality and information on hydrogeology, geology, climatic conditions, water use, agriculture use, environmental impacts etc. Those data should be then systematically analyzed and map out to identify the data gaps that essential for the overall assessment. Particularly, adequate sets of data on water quality, pumping tests, borehole yields and other technical details such as depths, water levels, overburden etc are necessary to determine the geometry of different aquifer regimes and their capabilities.

Once identified the required additional data it should be carried out field programmes to collect additional data by water sampling, chemical analyzing, geophysical surveying, Leveling surveys test well drilling and pumping tests and other Hydrogeological and hydrochemical tests. Further information on water use, prevailing condition on existing surface water bodies should also be collected by field programmes.

Third part of the study is preparation of base maps defining the major aquifers, Preparation of hydrochemical maps to present spatial and seasonal water quality variations, water potential maps etc. Preparation of the water resources data base including all above mentioned data is also expected under this project for the north province and make readily available it to the relevant agencies and individuals.

Finally, a detailed report containing all data, findings, results and recommendations will be prepared together with the other awareness materials necessary for capacity building of the relevant agencies.

6. Work Plan

The proposed project will be executed in three phases.

Phase I : (2 months)

A short term study, it will be carried out collecting & reviewing of available data/information on water resources in northern region covering the existing main aquifer units giving the priority to most sensitive and important areas for ongoing and proposed development activities.

Considerable information on water resources are available and documented by the WRB since its active participation on groundwater management processes in 1960's, 70's and 80's.Thereafter, during the conflicted period up to date WRB attended to conduct number of groundwater exploration and exploitation and conservation projects with the coordination of Government Agents of the Districts like Vavuniya, Jaffna and Mannar etc and Hydrogeological data of those activities are also available. However, some of the essential data for proposed assessment will be collected from relevant government and other agencies. This phase will involve

1. Development of a data base on groundwater exploration and exploitation.
2. Assembling all relevant available information on geology, hydrology, climate, hydrogeology, soil, tectonics, groundwater quality and water use etc.
3. Preparation of base maps.
4. Identification of gaps in database and prepare suitable programmes to collect required data.
5. Preparation of an inception report on data analysis with further recommendation and amendments to continue the Phase II of the project.

Phase II : (6 months)

Identification and collect additional data through field studies in relation to assessment of basin wise water resources as fallows.

1. Identification of representative areas for further Hydrogeological & geophysical investigations in order to establish exploratory boreholes.
2. Test well drilling. (Maximum 10 per each district. Those wells will be handed over to rural and urban water supply schemes if they would able to cater demands in sustainable and environmental friendly manner.
3. Conducting of water level monitoring and water sampling from dedicated well network (Dry season and wet season).
4. Chemical analysis of water samples.
5. Leveling surveys for selected monitoring wells.
6. Conducting pumping tests to determine present groundwater potentialities in deferent aquifers.
7. Compiling and analyzing of the data gathered through above studies and reporting.
8. Preparation of the hydrochemical and groundwater potential distribution maps and models.
9. Identify the deferent types of groundwater and surface water quality zones.
10. Suggest quality improvement methods and recommend methods for proper monitoring of water quality in future.

7. Conclution and Benefit of this Study

Clearly, studies of this nature require extensive topographical and landuse surveys, geological investigations, a detailed assessment of water resources, deployment of weather stations, development of a hydrometric network and establishment of water quality sampling stations.

A key factor to the success of the study is the protection of ground water from contamination that arises from application of fertiliser, weed killer and pesticides on agricultural land and from sewage pollution from pit latrine soak ways. Recent studies indicated that the nitrate concentration in some areas in Point Pedro ranged from 122 to 174 mg/l. Elimination of agricultural pollution, collection and treatment of sewage and supply of treated water for domestic needs are prerequisites to achieve the overall objectives effectively. It should be noted that over 84 000 wells rely on the aquifer for domestic and agricultural needs. Immediate action to prevent the contamination of the aquifer is essential to reduce the risk of health hazards in Jaffna peninsula.

Most of the researchers feel that the conversion of fresh water lagoons shall make very big contribution to the GWT (70%-80% of the total requirement) but the side effects of this conversion also has to be analyzed environmentally, socially and economically. Total conversion of fresh water in the lagoons may not be possible but controlling salinity in to the lagoons is very much important to have balanced environmental and social conditions in the lagoon and its surrounded area and this research will give a answer to the unanswered question for last few decades

7.1 Recomended Benefits

The benefits arising from the project are summarised below:

1. Potential increase in food production through availability of additional water
2. Increase in the quantity of water available to supplement rain fed agriculture when there is water deficit and for dry season cultivation
3. Increased employment and income and hence improvement in the living standard of the local community
4. Increased ground water resources through recharge from off stream reservoirs
5. Prevention of salt water intrusion into the aquifers of land region

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