Proceeding of

The Workshop

On

Challenges in Groundwater

Management in Sri Lanka

Organized by

Ministry of Irrigation & Water Resources Management, Water Resources Board

And

Dam Safety & Water Resources Planning Project

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Foreword

The Editorial Board is pleased to present this volume, which contains the technical papers presented at the workshop on "Challenges in Groundwater Management in Sri Lanka' held on the 15th March 2011 in Sri Lanka, and a summary formulated incorporating the proceedings of the group discussion conducted at the end of the day to gather key issues and the recommendations made by the panel. The workshop marks World Water Day and the inauguration of an enhanced groundwater monitoring program under Component 2 of the Dam Safety and Water Resources Planning Project in association with Water Resources Board of Sri Lanka.

In many parts of Sri Lanka, groundwater resources are subject to deteriorations in terms of both quality and quantity due to natural and anthropological activities as identified by the Water Resources Board of Sri Lanka. Sea water intrusion and rapid water level decline associated with over-abstraction, pollution due to excessive application of fertilizer in agriculture activities, bacteriological contamination as a result of poor sanitation facilities together with natural geologic conditions such as high concentration of fluoride are some of the challenges to our groundwater resources in Sri Lanka.

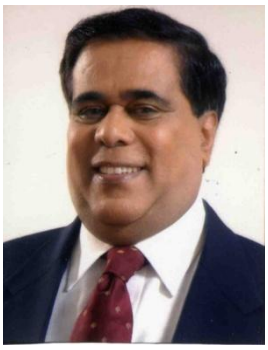
Given the finite groundwater resources and prevailing issues, there is a need to develop equable and acceptable groundwater policies and to implement effective management strategies based on the concept of sustainability.

The workshop was intended to provide a forum for professionals in the field of groundwater management in Sri Lanka to discuss groundwater related issues such as sustainable exploitation, efficient utilization, and methods for prevention and mitigation of groundwater pollution, and to reach consensus on groundwater resources management strategies required for the future.

Finally, the editorial board would like to thank the workshop participants, who made this event very successful.

Workshop on Challenges in Groundwater Management in Sri Lanka

Message from the Honorable Minister



Mr. Nimal Siripala De Silva

Minister of Irrigation and Water Resources Management

It is my pleasure to recognize the upcoming World Water Day celebrations on the 22^{nd} March 2011 and the workshop on the Challenges in Water Resources Management in Sri Lanka to be held on 15^{th} March 2011.

World Water Day is dedicated to focus attention on the importance of freshwater and to advocate the sustainable management of freshwater resources. This year's theme "Water for Cities: Responding to the Urban Challenge" aims to spotlight and encourage governments, organizations, communities, and individuals to actively engage in addressing the challenge of urban water management.

The availability of clean water is fundamental to the survival of present and future generations as well as for social and economic development. Surface water is important but on a global scale one third of the world's population depends on groundwater. Groundwater is less understood due to its presence being concealed underground. Nonetheless groundwater should be well managed and conserved in terms of quantity and quality as a reliable source for drinking water in urban as well as rural areas. Groundwater also plays a significant role in agriculture with an increasing portion of groundwater being extracted for irrigated agriculture.

In Sri Lanka the water sector is dominated by surface water sources. However, there is a growing demand for groundwater that is facilitated by low cost drilling, improved pumping technologies, and government subsidy for groundwater development for small scale agriculture that was introduced in the early 1990s. Impacts on groundwater are often long term and irreversible and as such requires that the precautionary principles must be used when making decision about groundwater.

Uncontrolled and increasing abstractions of groundwater has resulted in the deterioration of groundwater quality due to sea water intrusion, the high concentrations of nitrogen compounds as a result of the application of large quantities of inorganic fertilizer, and also the rapid decline of water levels in the areas where a large number of agro-wells intercept the shallow aquifers.

The potential effects of climate variability and change on our water resources are well recognized and as such climate change is a major issue facing the availability of groundwater resources in the world.

Given the complexity of these factors influencing the sustainability of groundwater resources in Sri Lanka, it is urgent that we develop and implement sound groundwater management policies and make wise decisions.

The Government of Sri Lanka is taking action with the establishment of a groundwater monitoring network under the Water Resources Board of Sri Lanka through Component 2 of the Dam Safety and Water Resources Planning Project. This is a very important project initiated by the Ministry of Irrigation and Water Resources Management to support the development of remedial actions and proper management strategies to mitigate the impacts on the country's water resources.

The proposed groundwater monitoring network will provide critical information on the hydrogeological and hydrochemical status of groundwater resources in the country with special reference to a number of selected pilot areas. The groundwater of these pilot areas has already been found to be adversely affected due to natural and anthropological activities.

The March 15th workshop will bring together scientists, academics, hydrogeologists, planners, and policy makers to present scientific information as well as to discuss and to initiate collective actions for revisions of existing groundwater policies in order to meet the new challenges in groundwater management.

In concluding, I wish all a very successful workshop, and I ask that the all participants dedicated their effort to indentifying solutions that will protect and sustain this hidden treasure for the long term benefit of Sri Lanka.

Message from the Chairman of Water Resources Board

Groundwater is a limited and strategic water resource, widely used for domestic, small scale irrigation, industrial, commercial and other purposes. Demand for groundwater has grown rapidly as a result of population increases and economic development of the country. In the past, it was assumed that water was always available as needed. However, we have now reached the stage at which demand for water is generally difficult to meet in some regions.

The over extraction of groundwater resources to satisfy the increasing demand for water, without due consideration to sustainability and protection of water resources, had contributed to depletion and degradation. In the other hand groundwater pollution occur in many aquifer systems of the country. Therefore, it is clear that the groundwater monitoring in Sri Lanka is very much important at this stage. Under the component 02 of the Dam Safety and Water Resources Planning Project, Water Resources Board is planning a groundwater monitoring programme in selected 30 DSD's in six districts, namely Jaffna, Puttalam, Anuradhapura, Gampaha, Matale and Anuradhapura districts on pilot basis. The selection of the respective DSD's for the monitoring programme is purely based on the issues identified by the Water Resources Board. Therefore, this would be a great opportunity to develop the ground water monitoring programme island wide at the final stage because "Mahinda Chinthana" is highly emphasized the importance of managing the groundwater resources for the future generation.

Bandula Munasinghe
Chairman
Water Resources Board

Acknowledgment

The organizing committee thankfully acknowledges insights and inspiration offered by the Honorable Mr. Nimal Siripala De Silva, Minister of Irrigation and Water Resources Management during the closing up ceremony of the workshop.

And the committee also wishes to express its sincere appreciation to Mr. Ivan De Silva, Secretary, Ministry of Irrigation and Water Resources Management for accepting the invitation to participate in the opening ceremony.

Thanks are also due to Mr. D. C. S. Elakanda, Project Director for actively supporting the workshop and also for his brief presentation on the core activities of the Dam Safety and Water Resources Planning Project with special reference to the design of groundwater monitoring network in Sri Lanka.

We extend appreciation to the Chairman of Water Resources Board, Mr. Bandula Munasinghe for his valuable cooperation given to the organizing committee to complete the task.

We further extends appreciation to the General Manager Mr. R.S. Wijesekara of Water Resources Board for his prominent role during the time of organizing the workshop and thereafter the assistance given in the process of compilation and completion of the proceeding of the report

Mr. Ruwan Rajapaksa - Senior Hydrogeologist, Mrs. D. Wijekoon - Chemist, Mrs. R.A.I.S. Ranawaka – Chemist, Mr. Nihal Kodithuwakku - Work Supervisor, Mrs. T. J. Pathiratne , Mrs. W. C. Priyani, Mr. G. Abeysena, Mr. W.A. Rathnasiri, Mr. R.P. Siripala, Mr. Laksiri Nagodawithana, Mr. K.G. Somasiri, Mr. Ajith Pushpakumara and Mr. B.G. Lakmal of WRB are thanked for giving enormous support in all aspects from the initial stage until the conclusion of the workshop.

Mr. A. Sellahewa, Procurement Specialist, Mr. Jayamanna, Accountant, Mr. Ranjith Amarathunga, Training Officer, Mrs. Udayanga Basnayaka, Engineer, Mr. Thisara Bandara, Engineer, Mr. Rathnamalala and the rest of the staff of the PMU of the Dam Safety and Water Resources Planning Project are sincerely thanked for their commitments for the workshop.

Mr. Russell Boals , Team Leader, Mr. Sarath De Silva, Groundwater Specialist and Ms Nishanthi Francis, Executive Assistant from the Hydrosult are acknowledged for their efforts and contribution in arranging and organizing the workshop.

We are also grateful to the hard work of Dr. M.U.A. Tennakoon, the Moderator of the workshop in finalizing the workshop report and producing the proceedings in a functionally appropriate manner.

Dr. C. R. Panabokke is thanked for presenting his valuable long time experience in groundwater management in Sri Lanka

Special thanks to the chairpersons of technical sessions, Dr. U.D.S. Jayawardane and Professor Athula Senaratne for sharing their expertise and guiding the technical sessions.

The organizing committee extends special thanks to Dr. Canna Jayasumane for creating awareness among the participant of findings of recent research related to Chronic Kidney Diseases reported in the north central province in Sri Lanka.

Finally, the organizing team is also grateful to both the resource persons who presented papers on important topics and the participants who represented the various organizations and enthusiastically participated in the activities of the program and made valuable comments.

Abbreviation

ADB	-	**Asian Development Bank**
CMB	-	**Chloride Mass Balance Method**
CWSSP	-	**Community Water Supply & Sanitation Project**
DANNIDA	-	**Danish International Development Agency**
DEM	-	**Digital Elevations model**
ET	-	**Evapotranspiration**
ETM	-	**Enhanced Thematic Mapper**
FINNIDA	-	**Finnish International Development Agency**
GIS	-	**Geographical Information System**
GND	-	**Grama Niladari Division**
GTZ	-	**German Technical Corporation**
IRDP	-	**Integrated Rural Development Project**
MODFLOW	-	**Modular finite–difference flow model**
NWSDB	-	**National Water Supply & Drainage Board**
PEST	-	**Parameter Estimating Program**
RMSE	-	**Root mean Square Error**
RS	-	**Remote Sensing**
SIDA	-	**Swedish International Development Co-orparation Agency**
USGS	-	**Unites state Geological Survey**
WHO	-	**World Health Organization**
WRB	-	**Water Resources Board**

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An Overview of the Papers Presented

Objectives Set Out:

Modeling groundwater had been the major objective in the three presentations made by Sanmuhananthan, Seneviratne and Sivakumar on groundwater in Kayts, Lower Walawe Basin and in a small catchment area (183 sq. km) in the Vavuniya district respectively.

Shanmuhananthan's modeling objectives were : (a) groundwater flow and salinity assessment in the island of Kayts; (b) an estimation of groundwater balance in fresh water in the same island; (c) determination of 'up-coning' of salt water through the thin fresh water lens and the re-charge scenario; and (d) impact assessment of surface water on groundwater. Seneviratne has attempted to develop regional groundwater models for the Lower walawe Basin dealing with a wide range of variables (parameters) which was rather a difficult and complicated task. Sivakumar's attempted model building was of a different type. In his model building task, it has been said that, a frugal saving of water in a tank (reservoir) by foregoing the cultivation of certain extents of land fed by it during the 're-charging' and 'discharging' periods, the groundwater levels can be kept artificially high closer to the surface, giving an advantage for the conjunctive use of both surface and ground water in agriculture.

Model building means developing some notions or hypotheses with a manageable number of variables (parameters) and calibrating (counterfeiting) them one by one using available authentic data and information, often by trial and error, to get closer to the real world situation. All three model builders have attempted to accomplish this task, whatever the flaws that these models have. There is room for their further refinement

Wijesekera's study objectives of the study of the Attanagalu Oya basin are very clearly aimed to : (a) identify different types of aquifers in the study area; (b) understand spatial and temporal water level variations as well as periodical shortages; (c) assess the increasing water pollution notably in the downstream areas; (d) highlight the environmental damages including river bank erosion; and (e) see what could be done to mitigate all those damages.

The paper of Karunaratne et, al., is a methodical as well as a cut-and-dry effort made to use the isotope measurement technique to ascertain the quality of groundwater, which is of practical use where rapid and widespread water pollution is a raging issue at present Prematilaka's paper is an informative presentation (largely based on scientific research findings of Panabokke and Fernando,2005) of the different types and locations of the aquifers, their physio-chemical status and amounts available for extraction. One of the most important points that had been highlighted was the absence of groundwater monitoring programs to identify the variation of water quality and water levels of the well fields maintained by NWSDB.

The objectives of Panabokke's presentation were to: (a) clearly explain the nature and extent of groundwater availability notably in the shallow regolith and in deep cavities in the hard rock base in the dry zone.; (b) and (c) suggest a groundwater monitoring system evolved after previous studies

Major findings

The need to maintain high water tables, water shortages due to excessive extraction, pollution due to man's reckless interference with nature and the consequential environmental damages and the need to monitor them have been the very broad concerns of all the papers. Drought, low and sometimes erratic rainfall, poor infiltration of surface water to the groundwater aquifer due to unchecked surface run-offs on bare land as well as the wide heterogeneity of relief, soil, geology, geomorphology and hydrology as a whole, too have been identified (notably in Seneviratne's paper) as the determinants of water transmission to the aquifers . Where thin fresh water lens exist over the heavy salt water layers at the bottom of the aquifers, there is (up- coning) of salt water into fresh water lens that is also observed in some of the shallow groundwater aquifers (Shanmuhananthan).A major finding of Wijesekare is the rapid downstream pollution of the Attanagallu Oya basin which is increasingly hampering the downstream economic activities which required to be checked early. And he has identified the requirement of establishing long term groundwater monitoring programs to have a better understanding of the status of groundwater regimes.

Panabokke's paper is a further confirmation of his long standing argument that shallow regolith aquifers on the hard rock base and in deep cavities in the hard rock base have some water for careful extraction which is to be done under careful monitoring .Referring to the fluoride contents of groundwater, one of his findings is, that, it varies very widely from well to well even they are in close proximity to each other. Though not elaborated, he has referred to a monitoring methodology evolved following his Deduru Oya basin studies. The paper of Karunaratne et. Al., have concluded that hard rock based aquifers are more of fluoride water than the surface water. Prematilake has highlighted the past failures of the policy formulations to better manage groundwater.

Recommendations/Conclusions

The paper presenters have preferred to make either conclusions or recommendations or both taken together.

- A strong emphasis is made more than in one paper, is the need to arrest on-going man-made pollution of water applying stringent rules and regulations
- Environmental damages including the curse of sand mining in vulnerable locations (in stream beds, coastal sand dunes etc) have been condemned and called to be banned.
- In general almost in all paper presenters have either demanded or recommended that: (a) groundwater monitoring; (b) rehabilitation; and (c) protection programmes be put in place urgently.
- Shanmuhananthan's simple but effectively workable recommendations such as (a) scaling down agricultural activities in accordance with available groundwater where surface water is minimally available as in Kayts, (b) limiting new development activities especially in the immediate catchment (re-charge), area of an aquifer, (c) introducing modern water saving irrigation technologies (e.g. drip irrigation) to save groundwater, (d) conducting research to introduce drought resistant crops replacing more water required crops, (e) rehabilitating ponds and other shallow depressions temporarily holding water in them to induce more and more percolation of surface water to the groundwater aquifers, (f) construction of salt water exclusion devices, and above all,(g) strengthening people's community based organizations to inculcate a sense of frugal use of water all round.
- Undertaking increased water quality testing over space and time and using the data obtained in them to educate the water users
- All papers suggested that research on groundwater be undertaken in a continuum to learn more from them and better educate the resource users.
- Lack of data and information is one of the major obstacles in developing good realistic groundwater models that should be one of the important issues to be addressed.

Water Quality Study in the Shallow Aquifer System of the Attanagalu Oya basin

R.S. Wijesekara, Senior Hydrogeologist, C.Kudahetti, Geologist

Water Resources Board, Hector Kobbekaduwa Mawatha, Colombo 07

Abstract

Attanagalu Oya basin is situated between two major river basins, the Kelani and Maha Oya in the Western Province of Sri Lanka, with an area extent of 727 km^2. Four streams; Diyaeli Oya, Attanagalu Oya, Uruwala Oya, and Kimbulapitiya Oya all discharge into the Negambo Lagoon as the Dandagamuwa Oya. A study was conducted for the Attanagalu Oya basin to assess the water quality of the shallow aquifer system of the basin.

The available qualitative data on groundwater were compiled and a groundwater database was developed for the basin. The total basin area was divided into five major divisions and a shallow groundwater monitoring network was designed for each division. Representative shallow dug wells were selected for the monitoring network and 100 samples were collected from each division. Samples were analyzed for 17 physical and chemical parameters (appearance, temperature, turbidity, pH, EC, total hardness, total alkalinity, total dissolved solids, Na^+, Ca^{2+}, K^+, Mg^{2+},total iron, fluoride, SO^{-2}_4, Cl^-, salinity, nitrate).. In addition, 10 samples were collected from surface and groundwater bodies in the paddy cultivated areas and analyzed for pesticides. Also10 samples were collected from industrialized area and analyzed for Pb and 10 samples were collected from urban areas of the basin and analyzed for bacteria. Based on the data collected, geo-chemical maps (pH, EC, Na, K, F, Fe, salinity, TDS) were prepared for the entire basin.

The geo-chemical maps indicated that pH of the shallow groundwater in some parts of the Attanagalu Oya basin was very low. The pH values varied from 4 – 8.5. High EC values were reported in the coastal area. Bacterial contamination was reported in groundwater sources in urban areas. No pesticide contamination was detected in any of the water samples collected from the paddy cultivated areas. The occurrence of Pb in shallow groundwater was reported within the range of 0.01 – 0.02 ppm. The major shallow aquifer types that exist in the basin are river alluvium and coastal sand.

1. Introduction

The Attanagalu Oya is considered to be a basin with abundance groundwater resources. The important water uses in Attanagalu Oya are the supply of drinking water and the maintenance of aquatic ecosystems. The Negombo lagoon and the Muturajawela marsh are two large aquatic ecosystems in the basin. The major environmental problems of the Attanagalu Oya basin are related to the deterioration of the water quality due to domestic, agricultural, and industrial activities. Uncontrolled disposal of industrial effluents (both solid and liquid) and use of agro-chemicals are the main cause for the deterioration of water quality in the basin. These effluents are attributed to the industrial areas such as the Katunayake industrial Processing Zone and the Ekala Industrial Estate. The water quality of Negombo lagoon has deteriorated over the last few decades. The growth of algae in the lagoon is primarily the result of the accumulation of nutrients in the lagoon.

2. Objectives of the Study

The main purpose of this study was to identify the water quality variation of the shallow groundwater and to make recommendations for further studies, including long term monitoring of groundwater quality in the area.

3. Study Area

Attanagalu Oya basin is situated between two major river basins, Kelani and Maha Oya in the Western Province of Sri Lanka, with an area extent of 727 km^2 (Figure 1). The three streams, Deyella Oya, Attanagalla Oya, and Uruwal Oya discharge into the Negambo lagoon as the Dandugam Oya and also through Ja – Ela. The dendritic drainage pattern can be seen in the study area map. Two streams originating from the Gallanda and Polgahagoda areas join to form the Waharaka Oya. The Basnagoda Oya originating from Bewangama and flows in a SW–NE direction and joins the Waharaka Oya to form the Attanagalu Oya.

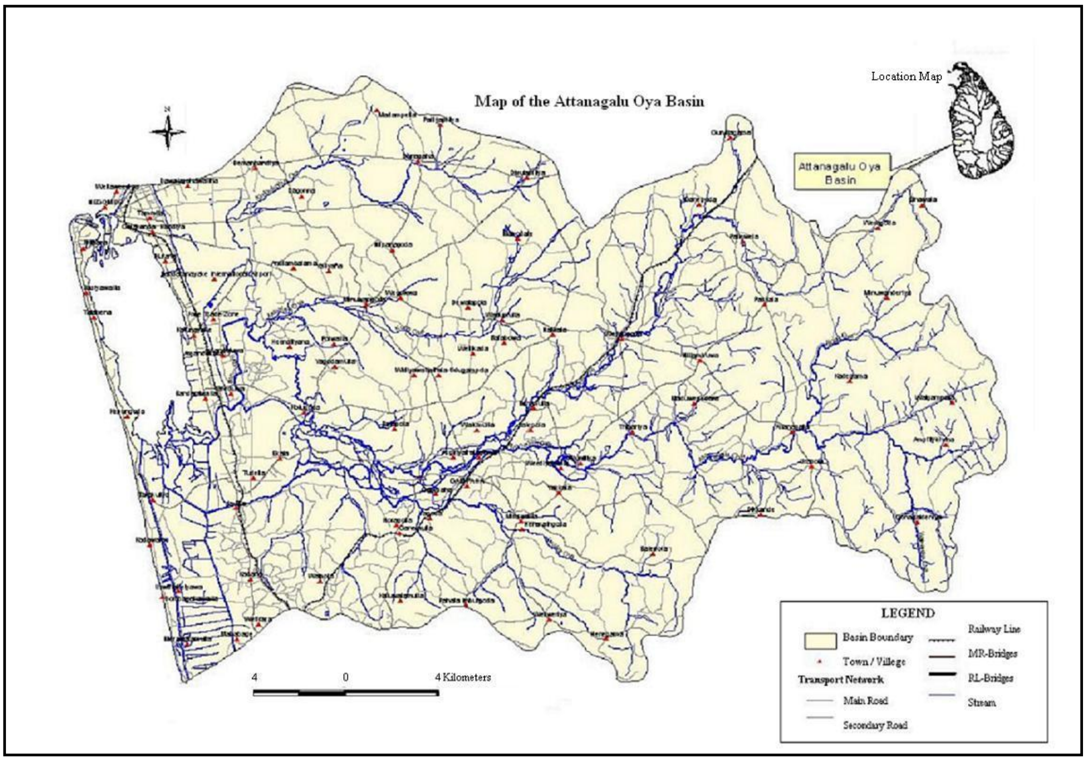

Figure 1: Map of the Attanagalu Oya basin

The main geological formations in the basin area are Laterite, Unconsolidated Sand, Alluvium, Peat deposits, and Crystalline basement rocks (Figure 2).

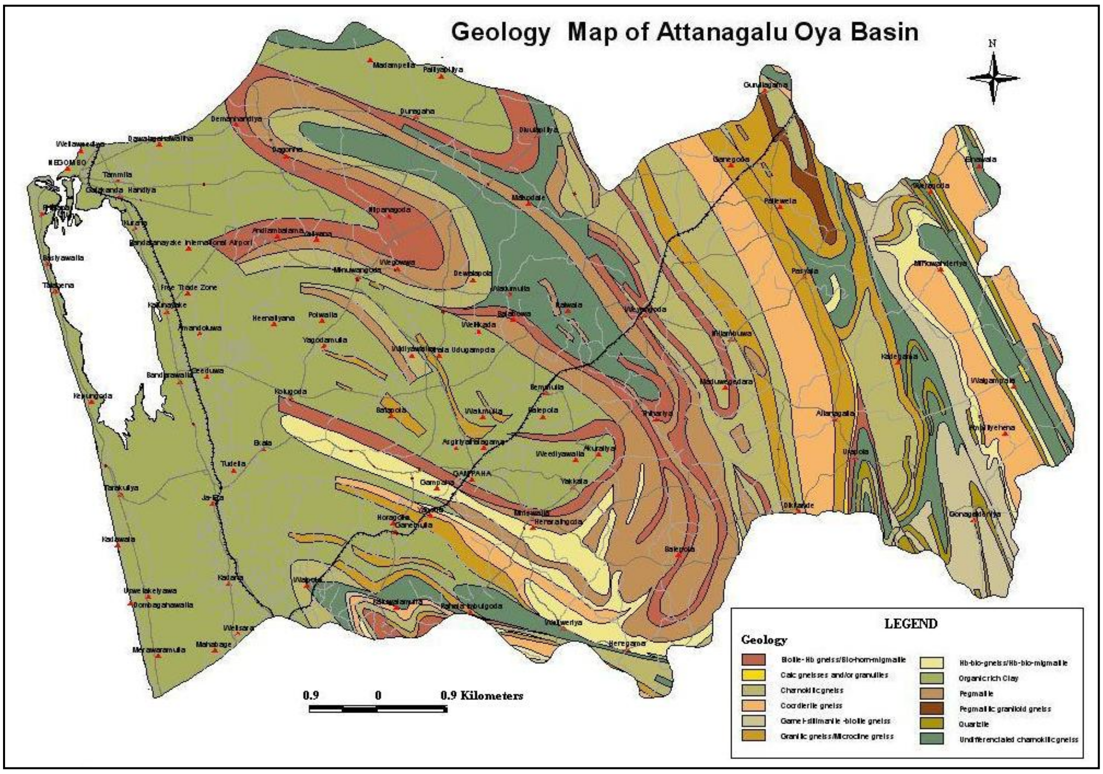

Figure 2: Geology map of Attanagalu Oya basin

4. Methodology

The activities undertaken to complete the study were:

- Conduct a desk study and compile available data (geological, hydrogeological, geochemical etc.)and identify any data gaps,
- Undertake field visits to verify and confirm the issues,
- Collect additional data to address the data gaps,
- Present these data on GIS maps, and
- Identify area specific problems,

Field investigations were conducted in order to collect data to fill data gaps. The basin area of 727km^2 was divided into five units and100 water samples were collected from each unit. Another 100 samples were collected from the problem areas such as industrialized and extensively cultivated areas. They were tested for 17 physical and chemical parameters and the results were compared with the Sri Lankan drinking water standards. In addition,10 water samples were collected from extensively cultivated areas of the basin and analyzed for pesticides, and 10 water samples were collected from the industrialized areas of the basin and analyzed for Pb. Another 10 water samples were collected from the urban areas of the basin and analyzed for bacteria. The analyzed data were used to prepare geochemical maps.

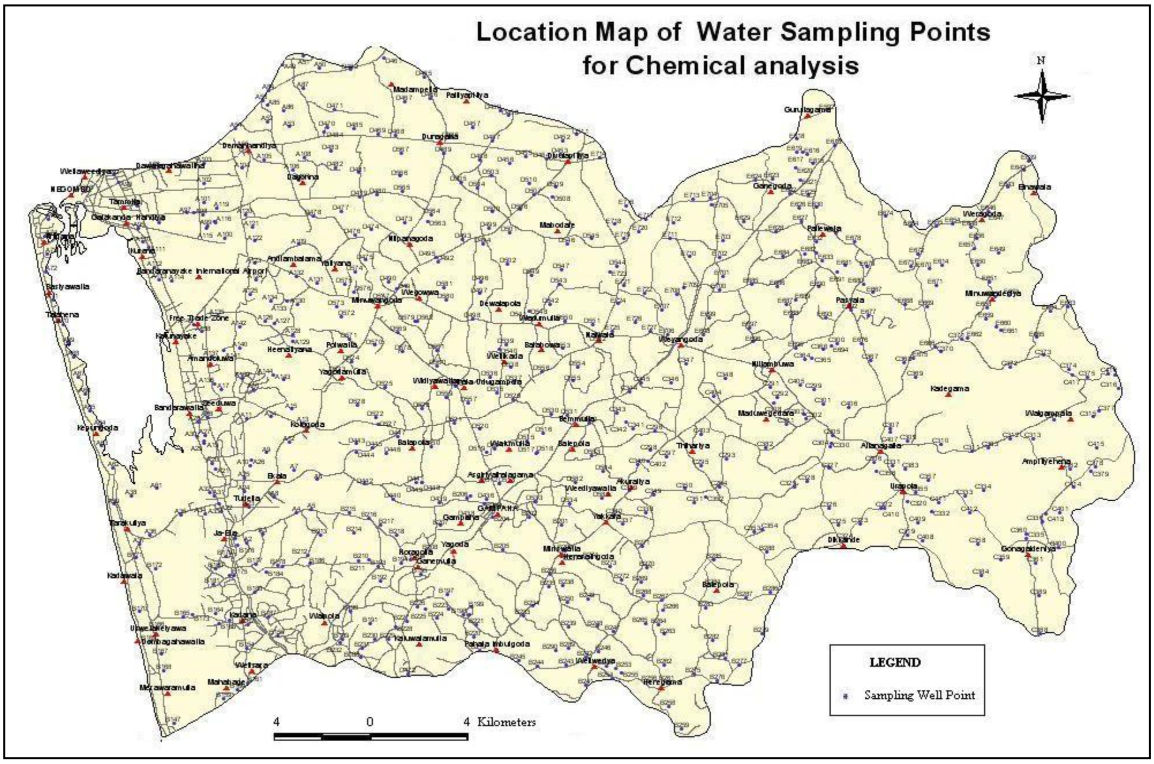

Figure 3: Location of the Sampling Points

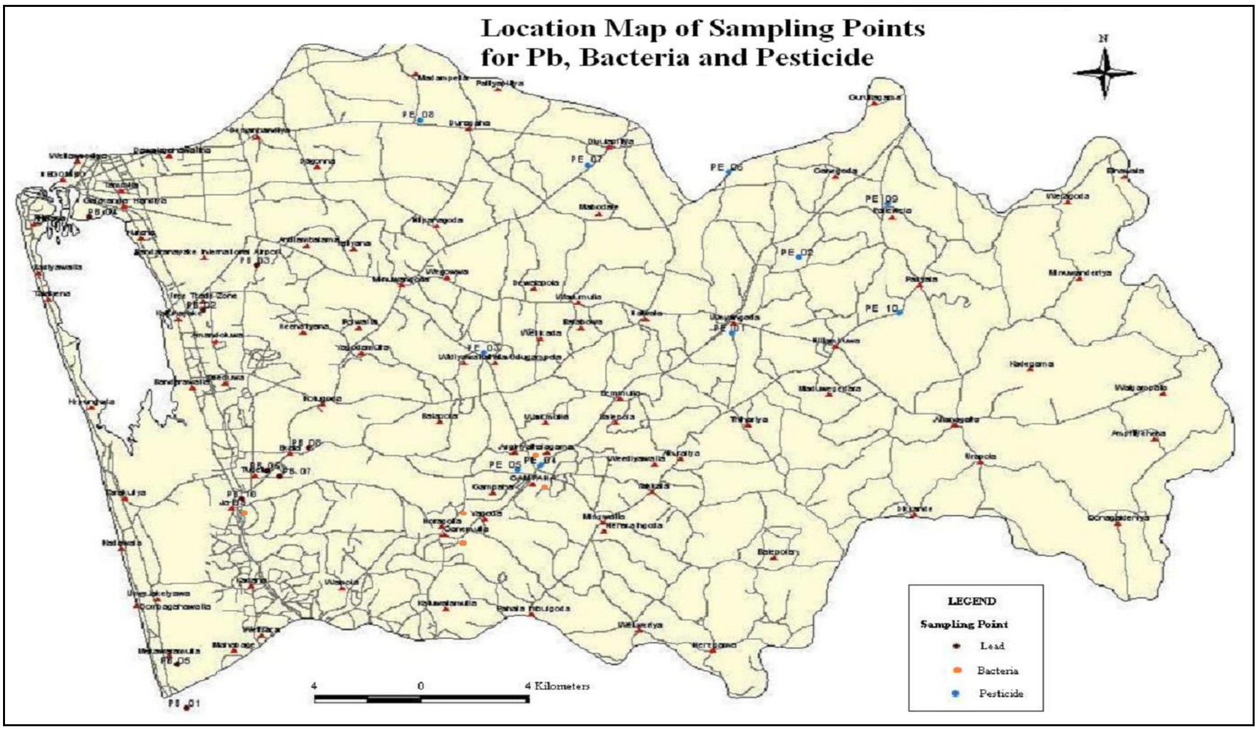

Figure 4: Location Map of Sampling Points for Pb, Bacteria and Pesticides

5. Aquifer Types in the Basin

The major shallow aquifer types identified in the Attanagalu Oya basin areLateritic aquifer, Alluvial aquifer, and the Coastal Sand aquifer.

5.1. Lateritic Aquifer

The major lateritic formations can be found in Ragama, Gampaha, Veyangoda, Andiambalama, Naiwela, Kimbulapitiya, Ganemulla and Katana areas. The water bearing lateritic formation behaves as a water table aquifer, where the water table can be found at about 7 metres at the top of the hills and 3 metres on the slopes. The most suitable sites for wells are the valley edges.

5.2. Alluvial Aquifer

Alluvium are one of the largest carriers of groundwater among the sedimentary formation**s** and those aquifers can be found in the major river valleys. They may vary from 8 -10metres in thickness and may extend laterally for several hundreds of metres on either side of the river course. The alluvial beds may compose of sand, clay, gravels etc. forming high potential aquifers. The alluvium beds in the Attanagalu Oya and other rivers can be considered as water table aquifer system. The wells located in this aquifer type indicate very shallow groundwater table that varies from 1 to 2 metres.

5.3. Beach Sand Aquifer

The unconsolidated sand belt running along the coastal belt specially from Ja–Ela, to Seeduwa and Katunayake up to Negombo. This sand belt is well developed in the Katunayake and Seeduwa areas. The Katunayake airport and the Katunayake Export Processing Zone fall within this sand belt and extract considerable amounts of water from the sandy aquifer system. In the Katunayake Export Processing Zone, 98 factories are established and part of their water requirement is supplied by surface water from Dandugam Oya and the rest is supplied by groundwater from 44 shallow and deep tube wells. The quantity of water extracted from these tube wells is estimated as 3000 cubic metres per day.The tourist hotels in the Katunayake area and most of the private establishments located along the coastal belt are also extracting groundwater from this aquifer. This aquifer is subject to pollution due to human, industrial, and agricultural activities in the area. Moreover, the Katunayaka airport extracts water from shallow tube wells constructed in the coastal sandy aquifer.

6. Issues identified within the basin

The **Divisional Secretariat Division**, Pradeshiya Sabas' and other relevant organizations in the basin area were contacted, the available data compiled and related water issues identified.

6.1. Divisional Secretariat Division – Negombo (Source – DS, Negombo)

- Water Scarcity - The areas surrounded by the Negombo lagoon such as Talahena - Peruwa and other 9 GND's have no water for drinking purposes. The piped water is available in the area but the supply is insufficient. Therefore, water scarcity exists in these areas. The total number of families that do not have sufficient waterin the area is 13,438 (Censes, 2004).The main water sources used by the people are dug wells, tube wells, and private tap lines.
- Water pollution due to industries -The industries established for production of boats-discharge their effluents into the Negombo lagoon resulting in considerable pollution. The sewage systems for many houses in the area and most of the drainage in the Negombo town are diverted to the Negombo Lagoon.

6.2.Pradeshiya Saba – Mirigama (source – Pradeshiya Saba Mirigama)

The area belongs to Mirigama Pradesiya Saba and is 189 km^2-in extent with a population of 144,000.Total number of families in the area with no proper water facility is 4500 (Census, 2004).

- Water Scarcity - A shortage of water is reported in the following areas.Kal Eliya, Nambuluwa, Koshena, Ehala Thawalampitiya, Botale, Galge Kanda, Thawalampitiya, Keenadeni Kanda, Danowita – Harankahawa, Ilukpathana, Weveldeniya – Pothawalakanda, Karagahatennakanda, Botale – Sonduruwatta, Botale – Ihalagama Andagala Kanda, Makkakeegoda Kanda, Botala – Mottewatta, Keenadeniya Town, Danovita Kalukanda, Horagasmankada, Pasyala – Embillapitiya watta, Mawahena, Kosetadeniya – Deegalakanda, Maladeniya kapuhenakanda, Metihakka watta, Pasyala Town, Kotakanda
- Major environmental problems - Due to the over extraction of water, people in the surrounding areas face water problems even in slight dry spells (ex. water spring at Botale). Pollution of water in the natural stream is due to the discharge of effluents of the Rubber factories and coconut mills.

6.3. Solid wastes

Dumping of solid wastes such as silages, plastic, metal cuttings and tailings is a common practice. Solid waste is a growing problem in Sri Lanka, aggravated by the absence of a proper waste management system. Inevitable this practice of solid waste disposal in landfills generates gas and leachatedue to microbiological composition, climatic conditions, refuse characteristics, and land filling operations. Piped water, protected and unprotected wells,tanks, and streams are the main sources of drinking water in the area. High concentrations of heavy metals (Pb, Cr, Cu) in shallow groundwater in the waste dumping areas (Katana and Negambo DSD) has been reported (Water Resources Research in Sri Lanka, 2004).

7. Results and Discussion

Some 600 water samples were collected and analyzed for seventeen physical and chemical parameters. The well network for monitoring of groundwater quality was 600 wells covering the entire basin. The number of wells selected for water quality analysis was considered representative for the chemical data of well water in the study area. Some 10 samples were collected from intensively cultivated areas and analyzed for Pb. In addition, 10 samples were collected from industrial areas and analyzed for pesticides and a further 10 samples were collected from urban areas of the basin for microbiological analysis.

8. Hydrogeochemical maps

Using the analytical data for 600 water samples of the Attanagalu Oya basin, geochemical maps were prepared for pH, Iron, Salinity, Total hardness, Sodium, and Potassium. Sri Lankan drinking water standards were considered in the determination of quality limits.

- pH concentration **-** The pH variation map of the shallow groundwater in the basin was prepared and different zones were identified (Figure 5). The pH values of zone 1 and 2 indicate–the shallow groundwater in these areas is acidic. This could be a serious problem. The zones with very low pH values (4 -5) are located in the central and southern part of the basin. The pH value for natural water is dependent on the carbon dioxide–carbonate–bicarbonate equilibrium. Presence of phosphates, silicates, fluorides, and other salts in a dissolved form may affect pH. Chemical changes such as reduction and oxidation, decomposition of organic matter, and many other causes may also affect the pH values in groundwater. The pH values of shallow groundwater in the western part of the basin fall in zones 3 and 4 have values ranging from 6 – 8.5.

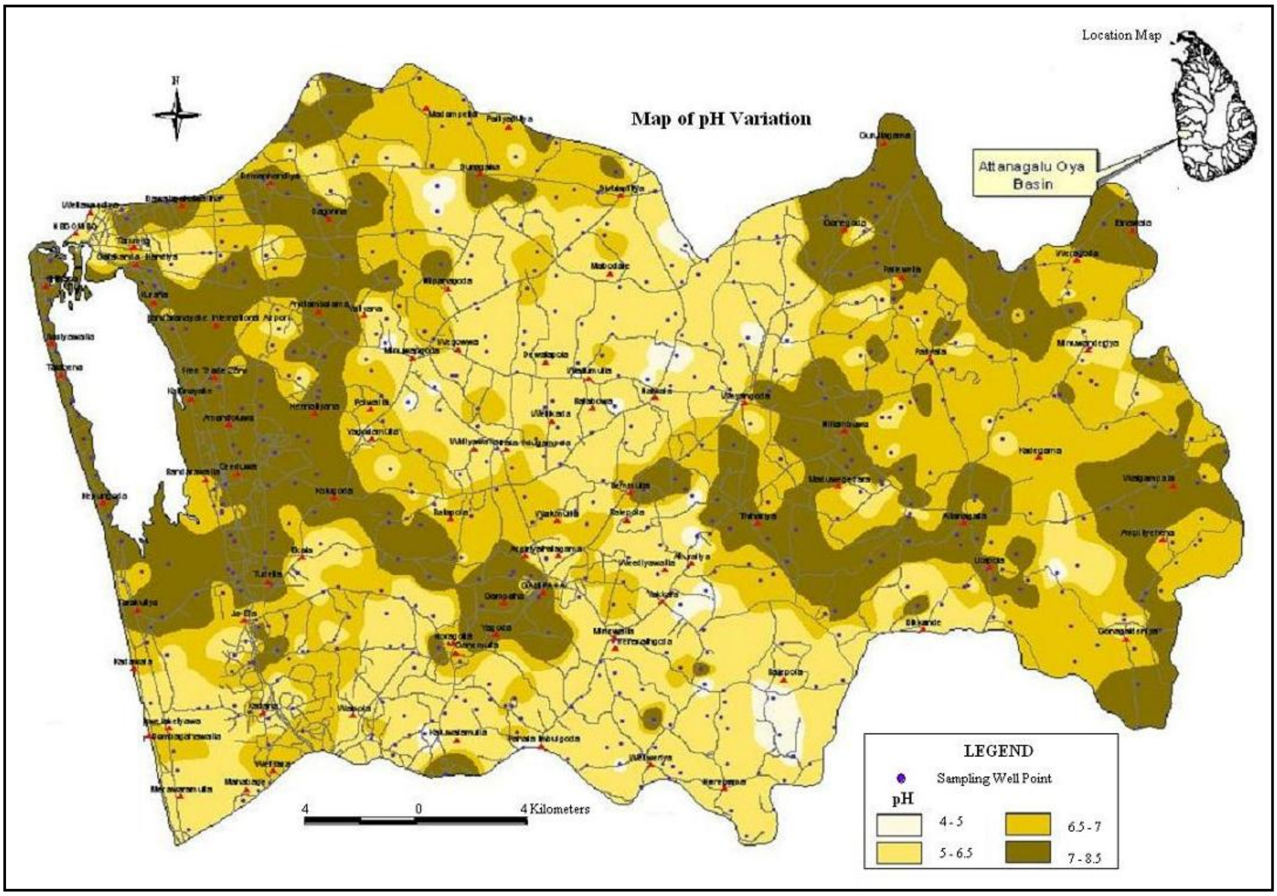

Figure 5: Map of pH Variation

- Electrical Conductivity-The map of electrical conductivity for shallow groundwater was prepared using the data collected from the basin (Figure 6). The zones with different values were demarcated according to the following criteria.

Classification	**Concentration µs/ cm**
1	5 – 250
2	250 – 500
3	500 – 750
4	750 – 1500
5	1500 -3500
6	3500 – 5000
7	5000- 8500

The majority of the shallow groundwater falls classification 1. The highest EC values are reported in the western coastal area.

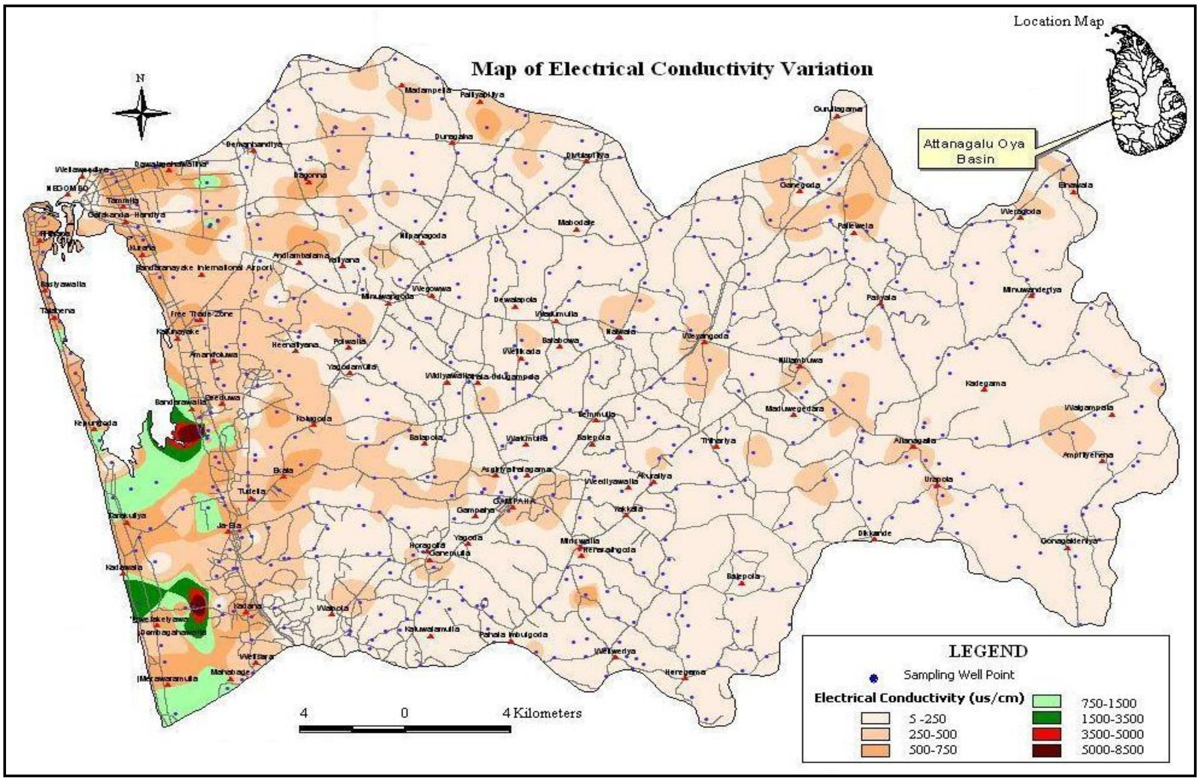

Figure6: Map of Electrical Conductivity Variation

- Sodium Concentration–A map of sodium concentration for shallow groundwater in the study area was prepared. The following criteria were used to demarcate the different zones.

Classification	Concentration (mg/l)
1	1 – 20
2	20 -40
3	40 – 60
4	60 – 80
5	80 – 100
6	100 – 120
7	200 - 800
8	800 – 1400

Majority of the area falls within classification 1 and 2. The highest values are in the western part of the basin.

- Potassium Concentration –***A map of*** *potassium* in the shallow groundwater for the study area was prepared. The zones were demarcated according to the following criteria.

Classifcation	Concentration (mg/l)
1	0.3 – 5
2	5 -10
3	10 -20
4	20 -30
5	30 – 40

Majority of the area falls within classification 1 indicate low levels of Potassium concentration. The potassium concentration in groundwater is very important factor for irrigation water.

- Fluoride Concentration - The map of fluoride in shallow groundwater was prepared. The zones with different values were demarcated according to the following criteria.

Classification	Concentration mg/l
1	0 – 0.2
2	0.2 – 0.4
3	0.4 -0.6
4	0.6 -0.7
5	0.7 -0.8
6	0.8 – 0.9

The southern and eastern part of the study area falls within classification1. The western, northern, and some of the central areas fall within classification 2.Patches of classification 4 can be seen in the central and western part of the study area.

- Iron Concentration - The iron concentration of shallow groundwater was evaluated and a map prepared. Most of the area of the basin falls in the range of 0 – 0.3 mg/l and 0.3 – 1.0 mg/l. Higher values are reported in the southwestern part of the study area.
- Salinity -The salinity levels of shallow groundwater were evaluated. The highest salinity values of shallow groundwater were found in the Western coastal belt. For most of the study area the salinity values were within the range of 0 – 0.2 mg/l.
- Total Hardness–The hardness of the shallow groundwater in the basin was evaluated. Different classifications were demarcated using the following criteria.

Classification	Concentration (mg/l)
1	5 -100
2	100 -250
3	250 – 400
4	400 – 600
5	600 – 800
6	800 – 1050

Most shallow groundwater for the study area has a total hardness within the range for classification 1. The highest values were reported in the western part of the study area.

- Lead -The analytical results of the water samples tested for Pb indicated that the values varied from 0.01 ppm to 0.02 ppm. All samples were within the permissible range of Sri Lanka's drinking water standard.
- Bacteriological pollution was reported in urban areas.

9. Conclusion

- The pollution of groundwater and surface water in the study area is mainly due to human, industrial, and agricultural activities. Wells in many urban areas are found to have bacteriological pollution. This was clearly observed in the urban areas of Ekala, Ja Ela, Negambo, Wattala, and Gampaha.
- The data collected from DSD's, Pradeshiya Sabas and other relevant agencies indicated that dug wells are the main water source for the families in the study area and a considerable number of families have no proper source for drinking purposes. This was reported in the DSD Meerigama, DSD Attanagalla, DSD Gampaha, DSD Negambo, and Pradeshiya Saba Areas of Mirigama and Katana.
- Significant erosion of river banks and extensive sand mining in some areas of the study area was identified as a serious environmental issue. This was reported in the DSD areas of Attanagalla, Gampaha, and Mirigama.
- pH values of shallow groundwater in the basin show uneven distribution throughout the basin. Shallow water is acidic in some parts of Naiwala, Minuwangoda, Ekala, Walpola, Henegama, Weliweriya, Pahala Imbulgoda, Weediyawatta, and Henarathgoda. pH values for the remainder of the study area fall within the drinking water standards.
- High salinity and iron concentrations were reported in the shallow groundwater along the coastal strip. Water quality of shallow groundwater in the remainder of the study area is suitable for drinking water use.
- These findings are critical for the proper design of a groundwater monitoring program that will provided long term data covering the dry and wet seasons for the study area.

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Groundwater Modelling to Predict Management Options for Kayts in Northern Sri Lanka

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Abstract Kayts is one of several islands which lie off the western end of the Jaffna Peninsula in the northern-most part of Sri Lanka. A low salinity groundwater lens is the only promising source of fresh water on the island. The return of refugees in the post conflict period has raised concerns for the quantity and quality of groundwater available for drinking and agriculture and on increased risk of seawater intrusion and upconing from unsustainably high extraction rates. The groundwater flow model MODFLOW, mass transport model MT3DMS, and salinity intrusion model SEAWAT were used to model the regional flow system and the interface separating the freshwater and saltwater flow systems, and for pumping and rainfall recharge scenarios. The water balance for the sand dune area in Kayts, found the available water from this region is 266 m^3/d. Preserving the sand dunes which are the only reliable source of potable water for Kayts remains a priority.

Keywords: Seawater intrusion, SEAWAT, modelling, water supply,

1. INTRODUCTION

Kayts is one of several islands which lies off the western end of the Jaffna Peninsula in the northern-most part of Sri Lanka. Like the Jaffna peninsula, Kayts and other surrounding islands have no streams or reservoirs of a perennial nature. Most of the islands in this region have very limited groundwater potential. A thin fresh water lens is present in the sand dune area on Kayts, which occupies a small area of the south-eastern part of the island (Fig. 1.). This low salinity groundwater lens that constitutes the Kayts aquifer system is the only promising source of potable water available for Kayts.

In most of the islands a thin fresh water lens accumulates water during the wet season, but these are exploited only for domestic use by shallow dug wells. The fresh water lens typically develops in limestone or coral reef formation and as such the storage potential is low.

During the 1990's there was a decrease in population due to people being displaced due to the continuing conflict in the region. However with the prospect of peace and refugees returning back to the peninsula and the islands the population is projected to increase. An increase in land development and projected population growth in this region has raised concerns for the quantity and quality of groundwater available for drinking and agriculture and on increased risk of seawater intrusion and upconing from unsustainable high extraction rates.

These concerns include the effects of increased groundwater pumping on the position of the freshwater – saltwater interface and the interaction of groundwater with ponds and lagoons. Groundwater discharge from springs along the coast plays an important role in the maintenance of ecologically sensitive areas. Declines in water levels due to increased groundwater withdrawals could have a detrimental impact on the environment and natural resources of this region. Particularly on islands, depletion of the fresh water lens can result in increased salinity rendering limited freshwater supplies unusable.

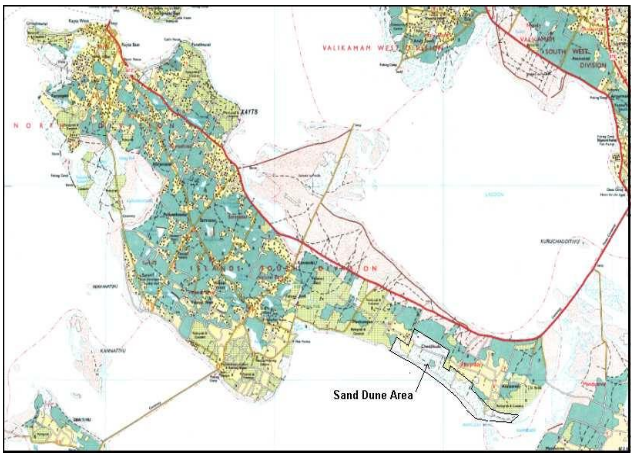

Fig.1. Island of Kayts showing sand dune area.

The intention of this study is to examine the behaviour of groundwater flow in this aquifer and come out with an appropriate management strategy to ensure sustainability in groundwater management for this region.

Studies were undertaken to develop sustainable management strategies for groundwater supplies for Kayts (Shanmuhananthan and Punthakey 2006). The objectives of the study are to develop groundwater flow and salinity transport models for the island of Kayts, estimate water balance for the freshwater lens, assess the potential for seawater intrusion and upconing for pumping and recharge scenarios, and the impact on fresh groundwater resources.

2. STUDY SITE

2.1 Location

Kayts is one of several islands which lie off the western end of the Jaffna Peninsula in the northern-most part of Sri Lanka. This island is narrow and elongated in shape and has a maximum elevation of about 4m. Like Jaffna Peninsula, Kayts has no streams or reservoirs of a perennial nature.

The extent of the Island's area is 64 km^2 and it has a coastline of approximately 69 km. Agriculture and built-up land covers 70% of the land area and 20% of the land is covered by sand or beach. The remaining 10% is covered by scrublands.

2.1.1 Sources of data

Geological data, type of aquifer and aquifer thickness details are collected from the driller's logs obtained from the Engineering Science report (Engineering Science, 1982) and from the Geology and soil maps published by the Survey Department.

The ground elevation of 220 dug wells on Kayts where water levels and chlorides were monitored monthly from 1979 to 1982 were extracted from the Water Resources Board's records and this was complemented by the findings of the topographical survey carried out under this study. The topographical survey covered 90 locations on Kayts.

Monthly water levels from 220 observation wells from 1979 tob1982 were obtained from records held by the Water Resources Board.
Possible range for the Hydraulic conductivity of the sand aquifer was determined based on the pumping data obtained from the pumping tests conducted by the Foundation and Water well Engineering (Pvt) Ltd under this study and from previous work undertaken on Kayts and described in the Engineering Science report.

Land use details were collected from the map prepared by the Survey Department.

Monthly rainfall data for the period from 1960 to 2004 were collected from Metrological Department records. Monthly evapotranspiration data were extracted from the Engineering Science report (Engineering Science, 1982).

Details of inland water bodies were collected from Agrarian Development Department's records.

Groundwater extraction related data such as human population, domestic water supply details, lift irrigation details and number of wells were collected from the Census, Water Supply and Drainage Board records, Department of Agriculture and Divisional Secretaries.

2.2 Hydrogeology & groundwater resources

The geology of islands to the west of the Peninsula has had the same origin as the Jaffna Peninsula. The Jaffna limestone formation in Sri Lanka is an important local aquifer and, together with thin sand layers that form an extensive cover for the limestone, provides a source of water for drinking and for irrigation. The bulk of the island of Kayts is covered by silt and clay overlying limestone. The clay is up to 3 meters thick with low permeability and does not serve as an aquifer. Dug wells have to penetrate the clay to reach the limestone before yielding water. Where the island narrows as it changes direction to the east, the clay is replaced by fine sand to form a two layer aquifer, sand over limestone. Because of the low permeability of these sands, a fresh water lens is able to form in this area. The area of exploitable aquifer system on Kayts extends eastward from Mankumpan to Allaipitty a distance of about 4 km, and southward from Jaffna road to the coast, a distance of about one and a third km (refer to the sand dune area outlined in Fig. 1). The rate of withdrawal from the aquifer is constrained by the permeability of the sand and thickness of the freshwater lens.

2.3 Aquifer Properties

Considering the importance of having a fairly accurate range of hydraulic conductivity and transmissivity for this study, at least for the sand aquifer, which seems to be the only promising source for additional developments, pumping tests in two test bores were conducted by the Foundation and Water Well Engineering (Pvt) Ltd. The data collected from this test was analyzed using the method derived from Darcy's law recommended by the Foundation and Water Well Engineering (Pvt) Ltd in its report. The results are given in Table 1.

Table 1 - Aquifer properties

Well No	Kay - 2	Kay - 1
Transmissivity m^2/d	28	35
Hydraulic conductivity m/d.	7	10
Aquifer thickness m	2	6

The area was demarcated into zones corresponding to the geology and each zone assigned appropriate values of hydraulic conductivities (Kh) and storage (S).

2.4 Zone division

Because recharge is a non–linear process, it is not possible to use average values of each controlling factor to derive an average recharge. Recharge should be estimated separately for each homogeneous zone; the spatially varying values are of course essential for groundwater modeling studies (Lerner, 1990). For this study, the total project area is divided into 7 groundwater extraction zones based on the availability of spatial coverage of groundwater withdrawal data and 9 recharging zones based on the geology, soil types and aquifer properties.

2.5 Land usage

The land use pattern plays a vital role in determining recharge and withdrawal of groundwater from the aquifer. Especially the type of vegetation cover decides the rate of actual evapotranspiration depending on its root constant and that ultimately decides the rate of recharge. Further percolation from irrigated lands may contribute significantly to the recharge of the aquifer. The map showing land use of Kayts is presented in Figure2.

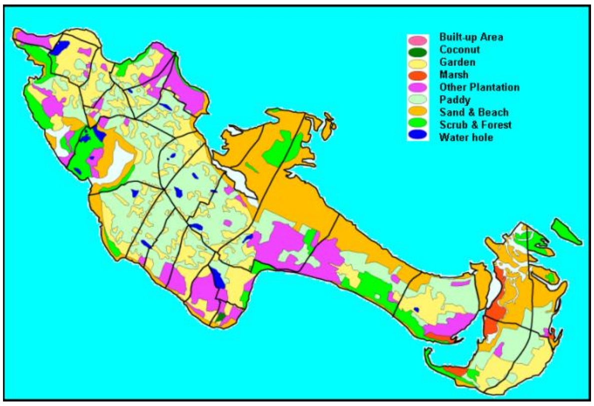

Fig.2. Map showing land use of Kayts.

2.6 Water-table & Salinity fluctuation

Rainfall is highest during the rainy season which extends from September to December. A minor monsoonal period extends from April to May. The aquifer in this region mainly gets recharged during September to December. From January onwards the groundwater table drops and in August the water level reaches its minimum. The Water Resources Board commenced measuring water levels in a network of 220 shallow wells on Kayts in early 1979 and extends to 1982. The data from this observation network constitute an exceptionally useful tool in assessing the current status of the groundwater system in the Kayts area.

Since Kayts is a small island, the coastal aquifers are usually in hydraulic continuity with marine water. Moreover the fresh water lens overlies progressively saline groundwater with depth. Excessive rates of abstraction with a consequent lowering of the water table may induce seawater intrusion and upconing, and thus contamination of the fresh water. Chlorides were monitored monthly by the Water Resources Board from 220 wells from April 1979 to December 1982.

2.7 Rainfall recharge

Runoff and infiltration due to precipitation events depend upon the amount and the intensity of the rainfall as well as the antecedent moisture condition of the soil profile (Athavale and Rangarajan, 1990)

Apart from these factors, the storage capacity of the aquifer also plays an important role in determining the recharge quantity. Even though the rainfall during Sept '80 to Dec '80 is 40% less compared to the rainfall during Sept '81 to Dec '81, there is no significant difference in the depth of water table gain. This clearly reveals that once the storage has reached its optimum level, there will be less recharge and the portion of runoff will be more.

However, most of the formulas do not consider these factors and as a result, the runoff is either overestimated or underestimated and in turn it affects the recharge. In this exercise, during the course of calibration, an attempt was made to establish a relationship between the rainfall quantity and percentage of recharge by taking the above factors into consideration.

2.8 Evapotranspiration

Water is held in a soil moisture store. Precipitation adds to the store, evapotranspiration depletes it. When full, excess precipitation is routed to groundwater as recharge. The most difficult item to measure is actual evapotranspiration, and in general a conceptual quantity called 'potential evapotranspiration' is defined. Good data on actual evapotranspiration is equally important as good precipitation data. Unfortunately actual evapotranspiration is rarely measured except in research projects. The average potential evapotranspiration values of various methods described in the Engineering Science report is used in this exercise.

2.9 Water Bodies - Groundwater Interaction

Recharge from Surface Water Bodies is sometimes underestimated because it is neglected. On the other hand, once irrigation has been recognized as a recharge source, the quantities are often overestimated because all losses are assumed to become recharge. Losses from irrigation occur in two overlapping areas (a) canals (b) fields. (Lerner, 1990).

According to the statistics given in the Jaffna District Statistical Hand Book, there are 50 ponds irrigating less than 400 ha of cultivable lands on Kayts. The total water holding capacity of these ponds is around 2200 ac.ft (2.7 million m^3 of storage). Most of them are small limestone sinkholes covered with clay beds. The average irrigable area and storage capacity of these ponds are 8 ha and 44 ac.ft (0.05 million m3 of storage) respectively. These statistics clearly indicate how small these ponds are.

A surface water body such as a lake or pond contributes water to the groundwater system or drains water from it depending on the head gradient between them. Such water exchange affects pond levels and groundwater heads. The seepage losses from reservoirs depend on the permeability of the reservoir bed and the flanks and are mostly a loss due to deep percolation. The methods of estimation of irrigation storage losses differ from region to region and depend on the principal factors such as head gradient, permeability of reservoir bed, thickness of accumulated silt and volume of storage which governs the percolation.

It is stated in the Engineering Science report that in the northwestern part of the Kayts, the limestone sinkholes covered with grey–brown clay create numerous ponds, some of which provide irrigation water during the dry season when the actual water table is below the bottom of the ponds. This implies that the water table and surface water bodies have less interaction due to the less impervious clay bed.

The method of estimation of recharge from surface water bodies and irrigated fields described by Ponrajah (1984) is one of well-tested method and is being practiced for several years by the Irrigation Department. This method has been adopted to estimate recharge from surface water bodies and irrigated fields in this exercise.

2.10 Groundwater withdrawals

The basic details required for the computation of Groundwater withdrawal such as human population, domestic water supply details, cultivation details, numbers of wells, extent of forest area are collected for each GN division. Using this basic data, groundwater withdrawals for each season were calculated separately for each zone. For the scope of this study, the total project area falling within the 25 GN Divisions are clustered into 7 water usage zones as shown in Figure3.

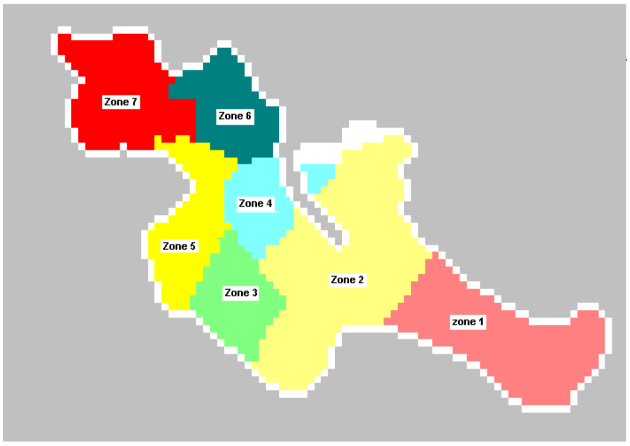

Fig.3. Map showing water use zones.

3. Conceptual Model

The groundwater models used were MODFLOW to model the flow system (McDonald and Harbaugh, 1988), MT3DMS to model mass transport (Zheng and Wang,. 1999) and, SEAWAT to model seawater intrusion (Guo and Langevin, 2002).

A 200 x 200 m grid was used to model the island of Kayts and the grid covered the main sand dune aquifer in the southeast of the island. To accommodate the horizontal component of flow, the groundwater system is considered to be formed of a series of layers, each of which is given a mathematical representation of the aquifer characteristics for that layer. The model consists of 7 active layers that correspond with the sand layer and the limestone formation.

The gridded area is between 96000 East and 114000 m East and between 488000 m North and 500000 m North. The model consists of 60 rows and 90 columns and 7 layers. The model was run for four years from January 1979 to December 1982 using 48 monthly stress periods, as data sets were available to aid in model calibration.

3.1 Boundary Conditions

Two types of boundary conditions are used in the model to define the sea boundary surrounding the peninsula. General head boundaries are used for the first two layers and constant heads are used for the remaining layers. Flows across model boundaries were specified using the general head boundary package in MODFLOW. Flows are controlled by head gradients between boundary heads and model heads, and the direction of flow is controlled by either of the heads whichever is the greater. The conductance term is the other parameter that controls the rate of flow across the boundary.

4. MODEL CALIBRATION

The procedure adopted in calibrating groundwater models is essentially a trial and error process involving adjustment of parameters and fluxes until model responses match field observations according to pre-set calibration targets. Adjustments in parameters are required because each parameter is associated with a level of uncertainty. The range of uncertainty influences the level of adjustment applied. Typically the procedure involves incremental changes in aquifer parameters within realistic limits such that there is a gradual improvement in the models ability to simulate field measured piezometric heads and salinities.

4.1. Steady state calibration

Aquifer parameters, hydraulic conductivity and storage were adjusted by trial and error so that the head simulated contours generated by the model matched the observed head contours at the end of a recharging season. MODFLOW was used for this simulation. The main purpose of the steady state model was to generate initial heads for the transient state model in addition to calibrating aquifer parameters, recharge and ET.

The performance of the calibrated steady state model is quantified by spatial calibration of heads in December 1979 and comparison of measured and predicted heads at selected bores in December 1979. The observed and predicted head contours for the steady state model is shown in Fig. 4, and the observed versus modeled heads is shown in Fig. 5. The match is found to be reasonably good. This confirms that the steady state model has been well calibrated and it can generate fairly accurate initial heads for the transient model.

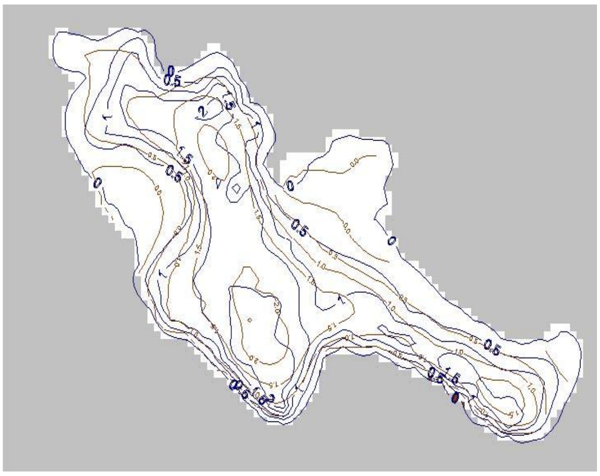

Fig 4. Steady state model calibration

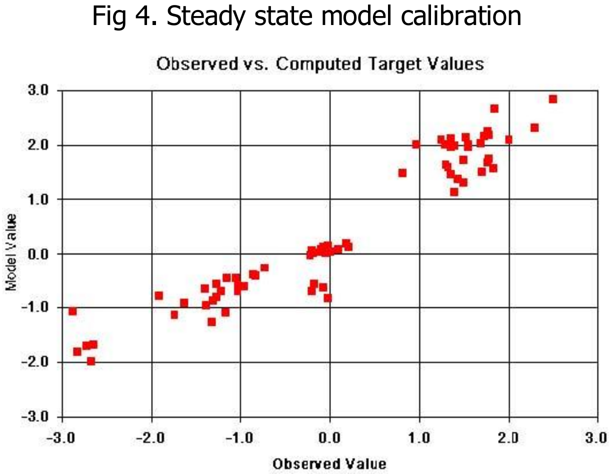

Fig 5. Observed vs. simulated head for the steady state simulation

4.2. Transient model calibration

The boundary conditions were the same as for the steady state model. Initial heads were imported from the steady state model. This model was calibrated with the data available for the four year period from January 1979 to December 1982.

Estimated values of recharge, evapotranspiration and pumping were used in this simulation run. Transient simulation allows comparison of temporal head changes in the aquifer.

The performance of the calibrated transient model is quantified by calibration of bore hydrographs from April 1979 to December 1982. The model computed head and salinity values are compared with the measured values in ten locations. The model predicted head hydrograph showed close match with the measured values although there are instances where the modelled salinities deviate from that observed.

Fig. 6, 7 for wells 13 and 89 shows a good match between observed and modelled heads. Analysis of measured and computed water levels showed a regular pattern with peak in water levels reached at the end of the wet season in January and lowest water levels at the end of the dry season in September. The seasonal variation in heads is pronounced and is simulated accurately by the model, and trends are predicted very well.

In Fig. 8, well 13 shows the model is able to simulate salinity trends with reasonable accuracy however the salinities are under predicted at times. The most probable cause for the deviation is that well 13 is in the area of the groundwater supply zone and the uncertainty of pumping records was the most likely contributing fact.

For well 89 the salinity trends are predicted with much greater accuracy as this well was far outside any zone of pumping influence. Given the high degree of both spatial and temporal variability that one encounters in the field, the match between modeled and simulated salinities is remarkably good.

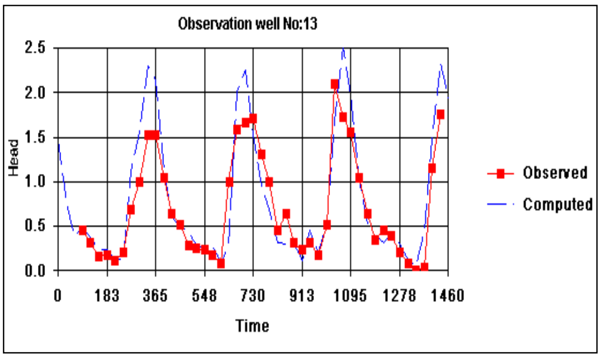

Fig 6. Observed and simulated heads for bore 13.

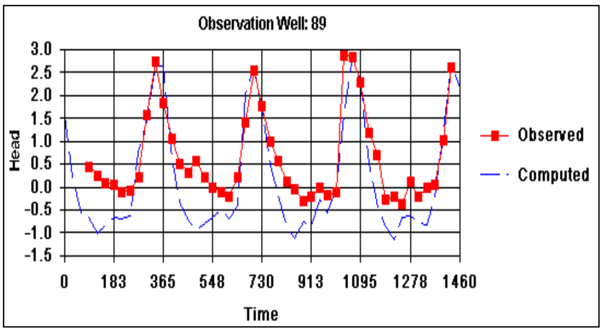

Fig 7. Observed and simulated heads for bore 89.

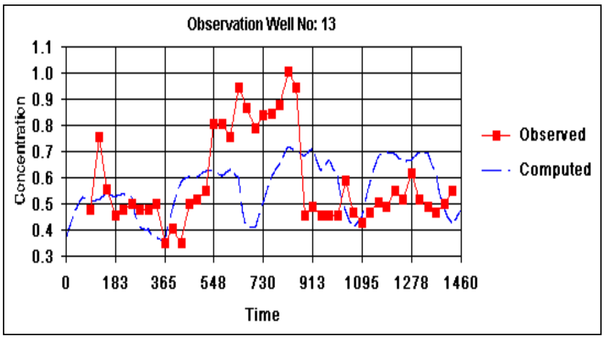

Fig 8. Observed and simulated salinity for bore 13.

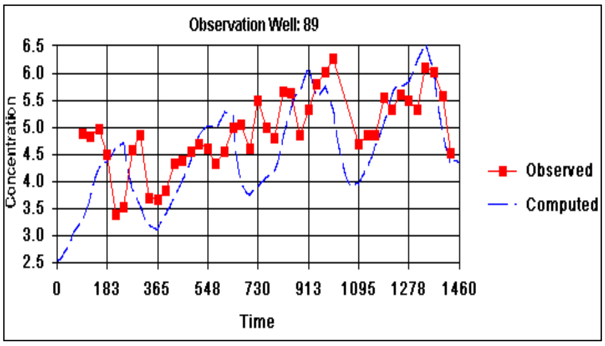

Fig 9. Observed and simulated salinity for bore 13.

The salinity distribution of groundwater during December 1982 for the wet period and in August 1982 during the dry period are shown in Fig. 10. This figure reveal that the water quality is beyond the permissible limit (2000 mg/l) in most parts of Kayts even at the end of recharging period except in the sand dune area and a small area near Naranthani.

This situation becomes worse during the dry period and at the end of the dry period a narrow stretch of freshwater lens is available only in sand dune areas. Fig. 7 shows that the area of fresh water lens with less than 2000 mg/l salinity only covers the sand dune areas. Therefore utmost care should be taken to limit groundwater extraction in all areas except in the sand dune area where some additional extraction is possible.

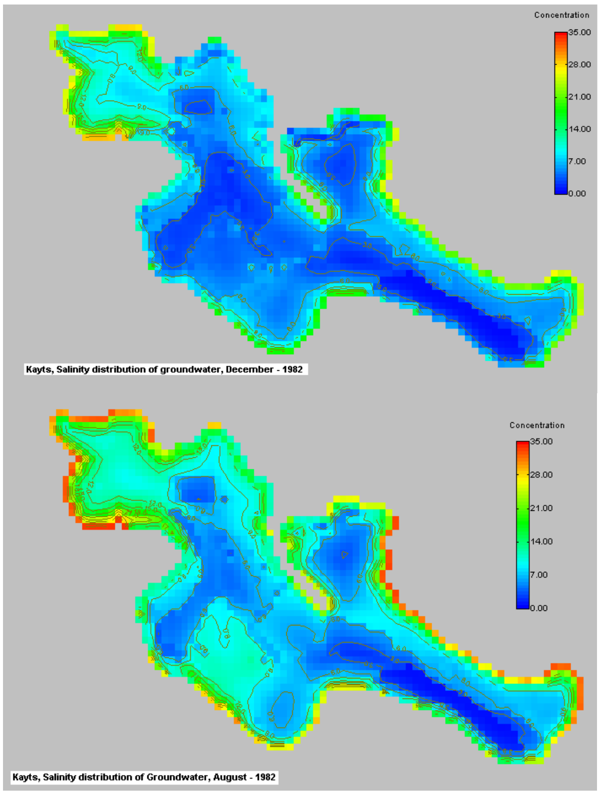

Fig 10. Salinity distribution (kg/m^3) during the wet season (Dec 82) and the dry season (Aug 82)

A small zone of fresh water found at the end of the recharge period near Naranthani area does not exists at the end of discharging period. In view of this simulation it is strongly recommended not to increase extraction during the discharging period.

5. Water balance for model

The water balance for the regional model is presented in Table 2.

Table 2 - Annual average water balance			
Components	**Value**		**%**
Surface			
Rainfall	+	1,185	100.0
Evaporation above WT	-	459	38.8
Surface runoff	-	356	30.0
Infiltration (recharge)	-	370	31.2
Aquifer			
Infiltration (recharge)	+	370	100.0
Pumping (Domestic)	-	23	6.1
Pumping (Agro)	-	100	27.1
Pumping (Garden)	-	49	13.3
Deep rooted tree	-	17	4.6
Evapotranspiration	-	130	35.1
Net flow out to sea	-	49	13.4
Change in Storage	-	2	0.4

6. Scenario Analysis

The Kayts regional model was simulated using the data set available for the four year period from January 1979 to December 1982. The model results reveal that additional quantity of groundwater is available only for the sand dune area of Kayts. The water balance for the sand dune area indicated that available water from this region is 265 m^3/d. Fifteen year scenarios starting from January 1983 were carried out to determine sustainable groundwater extraction rates and the most suitable method of pumping for the region.

7. Recommendations

Based on the results of the studies following recommendations are made for the sustainable management of groundwater resources in Kayts.

Maintaining the source

The sand dune area in Kayts is the only promising water source for Kayts island. Because of the relatively low permeability and high storage potential of these sands, a fresh water lens is able to form in this area. Following actions are recommended for the sustainable management of this water source.

- No sand mining be allowed.
- Limit development in this area which can reduce recharge to the aquifer.
- Agriculture activities have to be in limited scale to reduce the likelihood of pollution.
- Controlling the agriculture extent during dry season

Controlling the agriculture during dry season

The groundwater withdrawal for domestic consumption is less compared to agriculture consumption and domestic consumption can not be curtailed as it is an essential basic need. The cultivable extent for the recharging period need not be curtailed, since the main source of irrigation is rainfall during this period and lift

irrigation is a supplementary source of irrigation.
Therefore it is recommended to set a ceiling for the cultivable area for the dry season according to the available groundwater potential at the end of recharging period.

Introducing modern water saving technologies

It is recommended to introduce modern water saving technologies such as sprinkler irrigation and drip irrigation, by which evaporation losses can be reduced. This will require a farmer education and technology transfer program.

Conducting research to identify suitable crops

It is also recommended to extend research to identify alternative high value crops that can give satisfactory yield with comparatively less water consumption.

Appointing empowered regulatory committees.

The major groundwater issues are related to the fact that groundwater is essentially an unregulated resource. Therefore it is recommended to appoint a groundwater management authority consisting of the relevant sector representatives to ensure the sustainable management.

Rehabilitation of abandoned irrigation schemes

It is recommended to restore the abandoned small ponds for irrigation schemes in this region to tap more surface runoff for groundwater irrigation which would not only substitute a part of groundwater irrigation but also would enhance the groundwater potential through recharge of storage losses and irrigation losses.

Rehabilitation of salt water exclusion schemes

Salt water exclusion schemes can play a vital role in controlling sea water intrusion along the coastline if they are properly designed, constructed and maintained. Salt water exclusion schemes not only prevent seawater intrusion but also help to harvest rainwater which in turn influences the ground water recharge. Therefore it is highly recommended to rehabilitate salt water exclusion schemes and to allocate sufficient funds for their operation and maintenance.

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Development of Steady State Groundwater Flow Model in Lower Walawa Basin Sri Lanka (Integrating GIS, Remote Sensing and Numeric Groundwater Modelling)

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Abstract

The study focused on the simulation of groundwater flow system in lower part of Walawa Basin Sri Lanka using GIS, RS and Groundwater modelling. The aquifer system was modelled using PMWIN as pre and post processor for MODFLOW assuming steady state condition. Only the upper aquifer was modelled under unconfined condition represented by a single numeric layer. The grid cells of the model were taken 250x250m and the twenty five thousand six hundreds numbers of active cells were used to represent the entire study area which is approximated to 1600 km^2 in extent.

Model area and surface water bodies were delineated by the SRTM DEM optimisation and use of the topographic maps. Aquifer properties were assigned based on the analysis of pumping test data. Recharge to the major component of the system was considered to take place as direct infiltration of precipitation, or as lateral subsurface inflow. The Chloride Mass Balance Method (CMB) was employed to estimate the recharge.

A combination of trial and error and automatic methods were used to calibrate the models using the observed hydraulic head. Manual calibration was performed until the Root Mean Square Error (RMSE) reached 6.5m. The Parameter estimation program (PEST) was used for the automatic calibration. This resulted in a further reduction of the (RMSE) error to 4.5m. Then a sensitivity analysis was carried out showing that recharge is the most sensitive parameter of the model.

Optimised parameters (transmissivity and recharge) are spatially distributed over the model area. Transmissivity increased from Upper part to the lower part of the area. But high recharge can be observed in the agricultural area while the discharge takes place in the flat area belongs to the lower part of the study area.

INTRODUCTION

Numeric groundwater modelling is a critical component of modern hydrogeology because it can be applied to test specific hypotheses, predict future behavior, or simply to organize available hydrogeological data in a consistent conceptual framework. Numerical models basically represent an assembly of many single cell models. Tremendous advance in computer technology has made the standard procedure for the solution of groundwater flow and mass transport problems. This research is to develop the regional groundwater model which has capability to reproduce the field measured data under steady state condition.

OBJECTIVES

The purpose of this work is to study the groundwater flow system in lower part of Walawa basin integrating GIS, RS and numeric groundwater modelling.

The primary objective of the study is to understand the aquifer system conditions and from that understanding, develop realistic and scientifically accurate groundwater flow model under steady state condition representing the physical characteristics of the aquifer incorporating the relevant processes. Primary objective was achieved through the following sub objectives.

- Understand the hydrogeology of the study area by analysing available field data and remote sensing images.
- Investigate the system behaviour with regard to aquifer connectivity and distribution of the aquifer properties in GIS platform.
- Develop a conceptual model and based on that to build a numeric model which can be used to simulate the groundwater flow pattern under steady-state conditions.

METHODOLOGY

Data are collected from databases, maps and reports as well as through new field measurements. These data were analyzed in order to determine the aquifer properties such as, transmissivity, hydraulic conductivity, lithological variation and well yield required as enable to input into the numerical model. During the study six major stages were distinguished: data collection, satellite image processing, digitising building a data base, spatial analysis and modelling combining GIS techniques in ILWIS, Arc View 3.3 and PMWIN. The methodology adopted in the study is presented in Figure1.

STUDY AREA

Walawa Basin lies within the 100167 -181218 m Northing and 175420-234471 m Easting in South East dry zone of Sri Lanka having area extent of 2492 km^2 (Figure 2). The lower part of the Walawa catchment (1600 km^2) which has a high water demand due to the high population was selected for the detail study using GIS, RS and developing a numeric groundwater model.

Climate

The climate of Sri Lanka is known as a tropical monsoon climate with two monsoons as South-West monsoon and North-East monsoon. Eighty five percent of the catchment area belongs to the dry and intermediate zone the rest lies on the wet zone of Sri Lanka. About twenty five numbers of rain gauge stations and two agro meteorological stations are established in and around the study area.

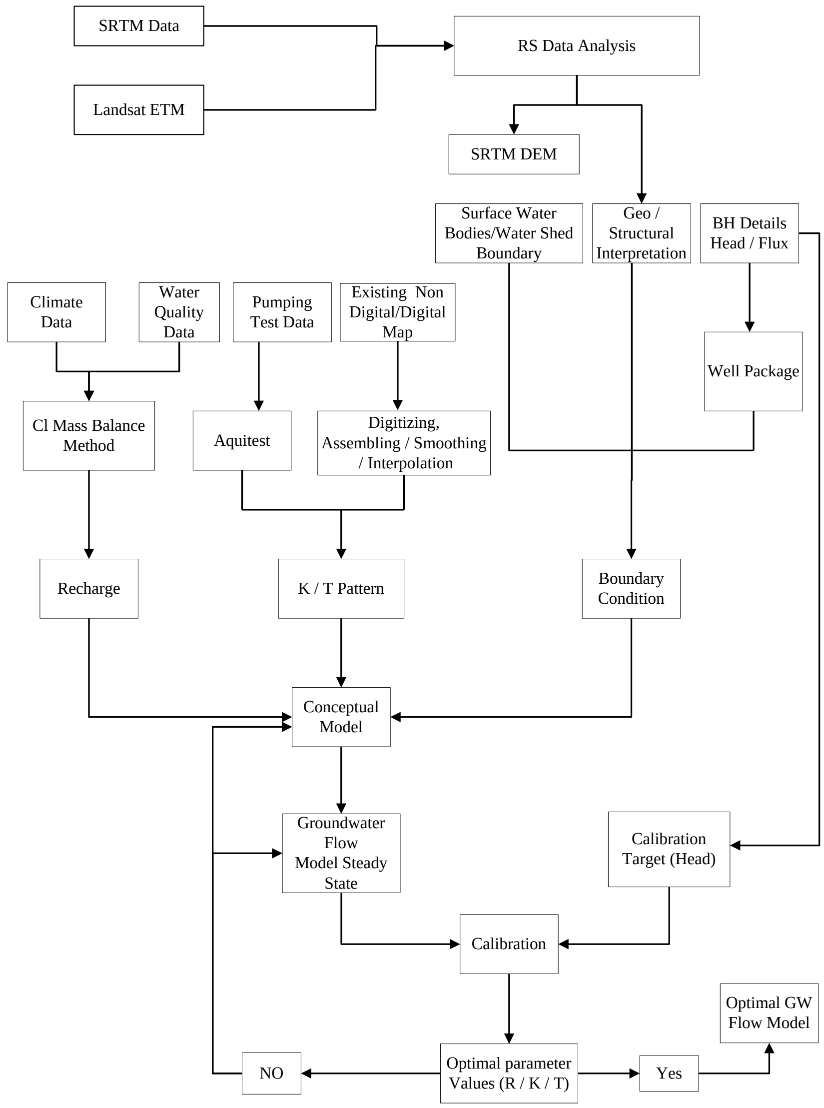


Figure 1 Methodology

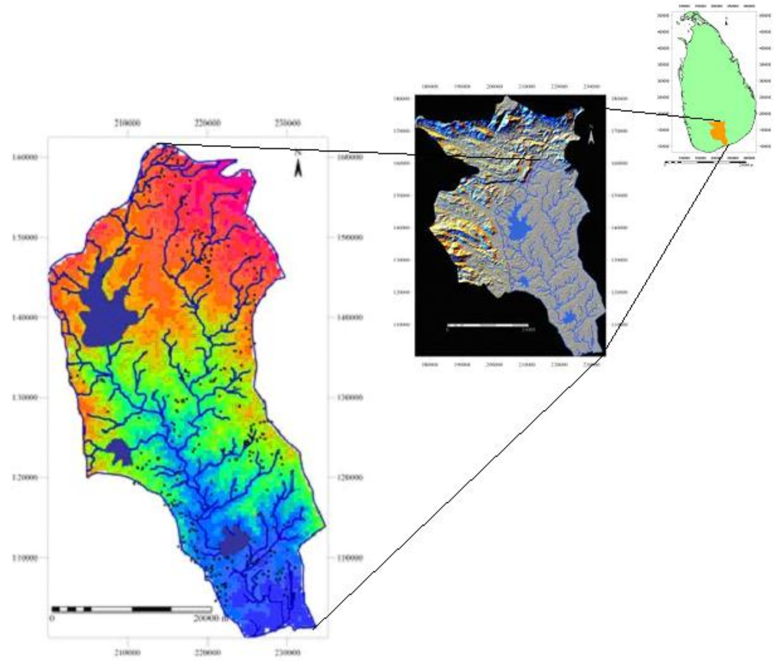


Figure 2 Study Area

Rainfall

Rainfall is the main water source of the catchment. The rainfall data of the rain gauge stations have been collected and analysed. The mean annual precipitation has a bimodal distribution with most of the rainfall occur during the South West monsoon season from March to July and North East from October to January (Figure 3). Dethanagalla gauging station in the upper parts of the catchment reported a maximum annual rainfall depth of 2500 mm and it belongs to the wet climatic zone of Sri Lanka. Minimum annual rainfall depth, i.e.950 mm was reported at Ambalantota gauging station, located close to the sea, in the lower part of the study area and this region belongs to the dry zone of the country. Generally the entire catchment receives an annual average rainfall depth of 1860 mm.

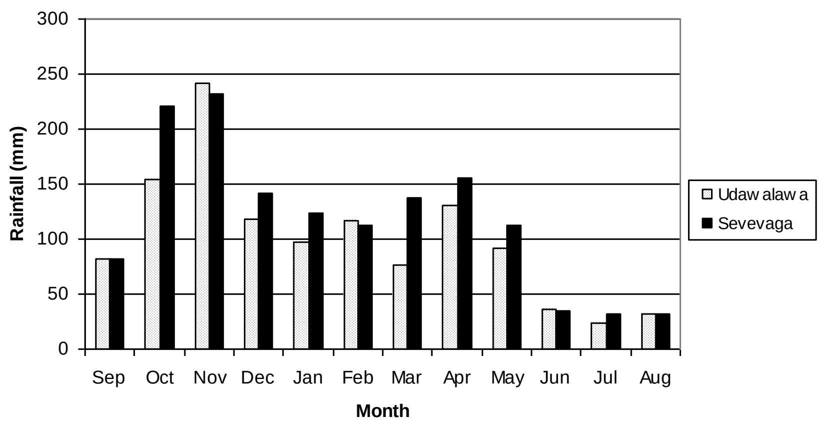


Figure 3 Annual Rainfall Distributions (1960-2001) (Source: Meteorological Department Sri Lanka)

Evaporation, Temperature and Relative Humidity

Pan evaporation data were collected from two agro-meteorological stations within the study area. Range of the average monthly pan evaporation of the catchment falls between 6.00 to 3.43 mmd^{-1}. The highest pan evaporation is reported during the months of July, August and the lowest in December and January. Temporal variation of evaporation with rainfall is illustrated in Figure 4. The catchment is experiencing long dry period with more sunshine over the year. Relative humidity, temperature and wind speed also comparatively high during this period. Because of that the average annual evaporation of the catchment, which is estimated as 1625 mm is also relatively high.

The mean annual temperature of the study area is about 32 ^{0}C with a fluctuation of 4 ^{0}C. The highest temperature was recorded during the month of July which is 37 ^{0}C while the lowest recorded in April around 27^{0}C.

Average mean monthly relative humidity from 1990 to 2002 at Sevenagala and Udawalawa gauging stations were analysed. Sevenagala station reported the highest, 89% and the lowest 60%. Monthly relative humidity at Udawalawa station is varying in between 99% to 66%. Both stations show their peak values during the rainy period in January, February following the lowest in July, August. Difference between the monthly humidity in day time and night time is ranging from 30% to 10% for both stations.

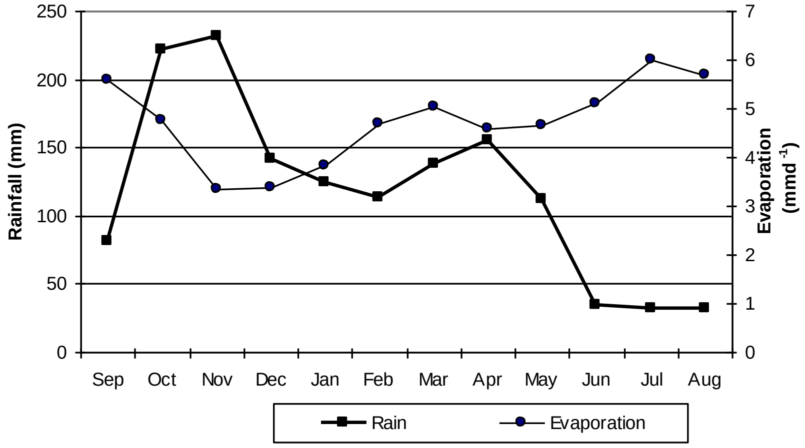


Figure 4 Temporal Variations of Rainfall and Evaporation

Geology ,Geomorphology and Surface Geo-structural Features

The rock types of the area were divided into three main groups, the Highland Series, Vijayan Complex and Quaternary deposits based on the geologic time scale of their origin. The Highland Series occupies a broad belt running across the centre of the island from Southwest to Northeast. It is mainly composed of charnockitic gneisses and metasediments. In the Southern regions, the series is present on the Western side from Timbolketiya to Hambantota, running towards ~~out to~~ sea near Amblantota. The Vijayan Complex occupies the greater part of the lowest peniplain, both Northwest and Southeast of the Highland Series. The lithology is made up of a varied group of gneisses, granites and small bodies of granite, and dolerite dykes have also been intruded into the crystalline rock during the Precambrian and Tertiary eras. The Vijayan complex has the largest aerial extent in the study area, covering approximately 80 percent.

Sri Lankas morphology is determined largely by its geologic history, rock types and structure. Generally three major morphological zones can be distinguished as highland region; the elevation is more than 1000m which consist with hills and valley land forms as well as major escarpment. Upland region with the elevation in between 1000-200 m and rest of the area with elevation less than 200 m is almost flat and slopes gently towards the sea.

Lineament analysis provides insight into movement and storage of groundwater and therefore gives important guidance for groundwater exploration. In remote sensing applications Landsat Enhanced Thematic Mapper (ETM) data in digital format is preferred over other satellite data due to the availability of near to mid-infrared bands, which is extremely useful for terrain and lineaments analyses. The study area shows regional structural trends in a NNW-SSE / NW-SE direction. An axial trace of the regional fold system is also similarly aligned. Major shear zones that run either sub parallel or oblique to the regional strike, dissect the area into several blocks. Among the brittle structures, two prominent joint systems developed in NW-SE and E-W orientations are significant.

Soil Types and Landuse

Study area consist of three major soils types. Immature brown loam is dominated in the upper part of the catchment associating with charnockitic gneiss. High rainfall associated in the area influences the formation of this soil. Reddish brown earth Solodised Solonetz is well developed in the lowest peniplain area with the association of Vijayan complex rocks. It occurs close to the sea and this part received relatively less rainfall compared to the other part of the study area and it is characterised by the present of salt in parent material. Alluvial soils can be distinguished along the river and surface water bodies, while beach sand and dune sand are limited to the coastal area.

Land use pattern is also important in groundwater studies, because it is a prominent factor affecting the recharge and the groundwater quality as well.

Landsat Enhanced Thematic Mapper (ETM) image was classified to determine the prominent land uses types of the area and summarised details in Table 1. Agriculture is the dominant land use pattern in the area. Land use distinguished as chane (Traditional shifting cultivation) representing the majority of the catchment. Paddy cultivation is limited to the lower part of the area, associated with river and water bodies. Areas with high elevation are associated with other plantations such as tea, rubber, coconut and teak.

Table 1Land use Types of the Study Area

land use	%
Chane	21
Forest	10
Paddy	21
Other Plantation	2
Scrubs	33
Water Bodies (working and abandoned Tanks)	4

DEVELOPMENT OF CONCEPTUAL MODEL

After defining the purpose of the model the most important step is formulation of a conceptual model, prior to the development of a numerical model. The purpose of building a conceptual model is to simplify the field problems and organise the associated field data, so that the system can be analysed more readily (Anderson, M.P, 1992). Because of that it is important to identify the hydrostratigraphic units as well as mechanism of recharge, discharge and groundwater flow through the aquifer. Moreover the conceptual model is very much important to establish the model framework i.e. dimension, type of model as well as selection of model codes.

The system was conceptualised for simplicity incorporating all important features and processes by simplifying assumption on the topography, soil, land use, hydrology of the area. Further it incorporates geological data (drill logs), geophysics (resistivity survey), hydrogeochemistry (major ions, mixing, water types), and various hydraulic measurements such as water levels, pumping tests and rainfall data.

The study area is adjacent to the ocean. Therefore the Southern boundary of the model can be taken as constant head boundary. East and lower west part of the model boundary is assigned as a no flow boundary assuming that surface water divide coincides with the groundwater flow divide. The North and upper west side of the model boundaries were demarcated as also no flow boundary condition assuming hills in the plains with outcrops are impermeable to groundwater flow. Due to lack of data the study assumed all the streams enter through this boundary flows to the sea without contribute to recharge along the boundary. The entire study area is surrounded by no flow boundary except the Southern end which is considered as constant head boundary (Figure 5).After the simplification three aquifer systems separated by granitic gneiss layer were identified within the study area. Pumping test analysis results give an indication about the interaction between the aquifer units. Since the data is not enough to determine the connectivity of entire aquifer system it was assumed that the connectivity may be due to localised fractures which are available in the area because majority of the drilling recodes do not provided any information on the fractures in the granitic gneiss layer which separate the upper and lower aquifer units. Hence, it was assumed that the upper aquifer system which was studied by modelling lies on the fully impermeable granitic gneiss layer.

River, streams and three huge storage tanks are available in the model domain as surface water bodies (Figure 5). Small abundant tanks were excluded form the model for its simplicity. The stream network of the area is well connected to the aquifer which provides water to the stream as base flow during the dry season. Furthermore, it was assumed that rivers and tanks are hydraulically well connected to the groundwater hence not impermeable at the bottom.

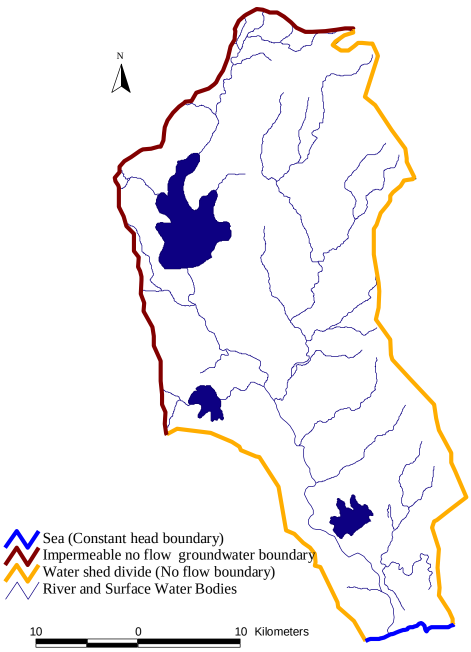


Figure 5 Boundaries of the Model Area with Major Internal Features

Type of the Model

A fully three dimensional distributed model was applied during the study that primarily focused on groundwater flow system. The model was established under unconfined conditions.

Code Selection

The selected code for the numerical model was MODFLOW; a modular three dimensional finite difference groundwater flow model developed by the United State Geological Survey (USGS) (McDonald and Harbaugh, 1988) with graphical interface for MODFLOW, MODPATH, PMPATH, MT3D, PEST, and UCODE, known as Processing MODFLOW for WINDOWS 5.1 (PMWIN 5.1) (Chang and Kinzelbach, 1998). Selection of the code is justifiable. Because, MODFLOW is a finite difference groundwater modelling code which has been extensively tested in various different environments under different conditions as one dimensional, two dimensional quasi- or fully three-dimensional systems. It is widely accepted in groundwater modelling. Theory behind the model is well documented and relatively easy to understand, can be applied to realistic conditions and it can be used for future developments of the model.

Model Domain and Discritization

Figure 6 shows the model domain with horizontal discretization. Approximate aerial extent of the model domain is 1600 km^2 with 62.5.km length and 25km width. The horizontal extent of the area is referenced with the coordinates of 200,000:100,000 m minimum and 235,000:162,500 m maximum. The vertical extent of the model unit was considered on the basis of the results of analysis of resistivity data, drilling records and the hydraulic head data.

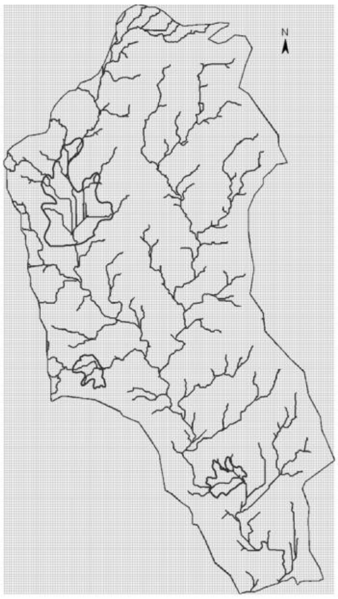


Figure 6 Discritization of Model Domain

By approximating the variation of internal properties, boundaries, and stresses of the system the model domain was discretized into 140 columns and 250 rows using the 250 x250 m grid spacing, resulting in thirty five thousand grids cells (Figure 6). Not all the grid cells are active cells. Cells outside the no flow boundaries were defined as inactive. The total number of active grid cells in the model is twenty five thousand six hundred. These dimensions are reasonable because to minimise a variety of sources of numerical errors, the model grid should be designed using the finest mesh spacing that is possible, given limitations on computer memory and computational time. Since the study is carried out with the interest of identifying the regional flow pattern of the area, refinement did not apply to the model. To overcome the unaccounted flux into or out of the grid, it is necessary that the grid be aligned with the flow system. Since the general groundwater flow direction of the catchment is in N-S direction the model grid was also oriented in the same direction.

Model Boundaries

To obtain a unique solution from a numeric model code corresponding to a given physical process, additional information about the physical state of the process is required. This information is supplied by boundary and initial conditions. No flow boundary was applied along the hill range as described in development of conceptual model and groundwater divide which surround the model domain. While implementing the internal boundary conditions, Walawa Major River and the three surface water bodies which contain ample volume of water throughout the normal years were modelled under specified head boundary condition assuming the aquifer is in direct contact with these surface water bodies. All the Second and third order tributaries were modelled under Cauchy boundary conditions and this situation is represented by the Figure 7.

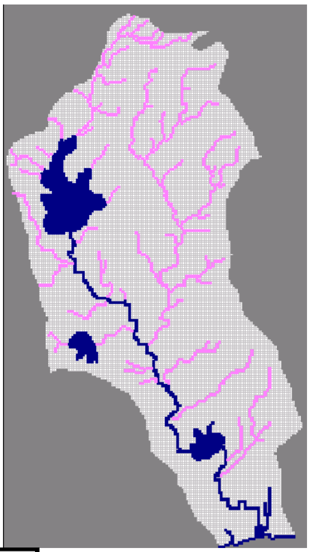


Figure 7 Model Boundaries

DATA PROCESSING

Data and information required by hydrogeological studies is complex because, it is necessary to analyze and combine information concerning geology, hydrology, geomorphology, soil climate, land use and topography. The analysed data are important to transfer the conceptual model in to numeric model. Moreover assigning parameter values to the grid is difficult because the model requires values for each node, cell or element and field data are typically sparse. Interpolations of measured data were used to define the spatial distribution of the model parameters over the model domain. Interpolation technique applied during the study was kriging, a statistical interpolation method that chooses the best linear unbiased estimate for the variables, that is assumed to be a random function whose spatial correlation is defined by a variogram which is available in GIS geostatistical tools for spatially distribute irregularly spaced point data.

Model Layer Elevations

Demarcation of top and bottom of the layers were based on the available technical details of the boreholes. The model was established under unconfined condition considering the interpolated hydraulic head surface as the top of the aquifer. As explained in the hydrostratigraphy of the area, bottom of the aquifer was determined using the drilling and resistivity data.

Initial Hydraulic Head

The spatial variation of groundwater level was studied by analysing the available average hydraulic head data. It was found that hydraulic head ranges from couple of meters near the coast to around 150m in the mountainous foothills.

For steady state models initial values are starting guest values for the iterative equation solver. The head at the fixed head cells must be the actual values others initial heads can be arbitrary values. Because of that it is better to have more reliable values especially for constant head features. But due to the lack of field measured data assigning the initial head at constant head boundaries were based on the average adjusted value extracted from the Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM).

Hydraulic Parameters

For the steady state model the primary parameter to be estimated and distributed across the model grid is either transmissivity or the hydraulic conductivity. In the model, properties are constant within a given grid cell. Transmissivity of the aquifer was obtained as the results of pumping test analysis, and the established relationship $T = 0.564\left[\frac{Q}{s}\right]^{0.9578}$ between transmissivity and specific capacity (Q/s). Then, each estimated value with respective to the well coordinate was allocated and natural log values were used to study the spatial correlation by means of Gaussian variograme model. Simple kriging was applied to obtain the spatial distribution of transmissivity over the study area.

Recharge

In typical model applications recharge can be defined as homogeneously as percentage of yearly average precipitation or calibration of an unknown parameter. The estimated recharge of this study based on Chloride Mass Balance method was 12 % of the annual rainfall. Since the method exclude the evapotranspiration of the groundwater the value obtained from the method was used for the model. As these are point values variograme was applied to study the spatial distribution of the points and power model which was the best fit model together with simple kriging was used to obtain the spatial distribution of the recharge. For this study it is assumed that return flow from irrigation system is insignificant due to the unavailability of reliable data. Hence irrigation return flow will not be accounted for in the model directly. However, the calibration process will automatically offer an indirect way to account for this recharge

Boreholes and Observation Wells

Well database was completed from the data obtained from WRB database and the previous study reports. Using the data available in the prepared well database 45 bore holes were selected as observation wells. These data were assigned to the model creating BOR and OBS file types.

Groundwater Exploitation

About 3.6 m^3d^{-1} average rate of the daily extraction was reported in the area (JICA, 2003). According to the WRB and National Water Supply and Drainage Board (NWS&DB) database the total daily abstraction of the area is around 9000 m^3d^{-1}.The abstraction of ground water was assigned to the model as negative recharge value with the help of this module. It is implicitly assumed in MODFLOW that the wells are fully penetrating the aquifer.

Evapotranspiration

Evapotranspiration also plays an important role in groundwater studies. In this study ET was already considered during the calculation of recharge by means of CMB method. Because of that ET was not considered as separate component of the model.

MODEL CALIBRATION

A numerical model is calibrated when it is capable of reproducing field measured heads which are the calibration targets of the study. The model was initially calibrated based on trial and error method. After that to overcome the limitations of trial and error calibration, automatic calibration was applied for the model.

Model calibration is judged by analysing the residual using statistical and graphical methods. The primary type of calibration target which is used ~~in~~ here is hydraulic head. The Calibration criteria for head is RMSE less than or equal to 10% of head variation within the aquifer being modelled .The head in the aquifer within the study area vary from approximately 0 to 145m resulting in an acceptable RMSE of approximately 14m or less. Only a total of 45 wells with average water levels during the period of two years (2001-2003) were selected for the calibration.

Trial and Error Calibration

During the calibration estimated transmissivity and recharge were changed manually and trial runs were repeated until convergence is reached. A number of parameter combinations were tried for the model and the optimised parameter values with respective to their errors are evaluated based Root Mean Square Error (RMSE).

Scatter plot with Observed vs simulation is given in Figure 8 and the RMSE was estimated as 6.9m.

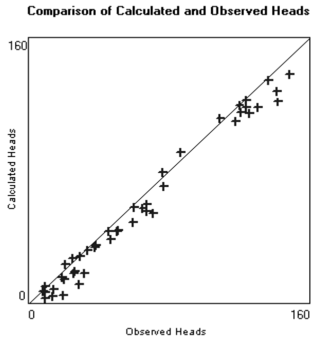


Figure 8 Scatter Plots of Manual Calibration

Automatic Calibration

Parameter Estimation Programm, PEST, which is linked to PMWIN, was employed to calibrate the model. To evaluate the automatic calibration, squared weight residual of each iteration was studied as calibration target and the obtained results are given in Figure 9. It depicts after the first iteration of automated calibration squared weighted of residual decreases suddenly followed by the gradual change until the iteration number seven. Then it shows slight changes due to the convergence of the model by achieving the optimal parameter values.

Figure 9 Variation of Squared Weighted Residual with Simulation Steps

Simulated head distributions were compared with the head distribution obtained from the field measurement. RMSE calculated after the automated calibration using PEST is 4.5 and scatter plots which illustrate the comparison between observed and simulated heads are given in Figure 10.

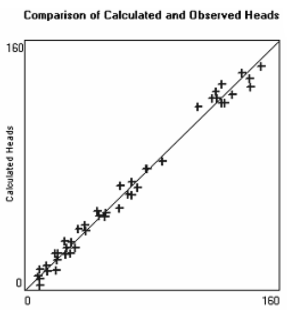


Figure 10 Scatter Plots of Automated Calibration

CORRELATION OF OPTIMISED PARAMETERS

Table 2 gives the parameters optimised during the model calibration. Correlation matrix of the each parameters related to the respective zones are given in Table 3. The determinant of the matrix was estimated as 0.0105. This evidence the parameters are not highly dependent on each other. R1R2, R1T6, R2R3 and R3T6, are negatively related with correlation coefficient of -0.20,-0.17,-0.33, and -0.28 in respectively. Hence the relationship between these parameters can be considered as genuine, because the probability of this correlation may close to zero. But as the relationship of parameters such as R2T6, R4P8, R5T8 and R5T9, are comparatively high they may depend on each other. Applied calibration target is depending on the ratio of the parameters. Hence to achieve better calibration with more independent parameters it is necessary to apply additional calibration target such as flux, together with the hydraulic head.

Table 2 Optimised Parameters

Parameter		Calibrated Value	Upper Limit	Lower Limit
Recharge (mm yr^{-1})	Zone R1	51	3650	$3.65x10^{-7}$
	Zone R2	91	3650	$3.65x10^{-7}$
	Zone R3	124	3650	$3.65x10^{-7}$
	Zone R4	155	3650	$3.65x10^{-7}$
	Zone R5	4	3650	$3.65x10^{-7}$
Transmissivity (md^{-1})	Zone T6	11	$1.00x10^{-3}$	1000
	Zone T7	54	$1.00x10^{-3}$	1000
	Zone T8	112	$1.00x10^{-3}$	1000
	Zone T9	705	$1.00x10^{-3}$	2000

Table 3 Correlation Coefficient Matrix of Optimised Parameters

	R1	**R2**	**R3**	**R4**	**R5**	**T6**	**T7**	**T8**	**T9**
R1	**1.00**	**-0.20**	**0.26**	**0.18**	**0.05**	-0.17	0.51	0.14	0.01
R2	**-0.20**	**1.00**	**- 0.33**	**0.19**	**0.11**	0.83	0.09	0.21	0.03
R3	**0.26**	**-0.33**	**1.00**	**0.10**	**0.04**	-0.28	0.42	0.09	0.01
R4	**0.18**	**0.19**	**0.10**	**1.00**	**0.25**	0.36	0.43	0.67	0.07
R5	**0.05**	**0.11**	**0.04**	**0.25**	**1.00**	0.13	0.15	0.63	0.59
T6	-0.17	0.83	-0.28	0.36	0.13	**1.00**	**0.08**	**0.31**	**0.04**
T7	0.51	0.10	0.42	0.43	0.15	**0.08**	**1.00**	**0.36**	**0.04**
T8	0.14	0.21	0.09	0.67	0.63	**0.31**	**0.36**	**1.00**	**0.21**
T9	0.01	0.03	0.01	0.07	0.59	**0.04**	**0.04**	**0.21**	**1.00**

CALIBRATION RESULTS

The steady state model was calibrated as described above and the calibration results in terms of hydraulic head, recharge, transmissivity and groundwater budget are described as follows;

Hydraulic Head

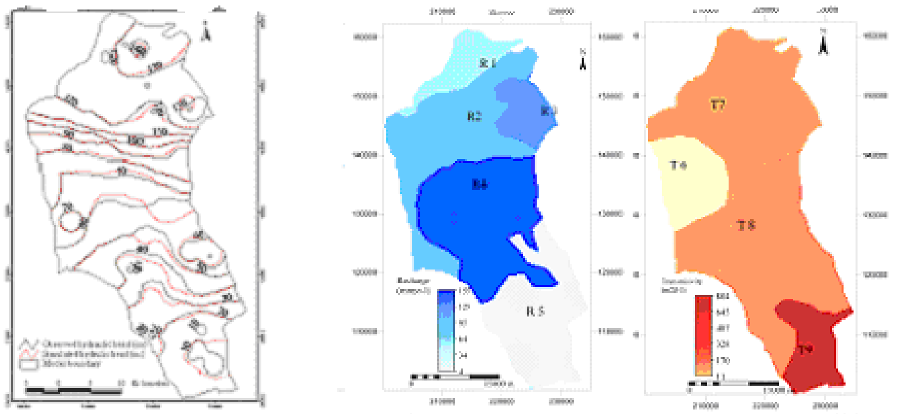
Figure 11(a) shows a map of the spatial distribution of the measured and simulated heads. Simulated head which is higher than the measured head indicates residual less than zero and simulated head which is lower than the measured head indicates residual greater than zero. It depicts often that in the calibration model, the simulate head is slightly higher than the observed head, this may be due to model boundary effect.

Recharge

Inverse calculation of the model resulted an average recharge of 94 mm yr^{-1} for the study area. Spatial distribution of the recharge is shown in Figure 11 (b) and the calibrated values are in Table 2.

Transmissivity

As the tranamissivity being the most uncertain parameter, values of tranamissivity were adjusted during calibration while restricting the them within the defined range for identified zones during the manual calibration based on the production capacities observed in wells in the area. Calibrated transmissivity of the area is illustrated are given in Table 2 and illustrated in Figure 11 (c).



(a) (b) (c)

Figure 11 Model Output (a) Hydrualic Head Distribution (b) Spatial Distribution of Recharge (c) Spatial Distribution of Transmissivity

Groundwater Budget

The groundwater budget component can be quantified on the basis of the calibrated model out put. Then groundwater budget of the study area can be expressed in more detail by means of the following equation.

$$GW_{in} + R_{ppt} + R_{sw} + R_{sec} = D_{sw} + D_{Et} + D_A + \Delta S$$

Where:

GW_{in} : Groundwater inflow from the outside of the study area

R_{ppt} : Net recharge from precipitation

R_{Sw} : Recharge from stream and reservoirs

R_{sec} : Secondary recharge

D_{sw} : Discharge from Stream and reservoirs

D_{Et} : Discharge from ET

D_A : Discharge from Abstraction

ΔS : change in storage

The conceptual model developed for the area assumes no groundwater inflow from out side the study area (GW_{in}=0). As describe in the conceptual model, due to the lack of reliable data secondary recharge was not considered (R_{sec} =0) in the study. Moreover, the model does not provide evapotranspiration and change in groundwater storage. The study uses recharge based on the Chloride Mass Balance Method (CMB). Hence the evapotranspiration is accounted in the net recharge precipitation (R_{ppt}). Since the area is modeled under steady state conditions the average inflow to the system assumed to be equal to the average out flow, resulting in zero groundwater changes (ΔS=0). Then, by substituting the calibrated model values with the above assumptions into the equation 6.5 a groundwater balance is found as summarized in Table 4 .The mass balance indicates that rivers and tributaries are both loosing and gaining water from the aquifer. But on average, the gaining process is dominant. There is flow from the rivers into the aquifer, but the discharge from the aquifer to the river is much larger. The flow from the surface water bodies may be due to pumping wells or due to some irrigation activities employed in the area.

Table 4: Groundwater Budget of the Study Area

Flow Term	In ($MCMyr^{-1}$)	Out ($MCMyr^{-1}$)
Recharge	108	-
Constant head		
Sea	-	36
Tanks	25	23
River	7	12
Head dependent flow	3	68
Wells (Abstraction)	-	4
Total	**143**	**143**

UNCERTANITY OF MODEL CALIBRATION

The uncertainty associated with the model may be due to the measurement errors, scale errors and calculation errors that are incorporated with the model input. Although the obtained RMSE (4.5m) is satisfied the calibration target, the residual error is not equally distributed over the model domain (Figure 11 (a)). The equipotential map constructed with field measurement and the model output gives fairly good visual calibration. But the model underestimated the hydraulic head in the areas associated with transitional slope in the Eastern part of the area (Figure 11 (a)). Model overestimated the hydraulic head close to the boundaries because boundary conditions are also uncertain particularly when the model boundaries are not corresponding to the natural physical boundaries of the aquifer.

Hydraulic head measurement error is on the order of 0.01 of meter and at the modelling scale it is insignificant. Difference between the land surface elevation and the corresponding elevation obtained from the SRTM DEM is significant. Errors due to averaging ground surface elevations available on 90m grid to 250m grid also appear significant and this could be even worse along the higher topographic slopes. The high residual existing in the Eastern part of the area may be due to this uncertainty. The nugget observed on kriged head map within the aquifer is 42 m affecting to the simulated head approximately by 6m. This nugget captures both uncertainty and variability of the calculated head values.

The regional groundwater flow model attempts to numerically represent the physical world. But because of the large lateral dimension of the model accurate simulation of local phenomena is not possible. The size of the each node is 250m by 250 m in size and, smaller features can not be represented exactly. Each model cell is assigned a single set of parameter values and many of the parameters are static during the simulation. Further the hydraulic head as the results of the model includes the single water level for each cell; even though it is possible that more than one well exists in each cell. To have better accuracy calibration values should ideally coincide with nodes of the model to improve accuracy, but practically this will seldom be possible. Field measured head may be influenced by small scale heterogeneities that are not captured in the model. Moreover, the area is said to be an agricultural area, lots of irrigation activities are going over it. Small features like irrigation canals are also not included to the model. This also may affect to the simulation results of the model.

Uncertainty of the model calibration may associate with the assumptions made in the event of conceptualising the system. The area was conceptualised as unconfined aquifer assuming fully impermeable granitic gneiss layer at the bottom of the model for the simplicity. But it may be a partially impermeable layer due to the localised fractures. Hence uncertainty of the calibrated model may be due to the leaky condition of the aquifer.

Ideally heads as well as flux should be measured at a large number of points uniformly distributed over the model domain. The model is limited and potentially skewed by the data that are available. This also may affect the output of the model calibration.

It is better to use more than one calibration targets such as head and flux in order to increase the likely hood of achieving a unique calibration. Because when calibrating a model, increasing in hydraulic conductivity/transmissivity creates the same effects on heads as a decrease in recharge matching it possible to calibrate the model to heads by adjusting either hydraulic conductivity or recharge.

SENSITIVITY ANALYSIS

Sensitivity analysis was carried out to the model developed for the study area. Transmissivity and recharge was selected as the most uncertain parameters. Sensitivity of the model was evaluated by RMSE after multiplying once the initial value of each parameter by a factor 0.8 to 1.2 and running the model. Then the RMSE related to each run were plotted against the multiplying factor. The model is more sensitive to recharge than transmissivity (Figure12). Because it is the primary input source and the model is steady-state where inflow balances out flow with no change in storage.

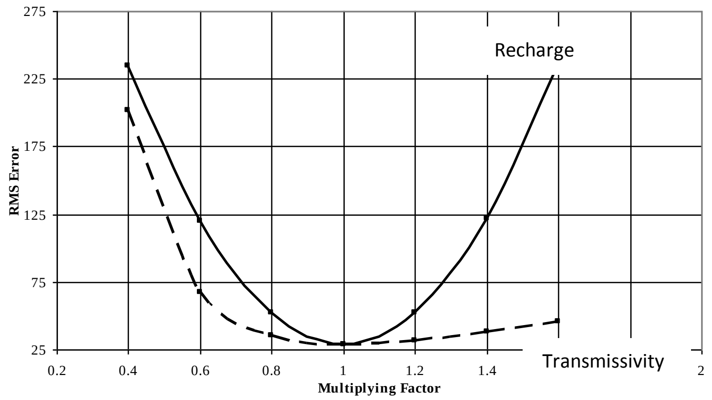


Figure 12 Sensitivity Analysis

CONCLUSIONS AND RECOMENDATION

The analysis field data together with the modelling results convince that the upper aquifer system of the lower part of the Walawa Basin may not be a fully unconfined system. There may be connectivity between the upper and lower aquifer through the granitic gneiss layer which separate these two systems. Most probably this connectivity may be related to the fracture system of the area. Geophysical tests can be employed to determine the surface geo-structures of the study area together with aerial photo interpretation and RS data. Detailed reliable drilling records and pumping tests also can be used to enhance the knowledge of the aquifer system connectivity and its behaviour.

The transmissivity of the area varies within a broad range due to the aquifer heterogeneity. Transmissivity obtained from the inverse modelling depicts the increase of transmissivity from the upper to the lower part of the study area. Geologically the upper part is associated with Highland complex with less fracture density while in the lower part the Vijayan complex rocks are more susceptible to weathering. Because of that more unconsolidated martial can be expected from the lower part and due to that transmissivity also can be increased within this area.

The annual average groundwater recharge calculated by CMB method was about 121 mm (12 % of annual rainfall) and the model calculation was about 94 mm (7 % of annual rainfall). Recharge of the area also shows high spatial variation. High recharge zones can be identified in the middle part of the study area. The high recharge may be influenced by the high rainfall and morphology associated with area. In addition the areas with irrigated agriculture may indicate with higher level of recharge due to return flow from excess irrigation. Moreover, with respect to the land use, paddy and chane cultivations dominate in the high recharge area convincing that most probably the return flow of excess irrigation may be the main factor that affect the spatial distribution of recharge of the study area. Recharge, as the most sensitive parameter of the model, should be determined in more precise way. Moreover as recharge is highly depending on precipitation rate, soil type, water level, soil moisture, topography and ET it is better to apply a tool like SWAT which has the capability to evaluate the aerial and temporal distribution of these parameters.

Network of observation wells should be equally distributed over the model domain. Further the technical details of the well constructions such as screen depth and casing depth, fracture density, detailed lithologs, and bore hole logging data would be more useful to improve the conceptual model as well as numerical model. This regional model can be used as adequate tool for the implementation of groundwater development in the area through down scaling to sub regional or local groundwater models.

The model can be further developed by applying river and reservoir or lake packages to simulate rivers and reservoirs because simulation of the river in the regional flow mode using specified head may cause some errors in the calculated head, consequently flow rates along the river change between the aquifer and streams. Moreover, it is better to consider the model results available in the areas which do not have adequate calibration data as a general indicator which represents the potential impact of the area. The model should be refined and updated as new data become available. Finally the study concluded that spatial and statistical techniques available in GIS are important to gain general understanding of the aquifer system together with numeric modelling even with a minimum available amount of field data.

Finally it can be concluded that, the analysis of available data are useful to investigate vertical distribution of aquifer and its parameters as well as the major processes such as recharge. This knowledge lays better foundation for the reasonable conceptual model which can be transferred to the numeric model that has capability to reproduce the field data with comparatively good accuracy. The field data together with the model output can be used to understand the aquifer behavior under steady state condition. But the model should be refined with more detail for the better accuracy and it is necessary to simulate the transient condition and validation prior to use the predictions.

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Alternate Management Options of Small Scale Surface Water Resource Systems to Develop Groundwater System for the Improvement in Food Productivity in the Dry Zone of Sri Lanka

A Research Finding

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Introduction

It is observed that at present the water that is available is not utilized effectively to achieve maximum productivity in terms of food production. Food scarcity is a pressing problem in many countries of the globe. The problem is, however, particularly serious in less developed countries with low agricultural production combined with a fast growing population. To meet food requirements, efforts should be made to increase the food production, at least several times over the present supply. This can be done by the use of better viable and vigour seeds, development and cultivation of new improved crop varieties, use of proper fertilizers, pesticides, and herbicides, better on-farm water management, better use of agricultural implements, provision of extension services, strengthening of the existing institutions and introduction of new socio-economic legal and organisational support together with proper implementation of suitable alternate policy regarding the conjunctive use of surface and groundwater.

Proper management of water economically, however, is of overriding importance in the production of food. The success and efficiency of most other measures are dependent on the quantity, quality and timing of the irrigation water supply, the way it is used, and the degree of control over it.

Water Resources and its Management Problems

Water is the web of life, but at the same time, it is a limited resource in many areas of the world. Proper economic management of this scarce resource is essential for improvement and sustainability of food productivity. Fresh water being one of the basic necessities for subsistence of life, the human race through the ages has striven to locate and develop it. Over ninety percent of liquid fresh water, available at any given moment on the earth, lies beneath land surface. Unlike other natural resources, water is a unique resource which renews it self. It is due to its constant circulation in the ocean – atmosphere – earth – ocean system. No matter how much water is consumed in daily life, its amount seldom dwindles. With time and under certain conditions water regains its property and becomes fit for reuse. This is probably the reason why water resource appears to be unlimited for a long time.

Water is available on earth in different forms and at different positions. Several types of resources of water on earth include:

- Fresh surface water in streams, lakes, reservoirs, estuaries, ponds and swamps
- Fresh groundwater in water table conditions, artesian aquifers, coastal aquifers, fractured rocks, karts and lava aquifers, etc.
- Precipitation from atmosphere in the form of rain, snow, ice, water vapour, etc.
- Soil moisture
- Surface or subsurface brackish waters with varying degree and nature of salinity
- Sea water, mixed estuarine water or desalinated water
- Effluent waters which may be partially or fully nontreated

The key consumer of fresh water is agriculture rather than industry. Irrigation fields, orchards and estates claimed almost 80% of the water consumed the world over.

Unfortunately, 97.5% of all water resource on earth is saline. Consequently, fresh water including that in glaciers accounts for only 2.5%. Even here the most accessible one is the 0.3%. Moreover the natural distribution is extremely uneven. This unevenness is aggravated by the still greater unevenness of the geographical distribution of human settlement. Shortage is noticed where there is an excess of population and industry.

Irrigation is necessary in one form or other in all parts of the globe where the mean annual rainfall is less than 250mm. Experience has shown that over most part of the globe one in five years is a dry year and one in ten years is a severe drought year.

Impounding surface water was practiced from ancient times for a variety of purposes such as domestic needs, irrigation, industry and recreation. Groundwater, unlike surface water, is available in some quantity almost every where that man can settle in, is more dependable in periods of drought, and has many other advantages such as the fact that it is directly consumable and that comparably less investment is required over surface water and that it has readily absorbable high nutrition content for crop production.

Utilisation of surface and groundwater singly or in conjunction is in vogue according to the relative availability of either in a locality. Of late, accent of intensive exploitation of groundwater has gained credence as a consequence of extreme pressures of population on water resources all over the world. The limited groundwater potential could not withstand the excessive exploitation and fast depleting water level.

Groundwater is an integral part of the hydraulical cycle. Its evaluation, planning and management have to be part of the total system. Most of these issues have therefore to be dealt with at the appropriate level of water resource system planning. Water resource potential assessment, conjunction of surface and groundwater development, groundwater quality assessment, groundwater recharge, conjunctive surface water - groundwater - energy planning, also nave to be taken in to consideration, while taking a policy decision regarding water resource planning. However, groundwater is a very important component of the water resource system and has special characteristics and management issues.

Necessities of stabilizing agricultural production in Asia where over 40% of the area is drought prone require speedy development of groundwater resources. Even in areas where there are surface water supplies available through major, medium and minor irrigation projects, groundwater is playing an increasingly vital role in supplementing surface water. The importance of the role of groundwater to meet water supply requirements for domestic, rural, urban, industrial and agricultural use needs no emphasis. The increasing demand placed on it has stimulated investigations, oriented towards quantification of the resource, which is basic for the formulation of plans for its exploitation, management and conservation.

The groundwater in a basin is not at rest but is in a state of continuous movement, the increase in the storage volume of the groundwater by the downward percolation of rain and surface water storage, causing the water table to rise. At the same time decrease in the storage volume of groundwater caused by domestic consumption, industrial use, evapotranspiration, discharge to springs, overflow into streams and other natural drainage channels, cause the water table to fall.

When considered over a long period, the average recharge equals the average natural discharge and the state of hydrologic equilibrium exists. The water table is virtually stationary, with seasonal fluctuations around the average level.

Human interference can also cause water table to rise. For example when irrigation is introduced into an area, millions of cubic meters of water is transported to and distributed over that area, which earlier had only scanty rain. Part of it seeps to the under ground from the canals and more of it percolates downwards from the irrigated fields. These water losses cause the water table to rise, because the recharge exceeds the natural discharge. This may eventually leads to water logging, in arid areas usually accompanied by salination of the soil which can render once fertile land into waste land, to the detriment of local farmers and even of national economy.

Man’s two foes of nature related to water supply are drought and flood. Both cause a water problem. One is a shortage and the other an excess. If proper planning can be done then both the above mentioned dangers lose their destructive effect to a great extent. This is the purpose of integrated conjunctive management in the use of groundwater and surface water.

By a judicial management and use of both surface and groundwater, the water resources can be conserved and utilised economically for food production drive as well as industrial revolution. For a healthy economic growth of a country, management and utilization of the two resources needs to be scientifically planned and managed keeping in view the future demands which are inevitable to increase manifold for domestic, irrigation and industrial purposes.

To address these problems a self financed research was carried out by the writer, selecting a restricted area of 185 square kilometres with more than two thousand dug wells (including forty one observation wells), six medium irrigation schemes and forty minor irrigation schemes in Vavuniya District.

Objective of the research

The main objective of this research is a complete water balance study in a restricted catchment (more than 150 square kilometres) area incorporating few medium irrigation schemes, several minor Irrigation schemes and a large number of dug wells to illustrate:

1. The development of a model to represent all the relevant variables connected with the movement and utilization of surface and groundwater
2. The usage of the above model to study the viability of conserving surface water by storage as groundwater by reducing the extent of cultivation using surface water and increasing the extent of cultivation using groundwater to achieve optimum crop yield
3. The economic viability of achieving optimum crop yield as in (2)
4. The creation of an artificial aquifer boundary to optimize the effectiveness of groundwater use to achieve optimum crop yield
5. The economic viability of the creation of artificial boundary in terms of productivity
6. Combining both 2 and 4 for the increased crop production
7. The economic viability of achieving optimum crop yield as in (6)

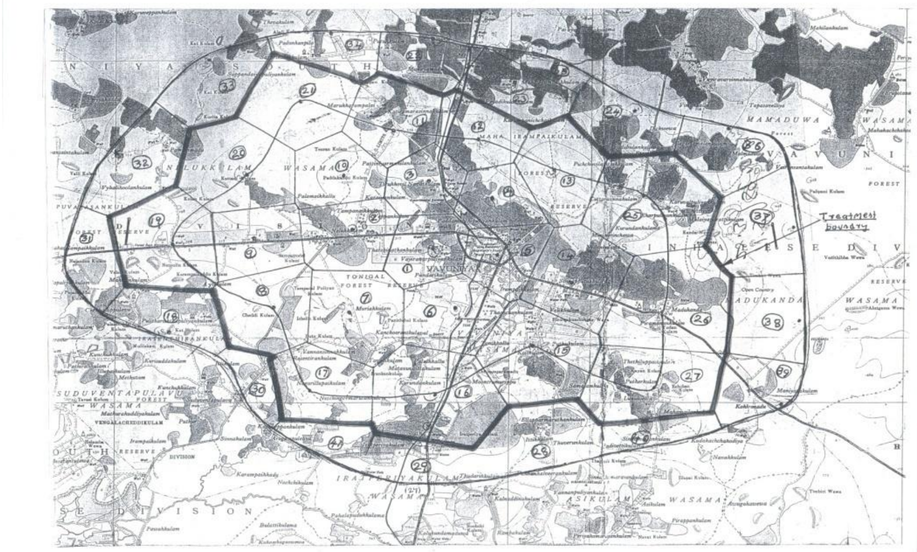
for the management and conjunctive use of surface water and groundwater resources in an efficient and economic manner to achieve optimum productivity in terms of food production.

Research Methodology

Many field experiments conducted by agronomists reveal that the increase in yield of a crop depends (in addition to other factors), on dissolved nitrogen in irrigation water supplied. More frequent and less intense irrigation tends to give a better crop yield due to reduced moisture stress, requires less water to fill the root zone to field capacity and reduces solute movement. General relationship between crop yield and water applied to the crop shows a trend to increase linearly up to about 50% of the full irrigation and then going in a convex curvature to the optimum yield and then reduce the yield with increase in applied water

Farmers whose sole objective is to get optimum net income, tends to irrigate their crop by spending minimum cost for their irrigation water to get optimum productivity of their crop, hence the main methodology adopted in this research regarding the optimum crop yield is economizing the cost of the irrigation water and increasing the extent of cultivation per unit of irrigation water.

A regional aquifer simulation model was formulated in Integrated finite difference method and a non-linear error optimization method was used for calibration of the model to a selected restricted catchment (around 185.23 km^2 as shown in figure below) in Vavuniya (having a shallowly weathered and rarely fractured crystalline rocks with thin soil mantle).



Study area with location of observation wells

This model was used to find out an operational policy for conserving surface water by storage as groundwater by reducing the extent of cultivation using surface water and increasing the extent of cultivation using groundwater to achieve optimum crop yield under minor and medium irrigation schemes together with creation of an artificial boundary to lift the water table up.

Data Collection

The following inputs were processed from the data available in statistical handbook Vavuniya (1997 – 2005), District Integrated Agriculture Development & Extension Program Vavuniya (1997 – 2005), Administration report of Central and Provincial Irrigation Department (1997 – 2005) and data collected from NWS&DB Vavuniya.

- Capacity of water stored in Irrigation scheme (m^3)
- Water issued for cultivation in irrigation scheme (m^3)
- Rainfall volume (m^3)
- Net pumping volume (m^3) that consists of the following
    - Pumping from domestic wells (m^3)
    - Pumping from agro wells (m^3)
    - Pumping from production wells (m^3)

Model Formulation

This study area was divided into forty one polygons by connecting the perpendicular bisectors of adjoining observation wells. Seven year seasonal water levels and one year monthly water levels, tank storage, field issues and total withdrawal from agro and domestic wells for each polygon were taken for the water balance of each polygon. A regional aquifer simulation model was formulated for this polygonal net work. Integrated finite difference method was used for the formulation of the model.

Model Calibration

Before the model can perform its task of predicting the future groundwater system behaviour it must be calibrated. This means that a check must be made to see whether the model can correctly generate the past behaviour of the ground water system, as known from past records. A non-linear error optimization method was used for calibration.

The calibration was done for the period from 1997 to 2002. The relevant hydrological information and observed data were fed into the computer model, which calculate the water table elevation for each nodal point. These values were then compared with the actual water table elevations, as they were known from observed records. Where ever the predicted values were not matching with the observed values the aquifer stress parameters and the hydrological stress parameters were systematically slightly adjusted to get a good match, and the water levels re-evaluated. This process was continued till the calculated values satisfactorily match with the observed values.

Model Validation

To test the validity of the model, using the calibrated parameters and using 10^{th} season (Sept. 2002) water level as initial water level and the rest of the inputs, the 11^{th} season (May 2003) water level was predicted using the prediction model. In the same way, using 11^{th} season (May 2003) water level as initial water level and the rest of the inputs, the 12^{th} season (Sept. 2003) water level was predicted using the prediction model. In the same way, the water levels of May 2004 and Sept. 2004 were predicted and compared with observed water levels.

This led to an observed error in depth of water table of the magnitude ranging from -0.08% to +2.1%. For a groundwater simulation model in integrated finite difference method, an error of this magnitude may be regarded as acceptable depending on the scope and purpose of the project.

Model Predictions for Various Operational Policies

Using the calibrated model, several prediction runs were carried out to determine the behavior of water levels to illustrate:

- The possibility of reducing the extent of cultivation using surface water and increase the storage of groundwater for economic cultivation
- The possibility of creating an artificial aquifer boundary to reduce the lateral flow to raise the water table for economic pumping to reduce the cost of irrigation water to increase the productivity
- The possibility of combining both 1 and 2 to raise the water table by improving the groundwater storage capacity to increase the crop yield by increasing the extent of economic cultivation per unit of irrigation water

An operational research was carried out using the calibrated and validated prediction model for the above three policy alternatives as below.

- The behavior of water table of this catchment was analyzed by keeping 10%, 20%, 30%, 40% and 50 % of the full capacity of the Irrigation schemes during season June – Sept. This was done by assuming that, to keep 10 % of full capacity of a medium and minor irrigation scheme, 12 % of cultivation has to be forgone.
- The first interior boundary of the study area was selected for the creation of artificial boundary by the way of boundary treatment. To create the artificial boundary, the transmissibility values (actually the permeability) were reduced in steps and behavior of water table was observed. The **T** values between seventeen very extreme peripheral nodes (18, 30, 41, 29, 28, 40, 39, 38, 37, 36, 24, 35, 22, 34, 33, 32, 31) and fourteen interior adjoining nodes (8, 17, 16, 15, 27, 26, 25, 13, 23, 12, 11, 21, 20, 19) of the study area were reduced in steps of 2 – 3 m^2 /day and the water levels were predicted.
- During this analysis every step of one was carried out for all five steps of two. Accordingly twenty five trials were carried out. Even though this was a very cumbersome exercise an interesting shift was observed as an outcome.

Summary of Operational Research

The summary of results of the operational research considering different options is given below.

- Changing the operational policy of minor and medium irrigation schemes by forgoing cultivation by 25% to 35% to conserve surface water by storage as groundwater is giving water table gains in almost all nodes except nodes 37 and 38 by 0.533 m to 0.914 m during discharging season and by 0.762 m to 1.143 m during recharging season. This is a reduction of almost 45% to 65% of water table loss in between two consecutive seasons in 80 % of the area of the catchment under study.
- Creating artificial aquifer boundary to optimize the effectiveness of groundwater in an elevated water table by peripheral boundary treatment to cause reduction of permeability by 35% to 45% is giving water table raise of nodes closer to treated boundary by 0.457 m to 0.838 m during recharging season.
- Combining peripheral reduction in permeability by 35% to 45% and forgoing cultivation of minor and medium irrigation scheme by 45% to 55% result an average gain of water table during discharging season (June – Sept) by 1.067 m to 1.448 m excluding node 37 and 38. The same trend is observed in recharging season to a lesser degree. This is a reduction of almost 60% to 70% of water table loss in between two consecutive seasons in 95 % of the area of the catchment under study.

Summary of the results of maximum water level change of the above operational research are given below in a tabular form for easy visualization and understanding of the water table behavior.

Summary of maximum water level change in m for various options

Options	Steps of each option	Discharging period	Recharging period	Nodes on which raise in water level occurred
Operational policy change	**Forgoing 24% - 36% cultivation**	0.762 to 1.143	0.533 to 0.914	**Scattered except 37 and 38**
	Forgoing 48% - 60% cultivation	0.838 to 1.371	0.610 to 1.067	**Scattered except 37 and 38**
Boundary treatment	**Reduction of permeability by 40%**		-0.381 to -0.610.	**18, 41, 29,35,34,33,32 and 31**
			0.305 to 0.686	**28, 39,36 and 24**
			-0.229 to -0.457	**13 and 14**
			0.457 to 0.838	**8,19,17,16,27,26,25,23,11,21,20 and 2**
Combination of policy change and creation of artificial boundary	**Step 4 of both options**	0.914 to 1.448		**95 % of the nodes within the catchment**

Impact of Economic Analysis on Outcome of the Considered Options

An economic analysis was carried out to find the economic viability of the research outcome to justify the economic implimentability of the objective achieved.

The main assumption adopted in this option regarding the optimum crop yield is economizing the cost of the irrigation water, leaving out the physiology of the crop. The gain in water table will reduce the cost of energy by way of fuel and electricity. This will increase the economic crop yield by increasing the extent of economic cultivation per unit of irrigation water. This will indirectly contribute to GDP and to GNP

The change in operational policy will reduce the extent of paddy cultivation. This could be taken as the indirect cost and will occur yearly.

The return was calculated based on the savings in electricity expenditure in pumping water for domestic agricultural and production by way of raise in water table during the implementation of this policy.

Summary of the economic analysis for all the three alternate options for the economically feasible steps is given below to get a very good idea of how the benefit/cost ratio varies for each options and steps.

Summary of benefit/cost ratio greater than unity option and steps

Option	Steps of each options	Benefit cost ratio							
		Discharging season				Recharging season			
Operational policy change	2	14.52				1.59			
	3	14.63				1.46			
	4	12.43				1.33			
	5	10.27				1.13			
Boundary treatment	Year of implementation					20		25	
	Interest rate					7.5%	10%	7.5%	10%
	3					0.73	0.97	1.15	1.66
	4					0.88	1.17	1.39	2.01
	5					0.83	1.10	1.30	1.88
Combination of policy change and creation of artificial boundary	Year of implementation	20		25		20		25	
	Interest rate	7.5%	10%	7.5%	10%	7.5%	10%	7.5%	10%
	3	0.97	1.13	1.28	1.78	0.82	1.09	1.17	1.75
	4	1.09	1.19	1.49	2.23	1.01	1.13	1.44	2.18
	5	1.04	1.13	1.42	2.22	0.97	1.15	1.37	2.02

Summary of Economic Analysis of the Operational Research

From the detailed cost benefit analyses for all the three options of the operational research the following findings were arrived.

- The alternate policy on changing the operational policy of minor and medium irrigation schemes by forgoing cultivation by 25% to 35% gave the benefit cost ratio based on present worth greater than unity with considerable rise in water table. The rise in water table occurred almost above 80% of the observation wells. The rise in water table was around 45% to 65% of the loss in water table between two consecutive seasons
- The boundary treatment showed positive results for the life time of the project exceeding 20 years and for the interest rate of 7.5%
- The combination of the above two alternatives yielded further improvement that, at any time water table will reduce 60% to 70% of loss in between two consecutive seasons in 95 % of the catchment under study.

Summery of the Research Finding

Summarizing all the three alternatives based on the operational research and economic analysis, the first and third alternatives out of the three alternatives mentioned previously would be the most economically feasible alternatives for implementation in any catchment.

- A change in operational policy of minor / medium irrigation schemes by forgoing one third of the cultivation under minor / medium irrigation schemes or keeping one fourth of the storage of minor / medium irrigation schemes at any time will recover an average of 45% to 65% of the loss of water table in any consecutive seasons in almost 80% to 90% of the catchment area under consideration
- A change in operational policy of minor / medium irrigation schemes by forgoing one third of the cultivation under minor / medium irrigation schemes or keeping one fourth of the storage of minor / medium irrigation schemes at any time together with creating an artificial aquifer boundary to reduce the permeability of the catchment boundary by 40% to 50%, will recover an average of 60% to 70% of water table loss in between two consecutive seasons in almost 95 % of the catchment under consideration

This will reduce the cost of irrigation water and in turn increase the extent of cultivation per unit of irrigation water. This will increase the crop yield per unit of irrigation water and lead to increase productivity in terms of food production.

Implementation of the Research Finding

This findings can be generalized with respect to time and space with suitable modification and does not require any additional resource to implement, but proper awareness about increase the extent of crop production in one unit of irrigation water, is required to implement this policy in field among the stake holders..

Even now the practice of alternate tract cultivation in different years depending on availability of water in the Irrigation schemes exists. Hence forgoing one third of cultivation extent will not be a serious problem in execution. It must be noted that the extent of cultivation under groundwater is increased considerably. Hence this policy implementation is very easy with proper knowledge based awareness among the stake holders.

Conclusion

In many regions in the world there is excess precipitation in one season and less or no precipitation in the rest of the year. This is especially true in the dry zones of Sri Lanka where during the monsoon period of about four months we get most of the rains and practically very minimal rain during the rest of the year. Surface storage is created to hold the excess water during monsoon for use in the non-monsoon seasons and supplementary irrigation for maha season. Where the hydro geologic conditions are favourable it would be possible to consider storing of the excess water in aquifers or keep apart a percentage of surface water to recharge the groundwater during the dry season.

Minor / medium irrigation schemes conserve surface run off and covey most part of it to recharge groundwater and as such serves as a recharge shed for the wells situated in the zone of influence. It is an insurance against water scarcity, as the yield increases considerably for every unit of rainfall. The minor / medium irrigation schemes prevent soil erosion and depletion of soil fertility. In the context of impending water deficiency looming large, construction of minor / medium irrigation schemes will be a dependable infrastructure in the development of water potential in any catchment. Acknowledgement of the remarkable role played by the minor / medium irrigation schemes on replenishment of groundwater and its spread over a large area would be a great asset in planning and execution of settlement and crop production projects.

This research finding shows that a change in operational policy of minor / medium irrigation schemes by forgoing one third of the cultivation under minor / medium irrigation schemes or keeping one fourth of the storage of minor / medium irrigation schemes at any time will gain an average of 45% to 65% of the loss of water table in any consecutive seasons in almost 80% to 90% of the catchment area under consideration.

The reduction of the loss of water table in any consecutive seasons will be between 60% - 70% in almost 95 % of the catchment under consideration by creating an artificial aquifer boundary to reduce the permeability of the catchment boundary by 40% to 50%, in addition to the above change in operational policy of minor / medium irrigation schemes.

Limitations of This Research

This research, using a numerical modelling technique called Integrated Finite Difference Method applicable to any type of polygonal network formulated for any restricted area, is having the following limitations.

- Aquifer is a two-dimensional flow system.
- Only one aquifer system is modelled
- Aquifer is bounded at the bottom by an impermeable layer
- There are no major irrigation schemes within the catchment above the aquifer
- The validation of the results cannot be done in the actual field within the study time because of its social component and the implementation authority is in the hand of bureaucrats not with the researchers
- Only the main recharge and discharge period is considered ignoring the February-March discharge
- Facilities are not accessible to this area (due to conflict situation) to carryout actual field tests to verify the rainfall recharge values found out from model studies

Groundwater Resources and Sustainability Experience in Sri Lanka

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Abstract

Sri Lanka utilizes groundwater from springs, tube wells, and shallow dug wells for domestic purposes and the demand has increased substantially during the past three decades. Point sources (tube well or dug well with a hand pump) and piped water schemes with or without treatment are the main types of groundwater supplies. There are about 24,000 hand pump wells and 1500 groundwater based piped supply schemes in Sri Lanka. Hand pump wells generally supply 1 to 3 cubic metres of water daily, while more than 20 cubic metres are extracted from piped water supply schemes. The average lifetime of a pumping well in Sri Lanka is 5 to 15 years. However no systematic monitoring of groundwater quality and quantity of pumping wells has been performed. Therefore, it is difficult to evaluate and assess the operational and well related or aquifer related problems in such water supply schemes.

Recently, the construction and maintenance of hand pump wells are implemented based on the Cabinet approved three-tier system (Village society, Local authority, and NWSDB). As a result, about 10,000 hand pump fitted tube wells have already been handed over to local authorities. However, lack of regular monitoring, lack of coordination among participatory groups, unavailability of spare parts, lack of funds for rehabilitation and new construction, seasonal demands, water quality problems, and alternative water facilities have emerged as critical problems associated with the sustainability of hand pump wells. The lack of specific laws and regulations regarding groundwater management could result in severe environmental, health and social problems. Hence law enforcement will be required for the sustainable development of the groundwater resources in Sri Lanka.

Introduction

Sri Lanka has a long experience in utilizing groundwater from springs and shallow dug wells for drinking and other domestic purposes. In the1980s and 1990s, the usage of groundwater in rural and semi-urban water supply schemes was based on tube wells, springs, and shallow wells and the supply substantially increased mainly in dry zone with assistance from several donor agencies such as DANNIDA, FINNIDA, GTZ, SIDA, ADB, IRDP, CWSSP, Gamidiriya etc.

About 72% of rural and 24% of the urban population in Sri Lanka depends on groundwater for their domestic water supplies (WHO/UNICEF-2004). The groundwater supplies are mainly two types; point source (tube well or dug well with a hand pump) and piped water schemes with or without treatment. There are about 24,000 hand pump tube wellsconstructed mainly by National Water Supply and Drainage Board (NWSDB) and Water Resource Board (WRB) throughout the country to supply 1 to 3 cubic metres per day per hand pump. In addition, there are a number deep wells with locally manufactured hand pumps (Abyssinia type) and shallow open dug wells that have been constructed by various local organization and individuals for which no reliable records are available.

The exact figures for groundwater based water supply schemes in Sri Lanka are not available. However, about 1500 groundwater based piped water supply schemes including about 360 NWSDB maintained water supply schemes are available in the country. Most of the other schemes are maintained by community based organizations and local authorities. The annual groundwater abstraction from NWSDB maintained water schemes is about 18 x 10^6 m^3 of which around 70% of schemes contribute between 20 to 40 cubic metres per day. About 10 water supply schemes are extracting more than 3000 cubic metres of groundwater daily.

In Sri Lanka, a fractured crystalline aquifer covers over 90% of the island is the primary source of groundwater and the remaining groundwater supply is from confined sedimentary type aquifers located mainly in the north and northwest areas of the country. Some unconsolidated aquifers are associated with beach and river deposits that overlie the crystalline basement. The total estimated groundwater potential of the country is approximately 7800 x 10^6 m^3/year (Natural Resource of Sri Lanka, 1991) and rainwater is the main source of recharge. The annual rainfall of the country varies spatially from 900 mm to 6000 mm per year. Some 7% to

30% of groundwater recharge is contributed from rainwater however the rate of infiltration depends on the geological and geo-structural conditions.

Many of groundwater based piped water supply schemes are facing problems such as gradual or sudden decrease in yield and deterioration in quality. These conditions reduce the lifespan of wells and the aquifer. The average lifespan of NWSDB maintained pumping tube wells is 5 to15 years, which is far below the lifespan of similar wells in the developed countries. Siltation, clogging, and well and pump maintenance problems are the main issues that can be observed especially in hand pump wells, in addition to the yield and quality deterioration. The procedure for construction and maintenance of hand pump wells must now be done according to the Cabinet approved three-tier system (Village society, Local authority, and NWSDB).

Groundwater monitoring, corrective and preventive maintenance, well and aquifer protection, and a supportive legal framework are key factors that provide proper guidance for the development of groundwater management systems which support long term sustainability. At present, plans are underway to implement guidelines for proper maintenance and management of groundwater based water supply schemes in order to develop sustainable groundwater management system.

Distribution of aquifers in relation to physical features

In Sri Lanka, six main types of aquifers have been identified and demarcated by the Water Resources Board (WRB) and the National Water Supply and Drainage Board (NWS&DB). Pioneering studies in the field have been carried out and reported by Sirimanne (1952, 1968) and Arumugam (1966, 1974). The six types of aquifers are given in the table 1.

Table 1: Different types of aquifers and their occurrences in Sri Lanka (after Villholth and Rajasooriya, 2010).

	Aquifer type	**Occurrence and distribution**
1	Shallow unconfined karstic aquifers	Occurs in the channels and cavities of the limestone formation, which underlain Jaffna peninsula in the north.
2	Deep confined sandstone and Miocene limestone aquifers	Occur within sedimentary limestone and sandstone formations of the north- western and northern coastal plains.
3	Shallow quaternary unconfined coastal sand aquifers	Consist of different types. i.e. raised beaches, coastal splits and bars. Occurs along, but narrow stretches of the coastal line, especially on the east and northwest coast.
4	Alluvial aquifers of variable depth	Occur in coastal and inland flood plains, inland river valleys and old buried river beds
5	Confined or semi confined lateritic (*cabook*) aquifers	Occurs in the south-western low laying parts of country.
6	Shallow regolith aquifers of the hard rock region	Groundwater in these formations is found as separate pockets formed in the shallow weathered mantel rock (regolith) or in deeper fracture zones of the unweathered material. Occurs in the large central part of the island.

In addition to the main aquifers (figure 1) numerous small groundwater pockets are found throughout the country (IGES, 2007). Seven distinct groundwater basins have been identified and mapped within the deep confined aquifer regions and are named as Mutative, Mulankavil, Paranthan, Murunkan, Kondachchi, and Vanathavillu basins. The shallow coastal sand aquifers that occur on the coastal areas are intensively used and occupy a total extent of approximately 125,000 ha. Groundwater in hard metamorphic rocks is found in the weathered zone or the regolith and in the deeper fracture zone of the hard rocks.

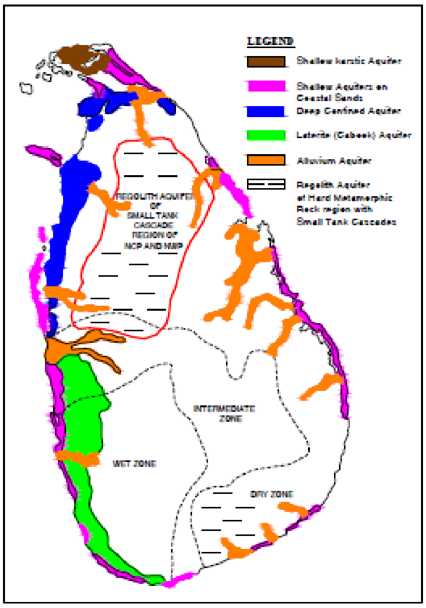

Figure 1: Distribution of main aquifers in Sri Lanka

Present status of groundwater supplies in Sri Lanka

Nearly 30,000 tube wells have been constructed in various parts of the country during last three decays for rural and semi urban water supplies by various organizations such as NWSDB, WRB, foreign funded projects (e.g. DANNIDA, FINNIDA, GTZ), and private sector organizations. The groundwater quality and flushing yield of deep tube wells are normally measured during the borehole construction. In semi urban water supply schemes however, optimum yield of the boreholes are being estimated by pumping test conducted at the initial stage, prior to commissioning. All hand pump wells are constructed for the rural populations and intended to exploit about 1 to3 cubic metres per day.

About 1500 groundwater based water supply schemes including NWSDB's 360 schemes are scattered throughout the country, producing 10 to1500 m^3/day. Other schemes are maintained by community based organizations and local authorities. Only about 10 schemes are used to extract more than 3000 cubic metres per day. These schemes use water from deep confined aquifers, alluvial aquifers, or shallow quaternary coastal sandy aquifers. In addition, there are about 597 tube wells constructed at government schools and health centers fitted with solar pumping systems and each scheme exploits about 10 to20 cubic metres per day.

The groundwater supply status by province is given in table 2 and tube well distributions in Sri Lanka are shown in figure 2.

Table 2: Summarized data on water supply schemas by province (Source: NWSDB, WRB, and others) Private wells (deep wells and shallow dug wells) are not included.

Province	Number of tube wells with hand pump (NWSDB, WRB, Others)	Groundwater based pipe schemes.	Groundwater schemes with solar power pumps
Uva	3177	250	134
Western	1530	55	
Central	3854	140	248
Southern	1810	207	
North central	6019	364	215
North western	3635	340	
Eastern	1576	80	
Sabaragamuwa	1023	55	
Northern	545	15	
Total	**23169**	**1501**	**597**

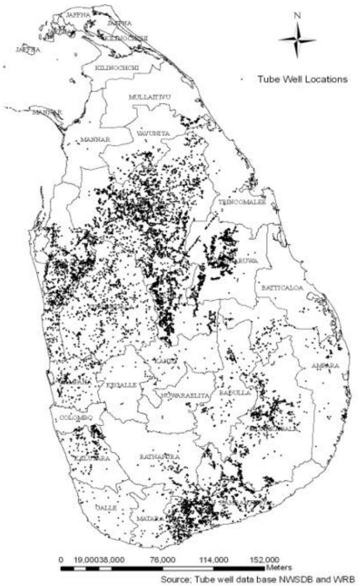

Figure 2: Distribution of tube wells in Sri Lanka (Source- NWSDB and WRB)

Groundwater quality and pollution

The available groundwater quality data, obtained before commissioning of tube wells, indicates excessive concentrations of some ions such as fluoride, chloride, nitrate, hardness, and iron. Table 3 summarizes the initial chemical quality of tube well water. Some 18% of these wells had fluoride concentrations greater than 1.5 mg/l (above the WHO guidelines levels). Excessive fluoride is mainly confined to the dry zone regions and occurs randomly. Some areas of the central, north-central, north- western, south and eastern regions of the country are reported to be having dental fluorosis due to excessive amounts of fluoride in drinking water. About 11% of wells had water with hardness greater than 600 mg/l. Excessive hardness is mainly limited to the specific parts of the dry zone and associated with Ca bearing rock formations. The excessive chloride in groundwater is mainly confined to the coastal regions. Iron prevails in the wet zone areas and in lateritic aquifer.

Table 3: Physiochemical properties of tube well water

Chemical parameter	Number of wells analyzed	Values below maximum desirable limit (WHO).	Values within WHO limit.	Values above WHO limit.
Electrical Conductivity(μS/cm)	13,945	7,303(52%)	5,902(43%)	740(5%)
Hardness (mg/l)	12,955	7,338(56%)	4,131(33%)	1,486(11%)
Fluoride (mg/l)	13,081	5,213(40%)	5,508(42%)	2,360(18%)
Total iron (mg/l)	13,014	5,418(42%)	2,889(22%)	4,709(36%)
Chloride (mg/l)	10,557	7,451(71%)	2,597(25%)	509(4%)
Sulphate (mg/l)	7,023	6,597(93%)	210(3%)	216(3%)
Total alkalinity (mg/l)	10,609	5,206(49%)	4,012(38%)	1,391(13%)
Nitrate (mg/l)	9,626		9,491(98%)	135(2%)

Due to human and agricultural intervention, groundwater in some places is polluted or is under threat. The impact of anthropological activities is frequently observed in the shallow regolith aquifers, coastal sand aquifers, and shallow karstic aquifers in Jaffna (Panabokke and Perera, 2005). Saline water intrusion is another type of groundwater pollution that occurs due to over pumping of fresh water in coastal aquifers. The northern and north western provinces, mainly in the Mannar, Puttalam, Paranthan, Mutative, and Killinochchi, regions are important agricultural regions of the country where groundwater studies for 130 tube wells showed that they have been affected due to salt water intrusion.

Leaching of agrochemicals from intensively cultivated soils is the main contributing factor for nitrate (40-100 mg/l), potassium, and chloride. Excessive levels of such ions occur in many irrigation wells in the Kalpitiya peninsular (Lawrance and Kuruppuarachci, 1986). Nitrate problems derive from intensive fertilizer use for irrigated cash crop farming in the Jaffna and Kalpitiya area (Liyanage et al., 2000; Kuruppuarachci and Fernando, 1999; Nagarajah et al., 1988; Maheswaram and Mahalingam, 1983).

In addition, poor handling of wastewater and household and industrial waste in Sri Lanka pose a considerable threat to the groundwater resources, particularly to the shallow unconfined aquifers. These wastewater and wastes are a source of pathogenic contamination and nitrate contamination (Piyadasa et al., 2005). The nitrate contamination is less significant in the paddy soil areas in the crystalline formations (Villholth and Rajasooriyar 2010) where intensive agriculture also takes place due to the low permeability of the soil (De Silva and Ayomi, 2004). Widespread water contamination in the Jaffna peninsula results from agriculture washout and pit latrine soak ways (Lawrance and Kuruppuarachchi, 1986). In some areas in Point Pedro, nitrate concentration ranged from 122 mg/l to 174 mg/l due to sewage pollution. The fecal contamination of shallow groundwater has been reported in Jaffna peninsula due to open sewers, pit latrines, soak ways and septic tanks.

Groundwater quality close to landfill sites in Colombo Metropolitan regions has been investigated and revealed that some wells located close to the land fill sites are contaminated with heavy metals (Pb, Cr, Cu), organic matters, nitrate, and phosphate (Gunawardhana et al., 2002).

Changes in groundwater quality of the aquifer systems in the tsunami affected coastal belt in southern area have also been extensively studied. In these regions, the electrical conductivity of groundwater increased to about 3500 µS/cm, and has fallen to 1000 µS/cm as the result of subsequent rains (Villhoth et al., 2006).

Problems associated with groundwater based pipe bore water supply schemes.

The monitoring of groundwater quality and quantity for pumping wells has not been performed systematically. Furthermore groundwater level measurements have not been recorded for any of pumping bore holes and systematic quality monitoring has not been carried out. However, intermitted groundwater quality measurements are available for selected water supply schemes. With this limited data set it is difficult to evaluate and assess operational or aquifer problems in such water supply schemes. In most cases well structure or well rehabilitations are conducted only after the system has completely failed. This approach results in a reduced the lifespan of the wells. As an example, the groundwater extraction and extraction amount per kilowatt-hour for the Kulugammana groundwater intake wells in the Kandy district are shown in figure 3 and 4).

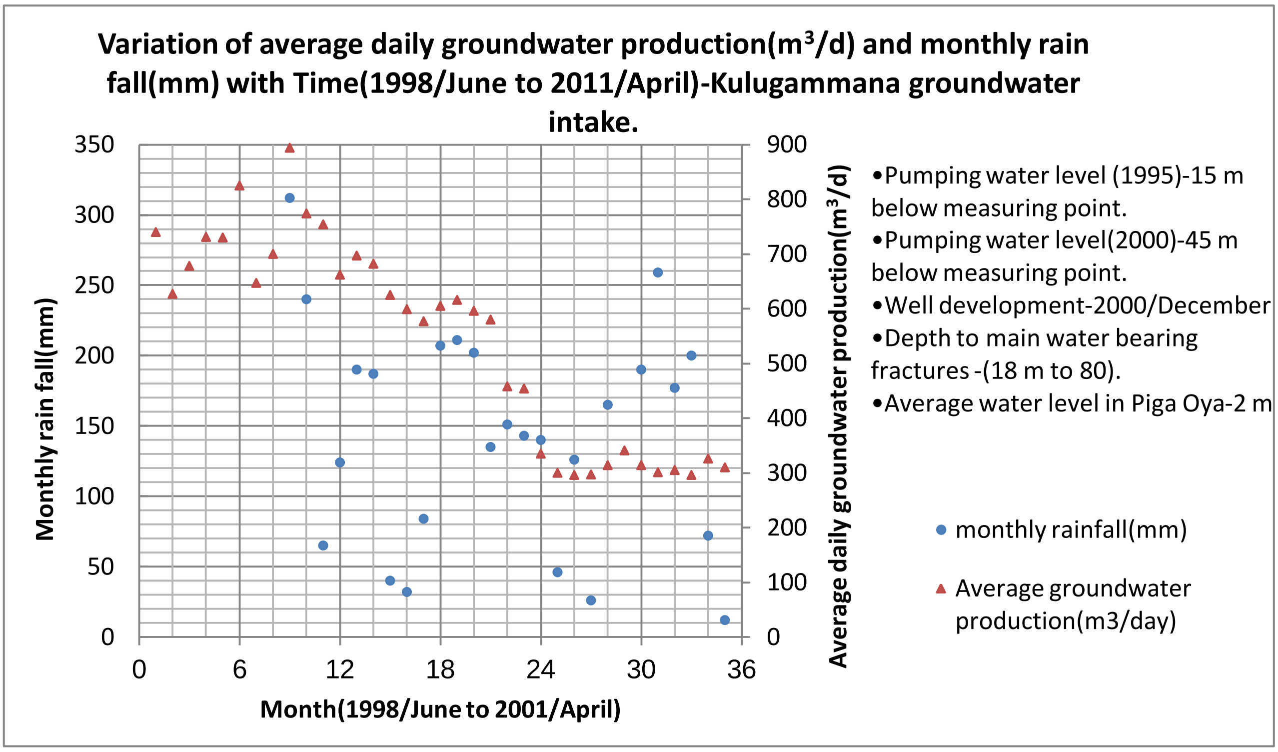

Figure 3: Average daily groundwater production and monthly rain fall with Time (1998/June to 2001/April) in Kulugammana groundwater intake wells.

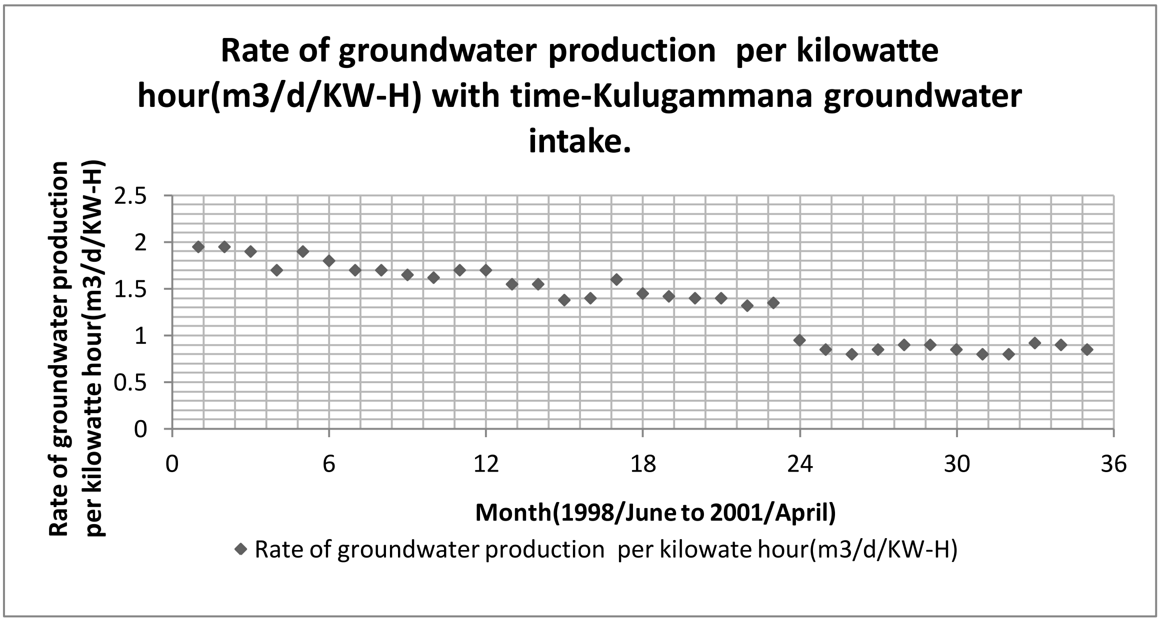

Figure 4: Extraction amount per kilowatt-hour with period in Kulugammana groundwater intake wells

In 1995, three deep tube wells were used to supply 600 to700 m^3/day for Kulugammana Water Supply scheme. All three wells were constructed within a 100 radius on the right bank of Piga Oya. The average pumping water level was about 15 m below the ground level during the commissioning period. It has been noticed that the pumping rate recorded during the period of 1999-December to 2000-July is 300 m^3/d indicating a sharp drop in the production. Well development was conducted in the latter part of 2000 and the average pumping water level was at 45 m below the ground level. The rainfall and pumping quantity did not show any correlation. As shown in figure 4, the energy requirement for pumping is has significantly increased over time.

Another operational related problem is over exploitation in some schemes without considering the recommended yields and aquifer drainage. In addition, the influence of other pumping wells is also affecting supply in some areas due to the limited management of groundwater resources.

As mentioned, the construction and maintenance of hand pump wells are now being implemented according to the Cabinet approved three-tier system (Village society, Local authority and NWSDB). Each group of the three-tier system is entrusted with their responsibilities. Up to 2008, about 10,000 hand pump fitted tube wells have been handed over to the local authorities by the NWSDB. During the handing over, all hand pumps were standardized into India Mark 111 and logistic supports (stores, tool kits, free spares, training, and transport facilities) were provided to the local authorities. After hand over, well development and water quality analysis were conducted. Table 4 provides the hand over status by Province of wells to the local or community based authorities.

Table 4: Handing over status of wells (Source: NWSDB).

Province	**Number of tube wells with hand pump (NWSDB, WRB, Others)**	**Handing over details**
Uva	3,177	639(20%)
Western	1,530	-
Central	3,854	2823(73%)
Southern	1,810	537(30%)
North central	6,019	4,200(70%)
North western	3,635	1,747(48%)
Eastern	1,576	-
Sabaragamuwa	1,023	-
Northern	545	-
Total	**23,169**	**9,946(43%)**

The process of transferring hand pump wells was completed for a number of local authorities. However, lack of regular monitoring, lack of coordination among involved groups, unavailability of spare parts, lack of funds for rehabilitation and new construction, seasonal demands, water quality problems, and alternative water facilities are few problems associated with the sustainability of hand pumps.

Groundwater management

A number of Parliamentary Acts cover different aspects of water resource utilization and management of Sri Lanka. However, only a few have significant importance. Irrigation Ordinance, Crown Land Ordinance, NWSDB Law, and National Environmental Act and its 1988 and 2000 Amendment are among them.

There is still no specific legislation covering management of groundwater, groundwater monitoring and wellhead protection. Therefore, it is very difficlt to protect and manage groundwater effectively. However, the National Environmental Act with Amendment 1988 and 2000 empowered the Environmental Authority with approval procedures for projects having an impact on natural resources. In addition, Gazette Extra-ordinary No .722/22 of 24 June 1993 prescribed a list of projects including water supply projects exceeding 0.5 million cubic metres per day of groundwater extraction must undergo an EIA process. It has also been determined that distance between a well and a pit latrine should be a minimum of 15 m.

However, several attempts in the recent past to develop a policy for the improved water resources management were not successfully concluded (Imbulana, 2008). As such, there are several policy and institutional gaps in the water sector particularly in the scientific development and management of groundwater subsectors. This situation leaves several crucial areas of groundwater management unaddressed.

Conclusion

Groundwater development in Sri Lanka is improving the living standard in rural community. Although the construction of number of wells and groundwater extraction has sharply increasing over the past 20-30 years, groundwater use has not been regulated properly. Unless the extraction and use of groundwater are managed in a sustainable manner, adverse environmental, health, and social problems will occur. In addition proper monitoring, rehabilitation, and well protection programs are required to increase the lifespan of wells and aquifers.

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An Investigation on the Trends of Water Quality Deterioration in Northwestern Limestone Aquifer System in the Puttalam Region based on Stable Isotope Composition

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Abstract

The availability of good quality water in sufficient quantity is declining because of the increasing demand on groundwater resources and the deterioration in groundwater quality in the Puttalam limestone aquifers. The aquifer system is a complex carbonate aquifer characteristic of a highly cavernous sedimentary limestone formation. The limestone layers are inter-bedded with sandstone and other unconsolidated deposits such as thick clay layers, sand, and sandy clay. Due to the unlimited extraction of freshwater from these aquifers for both water supplies and agricultural activities, most borehole water has become saline. The literature suggests that the analysis of environmental isotopes $\delta\ ^{18}O$, and $\delta\ ^{2}H$ along with major, minor and trace ion chemistry offers useful insight into the source of salinity, the recharge aspect of aquifer system, and also the residence time of saline groundwater. Under this study, twenty two (22) boreholes representing different aquifer units and eight (8) surface water samples for the Puttalam region were collected and analyzed for $\delta\ ^{2}H$, $\delta\ ^{18}O$ and other chemical parameters. The results indicated the high evaporation has a significant effect on surface and shallow water bodies. The samples collected from boreholes of different depths, representing different zones of limestone terrain, indicate unique isotope signatures.

Introduction

Due to rapid expanding and intensifying urban, industrial, and agriculture activities, groundwater extraction and use has significantly increased in the Puttalam District (Panabokkea and Perera, 1995). Deep borehole construction for groundwater extraction in Puttalam area commenced in the 1970s and now there are over 1000 tube wells (WRB data base). Among them the Puttalam town water supply scheme is one of the most important public water supply schemes operating in the area. It is reported that the water quality of some of the tube wells has sinificantly deteriorated due to increasing salinity level (NWS&DB, 2008). During 2008, the tendency of increasing salinity was closely monitored as well as the affect on the well field supplying water to the town of Puttalam and the surrounding aquifers. Considering the increasing trend of salinity in borehole water, pumping of several wells was stopped and pumping rates reduced for others. Therefore, it is necessary to conduct a detail hydrogeological and hydrochemical assessment to identify the extent of the intrusion and possible mechanism for decreasing the salinity level.

Since the available hydrogeological and geochemical data of the aquifers of Puttalam Limestone and surroundings have limited use for understanding the process by which salinity increases, stable isotope composition of groundwater was used as a technique in the study.

Generally groundwater salinity originates from one or more of the following mechanisms: (a) intrusion of old or modern marine water, (b) mixing of meteoric water with connate water or fluid inclusions, (c) concentration of dissolved salts by evaporation near the soil surface during slow diffuse recharge, (d) dissolution of aquifer material and (e) anthropogenic source. Each of these mechanisms will have a distinct effect on the geochemical and isotopic relationships of the groundwater (Shivanna *et al.,*1998).

Study Area

The study area is 600 km^2 , located in the Puttalam District. (Fig.1)

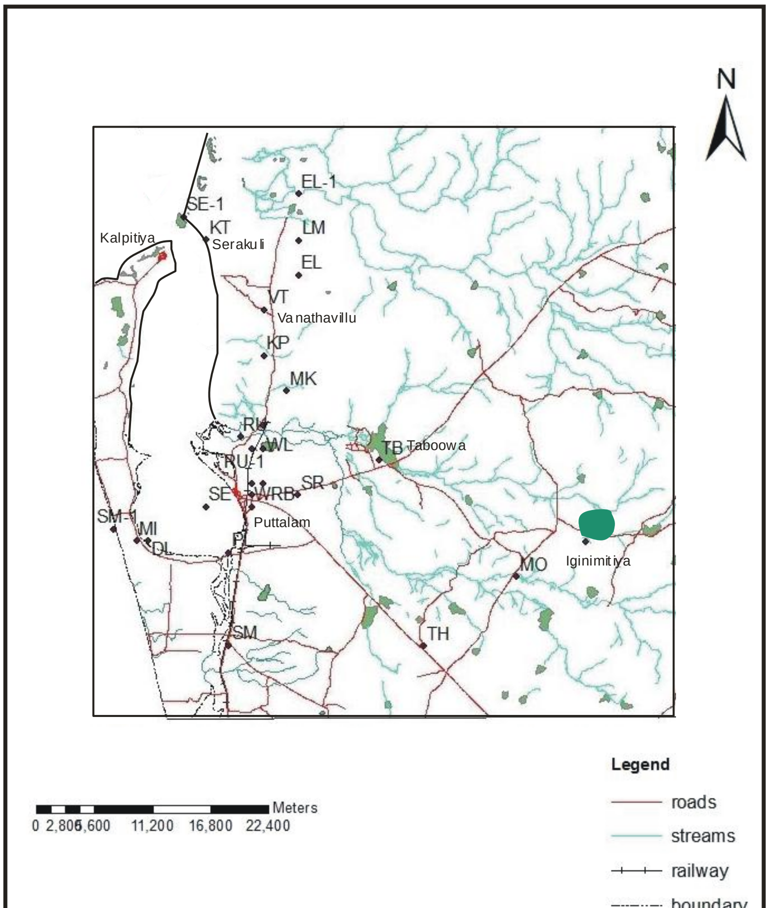
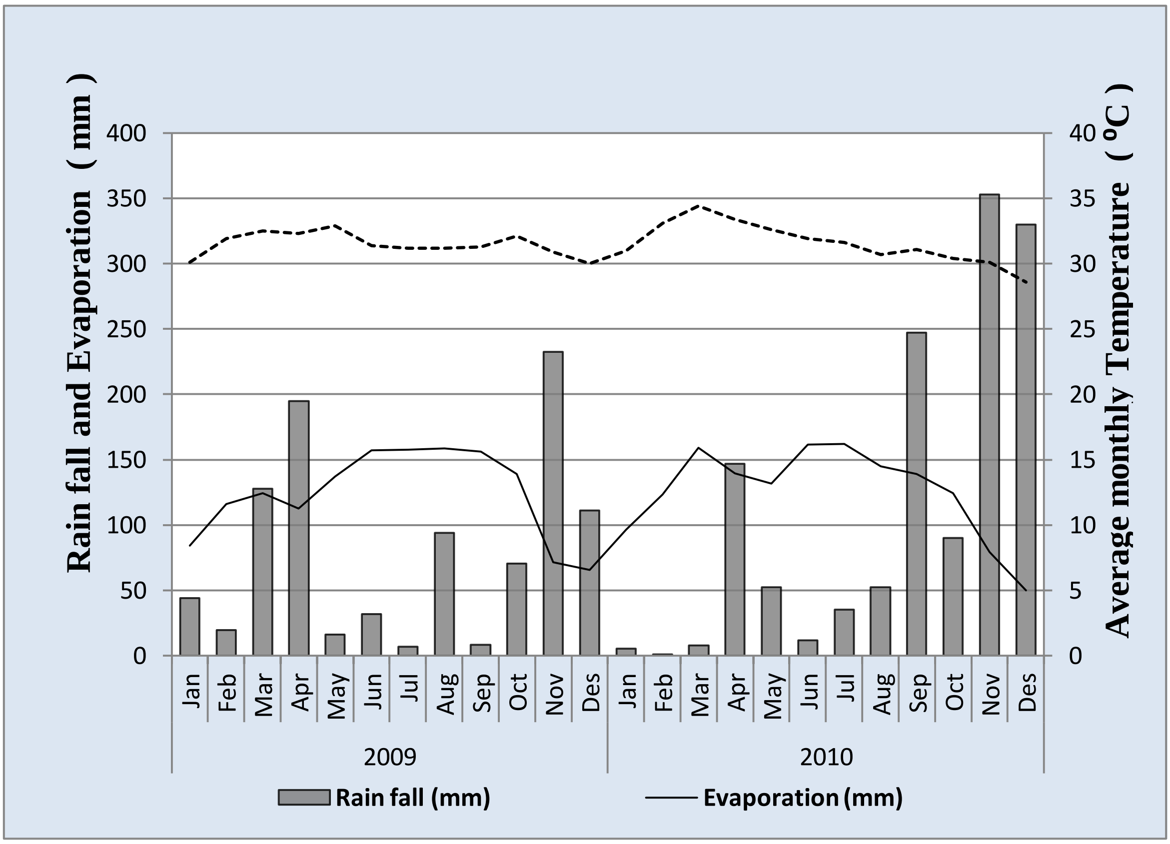


Fig 1: Location of the Study area and the sampling sites

The Puttalam-Vanathavilluwa aquifer system is found in the western part of the study area. The Eastern part of the study area is composed of hard rock aquifers developed by post metamorphic activities such as brittle deformation and weathering in the Precambrian formation (Cooray, 1984). The geographical coordinates of the area are 7^0 $52^/$ - 8^0 $17^/$ latitude and 79^0 $41^/$ - 80^0 $12^/$ longitude. There are two river systems flowing from east to west; the Kala Oya in the north and Mee Oya in the south (Fig. 01.). The area lies within the dry zone and receives less than 1000 mm of rainfall per annum with most of the rainfall occurring during September to December (Source; Puttalam meteorological station). Evaporation is generally 3mm to 5mm per day. The temperature ranges from a minimum of 21 ºC for the November to March period and a maximum of 33 ºC for June to September period. Coconut and cashew plantations are the main cultivation in the area with a mixture of other cash crops in the western part of the area. The North-Eastern part of the study area is comprised of scrub jungles and thick brush. Thabbowa and Ignimitiya are the major reservoirs in the study area.



Hydrogeology

The Puttalam-Vanathavilluwa aquifer system is associated with a complex carbonate aquifer of a highly avernous sedimentary limestone formation. The aquifer is composed of different layers interbedded with sandstone and other unconsolidated deposits such as thick clay layers, sand, and sandy clay (Balendran., 1970). The available borehole data implies that the thickness of limestone aquifer varies greatly from one area to another (WRB groundwater data base). It was recorded that the limestone layer occurs at the depth of 200 m in Serakuliya and Karthive areas whereas the same is found at the depth of 25 m in the Puttalam urban areas (Fig 3). The aquifers in the area are characterized by confined to semi-confined conditions and overflowing wells under confined conditions are observed in the coastal belt, Serakuliya and Madurankuliya areas (Fig 1). The eastern boundary of the limestone belt lies 30-40 m below surface in the North–South direction. The overburden is made up of unconsolidated sand, which is identified as one of the shallowest aquifer systems in the area. (WRB Data base).

Groundwater quality over the region is complex and the available borehole data indicate that the chemical composition of the gorundwater varies with the depth.

There are 12 deep boreholes constructed for the Puttalam town water supply project and these wells are located about 3 – 5 Km north ot the Puttalam Town. Daily production of the well field is about 20,000 m^3 (NW and SDB Puttalam records).

Methodology

Water Resources Board and Atomic Energy Authority of Sri Lanka conducted a study to evaluate the processes of the water quality deterioration in the limestone and hard rock aquifer systems in Puttalam area. The environmental isotopes of D, and ^{18}O have been deployed in view of collecting data about the salinity intrusion. These data were used together with other existing hydrogeology and hydrochemical data for the study.

Considering the hydrogeological settings and recent increasing trends of salinity values in the Puttalam region, a sampling plan was designed covering the eastern hard rock terrain and western sedimentary belt. The first set of samples was collected in September 2009, before the start of the north-east monsoon. Twenty two (22) groundwater samples and eight (8) surface water samples were collected for the study. Rain water samples were also collected for isotope analysis. The Atomic Energy Authority of Sri Lanka sent the samples to the

Radiation and Isotope Application Division of Pakistan Institute of Nuclear Science and Technology (PINSTECH) for the analysis. The second sampling programme was started in March 2010.

Results and Discussion

The analytical results of the Isotopes for the September 2009 and March 2010 sampling programme are given in Table 1.

Table 1: H and O Isotope Composition of Surface Water and Groundwater for the Study Area.

Sample Code	Location	September 2009		March 2010	
		·¨O	·˙·	·¨O	·˙·
		(‰)	(‰)	(‰)	(‰)
IG	Iginimitiya reservoir	0.55	1.25	-	-
MO	Mee Oya bridge	-1.85	-14.01	-	-
KO	Kala Oya bridge	-1.11	-7.65	-	-
MO -1	Mee Oya	-0.79	-6.83	-2.9	-19.6
EL	Eluwankulama, Kala Oya	-1.51	-9.97	-	-
SM-1	Sea, Mampuri	0.16	2.03	0.22	0.22
PL	Lagoon, Palaviya bridge	2.56	15.44	-	-
SE-1	Lagoon, Serakkuliya	1.46	6.64	-0.15	-0.28
DL	Daluwa	-5.56	-35.54	-5.26	-34.46
MI	Navakkadu	-6.09	-31.20	-	-
TH	Thonigala	-5.85	-35.86	-5.8	-36.25
TB	Thabbowa tank	-6.51	-39.72	-6.48	-42.87
SR	Sirambiadiya	-6.09	-39.50	-6.17	-38.69
WL	Wiluka	-5.93	-37.60	-6.37	-44.34
KP	Karadipuwal	-5.70	-35.31	-5.59	-34.99
VT	Vanathavilluwa	-7.09	-45.06	-6.76	-43.41
KT	Karathiew	-5.58	-34.92	-5.94	-36.59
SE	Serakkuliya	-5.73	-35.30	-5.66	-37.31
EL -1	Army camp near Kala Oya	-2.04	-14.79	-	-
LM	Rahalmaduwa	-5.45	-37.50	-6.02	-41.21
MK	Mailankulam	-6.43	-40.27	-	-
SM	Madurankuliya	-5.38	-35.33	-5.31	-34.54
KS	Karsim city	-5.70	-35.28	-5.75	-40.03
NWDB-4	Senakudirippuwa	-6.58	-37.43	-	-
NWDB-1	Manangundru	-6.76	-37.63	-6.51	-40.03
NWDB-2	Manangundru	-6.34	-39.91	-6.17	-43.16
NWDB-3	Abayarama	-6.48	-39.96	-6.33	-38.56
RU	Rahumathnagar	-3.63	-25.37	-3.93	-28.1
RU-1	Rahumathnagar	-5.58	-37.55	-5.6	-34.8
WRB	WRB office, Puttalam	-5.48	-37.25	-5.93	-36.9

The Isotopic composition of the different water bodies types is given in Table 2.

Table 2 : Ranges of Isotope Compositions for Different Water Bodies

Water source	Range of Isotope composition							
	·¨··(‰)				·˙··(‰)			
	September 2009		March 2010		September 2009		March 2010	
Groundwater	-5.38	-7.09	-5.26	-6.76	-31.2	- 45.6	-34.46	- 42.87
Inland surface water	-0.79	-1.85	-2.9	-6.37	-6.83	-14.01	-19.6	-44.33
Lagoon	1.46	2.56	-0.15	0.22	6.67	15.44	-0.28	0.22

Chemical analysis results for the existing boreholes available in the database of WRB are shown in Table 3. These data represent the chemical composition of deep wells immediately after construction.

Table 3: Chemical Data of Borehole Water in the Study Area.

Sample Code	Location	Sample Depth (m)	pH	EC	Ca^{+2}	Mg^{+2}	SO_4^{-2}	Cl^-
				µS/cm	mg/l	mg/l	mg/l	(mg/L)
TH	Thonigala	40			62.5	33.5	2	672
TB	Thabbowa tank		6.08	991	19.4	7.1	6.2	78
SR	Sirambiadiya	44	6.91	621	21.1	5.6	1.6	50
WL	Wiluka	18	7.31	1434	80	72.8	73	145
KP	Karadipuwal	90	6.92	3270	42.5	22.5	73	82
KT	Karathiew	60	7.98	1864	75.4	45.4	170.5	337
SE	Serakkuliya	60	7.97	1906	75.2	116		679
LM	Rahalmaduwa	62	7.14	2080	114	69.4	35.3	490
MK	Mailankulam	28	6.82	1605	51.2	28.1	31.9	163
SM	Madurankuliya	60	7.05	4890	155	117	248	814
DL	Daluwa	60	7.48	6650	38.4	52.4	10.2	318
NWDB-4	Senakudirippuwa	70	6.95	2430	148	89.8	112	544
NWDB-1	Manangundru	73	7.39	2210	245	57.3	75	352
NWDB-2	Manangundru	42	7.44	1815	89.7	49.5	42.3	302
NWDB-3	Abayarama	52	7.25	2190	97.7	59.5	56.3	504
WRB	WRB office, Puttalam	32	7.33	1689	45	11.2	29.4	72

Surface Water

A limited number of water samples (Inginimitiya reservoir, Mee Oya, Kala Oya, Puttalam lagoon and open sea) were analyzed for δ ^{18}O and δ ^{2}H. The analytical results (Table 1) obtained from the September 2009 samples show that the values obtained for the Mee Oya increase as one moves inland (δ ^{18}O :- -1.85 to -0.79**‰** and δ ^{2}H: -14.01 to -6.83**‰)** In the Kala Oya these values decline as compared to those of Mee Oya (δ ^{18}O : -1.11 to -1.51**‰** and δ ^{2}H:- -7.62 to -9.97**‰).** The Inginimitiya reservoir shows values of δ ^{18}O : 0.55**‰** and δ ^{2}H: 1.25**‰**. The δ ^{18}O and δ ^{2}H composition of lagoon water shows positive values of δ ^{18}O : 1.46 to 2.56**‰** and δ ^{2}H: 6.67 to 15.44**‰** and these values are higher than the values for open sea water (δ ^{18}O : 0.16**‰** and δ ^{2}H: 2.03**‰**.)

The relationships between δ ^{18}O and δ ^{2}H in the samples are shown in Figure 2 and Figure 3.

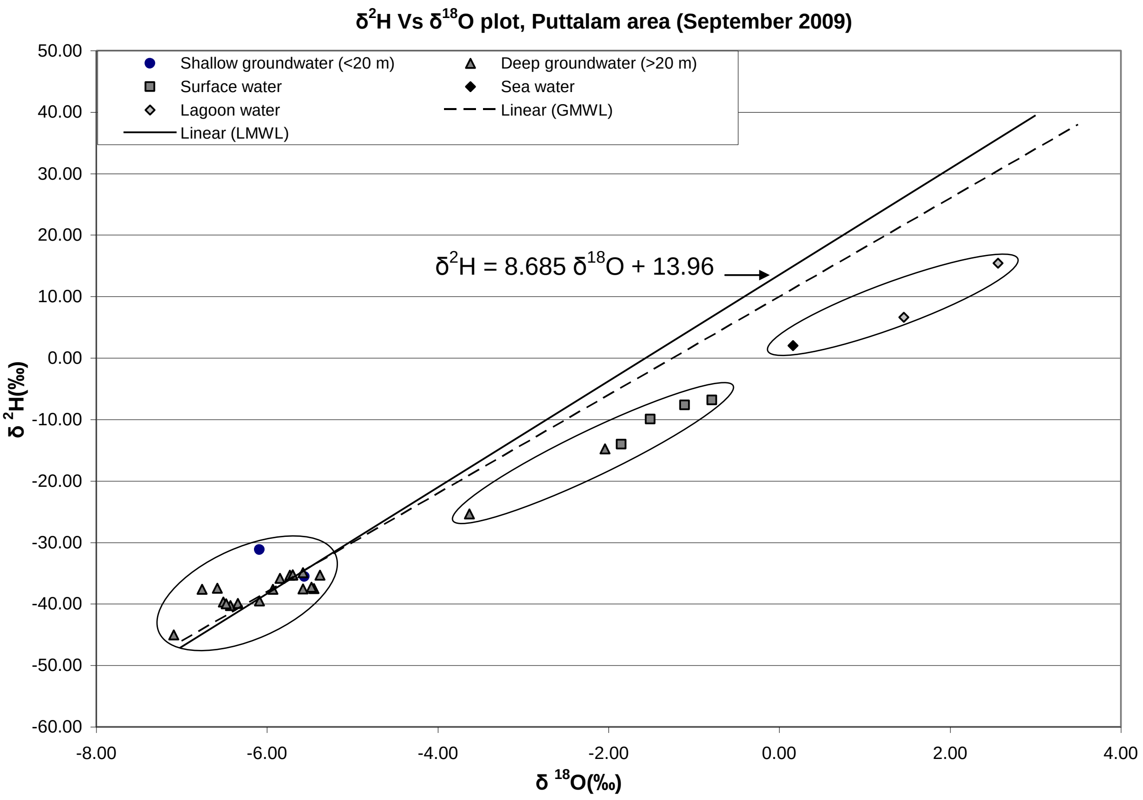


Figure 2: Relationship of H and O Isotope Composition - September 2009 Samples

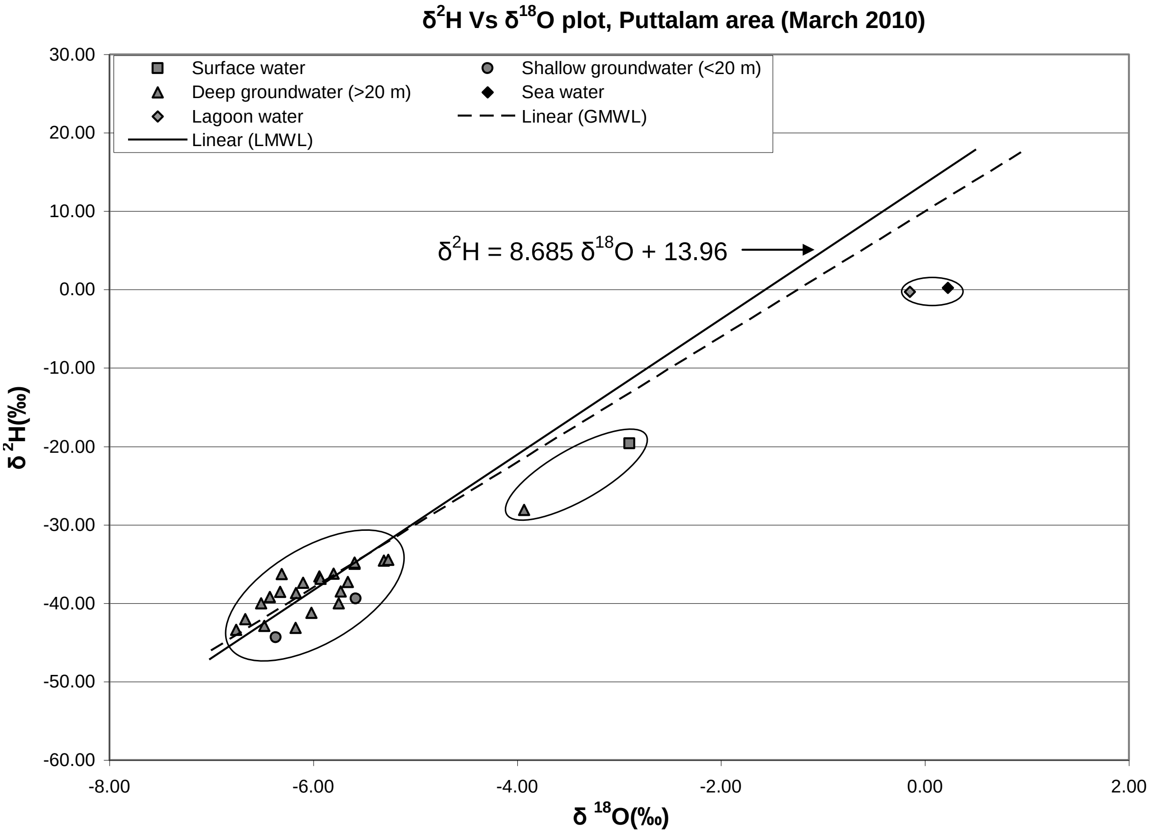


Figure 3: Relationship of H and O Isotope Composition - March 2010 Samples

The equation for LMWL is given by $\delta\ ^{2}H = 8.685* \delta\ ^{18}O + 13.96$. It is observed that most of the Isotope values of surface water samples do not fall on the GMWL and LMWL (Figures 2 and 3). The reason for this could be due to high evaporation in the region. Although the groundwater samples collected from different regions representing separate hydrogeological units, they fall wihin one cluster as the values ranging from $\delta\ ^{18}O$ -5.38‰ to -7.09‰ and $\delta\ ^{2}H$ -31.20‰ to - 45.06‰ respectively. The ground water samples collected from middle, upper and deep artisan wells show a similar Isotope signature. The Isotope composition of limestone aquifers and sandy unconsolidated aquifers also shows similar characteristics.

Two groundwater samples have similar Isotopic composition as that of the inland surface water bodies as shown in Table 1. These samples were collected from adjacent areas downstream of the Kala Oya and close to the Mee Oya. The common Isotopic composition suggests the groundwater is recharged from surface water.

Conclusions and Recommendations

The application of stable Isotope, $\delta\ ^{2}H$ and $\delta\ ^{18}O$ has provided relevant information on water quality changes in surface and groundwater in the study.

Although the information gathered in this study is limited, the monitoring of Isotope composition of the groundwater and surface water bodies after the monsoon period is very essential. It is suggested in addition to the $\delta\ ^{2}H$ and $\delta\ ^{18}O$ Isotope analysis that $\delta\ ^{3}H$ and $\delta\ ^{14}O$ isotope (half life 12.43 and 5730 years respectively) be analyzed to determine the aging of the groundwater of the region. To identify the extent of seawater intrusion to the deep and shallow ground water systems, the $\delta\ ^{34}S$ Isotope should be analyzed.

Some of the specific recommendations of the result of the study are:

(1) The study revealed that the Isotopic composition of deep groundwater is different from that of the surface and shallow groundwater.
(2) The stable are Isotopic values suggest that high evaporation may be controlling the salinity levels of surface water bodies.
(3) There is no apparent change of Isotope values for shallow groundwater after the monsoon period.
(4) The groundwater quality for the deep wells of the Puttalam water supply well field of Rahumathnagar affected as the result of the mixing of poor quality shallow water in the upper layers. This may be due to the corrosion of the iron material in the well casing.

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A Rational Approach to Groundwater Monitoring in the Various Irrigation Systems of Sri Lanka's Dry Zone

C.R. Panabokke

WRB and IWMI

Introduction and General Background

It is now unequivocally recognized that the groundwater in the metamorphic hard rock regions of Sri Lanka's dry zone exists both in the 'shallow regolith' (weathered bed rock and saprolite), as well as in the deeper fracture zone aquifers. In the course of studies conducted on the shallow weathered zone of the hard rock areas of Sri Lanka, it has been observed that the agro wells penetrate only the top of the saprock horizon, because digging becomes more difficult once this layer (horizon) is reached. The thickness of this regolith horizon in the dry zone is variable and is usually not greater than 10 m. The nature of occurrence of this regolith aquifer in the hard rock region of the dry zone of Sri Lanka has been adequately described and discussed by Panaboke (2003) and (2007).

More than 90 percent of both major and minor irrigation reservoirs together with their command areas are situated within the metamorphic hard rock basement of the lower peneplain of Sri Lanka. Our understanding of the lower peneplain of Sri Lanka has undergone considerable change over the last 25 years. It is now recognized that this lower peneplain of Sri Lanka is equivalent to an 'Etched Plan' as found in the hard rock basement complex of continental Africa. This explain why the small village tanks occur in the form of well defined cascades within the small inland valley systems of this weathered rock basement landscape.

The major irrigation reservoirs in this landscape are usually situated across the higher order streams/rivers (3rd and 4th order streams) that dissect this landscape. However, the irrigation command areas of under these reservoirs an all situated within the component sub-watersheds that make up the individual river basin, as well as along various inland alluvial plains of varying form and size.

Past Studies and Findings

The trend in groundwater level fluctuation of 28 agrowells located within the command area of the major Huruluwewa Irrigation System was studied by de Silva, Fernando, Sakthivadivel and Merrey (1999). Based on their field studies, a methodology was developed which could regulate the manner of abstraction of the regolith aquifer. It was demonstrated that this methodology could be applied to places with similar hard rock aquifers as occurring in South Indian and parts of Africa.

A detailed study which characterizes and monitor the Regolith Aquifers under the small village tanks cascades of the Malala Oya basin in Southern Sri Lanka was reported by Panabokke it al in a IWMI Workshop Paper 122 of 2007. The results of this study showed that the depletion of groundwater levels take place form May onwards over a 23 week period up to October; and that the depth to depletion of the groundwater levels closely follows the macro-elevation of the landscape.

It was also shown that the findings from this study would serve as an appropriate methodology for monitoring the groundwater behaviour of these small village tank cascade system wherever they occur in the dry zone landscape of Sri Lanka.

A special feature of this DEO basin is that it is made up of equal proportions of the production zone transfer zone Depositional Zone respectively. Further more it has a total of 3274 small tanks which constitute 26% of the all-island total of small tanks.

The first step in this study was to identify and demarcate the component sub watersheds SWS that make up the whole basin by an interpretation and analysis of the 1 inch 1 mile topo sheet of the Survey Department. A total of 15 component sub-watersheds (SWS) were identified and demarcated, the final results shown in Figure 01. The next sequential step was the demarcation of the component small tank cascade across all the fifteen sub-watersheds. During this phase of the study it was found that ninety percent of all small tanks fall in within the five sub-watersheds (SWS) of the Koh Oya, Kolamuna Oya, Rambukkan Oya and Mid Deduru Oya.

In the next subsequent step the following four SWS were finally selected for further detailed study. This involved field verification and confirmation of the individual cascade boundaries, field verification of the tanks and command areas using the 1:50,000 scale ABMP map, grouth of agro wells ; and field verification of the spread and occurrence of both the (a) Regolith aquifer and (b) alluvial aquifer Figure 02 shows the distribution patterns of the small tank cascade and the shallow regolith aquifer as well as the alluvial aquifer. Selective sampling within these cascades and aquifer types unabled an economy of operational studies. Results will be presented and discussed.

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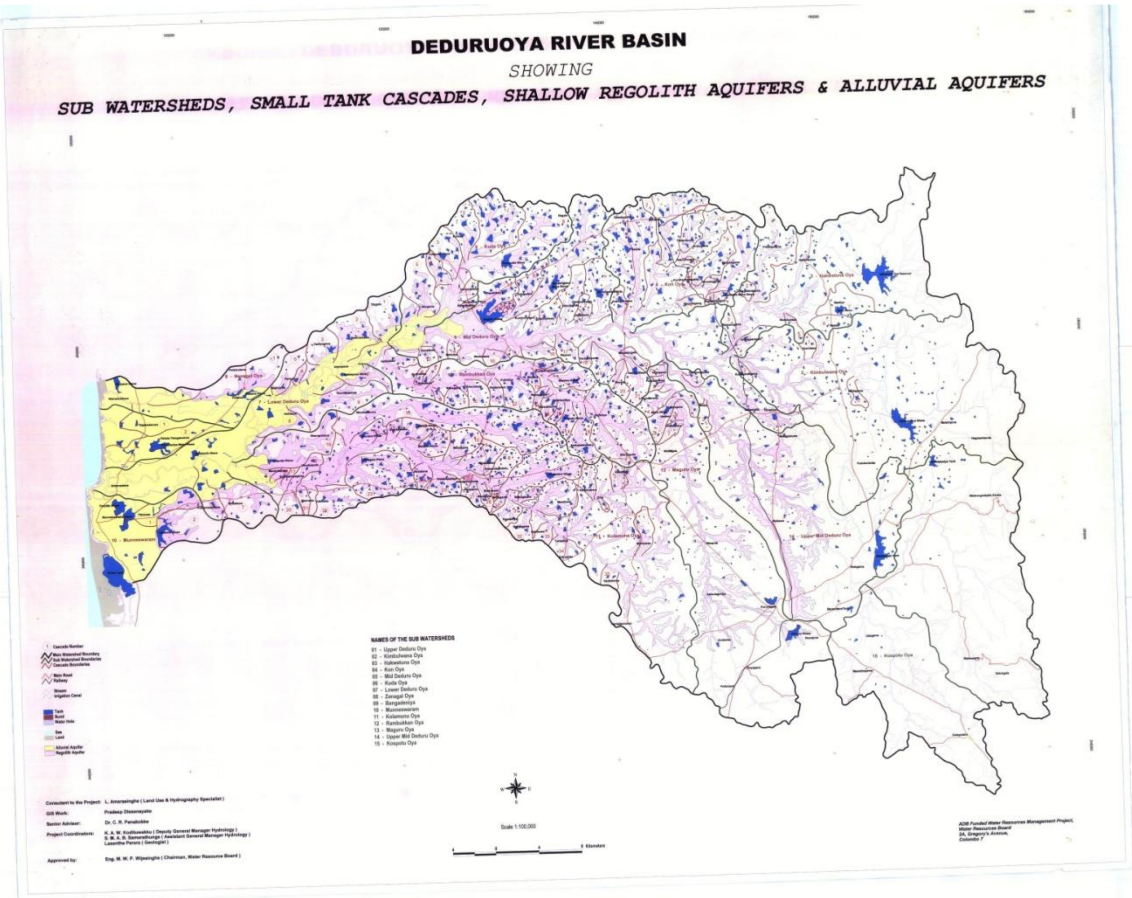

Chronic Kidney Disease of Unknown Etiology (CKDu) and Arsenic in Groundwater in Sri Lanka

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Introduction

In recent years a significant increase in patients of Chronic Kidney Disease of unknown etiology (CKDu) has been observed in some parts of Sri Lanka, especially in Medawachchiya, Padaviya, Kebitigolawa, Medirigiriya (North Central Province), Nikawewa (North Western Province), Dehiattakandiya (Eastern Province) and Giradurukotte (Uva Province). Uniqueness of this disease is that its victims do not share the same history as other kidney patients who have had it either due to diabetes, high blood pressure, past snake bites or urinary tract infections. Etiology of this disease has since been attributed to a range of causes, including presence of the heavy metal cadmium in water that would potentially have introduced to water from inorganic fertilizer used in paddy fields, presence of excessive amounts of fluoride in drinking water and prevalent use of low quality aluminum utensils, presence of toxins produced by microorganisms such as cynobacteria in water. Despite the effort of about 60 researchers including those who were funded by WHO (World Health Organization) over the last decade, none of these hypotheses have been supported with evidence; in fact, the data available prove them not to be the cause. The causative factors and etiology of this chronic kidney disease therefore is still considered uncertain or unknown and abbreviated as CKDu with recommendations of the National Research Programme for CKD of the Ministry of Health in Sri Lanka.

Endemic occurrence of the disease was firstly recognized in the 1990s in certain areas of North Central Province, and this has been on the increase dramatically over a period of 10-15 years and Table 1 presents the registered number of CKDu patients in government hospitals and renal clinics in the respective disease affected areas.

Table 1: Number of patients reported at the end of 2010

Area	**Number of patients**
Anuradhapura	1800
Medawachchiya	2500
Padaviya	1300
Sri pura	500
Medirigiriya	600
Hingurakgoda	600
Polonnaruwa	900
Giradurukotte	2500
Nickawewa	500

There are also records that CKDu has reached epidemic proportions in the above mentioned parts of Sri Lanka, as the affected number of people is on an alarmingly steady increase over the years Figure 2 presents the distribution of CKDu patients in North Central, Eastern, Uva and North Western Provinces of Sri Lanka and it highlights that highest density is found in Giradurukotte,Padaviya and Medawachchiya areas.

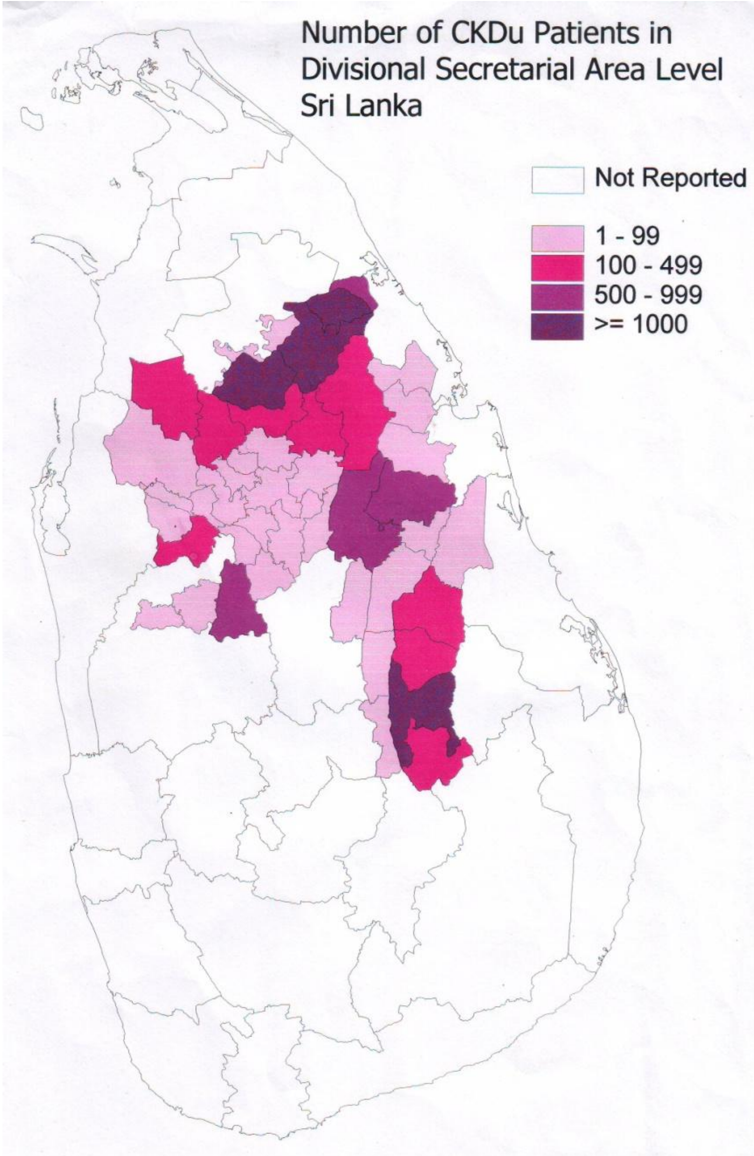


Fig. 2: Distribution of CKDu patients in Divisional Secretariat level

Recent research on CKDu

Few months ago, a group that consists of university academics, medical doctors, mathematicians from relevant institutions commenced a new research with the intention of finding the causes and also treatment and prevention methods for this miserable disease.

During the assessment of patients (n=197)our group noticed hyper-pigmentation and keratosis in palms and soles of patients,a symptom characteristic for chronic **Arsenic(As)** poisoning (Plate 1)

Plate 1: Hyper pigmentation and keratosis observed in the palms and soles of CKDu patients

Further we were able to detect other clinical features of chronic arsenic poisoning including generalized body weakness, headache, burning of the eyes, anaemia, nausea, hepatomegaly and spleenomegaly,epigastric pain, paresthesia .

Arsenic in drinking water

These observations have led us to analyze drinking water of patients for Arsenic and these analyses were carried out in the analytical chemistry laboratories at University of Kelaniya and Water Recourses Board in Colombo 07. Surprisingly we were able to detect abnormally high amounts of Arsenic and Mercury in our water samples which are well beyond WHO permissible values (Table 2).

Table 2: Maximum permissible content of Arsenic in drinking water and the content observed in Drinking water of CKDu patients in Mahawilacchiya and Padaviya areas

	WHO upper limits in drinking water	Concentration in drinking water sources of CKDu patients in Sri Lanka (n=107)
Arsenic	10 ug/L	73-208 ug/L
Mercury	01ug/L	08-31 ug/L

Chronic Arsenic poisoning is a severe crisis in State of Bengal in India and Bangladesh. It has been identified as the worst chemical disaster in human history. In Bangladesh, drinking **As** contaminated water and rice are the main sources of Arsenic in human bodies.

Arsenic in Sri Lankan Rice

Chandrajith and his team in 2010 have identified relatively high amounts, ranging from 100 – 260 micro grams (ug) of Arsenic in rice that have been collected from CKDu endemic regions (Giradurukotte and Nickawewa)but they have not correlate the findings with disease prevalence.

Our analyses also revealed high amounts of Arsenic in rice which are compatible with that from West Bengal and Bangladesh-Arsenic poisoning areas (100-500 ug/kg)

Arsenic (As) in hair samples of CKDu patients and body parts of deceased patients

Chronic **As** poisoning is confirmed by high **As** levels present in hair samples of CKDu patients, which ranged from 3-10 mg/kg (3.04-7.18 mg/kg).

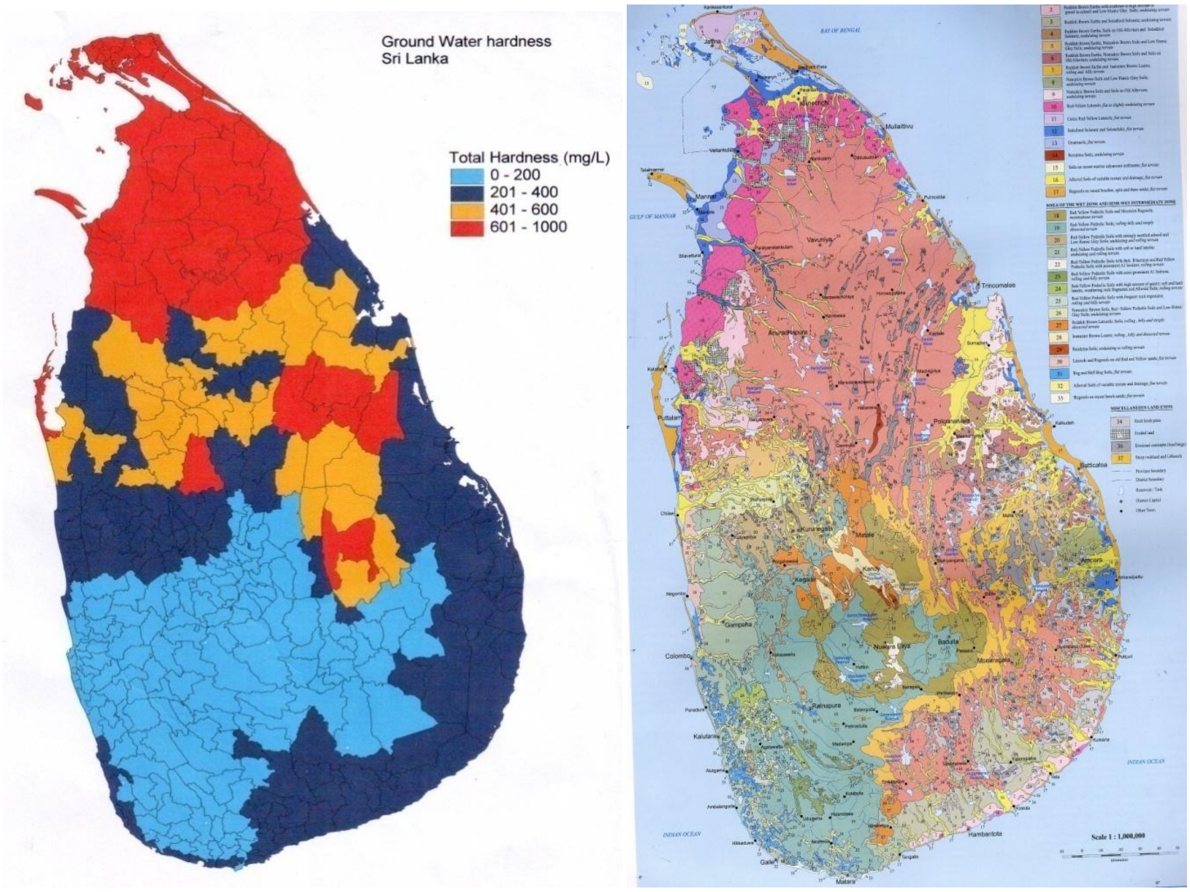
High amounts of Arsenic have been detected in body samples obtained from deceased CKDu patients. All these data further confirmed chronic Arsenic poisoning that have taken place in CKDu victims.

Body part	Arsenic in our study(ug/kg)	Normal As values(ug/kg) Muzumdar 2000
Large Intestine	292	20
Rectum	301	-
Liver	395	30
Spleen	1115	20
Kidney	1558	30

Relationship between prevalence of CKDu and ground water hardness

We also observed that the number of CKDu patients observed had a marked positive relationship to the extent of ground water hardness, i.e. higher the ground water hardness, more the number of patients encountered in those areas (Fig. 3).

Also it was observed that Arsenic was present in higher concentrations in the hard water of a certain type of soil (Reddish brown earth and low humic gley soil) in that part of the country which are reported to have a high heavy metal retention capacity due to their chemical unique properties (cation exchange capacity).



(A) (B)

Fig. 3: Geographical distribution of CKDu patients has shown a correlation with ground water hardness and soil type.

- (A) – Map of hardness of ground water in Sri Lanka
- (B) - Distribution of different soil types in Sri Lanka

Difficulty in detecting Arsenic in water

Arsenic form strong bonds with Calcium and therefore they are not easily detectable in hard water. The conventional analytical methods used for soft water therefore were not suitable to detect Arsenic in hard water. This may be the reason why most of the time other investigators have not detected presence of Arsenic in water collected from CKDu-endemic areas. High Arsenic retention capacity of dry zone soils also would have contributed to this situation.

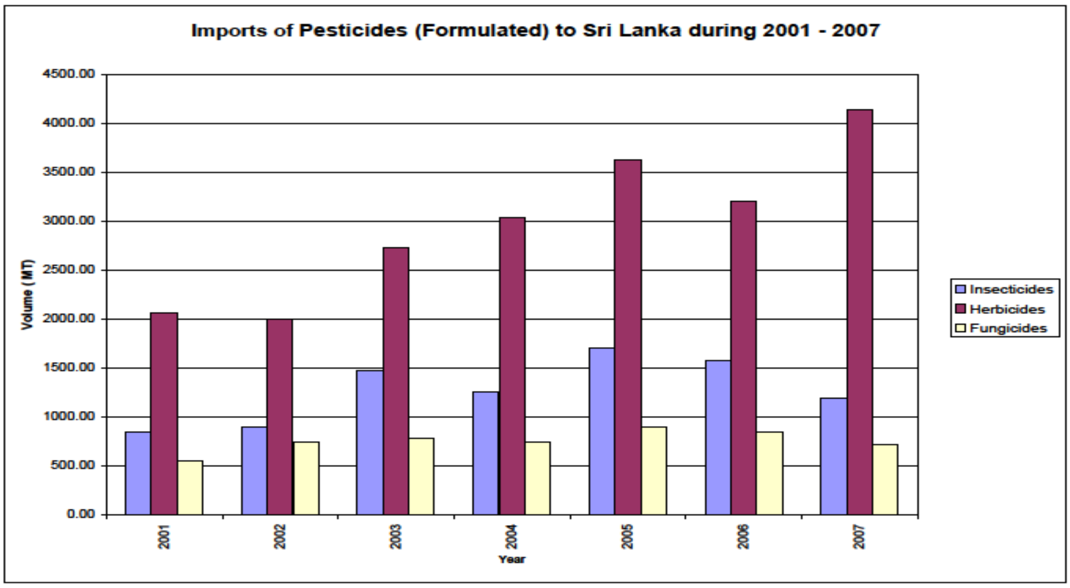
Potential source of arsenic

Use of pesticides has already been identified as a risk factor for CKDu *(Wanigasuriya et al 2007).* Logically, we have investigated pesticides for Arsenic as well as Mercury and our alarming results are presented below (Table 4)

Table 4: Amount of Arsenic and Mercury detected in major brands of pesticides and herbicides abundantly used in Sri Lanka

Brand	Arsenic ug/L	Mercury ug/L
1	77	2652
2	1908	818
3	757	00
4	323	23270
5-a	183	1018
5-b	175	2765
6	2457	1405
7	2752	928
8	00	6037
9	1197	928

Amounts of pesticides, i.e. insecticides, herbicides and fungicides imported and uses in Sri Lanka are on the increase as presented in the following graph (Fig.4).



According to the provisions of the Control of Pesticides Act No 33 of 1980, importation and distribution of pesticides containing Arsenic and Mercury are among the prohibited acts and it has been notified with the Gazette Extraordinary (No 1100/24) on the 29^{th} June 2001.

National importance of the pesticide issue

Chronic kidney disease is not the only problem associated with chronic Arsenic poisoning. There are many long standing non communicable diseases associated with chronic Arsenic poisoning and they include,

1. Cancers in skin,lung and kidney
2. Ischemic Heart Diseases
3. Cerebro Vascular Diseases-Strokes
4. Diabetes Mellitus
5. Gastritis

Since tons of pesticides have been used in Sri Lanka for the last 20-25 years, Arsenic (and also Mercury, for which we are in the process of investigating for evidence on health impacts) in them may potentially be the cause for rapidly increasing prevalence of CKDu, heart disease, diabetes and cancer in Sri Lanka, curing for which the Sri Lankan Government allocates substantial resources annually.

Rice being the staple food, incredibly high Arsenic content in rice poses the greatest threat to health of Sri Lankans. As such, it is prudent that immediate action is taken to curb the influx of Arsenic and Mercury containing pesticides to Sri Lanka.

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Summary of Group Discussion

GROUP DISCUSSIONS

The workshop has been planned to capture the views of three main types of stakeholders – researchers, resource managers and resource users - in order to understand the behavioural status of available groundwater, its management and use. Seven of the researchers on groundwater have presented papers broadly on the above three areas setting out their objectives, findings and recommendations which were briefly discussed by the participants at the workshop. Nevertheless, as expected, these research papers have only marginally dealt with management issues that the resource managers are saddled with and the resource use issues that the groundwater users confront. It is to get a deeper understanding of these two issues, in addition to what the researchers have expressed about them, that a group discussion was held to further highlight management and user issues. With the paper presenters, there were participants mainly comprised of both public and private sector resource managers at national and regional levels and a limited number of resource users

As could be seen in Appendix 4 the three issues set out for discussion are : (i) methods of human interference with groundwater (farming, livestock keeping, fish breeding, manufacturing, service provision and others); (ii) damage minimization through self discipline in resource use and damage minimization through the imposition of rules and regulations, and (iii) data management including water resource data compilation, data updating, data banking and dissemination of data to the users in particular

Group I.

The discussants agreed that **water pollution** is a major cause for concern . The pollutants that they identified are : (i) agrochemicals used in farming; (ii) dung and urine contaminations arisen from unsystematic livestock breeding; (iii) industrial wastes diverted or made to find their way to water courses; (iv) improper urban waste disposals; (v) lack of proper drainage systems causing further stagnation and pollution of urban waste water; (vi) unsatisfactory solid waste disposal and the use of unhygienic pit latrines; (vii) unsystematic hospital waste disposals; and (viii) unplanned land reclamation. They also discussed the problem of **over exploitation** of limitedly available groundwater caused by: (i) unplanned land use in agriculture and the inefficient use of groundwater extracted thereby; (ii) excessive use of groundwater in industrial ventures; and (iii) using more water than required by liberal spraying of water to farm plots; and (iv) pumping water in a well at a faster rate than its replenishment rate, causing more and more **salt/alkaline** water build up in the agro-wells. The group also discussed the poor or slowed down rates of recharge due to man's reckless interference with soil and vegetation as well as due to hard pan formation and soil compaction which is a serious problem in the tropical soils Their active discussion showed that the resource managers are deeply concerned about pollution and fast depletion of groundwater in aquifers..

Group II

Damage minimization to the limitedly available groundwater through users' self discipline and through the imposition of strict rules and regulations by the authorities came under an active discussion. All the participants agreed that the problem has to be attacked from both fronts **- self discipline** and application of **rules and regulations** strictly. To inculcate self discipline, they recommended, with elaborations, the need to: create a public awareness of the problem; provide education; organize demonstrations; and carry out media publicity.. In the area of implementation of damage minimization, they urged that some supportive activities to retain groundwater levels free of danger and stress, the importance of the rehabilitation of abandoned tanks, introduction of soil and water conservation methods to agriculture in particular, catchment and forest management in collaboration with the resource users, construction of special reservoirs to keep the ground water table artificially close to the surface as far as possible and arrest free flow of even ephemeral rivulets by throwing low earth dams to delay the flow giving more time for percolation to the aquifers. Having seen **water pollution** as a major threat they have virtually agreed to arrest the causes of pollution from (i) to (viii) and to mitigate the dangers of **over exploitation** of groundwater from (i) to (iv) discussed in Group I. Additionally, they urged that existing rules governing the extraction of groundwater be strictly put in place with a continuous system of monitoring and new and stringent laws be framed anew if the need be, to halt over extraction of ground water.

Group III

The group was required to discuss and recommend actions that are necessary to : (i) systematically compile available scattered data; (ii) update collected data regularly; (iii) organize a data bank and to determine the depository of the same; and (iv) propose a strategy to disseminate data between the resource managers and resource user categories and among the members of each category. Under item (i), the recommendations were to :list agencies who should collect data, their mandates, types of data to be collected at national, regional and local levels, how to acquire requisite data , collection of available research literature, ascertainment of the reliability of data and identification of data gaps.. In respect of updating data under item (ii), the group emphasized the importance of spatial and time series data in addition to the emphasis on the data needs in respect of hazard situations.(For instance well water pollution following a tsunami).. Following a lengthy discussion on setting up a data bank, the emphasis was on the provision of access to the data bank for the resource users.. It was also agreed that for the dissemination of data there has to be a legal framework in place and , publications of data reviews with satisfactory data standards have to be worked out

On the whole the group discussions enabled to capture interesting and meaningful ideas in a broad spectrum beneficial to achieve the purpose of the workshop. The views that came to the surface at the group discussions are comfortably in juxtaposition with the paper presenters expressed views on resource management and resource use..

Workshop organizer's Specific Recommendations

1. Water Resources Board has been mandated with broad powers to address issues related to groundwater resources and it should be given legal powers to control, regulate and manage groundwater resources of the country. There should be an institutional mechanism between the Water Resources Board and the Water Supply and Drainage Board for the coordinated assessment, development, and management of groundwater resources.

2. Improved communications with the stakeholders is required and it is recommended that an appropriate institutional mechanism or central body to act as a focal point for the stakeholders be investigated.

3. Dissemination of information is critical to sustainable groundwater management. At present there is no proper mode for the dissemination and sharing of information among resource managers and from the central agencies to decision makers at the region level. An open and transparent approach is required to ensure the timely access to and s exchange of groundwater information.

4. Traditional knowledge and methods are available for water quality treatment and to enhance groundwater recharge. This traditional knowledge should be made widely available and linked to science based methods and technologies.

5. Formal training for middle management staff to improve technical and management skills is recommended. Training programs offer significant value in exposing middle management staff to groundwater issues and science based knowledge for sustainable groundwater management decisions and policies.

6. Several health related problems prevail in the country due to various groundwater related issues such as fluorosis, Chronic Kidney disease, and diseases originated from groundwater contamination. It is recommended that at least two research publications be produced annually addressing current groundwater related problems, provided that adequate funds are available.

7. Awareness programs with folkristic appeal targeting the grassroots level are required to enhance the knowledge of groundwater related issues. The organization of annual awareness events and the distribution of brochures, informative literature, and briefs through the divisional secretariat offices or the local school system are recommended.

8. The development of laboratory and other facilities at the regional level is recommended. These facilities will address regional and local issues, provide easy access for the local public, and offer guidance on water related issues and water borne diseases.

9. Methods of best practices be brought to the notice of youths to create awareness on conservation of water resources to encourage them to be self-motivated and self disciplined in consumption of water resources.

10. Well rigid monitoring networks should be designed and established to observe continuous changes to groundwater quality and water level declines at different time periods over the year in order to identify and interpret sources of contamination and causes for rapid water level decline. Programs have to be long term and extended to other parts of the country where specific problems prevail.

11. Catchments of coastal aquifers in the arid zones be assessed and appropriate measures are taken to protect them from pollution and over-abstraction in order to mitigate of impacts on fresh water from saline intrusion.

Appendix – 1: List of Participants

Sl No.	Name	Institute	Designation
01	Eng. Karunarathna Hettiarachchi	National Water Supply & Drainage Board	Chairman
02	Eng. D.N.J. Ferdinando	National Water Supply & Drainage Board	Addl. General Manager
03	Eng. D.S.D. Jayasiriwardana	National Water Supply & Drainage Board	Dy. General Manager
04	Eng. D.F.S. de F.Gunawardana	National Water Supply & Drainage Board	Dy. General Manager (North)
05	Eng. S.G.T. Rajkumar	National Water Supply & Drainage Board	Asst. General Manager
06	Eng. Chrishantha	National Water Supply & Drainage Board	Asst. General Manager (GW)
07	Mr. H.A.S.A. Perera	National Water Supply & Drainage Board	Manager
08	Mr. K.M. Premathilaka	National Water Supply & Drainage Board	Manager
09	Mr. H.U.S. Wickramarathne	National Water Supply & Drainage Board	Manager
10	Mr. G.D.S.P. Ranjan	National Water Supply & Drainage Board	Manager (GW Maintenance)
11	Mr. A.M.R. Bandara	National Water Supply & Drainage Board	Senior Hydrogeologist
12	Mr. M. Rajapakse	National Water Supply & Drainage Board	Senior Hydrogeologist
13	Mr. U.G.M. Ariyarathna	National Water Supply & Drainage Board	Senior Hydrogeologist
14	Mr. D.G.S.W. Pitakumbura	National Water Supply & Drainage Board	Senior Hydrogeologist
15	Mr. D. Malalgoda	National Water Supply & Drainage Board	Hydrogeologist
16	Mr. C.N. Thilakaratne	National Water Supply & Drainage Board	Hydrogeologist
17	Mr. C. Kularatne	National Water Supply & Drainage Board	Geologist
18	Mr. W.G.T. Indrajith	National Water Supply & Drainage Board	Geologist
19	Mr. P.M.S.S. Gunaratne	National Water Supply & Drainage Board	Geologist
20	Mr. S. Ranmadugala	National Water Supply & Drainage Board	Geologist
21	Mr. H.M.S.B.G. Thilakaratne	National Water Supply & Drainage Board	Geologist
22	Mr. H.M.K.J. Herath	National Water Supply & Drainage Board	Geologist
23	Miss Anoja Munasinghe	Department of Management Services	Director (Dept. of Management Services)
24	Dr. H. Manthrithilake	International Water Management Institute	Country Director
25	Mr. Nalin de Silva	Geological Survey & Mines Bureau	Geophysicist
26	Mr. Saman Kalubandara	Geological Survey & Mines Bureau	Geophysicist
27	Eng. Ivan de Silva	Ministry of Irrigation & Water Resources Management	Secretary
28	Mr. Linton Wijesuriya	Ministry of Irrigation & Water Resources Management	
29	Eng. K.A.U.S. Imbulana	Ministry of Irrigation & Water Resources Management	Addl. Secretary (TS)
30	Eng. W. Gamage	Ministry of Irrigation & Water Resources Management	Director (Water Resources)
31	Eng. P.U. Wickremaratne	Ministry of Irrigation & Water Resources Management	Director (Planning)
32	Mrs. Krishanthie Fernando	Ministry of Irrigation & Water Resources Management	Asst. Director (Planning)
33	Mr. S.S. de Silva	Ministry of Irrigation & Water Resources Management	Hydrosult Inc.(GW Specialist)
34	Miss Nishanthi Francis	Ministry of Irrigation & Water Resources Management	Hydrosult Inc. (Executive Assistant)
35	Eng. U.W.L. Chandradasa	Disaster Management Center	Director (Tech / Miti)
36	Miss A.A.A.K.K. Seneviratne	Disaster Management Center	Asst. Director
37	Mrs. Madara Dissanayake	National Building Research Organization	Scientist
38	Mr. Iddamalgoda	National Building Research Organization	Chemist
39	Mr. D.M.C. Dissanayake	Mahaweli Authority of Sri Lanka	Director General
40	Eng. G.K.T. Samaratunge	Mahaweli Authority of Sri Lanka	Dy. Director (WMS)
41	Eng. N.C.M. Nawaratne	Mahaweli Authority of Sri Lanka	Executive Director (IS)
42	Eng. (Mrs.) P.T. Thalagala	Mahaweli Authority of Sri Lanka	Director (PP)
43	Eng. H.H.P. Premakumara	Mahaweli Authority of Sri Lanka	Director (RBD&R)
44	Eng. B.S. Liyanagama	Mahaweli Authority of Sri Lanka	Director (WMS)
45	Eng. (Mrs.) Kusum Jayawardena	Mahaweli Authority of Sri Lanka	Deputy Director (TS)

46	Eng. (Mrs.) Manel Atapattu	Mahaweli Authority of Sri Lanka	Chief Engineer (TS)
47	Eng. (Mrs.) M.L. Nimanthi Manjula	Mahaweli Authority of Sri Lanka	Civil Engineer (WMS)
48	Eng. (Mrs.) H.A.D.P. Hapuarachchi	Mahaweli Authority of Sri Lanka	Civil Engineer (TS)
49	Mrs. Jeewa Warnakulasuriya	Central Environmental Authority	Asst. Director
50	Mrs. Kosala Mahalekam	Central Environmental Authority	Asst. Director
51	Mrs. Chandani Edussooriya	Central Environmental Authority	Asst. Director
52	Mr. G.B. Samarasinghe	Department of Meteorology	Director General
53	Mr. M.D. Dayananda	Department of Meteorology	Deputy Director
54	Mr. G.G.A. Godaliyadda	Department of Irrigation	Director General
55	Eng. P.C. Senaratne	Department of Irrigation	Director (SS & TR)
56	Eng. B.K. Jayasundera	Department of Irrigation	Director
57	Eng. U.S. Wijesekera	Department of Irrigation	Deputy Director (Hydrology)
58	Eng. S.P.P. Gamage	Department of Irrigation	Deputy Director (Eng./Geology)
59	Eng. S. Shanmuhananthan	Department of Irrigation	Deputy Director
60	Eng. D.C.S. Elakanda	Dam Safety & Water Resources Planning Project	Project Director
61	Eng. A. Sellahewa	Dam Safety & Water Resources Planning Project	Procurement Specialist
62	Mr. T.S. Jayamanna	Dam Safety & Water Resources Planning Project	Project Accountant
63	Eng. G. Sarawanbawan	Dam Safety & Water Resources Planning Project	SPO(CM)
64	Mrs. L.P.U.R. Basnayake	Dam Safety & Water Resources Planning Project	Civil Engineer
65	Mr. Malaka Dasanayake	Dam Safety & Water Resources Planning Project	Environmentalist
66	Eng. Miss W.G.H. Hemawansa	Dam Safety & Water Resources Planning Project	Civil Engineer
67	Eng. Miss W.A.R. Vinodani	Dam Safety & Water Resources Planning Project	Civil Engineer
68	Eng. Mrs. A.R.D.K. Aluthgama	Dam Safety & Water Resources Planning Project	Civil Engineer
69	Eng. T.M.S.H. Weerawardhana	Dam Safety & Water Resources Planning Project	Civil Engineer
70	Mr. R.I.B.R. Rathnamalala	Dam Safety & Water Resources Planning Project	Technician Engineer
71	Mr. Ranjith Amarathunge	Dam Safety & Water Resources Planning Project	Training Coordinator
72	Mr. A.M.T.N. Bandara	Dam Safety & Water Resources Planning Project	Mechanical Engineer
73	Mrs. Dishani	Dam Safety & Water Resources Planning Project	Civil Engineer
74	Mrs. Thiranka	Dam Safety & Water Resources Planning Project	Civil Engineer
75	Mrs. Y.G.A.C.G. Myald	Dam Safety & Water Resources Planning Project	Director (RD & C)
76	Prof. Ranjith Premalal de Silva	University of Peradeniya	Dept. of Agricultural Engineering
77	Prof. A. Senaratne	University of Peradeniya	Dept. of Geology
78	Dr. Mrs. N.D.K. Dayawansa	University of Peradeniya	Dept. of Agricultural Engineering
79	Dr. U.de S. Jayawardena	University of Peradeniya	Faculty of Engineering
80	Mr. D.C.D. Dissanayake	Information & communication of Sri Lanka	Programme Head
81	Mr. A.J.M. Rashid	Information & communication of Sri Lanka	Project Officer
82	Mr. Samantha Wijesundera	World Bank	Water & Sanitation Specialist
83	Mr. Viraj Edirisinghe	Atomic Energy Authority	Scientific Officer
84	Mr. D.G.L. Wickremanayake	Atomic Energy Authority	Head, Industrial Application

			Division
85	Mrs. Janitha Edirisinghe	Atomic Energy Authority	Techical Assistant
86	Mr. Gayan Perera	Atomic Energy Authority	Techical Assistant
87	Dr. Ananda Mallawathanthri	UNDP	
88	Dr. Mrs. T. Ariyananda	Rainwater Harvesting Forum	Executive Director
89	Mr. Chamila Perera	Department of Agriculture	Research Officer
90	Dr. W.M.J. Bandara	Department of Agriculture	Director - Ministry ofAgriculture
91	Dr.(Eng.) S.S. Sivakumar	Emergency Northern Recovery Project	Project Director, ENReP
92	Dr. Palitha Abeykoon	World Health Organization	
93	Dr. C.R. Panabokke	Scientist	Scientist
94	Dr. M.U.A. Tennakoon	Scientist	Scientist
95	Mr. Bandula Munasinghe	Water Resources Board	Chairman
96	Mr. R.S. Wijesekera	Water Resources Board	General Manager
97	Mr. J. Weerakoon	Water Resources Board	Dy. General Manager (Hydrogeology)
98	Mr. A.B.M. Chandrasiri	Water Resources Board	Asst. General Manager (Finance)
99	Mr. M.A. Pushpakumara	Water Resources Board	Asst. General Manager (Admin.)
100	Mr. Nihal Wellalage	Water Resources Board	Asst. General Manager (Drilling)
101	Mr. M.J. Deshapriya	Water Resources Board	Actg. Asst. General Manager (Engineering)
102	Mr. G.R.R. Karunaratne	Water Resources Board	Senior Hydrogeologist
103	Mr. S.R.K. Pathirana	Water Resources Board	Senior Hydrogeologist
104	Mr. K.M.U.C.B. Kulathunge	Water Resources Board	Senior Hydrogeologist
105	Mr. D.G. Sumith Wickrema	Water Resources Board	Senior Hydrogeologist
106	Mrs. Swarna Kariyawasam	Water Resources Board	Accountant
107	Mr. M.B. Amunugama	Water Resources Board	Administrative Assistant
108	Mr. R.M.S. Rathnayake	Water Resources Board	Geologist
109	Mr. R.R.G.R. Rajapakse	Water Resources Board	Geologist
110	Mr. S.M.A.N.B. Samarakoon	Water Resources Board	Geologist
111	Mrs. D.V.K. Wijekoon	Water Resources Board	Chemist
112	Mrs. R.S.A.I. Ranawaka	Water Resources Board	Chemist
122	Dr. M.A.C.S. Jayasumana	Rajarata University	Lecturer in Pharmacology
123	Prof. Priyani Paranagama	University of Peradeniya	Head, Dept. of Chemistry
124	Prof. M. Amarasinghe	University of Kelaniya	Head, Dept. of Botany
125	Mr. G. Siriniwasan		Addl. Government Agent, Kilinochchi
126	Mr. David Milton	SMEC International	Team Leader (Com. 03)
127	Mr. Mahesh Perera	Rupavahini Corporation	
128	M/s Disna Mudalige	Daily News	
129	Mr. Lynn Ockersz	The Island	
130	Mr. S. Subachchelvan		Asst. Director
131	Mr. S. Weerasekara		

Appendix – 2: Program Schedule

Program Schedule

08.30 am - Registration

09.00 am - Participants to be seated.

09.10 am - Arrival of the Chief Guest

09.10 am – 09.20 am - Lighting of the traditional oil lamp and National Anthem

09.20 am - 09.30 am - Welcome address by the Chairman, Water Resources Board

09.30 am - 09.45 am - Address and presentation on the DSWRPP - Project Director (DSWRPP)

09.40 am - 09.55 am - Address by the Secretary of Ministry of Irrigation & Water Resources Management

09.55 am - 10.00 am - Announcement

10.00 am - 10.15 am - Tea

Technical Session I

10.15 am – 10.45 am - Water Quality Study in the Shallow Aquifer System in Attanagalu Oya Basin - Mr. R.S. Wijesekera

10.45 am – 11.15 am - Groundwater Modelling to Predict Management Options for Kayts in Northern Sri Lanka - Mr. Somasuntharam Shanmuhananthan

11.15 am - 11.45 am - Development of Steady State Groundwater Flow Model in Lower Walawa Basin Sri Lanka (Integrating GIS, Remote Sensing and Numeric Groundwater Modelling) - Miss A.A.A.K.K. Seneviratne

11.45 am - 12.00 pm - Chronic Kidney Disease of unknown etiology (CKDu) and Arsenic in ground water in Sri Lanka
Channa Jayasumana, Priyani Paranagama, Mala Amarasinghe

12.00 pm – 12.30 pm - Alternate Management Options of Small Scale Surface Water Resources Systems to develop Groundwater System for the Improvement in Food Productivity in the Dry Zone of Sri Lanka - Dr. S.S. Sivakumar

12.30 pm – 01.15 pm - Lunch

Technical Session II

01.15 pm - 01.45 pm - Groundwater Resources & Sustainability-Experience in Sri Lanka - Mr. Mahinda Premathilake

01.45 pm – 02.15 pm -	*An Investigation on the Trends of Water Quality Deterioration in Northwestern Limestone Aquifer System in the Puttalam Region Based on Stable Isotope Composition - Mr. G.R.R. Karunaratne*
02.15 pm - 02.30 pm -	*Dr. C.R. Panabokke's Presentation*
02.30 pm - 03.45 pm -	*Group Discussions and Presentations*
	*(**Tea will be served while the discussions are going on).***
03.45 pm - 04.00 pm -	*Summing up*
04.00 pm - 04.25 pm -	*Address of Hon. Nimal Siripala de Silva – Minister of Irrigation & Water Resources Management and launching of Water Resources Board Web Site*
04.25 pm - 04.30 pm -	*Vote of Thanks*
04.30 pm -	*End*

Appendix – 3: Participants Program Evaluation

Workshop Evaluation Form

Survey Consent

The following questionnaire is a part of our efforts to evaluate the program in which you participated today.

Please indicate your willingness to participate in this study below. Selecting 'yes' means you will allow your responses to be used in the evaluation of this program and that you understand that your responses will be recorded only in aggregate with other responses.

oYes

oNo

Workshop Evaluation

Your candid and frank responses to this evaluation will help us learn more about your expectations for this workshop and your ideas on how it might be improved or strengthened. We will also the results to assess the impact of conducting this and similar kinds of workshops in the future.

Workshop Title: ……..

Institution / Organization Name: …………………………………………………………………………………………………..

Opinions about the Workshop

	Little / None 1	Some 3	A Great Deal 5
To what extent do you think that the workshop met its objectives?	o	o	o
To what extent did this workshop contribute to what You now know about the topic?	o	o	o

Please rate the effectiveness of the following aspects of the workshop objectives.

	Little or None 1	2	Some 3	4	A Great Deal 5	Don't Know, NA
Presentation during the technical session	o	o	o	o	o	o
Group discussion & Panel discussion	o	o	o	o	o	o

Please circle response that best reflects your rating for this workshop as to its overall objectives.

Value of the workshop to you					**Satisfaction** with the workshop				
Not at all Valuable		Valuable		Extremely Valuable	Not at all Satisfied		Satisfied		Extremely Satisfied
1	2	3	4	5	1	2	3	4	5

As a of attending this workshop, what one or two methods, ideas, techniques, knowledge, etc. do you foresee applying to your profession?

If offered again, how might the workshop be improved?

Other comments you wish to make regarding the workshop.

Appendix – 4: Topics for Group Discussion

Topics for Group Discussion

Topic 01

Amplify numerous ways of human interferences with groundwater in terms of

(a) agriculture;

(b) livestock;

(c) aquaculture;

(d) industries;

(e) service sector needs; and

(f) any other need, causing

(i) groundwater depletion,

(ii) pollution and

(iii) their respective consequences

Topic 02

In order to meet present and future groundwater needs, make recommendations for:

(a) the inculcation of self-disciplined water management by the water- users; and

(b) the formulation of requisite regulatory measures for groundwater governance, including the monitoring of groundwater in respect of ,

(i) re-charge,

(ii) over-extraction/depletion, and

(iii) pollution which affect quality, quantity and environment

(Look at Topic 01 before you start)

Topic 03

Point out the measures that are necessary to:

(a) systematically compile scattered data available;

(b) update data regularly (saying how regularly as well);

(c) build a comprehensive data bank and determine who should be the depository/depositories at national/regional level(s); and

(d) diffuse data and information among and between resource- managers and resource-users as and when necessary

(Please deal with each and every sub-category once a topic is given)

Appendix – 5: Outcomes of Group Discussion

Outcomes of Group Discussion

Group 01 : Human Interference with Groundwater

AGRICULTURE

- Groundwater pollution due to pesticide and fertilizers
- Groundwater depletion due to over abstraction.
- Groundwater enrichment over sustainable use
- Construction of unplanned agro wells
- Inefficient use of GW for Agriculture
- Unplanned Agriculture
- Increase of soil salinity
- due to hard pan formation recharge will be decreased

Livestock

- Contamination
- Over grazing

Aquaculture

- Salinity
- Contamination
- Abstract more groundwater for commercial activities
- Destabilized soil

Industries

- Chemical pollution
- Point source contamination
- Excessive abstraction of Groundwater
- Unplanned land use practice
- Cause of decrease infiltration
- Emission of gasses cause to Acid rain

Service sector needs

- Disposal of hospital waste
- Solid waste disposal of LA
- Hospitality industries
- Lack of Sewerage & drainage system
- Increase in water demand
- Over extraction
- Water scarcity

Other

- Social Function
- Unplanned land reclamation
- Mining activities (Sand, gem etc.)
- Not adopting traditional way for groundwater recharge
- Restricting recharge
- Unprotected dug wells
- Use of pit lavatories

Group 02: Self – Discipline

1. Awareness
2. Education — School, Farmers, Industries & Public
3. Demonstration
4. Advertise — TV, Media, Films

B1 Recharge

1. Implementation of the policies & law
2. Rehabilitation of abundant tanks
3. Soil & Water Conservation
4. Catchment & Forest Management
5. Special Reservoirs for Recharge
6. Artificial Recharge

B2 Over extraction

1. Awareness
2. Monitoring & Regularity(Responsible Agency)
3. High level users should be metered
4. Conjunctive use & Reuse Encourage
5. Develop crop verities with low water requirements

B3 Pollution

1. Waste Disposal Regulation
2. Non- Point Sources ***Control***
3. Point Sources
4. Implementation of Regulations
5. Use of Agro-Chemicals
6. IPM + IPNS
7. Guidelines for reducing Pollution
8. Protection Wells
9. Regularize Guidelines
10. Salt water exclusions structure

Group 03: Data and information, Looking beyond groundwater data

Water resources data compilation

- List of agencies, their mandate, type of data, how to acquire data (MOU, data sales, sharing, etc.)
- Collection of available local literature
- Evaluation of accuracy of data
- Identify what is required at national scale, regional scale
- Identify data gaps

Updating data

- Type of data
- Areas/ locations
- Time series
- Hazard situations – special needs
- Seasonal data

Data Bank (meta data ?)

- What type of data
- Levels of data
- Access
- How to share the data by public

Dissemination of data/ info

- Legal frame work
- Publications
- Review data
- Data standards