GROUNDWATER AVAILABILITY AND USE IN THE DRY ZONE OF SRI LANKA

Symposium Proceedings

Editor
S. Pathmarajah

Cap-Net Lanka, Postgraduate Institute of Agriculture and
International Water Management Institute

GROUNDWATER AVAILABILITY AND USE IN THE DRY ZONE OF SRI LANKA

SYMPOSIUM PROCEEDINGS

22 July 2016

Editor

S. Pathmarajah

Sponsors

Cap-Net UNDP
Postgraduate Institute of Agriculture (PGIA)
International Water Management Institute (IWMI)

Publisher

Cap-Net Lanka
Postgraduate Institute of Agriculture
University of Peradeniya
Sri Lanka, 2016

Groundwater availability and use in the dry zone of Sri Lanka

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Suggested citation:

Pathmarajah, S. (Ed.) (2016). Groundwater availability and use in the dry zone of Sri Lanka. Cap-Net Lanka, PGIA, Peradeniya, Sri Lanka,161p.

ISBN: 978-955-589-229-2

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Foreword

Use of groundwater for agriculture and domestic purposes has been an age old practice in Sri Lanka. However, owing to many reasons, it has become a challenge at present to manage groundwater in a sustainable manner while striking the right balance between availability and demand. Lack of understanding on the availability, demand and vulnerability are continued to be the major issues at all levels from farmers to policy makers. Therefore, it is important to understand the present status and potential risks associated with the use of groundwater before formulating guidelines to manage the resource sustainably.

A national symposium on “Groundwater Availability and Use in the Dry Zone of Sri Lanka” was held on the 22 July 2016 to address the above issues. Altogether, eleven invited papers covering the areas of groundwater availability and use, problems and remedial measures, and groundwater policy and governance were presented in the symposium. In addition, a key note speech on “Water Quality and Health” by Prof. Rohana Chandrajith, Department of Geology, University of Peradeniya and a guest speech on “Groundwater: Water and Food Security” by Mr. Ian W Makin, Interim Deputy Director General, International Water Management Institute (IWMI) also were delivered.

A panel discussion on policy issues with the participation of eminent groundwater professionals in the country representing International Water Management Institute (IWMI), Water Resources Board (WRB), Irrigation Department, Department of Agriculture (DoA) and University of Peradeniya, was also held. Nine selected papers and the outcome of the panel discussion are included in this publication. Slides of all the presentations and are available at the website of the Cap-Net Lanka - http://www.capnetlanka.lk/.

It is hoped that this publication would provide the readers with up-to-date information on groundwater availability, groundwater quality and policy guidelines for sustainable management of groundwater, and other emerging issues related to groundwater utilization.

Finally, I would like to sincerely thank all the sponsors, speakers, authors of the papers, participants of the symposium, and everyone who supported me directly and indirectly in organising the symposium and producing this publication.

S. Pathmarajah
Symposium Co-ordinator / Editor

Potential and constraints of climate for groundwater management in the dry zone of Sri Lanka

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ABSTRACT

Agro-ecological map of Sri Lanka was developed as back as 1960s and revised substantially in 2003. Since then, various complementing publications and supplementary notes have been released by the Department of Agriculture and the Department of Meteorology with special reference to Climate Change. The map has been extensively used by researchers and practitioners in planning and recommending agricultural practices for surface irrigated and rainfed areas giving little consideration to the groundwater irrigated areas. Therefore, in this paper it is intended to provide necessary agro-ecological information to the groundwater irrigated areas which extensively fall into the northern, north-western, north-central north-eastern and eastern parts of the country.

INTRODUCTION

The dry zone of Sri Lanka

Sri Lanka exhibits a vast climatic heterogeneity due to its tropical location in the Indian Ocean and its geographical setting. Depending on the basis of the amount and distribution of annual rainfall, three main climatic zones have been identified namely, Wet Zone, Intermediate Zone and Dry Zone. The Wet zone covers the area, which receives moderately high mean annual rainfall over 2,500 mm with no pronounced dry periods. The Dry Zone is the area, which receives a mean annual rainfall of less than 1,750 mm with a distinct dry season from May to September. The Intermediate zone demarcates the area, which receives a mean annual rainfall between 1,750 mm to 2,500 mm with a short and less prominent dry season. Even though these climatic zones have been identified on the basis of amount and distribution of annual rainfall, effect of other physical factors such as soil, terrain, altitude, vegetation and land use has also been dominant in those climatic zones (Punyawardena, 2010).

Wet Zone covers mainly south western part of the country including major part of central highlands; the total land extent belongs to this region is about 12,740 km^2 and it is only 19 % of the island. Intermediate Zone consists of about 14,220 km^2 of land area which is 22 % of the total land extent of the country. The northern, north-central south eastern and eastern parts of about 38,650 km^2 covers the Dry Zone accounting for about 59 % of the total land extent (Figure 1).

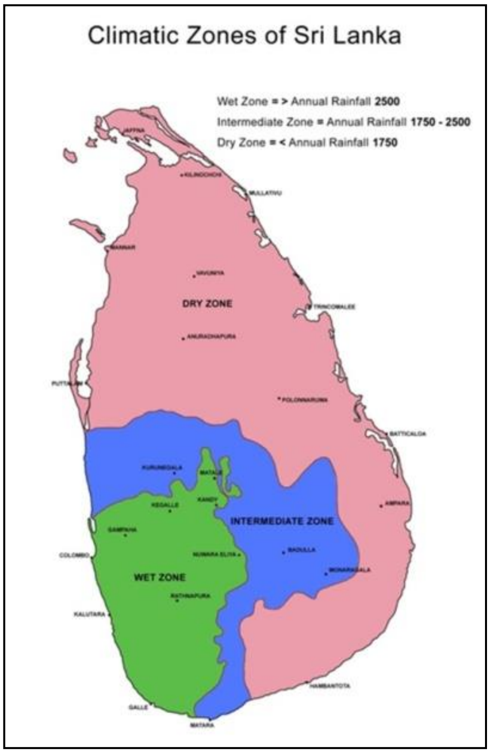

Figure 1. Climatic zones of Sri Lanka
(Source: Department of Agriculture)

GENERAL CLIMATE OF THE DRY ZONE

Rainfall

Even though the Dry Zone in Sri Lanka has been identified on the basis of amount and distribution of annual rainfall, according to the spectrum of world rainfall, an annual rainfall of less than 1,750 mm would hardly be a valid threshold value to demarcate a "Dry" Zone and in fact it is a climatic misnomer (Thambyapillay, 1960). However the area, which is classified as “Dry” compared to the other parts of the country receive an annual rainfall of 800 mm to 1,750 mm (Table 1).

Temperature

In Sri Lanka, by virtue of its size and location in the Indian Ocean (between the latitudes 6^{O} and 10^{O} N in the tropical belt), the temperature at any given place remains relatively uniform throughout the year (Somasiri and Nayakekorala, 1999). However, descending southwest monsoon winds over the Central Hills towards lee side get warmer adiabatically causing ambient temperature be increased along with decreased humidity. Hence, the Föhn effect (*Yal Hulang* or *Kachchan wind*) causes remarkable rise in temperature and desiccating conditions in the Dry Zone locations during May to September (Punyawardena, 2010). Monthly average maximum temperature of the Dry Zone ranges from 25.0 ^{o}C - 37.7 ^{o}C and monthly average minimum temperature ranges from 17.4 ^{o}C - 26.8 ^{o}C (Table 2 and Table 3).

Evaporation

In general, it is observed that open pan evaporation of the Dry Zone during the *Yala* season may range between 3 to 8 mm per day depending on time of the season and location with an average of 5.5 mm per day. Meanwhile, a range of 1.5 to 7 mm per day is generally observed during the *Maha* season across different localities depending on time of the season. "Class A” pan evaporation values of the Dry Zone during the period of May to September experiences comparatively higher evaporation rates due to Föhn like winds commonly known as *Kachchan wind* or *Yal hulang*. Meanwhile, the period from November to January of the *Maha* season, the entire Dry Zone experiences comparatively lower evaporation rates with an average of 4 mm per day due to reduced solar radiation of winter months and overcast sky conditions (Table 4).

Relative Humidity (RH)

Similar to the other regions of the country, the relative humidity in nights of the Dry Zone is generally higher than that of the day time. It could range commonly between 65 to 90 % during morning and 50 to 80 % during evening depending on the geographical location. Very low humidity values of the Dry Zone are reported in June and July owing to the Föhn like wind (*Kachchan* wind) and high humid conditions prevailing during winter months (December to January) of the *Maha* season (Table 5 and Table 6).

Sunshine duration

The mean annual bright sunshine duration of the Dry Zone has a comparatively wider range of 4.1 to 9.4 hours per day depending on the season and location. The period from February to April records the highest bright sunshine hours per day in the entire Dry Zone having more than 7 hours of clear sky conditions (Table 7). The lowest sunshine durations are recorded during November and December in most parts of the Dry Zone. Meanwhile, eastern and south-eastern sectors of the Dry Zone could experience extended overcast weather conditions even during January and February depending on the activity of northeast monsoonal circulation and occurrence of weather systems in the Bay of Bengal (Punyawardena, 2010).

Wind velocity

The average wind speed of Dry Zone ranges from 1.9 to 13.3 km/hr. When the large scale monsoonal winds are weaker during inter-monsoon periods (March-

April and October-November), coastal areas of the Dry Zone can experience a mild wind blow from sea to land (sea breeze) during the day and weak wind blow from land to sea (land breeze) during late night and early morning. Meanwhile, places located on more interior locations of the Dry Zone experience variable winds during this time of the year due to convectional activity depending on the landscape and land use. When the South West Monsoon (SWM) is in force over the Wet Zone during the period of May to September, the eastern and south-eastern sectors of the country experience dry and desiccating Föhn like wind (*Kachchan wind* or *Yal Hulang*) due to adiabatic warming of southwest monsoonal winds upon crossing over the central highland (Punyawardena, 2010) (Table 8).

Table 1. Long term averages of monthly rainfall (mm) at selected locations in the Dry Zone

	Annual RF (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Hambegamuwa	1296	49.2	68.3	147.5	210.5	87.6	14.4	28.8	26.7	57.1	203.4	266.5	135.8	1964-1994
Weerawila	891	67.3	40.0	52.8	90.4	55.4	17.5	20.0	25.5	39.4	130.4	221.0	131.2	1976-2014
Maha-Lewaya	918	59.8	41.7	53.1	92.8	74.8	41.9	30.1	41.5	61.4	120.7	189.7	110.3	1969-2006
Angunakolapellessa	1149	66.6	54.5	69.0	109.4	99.3	63.8	41.2	54.0	87.5	149.8	228.8	124.9	1976-2014
Medawachchiya	1240	65.8	66.5	54.1	136.2	72.5	5.5	33.2	51.4	83.6	217.6	247.3	205.9	1960-1985
Maha-Illuppallama	1400	89.5	75.9	72.4	170.1	85.9	15.5	29.4	31.6	85.8	269.7	277.5	196.8	1976-2014
Vaunia	1351	117.7	48.8	67.0	155.2	28.8	12.2	29.4	55.6	90.9	222.1	294.9	228.6	2001-2010
Siyambalanduwa	1528	156.1	123.7	72.2	133.0	74.5	29.9	49.0	76.6	78.5	198.7	294.6	241.0	1943-1980
Polonnaruwa	1528	168.3	113.4	66.9	92.8	48.9	6.9	32.6	46.1	91.6	210.8	308.1	341.4	1975-2013
Aralaganwila	1852	269.9	142.6	77.5	117.6	68.9	16.1	47.6	56.3	83.8	221.0	349.2	401.9	1984-2014
Padawiya	1608	140.3	90.1	52.8	77.4	70.3	19.0	64.8	72.8	133.0	228.6	339.4	319.4	1960-2013
Trincomalee	1609	151.5	100.4	54.9	53.5	52.9	26.6	59.9	80.4	109.8	217.4	351.9	349.8	1961-2013
Gomarankadawala	1710	184.9	98.3	48.6	88.7	74.0	14.1	47.0	132.6	96.4	206.2	315.1	403.9	1937-1972
Batticaloa	1685	242.0	125.9	75.0	56.0	38.0	34.2	34.6	39.5	75.8	172.5	367.8	424.2	1971-2011
Ampara	1691	237.7	125.2	71.2	89.4	64.3	27.1	47.6	51.6	92.6	192.2	293.8	398.6	1969-2010
Pottuvil	1353	297.6	159.2	61.4	78.2	38.0	8.7	20.5	16.7	49.1	114.3	264.1	245.5	1983-2004
Panama	1478	227.6	187.7	118.2	80.3	34.8	12.5	24.7	33.7	44.8	148.5	266.8	297.8	1950-1988
Yala	900	78.9	50.2	59.0	71.7	36.4	18.5	14.7	8.1	30.9	149.0	238.4	143.8	1976-1997
Mullativu	1397	107.0	110.1	22.0	55.5	40.8	23.8	54.1	76.0	72.8	206.1	396.1	232.5	1958-1990
Mankulam	1422	72.6	51.6	51.2	141.9	81.1	13.0	38.2	44.2	86.8	222.0	337.5	282.3	1956-1989
Iranamadu	1327	99.6	63.1	30.0	65.7	56.1	15.3	27.5	28.3	82.6	230.3	364.5	264.4	1970-1999
Jaffna	1355	54.3	33.4	55.1	95.6	51.7	17.2	15.3	59.3	60.4	227.0	423.4	262.4	2002-2013
Mannar	988	51.3	49.1	44.2	89.6	50.5	5.7	14.3	10.9	40.2	174.8	253.4	203.9	1960-2010
Puttalam	1180	50.6	45.2	57.9	165.9	115.8	34.6	20.8	11.4	67.9	227.7	261.8	120.7	1970-1999
Vanathavillu	1169	62.9	57.9	63.9	140.1	64.5	18.6	15.1	13.9	55.0	231.8	291.5	153.7	1976-2013
Marichchukaddi	822	55.7	37.0	44.8	92.0	44.7	8.2	6.1	9.1	13.3	149.3	208.3	153.9	1950-1990

Source: Natural Resource Management Centre, Department of Agriculture and Department of Meteorology

Table 2. Long term averages of monthly maximum temperature (^{0}C) at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	31.2	32.3	33.1	33.0	33.1	32.7	32.9	32.8	32.5	32.4	31.3	30.9	2005/2014
Aralaganwila	29.9	31.6	34.1	35.5	36.1	35.1	34.6	35.3	35.4	34.2	31.6	29.8	2005/2014
Maha-Iluppallama	29.5	31.4	33.6	33.7	33.1	32.7	32.8	33.2	33.1	32.3	30.5	29.1	2005/2014
Weeravila	31.2	32.6	33.6	33.6	33.7	33.7	34.2	33.7	33.4	33.1	31.8	31.4	2005/2014
Potuvil	30.1	31.0	32.4	33.0	34.6	34.3	34.0	34.2	33.4	32.4	30.9	30.1	1996/2004
Vanathavillu	30.5	32.0	33.3	33.5	32.8	32.3	32.2	32.4	32.2	32.0	31.1	30.1	2004/2013
Kalpitiya	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	2005/2014
Puttalam	29.8	31.3	32.3	31.9	31.4	30.4	30.2	30.4	30.7	30.3	29.9	29.4	1961/1990
Vavunia	28.9	30.7	33.2	34.0	33.1	33.2	33.6	33.4	33.3	31.8	29.9	28.6	1961/1990
Ambalantota	30.6	30.9	31.4	31.7	31.9	31.4	31.0	31.2	31.5	31.8	30.4	30.2	2000/2009
Kantale	29.5	31.2	32.4	33.6	32.9	33.5	33.6	33.4	33.3	33.2	31.1	29.8	2005/2014
Thirunelvelly	29.1	30.5	32.6	33.7	31.5	32.4	32.4	31.7	31.8	31.4	29.8	28.9	1976/1983
Jaffna	28.4	29.8	31.6	32.1	31.3	30.4	30.1	30.1	30.2	29.9	28.9	28.1	1961/1990
Batticaloa	27.5	28.2	29.7	31.1	32.4	33.6	33.2	32.5	32.1	30.6	29.0	27.8	1961/1990
Mannar	28.4	29.9	31.7	32.3	31.9	31.1	30.6	30.6	30.8	30.3	29.1	28.1	1961/1990
Trincomalee	27.0	28.1	29.9	32.0	33.6	33.7	33.7	33.5	33.5	31.3	28.7	27.3	1961/1990

Source: Natural Resource Management Centre, Department of Agriculture and Department of Meteorology

Table 3. Long term averages of monthly minimum temperature (^{0}C) at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	21.9	22.2	23.1	24.1	25.1	24.9	24.7	24.4	24.2	23.7	23.3	22.8	2005/2014
Aralaganwila	20.7	20.6	21.2	22.4	22.8	23.3	23.3	22.2	22.1	22.0	21.8	21.3	2005/2014
Maha Iluppallama	20.8	20.9	22.3	23.8	25.1	25.0	24.7	24.4	24.2	23.3	22.4	21.7	2005/2014
Weeravila	22.5	22.8	23.4	24.0	25.0	25.0	24.6	24.3	24.3	23.8	23.3	23.0	2005/2014
Potuvil	22.5	22.5	23.2	24.3	25.4	24.9	24.9	25.3	24.9	24.6	23.8	22.6	1996/2004
Vanathavillu	21.0	21.2	23.0	24.7	26.4	26.3	25.9	25.8	25.8	24.8	23.3	22.1	2004/2013
Kalpitiya	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	2005/2014
Puttalam	21.2	21.3	22.8	24.5	26.0	26.3	25.7	25.6	25.6	24.3	22.9	21.9	1961/1990
Vaunia	20.3	20.4	21.8	23.6	24.6	24.7	24.3	24.0	23.8	22.9	22.0	21.3	1961/1990
Ambalantota	23.4	22.9	23.4	24.6	25.5	25.4	24.9	25.3	24.7	24.5	24.4	23.7	2000/2004
Kantale	22.4	23.6	23.7	25.1	24.7	25.6	24.8	25.2	24.9	24.7	24.1	23.4	2005/2014
Thirunelvelly	20.7	20.4	22.1	25.5	26.0	27.1	26.2	25.5	25.7	24.7	22.8	21.3	1976/1983
Jaffna	22.3	22.4	24.3	26.8	27.6	27.2	26.6	26.3	26.4	25.4	23.8	22.9	1961/1990
Batticaloa	23.2	23.2	23.9	24.9	25.5	25.4	25.0	24.8	24.6	24.1	23.5	23.2	1961/1990
Mannar	23.6	23.3	24.1	25.6	27.1	27.1	26.2	25.9	26.1	25.2	24.3	23.9	1961/1990
Trincomalee	24.2	24.3	24.8	25.4	26.1	26.2	25.6	25.3	25.1	24.3	23.8	24.0	1961/1990

Source: Natural Resource Management Centre, Department of Agriculture and Department of Meteorology

Table 4. Long term averages of monthly pan evaporation (mm/day) at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	3.8	4.6	4.8	4.4	4.5	4.6	5.0	4.8	4.5	4.3	3.3	3.2	2005/2014
Aralaganwila	2.5	3.3	3.6	3.9	4.9	6.0	6.3	5.8	5.8	4.3	2.8	2.3	2005/2014
Maha Iluppallama	2.2	2.9	3.5	3.2	3.8	4.2	4.4	4.5	4.4	3.2	2.2	1.7	2005/2014
Weeravila	3.2	4.1	4.2	3.7	4.5	5.2	5.9	5.4	5.0	4.2	2.8	3.0	2005/2014
Vanathavillu	3.4	4.1	4.8	4.5	4.7	4.8	4.9	5.5	5.1	3.6	2.9	2.8	1992/1999
Kalpitiya	4.3	4.5	5.4	5.3	5.9	5.9	5.6	5.9	6.0	4.8	4.2	3.9	1992/1996
Ambalantota	3.8	4.5	4.4	4.5	4.6	4.7	5.1	4.6	4.8	4.4	4.0	3.4	2005/2014
Kantale	4.5	4.7	5.5	5.7	6.6	7.4	7.1	7.7	7.3	5.6	3.7	3.4	1977/1986
Thirunelvelly	3.8	4.3	4.7	5.2	5.6	6.1	5.5	4.7	5.2	3.5	2.8	2.9	1976/1981

Source: Natural Resource Management Centre, Department of Agriculture

Table 5. Long term averages of monthly Relative Humidity % (Morning - around 8.30 am) at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	85	84	82	82	81	81	79	80	80	81	85	86	2005/2014
Aralaganwila	88	86	83	79	72	64	65	67	66	74	84	87	2005/2014
Mahailuppallama	91	88	85	84	80	80	79	78	77	82	89	91	2005/2014
Weeravila	81	80	80	80	78	76	74	74	74	76	84	84	2005/2014
Vanathavillu	85	83	81	78	77	78	79	78	77	79	81	84	2004/2013
Kalpitiya	85	83	82	80	78	79	79	79	77	81	81	82	1991/2000
Ambalantota	84	81	81	81	82	82	81	81	80	81	83	84	2005/2014
Kantale	85	83	80	77	70	70	70	78	70	76	85	88	1977/1986
Thirunelvelly	81	81	77	81	81	81	78	79	81	82	85	85	1976/1983

Source: Natural Resource Management Centre, Department of Agriculture

Table 6. Long term averages of monthly Relative Humidity % (Evening – around 3.30 pm) at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	73	71	72	76	74	72	68	71	72	74	79	78	2005/2014
Aralaganwila	73	65	61	62	56	53	54	53	52	63	73	76	2005/2014
Mahailuppallama	70	60	55	62	65	62	60	58	57	66	76	77	2005/2014
Weeravila	71	67	67	70	70	65	62	63	66	69	78	77	2005/2014
Vanathavillu	72	69	70	69	71	73	73	72	72	75	78	77	2004/2013
Kalpitiya	68	66	64	68	71	71	73	71	72	72	74	72	1991/2000
Ambalantota	72	71	72	75	77	77	72	74	75	77	76	78	2005/2014
Kantale	69	65	64	64	60	56	56	54	57	68	77	80	1977/1986
Thirunelvelly	71	69	65	68	69	73	69	69	74	77	71	81	1976/1983

Source: Natural Resource Management Centre, Department of Agriculture

Table 7. Long term averages of monthly bright sunshine hours at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	7.0	8.2	8.5	7.7	7.7	7.4	7.5	8.3	7.1	6.8	5.7	6.4	1996/2005
Aralaganwila	5.6	7.5	8.1	7.8	8.9	8.4	8.5	8.5	8.1	7.2	5.5	4.1	2005/2014
Maha Iluppallama	6.0	7.9	8.3	7.9	8.7	7.8	7.7	8.1	7.9	6.7	5.2	4.3	2005/2014
Weeravila	7.1	7.9	8.0	7.1	8.1	7.3	7.8	7.9	7.5	7.1	5.9	5.5	2005/2014
Vanathavillu	6.6	7.9	7.9	7.4	7.4	6.3	6.4	7.3	7.0	6.4	4.8	4.4	2004/2013
Ambalantota	5.8	6.5	6.2	6.2	6.0	5.5	5.9	5.9	5.5	5.7	4.5	4.7	2005/2014
Kantale	7.9	9.1	8.6	7.5	8.5	7.9	7.2	7.9	7.2	7.1	5.8	5.4	1977/1986
Thirunelvelly	8	9.4	9.4	8.9	8	4.7	7.4	7.3	7.3	5.8	5.4	5.3	1976/1983

Source: Natural Resource Management Centre, Department of Agriculture

Table 8. Long term averages of monthly wind velocity (km/h) at selected locations in the Dry Zone

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Angunakolapellessa	4.9	5.3	4.9	4.2	5.9	5.8	6.8	6.2	5.8	4.9	3.5	4.1	2005/2014
Aralaganwila	2.3	2.3	2.2	2.1	3.0	5.6	5.9	4.4	4.4	3.1	2.1	2.3	2005/2014
Maha Iluppallama	4.7	4.7	4.0	3.6	7.5	9.4	9.5	8.7	8.3	5.2	3.4	4.4	2005/2014
Weeravila	3.3	3.3	2.6	2.3	5.6	7.6	8.3	7.2	6.9	4.2	1.9	2.5	2005/2014
Vanathavillu	2.9	3.0	3.0	3.6	7.9	9.7	10.1	10.2	9.7	5.5	2.7	3.0	2002/2011
Kalpitiya	4.1	3	4.6	3.7	11	11.5	12.2	12.6	10.5	5.4	2.3	2.9	1991/1997
Kantale	5.1	4.4	4.4	4.8	7.9	13.3	12.6	13	10.8	7.5	4.5	4.6	1977/1986
Thirunelvelly	4.6	4.4	4.3	6.4	10.4	11.3	11.6	12.7	10.4	5.2	5.5	4.5	1976/1983

Source: Natural Resource Management Centre, Department of Agriculture

RAINFALL SEASONS

A climatic year or hydrological year of Sri Lanka begins in March and ends in February. It is generally accepted that there are four rainfall seasons in Sri Lanka; First Inter Monsoon season (FIM), South West Monsoon season (SWM), Second Inter Monsoon season (SIM) and North East Monsoon season (NEM). During the two distinct inter-monsoon periods the rains are mainly received due to convectional activity. The FIM occurs from March to April and the average annual rainfall during this period is about 260 mm. The average annual rainfall during SIM is about 548 mm (Source: Department of Meteorology) and this period falls in October to November. The SWM rains occur from May to September mainly due to monsoonal wind. The south-westerly wind drops most of its moisture within the south-western quadrant on the windward side of the Central Hills (Somasiri and Nayakekorala, 1999). The average annual rainfall during this period is about 546 mm (Source: Department of Meteorology) The NEM rains occur from December to February and the average annual rainfall during this period is about 459 mm (Source: Department of Meteorology). Heavy downpours are common during this period particularly in late November and December due to disturbances occurring in the Bay of Bengal. These four rainfall seasons do not bring homogeneous rainfall regimes, where SIM and SWM contribute similar amount of rainfall to the total and it is about 60 % as the sum of 30 % from each. The contribution from NEM and FIM are 26 % and 14 %, respectively. Depending on the geographical location, the Dry Zone exhibits both bi-modal and uni-modal distribution pattern of rainfall.

First Inter Monsoon season (FIM)

By mid-March, FIM rains begin in most parts of the Dry Zone and farmers call it as *"Thala Wessa"* by which Sesame seeds which are sown in advance on the dry highlands begin to germinate. The highest rainfall during FIM season is recorded during April in almost all locations of the Dry Zone with greater number of thunder and lightning days and increased number of rainy days (Punyawardena, 2010). Compared to other rainfall governing mechanisms, convective type rain possesses high kinetic energy and momentum. This increase the surface runoff rather than percolation resulting in more inflow to the cascade of village tanks and other major reservoirs in the Dry Zone with increased soil erosion where appropriate soil conservation measures have not been adopted.

Southwest Monsoon (SWM)

Although SWM rain is heavily moisture laden as it traverse over the Indian Ocean, being in the leeward side, the Dry Zone does not receive considerable amount of rains from SWM period. During this period, any rain experienced in the Dry Zone is purely due to the convectional activity. Such high intensity convectional rains are experienced in June, soon after the conclusion of annual pilgrimage to Anuradhapura and Mihintale, is popularly known as the "*Maluwa Hodana Wessa*" by Buddhists (Punyawardena, 2010).

Second Inter Monsoon season (SIM)

Among four rainfall seasons, SIM is the period when Sri Lanka receives well distributed rainfall throughout the country and so in Dry Zone. The thunderstorm-type of rain, particularly during the afternoon or evening, is the typical climate during this season. But unlike in the FIM season, the influence of weather system like depression and cyclonic storms in the Bay of Bengal is common during the SIM season. Under such conditions, the whole country experiences strong winds with wide spread rain, sometimes leading to floods and landslides (Department of Meteorology, 2016).

North East Monsoon (NEM)

Dry Zone receives substantial amount of rains with distinct spatial variability during NEM period. Normally, NEM rains does not bring heavy down pours compared to SWM in the Wet Zone as it capture only a little amount of moisture during its short voyage over the Bay of Bengal. However, in some years, NEM wind blows from easterly direction over both Pacific Ocean and Bay of Bengal as an Easterly Wave. Under such situation, it becomes a heavily moisture laden-wind and gives copious amount of rains to the entire island, which may last one to three days in a year during tail end of the NEM period (Punyawardena, 2010). However, the rainfall during NEM is quite substantial to replenish the groundwater resources in the Dry Zone as the two previous months of SIM have already soaked the soil up to deeper layers of the entire Dry Zone’s landscape while supporting the rainfed upland agriculture in the region.

GROWING SEASONS

There are two major growing seasons that are important to Sri Lankan agricultural sector, namely, *Yala* and *Maha*. Out of the four rainfall seasons, two consecutive rainy seasons contribute to make these two growing seasons. The *Yala* season receives rainfall by FIM and SWM from March to August. However, since SWM rains are not effective over the Dry Zone, it is only the FIM rains that fall during the *Yala* season in the Dry Zone from mid-March to early May. Hence, *Yala* season is considered as the minor growing season of the Dry Zone. The higher amount of rainfall received by SIM and NEM rains contribute to the major growing season of the Dry Zone, the *Maha* season. The effective period of this major growing season is from September to February depending on the geographical location.

DISTRIBUTION OF VILLAGE TANKS OVER RIVER BASINS

The 103 river basins in Sri Lanka are classified into three major groups based on the source of monsoon rains: Group I has 16 rivers in the Wet Zone that receive water from the south-west monsoon (SWM) and carry about half the annual run-off. Group II has 26 rivers in the Dry Zone that are fed by the north-east monsoon (NEM), and Group III has three rivers that receive rainfall from both monsoons including the Mahaweli and Walawe rivers. The rest are very small coastal basins where the runoff is negligible (Source: Ministry of Irrigation and Water Resources Management).

In the high rainfall areas of the Wet Zone river discharge accounts for 50-70 % of rainfall, but drops to less than 30 % in the Dry Zone, even during high rainfall seasons due to a high infiltration rate. Many of the rivers in Sri Lanka show extreme seasonal variability of flow: some have a propensity for flooding during high intensity rainfall, while others that originate and flow mainly through the Dry Zone may dry up, or have a minimum flow, for a few months annually (Ministry of Environment, 2010). Therefore, the ancient farmers in the Dry Zone demanded man–made surface water bodies from their rulers to continue their agricultural production even during *Yala* season. As a result, high density of village tanks can be observed in the Dry Zone, especially in the north central and north western parts of the Dry Zone including Vavuniya district where the northeast monsoon rains are comparatively weak resulting frequent water deficit conditions at the later part of the *Maha* season. Superimposing a map of major rice growing regions in Sri Lanka on the map of village tank cascade system, it can be clearly showed that the high dependence of paddy cultivation on the tank cascade system in the Dry Zone (Figures 2 and 3).

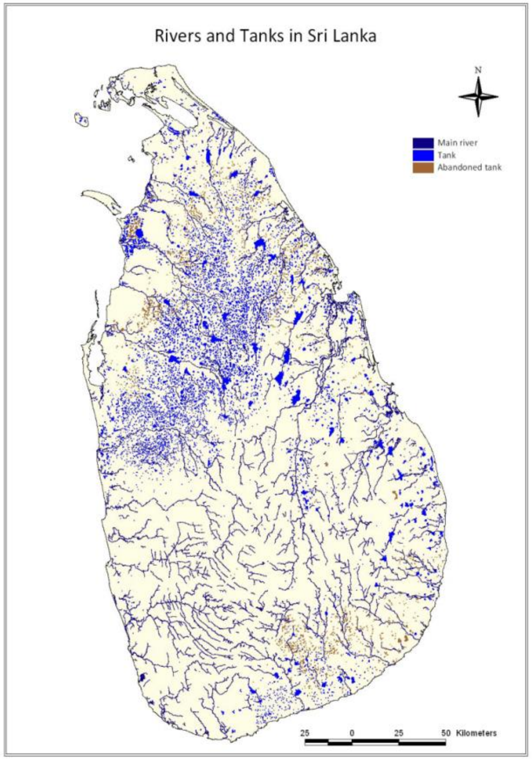

Figure 2. Distribution of working village tanks over river basins of Sri Lanka (Source: Department of Agrarian Development)

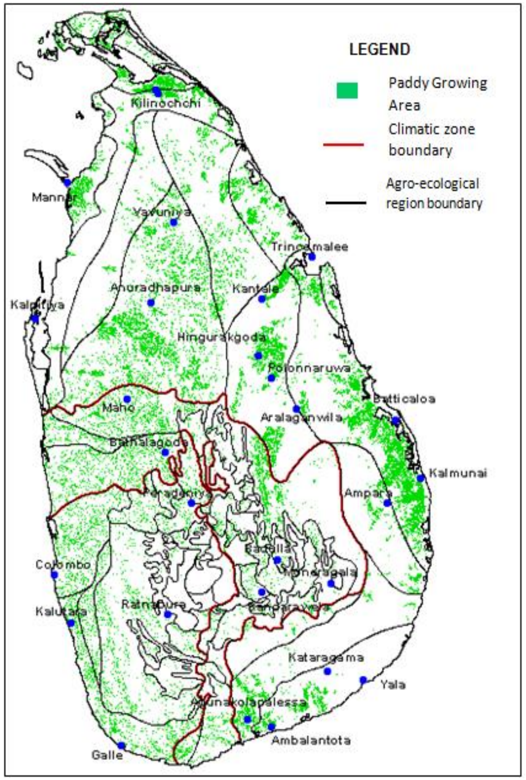

Figure 3. Major Rice Growing Regions in Sri Lanka (Chithranayana and Punyawardena, 2014)

AGRO - ECOLOGICAL DIVERSITY OF THE DRY ZONE OF SRI LANKA

In the Dry Zone, there are 11 agro-ecological sub-regions with different rainfall distribution and edaphic features (Figure 4). The DL3, DL4 and DL5 agro-ecological regions of the Dry Zone receive the lowest annual rainfall of the country in combination with some soil limitations that are found in these regions (Punyawardena, 2007).

Out of the 11 agro-ecological sub-regions, only DL1a and DL1b are characterized by two discernible peaks in the rainfall distribution and thus, support crops in both *Maha* and *Yala* growing seasons. Those agro-ecological sub-regions found in the eastern sector of the Dry Zone, i.e., DL1c, DL1d, DL1e and DL2a and DL2b, exhibit a distinct uni-modal rainfall pattern, and support only the crops in *Maha* season. The rest of the agro-ecological sub-regions of the Dry Zone also support only the *Maha* crop since *Yala* rains in those sub-regions are not adequate to meet the evapotranspiration requirements (Punyawardena, 2004).

The pattern of rainfall (RF) distribution throughout the year (Punyawardena *et al.*, 2003) and the potential evapotranspiration (PET) rate (Munasinghe and Chithranayana, 2004) are illustrated in the graphs plotted for 11 agro-ecological sub-regions (Figure 5 - Figure 15).

DL_{1a} Agro-ecological region

This region receives over 1,100 mm of rainfall and shows a bi-modal rainfall pattern making conducive environment for both *Yala* and *Maha* season rainfed cultivations. It mainly covers South-eastern area of the Dry Zone including the parts of Moneragala, Badulla and Ratnapura districts. Compared to the other regions of Dry Zone, this agro-ecological region (AER) receives the highest amount of rainfall. The period from October to December and April are the only period where rainfall can meet the PET demand and thus other months of the year contribution of rainfall to groundwater replenishment may not be substantial (Figure 5).

DL_{1b} Agro-ecological region

It is the largest AER of the country which covers mainly part of the north-central and southern area. Over 900 mm of annual rainfall is received in this region and shows a bi-modal rainfall distribution pattern. However, compared to DL_{1a} AER, this region does not support successful *Yala* season cultivation without supplementary irrigation and thus, the tank density of this region is relatively high compared to other AERs of the Dry Zone. PET values in this region exceed rainfall values in all months of the year except November (Figure 6).

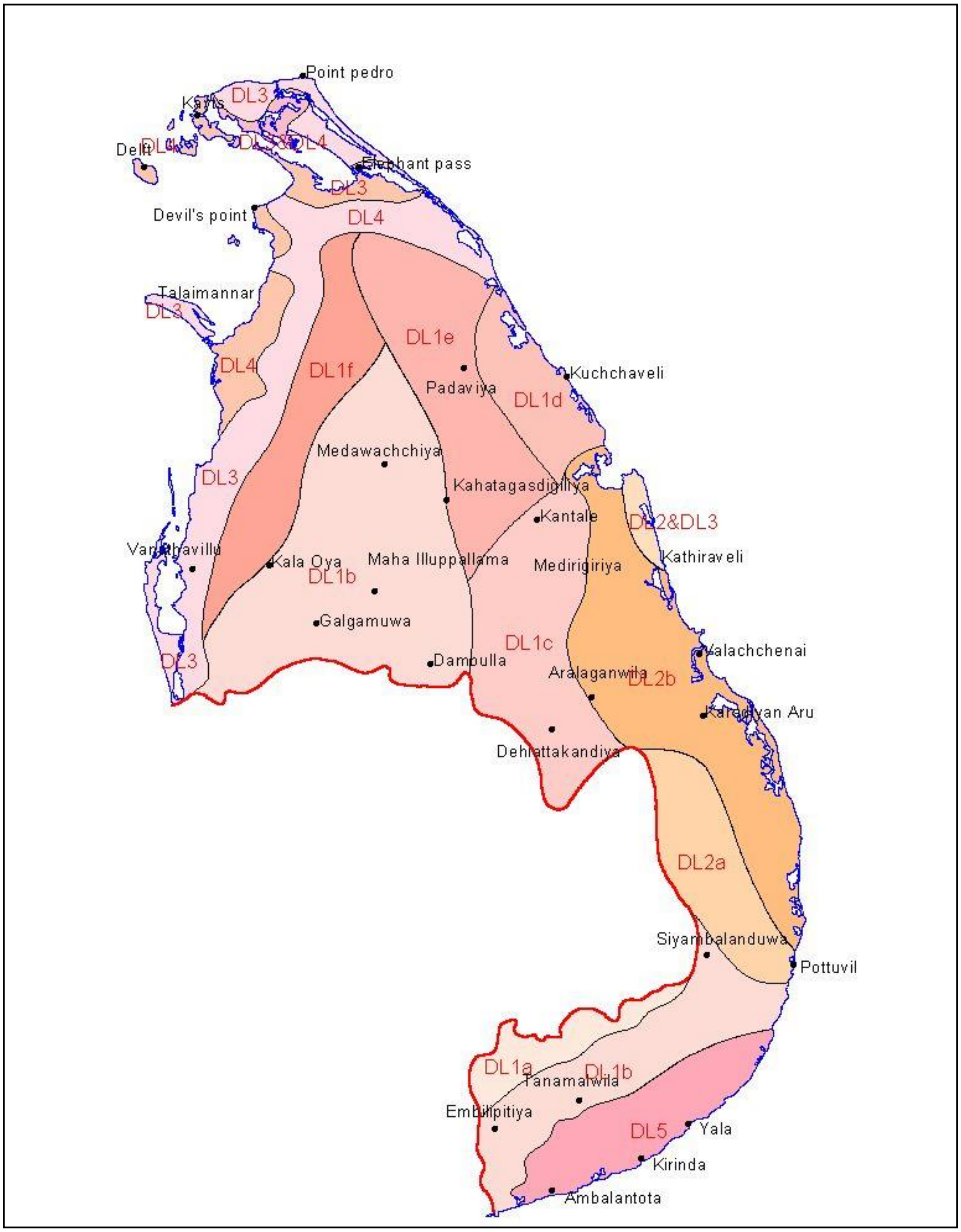

Figure 4. Agro-ecological diversity of the Dry Zone of Sri Lanka
(Source: Punyawardena *et al*., 2003)

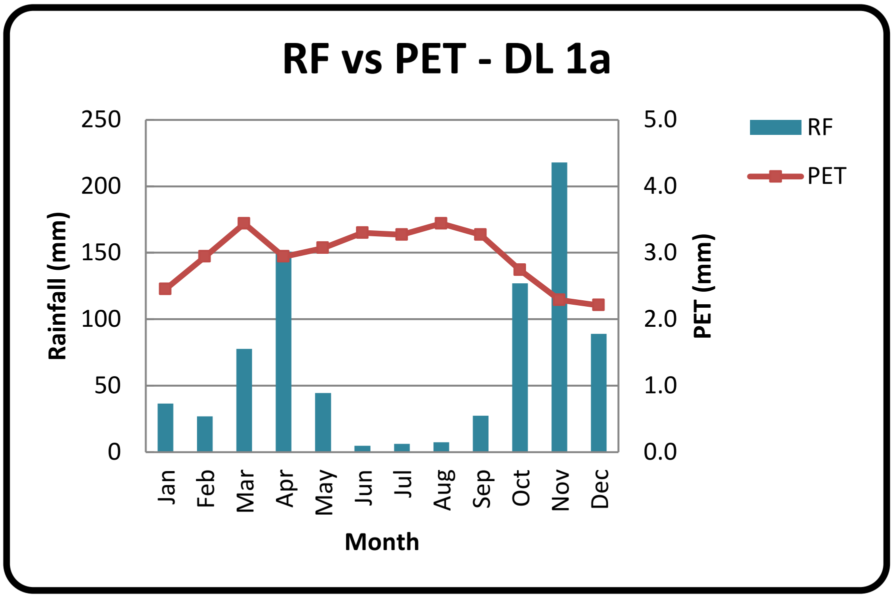

Figure 5. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{1a} AER

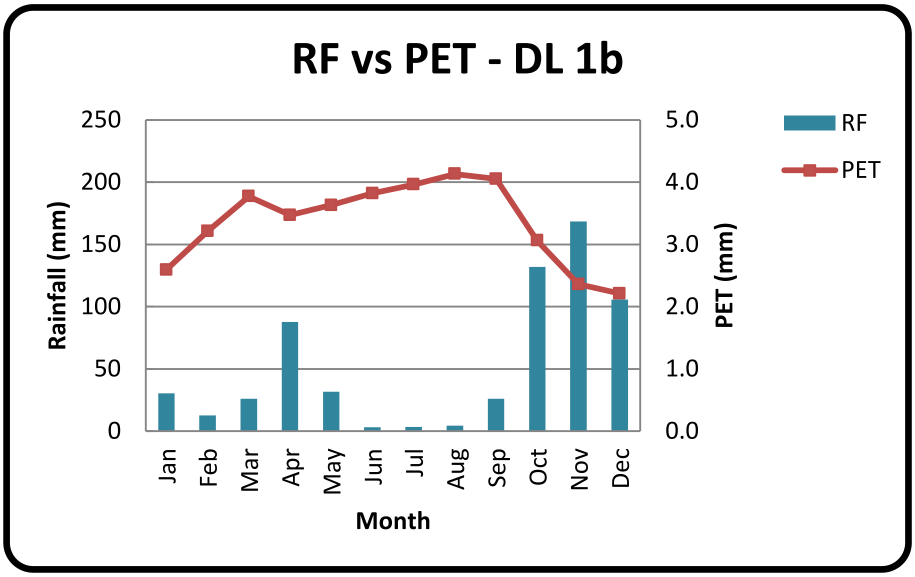

Figure 6. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{1b} AER

DL_{1c} Agro-ecological region

DL_{1c} AER covers parts of Polonnaruwa, Matale and Ampara districts. This area possess considerable long *Maha* season having a uni-modal rainfall pattern with over 900 mm of annual rainfall Although, one or two months of a year, RF values exceed PET values, it may not lead to replenish the groundwater source of the region (Figure 7).

DL_{1d} Agro-ecological region

North-eastern part of the Dry Zone, Mainly Trincomalee district is included into this AER. Having an uni-modal rainfall pattern this area receives 900 mm of annual rainfall. During the *Yala* season none of the months receives rainfall in excess of the PET in this region (Figure 8).

DL1e Agro-ecological region

$DL1_e$ AER covers parts of Anuradhapura, Trincomalee and Vavuniya districts. Annual rainfall of this region is over 900 mm and it shows a uni-modal distribution of rainfall. Except November and December, in all other months of the year rainfall does not meet the evapotranspiration demand of the atmosphere (Figure 9).

DL_{1f} Agro-ecological region

Annual rainfall of this region is over 800 mm. Although DL_{1f} exhibit bi-modal distribution of rainfall, it does not guarantee a good *Yala* season rainfall (Figure 10).

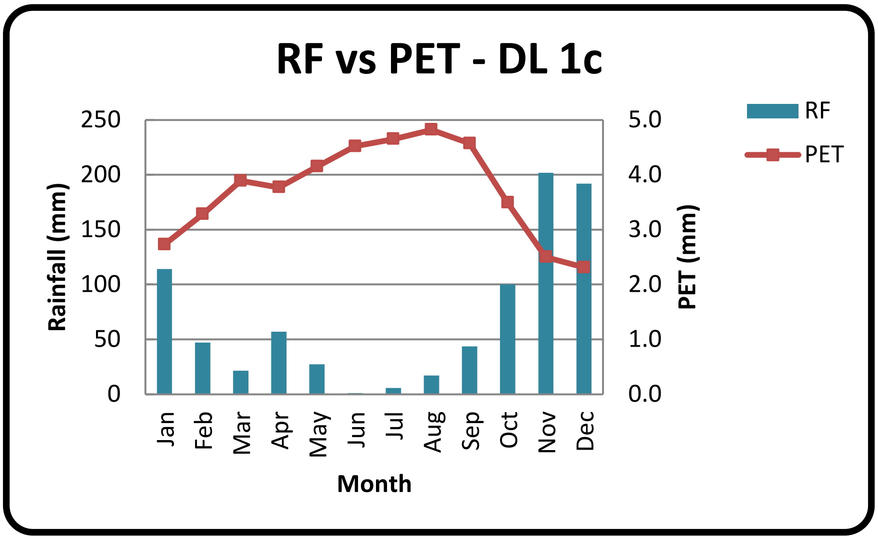

Figure 7. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{1c} AER

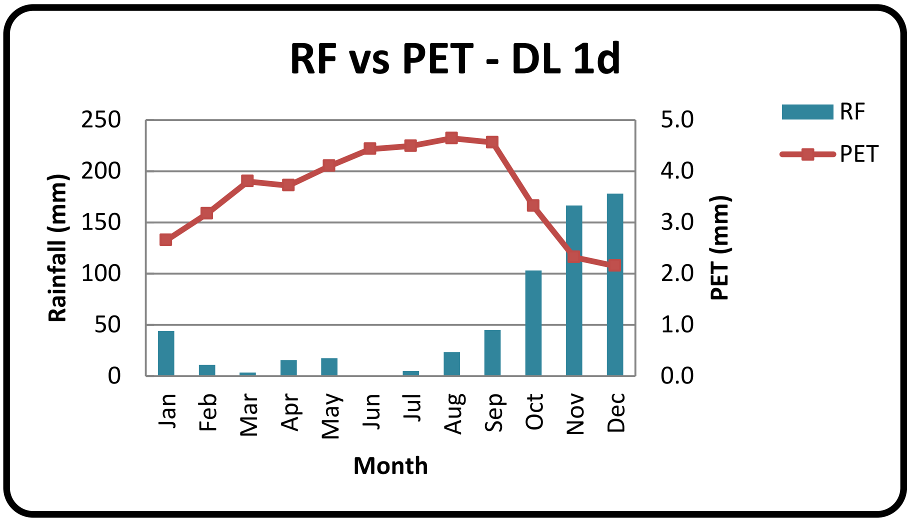

Figure 8. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{1d} AER

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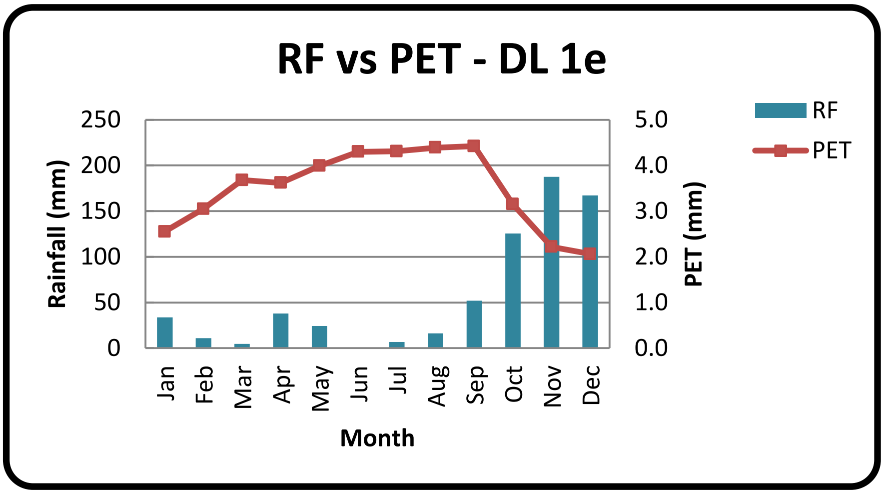

Figure 9. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{1e} AER

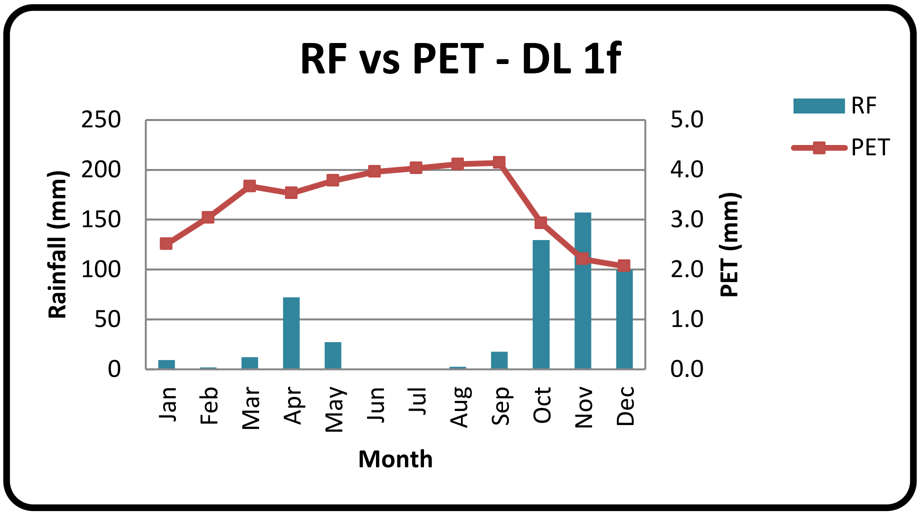

Figure 10. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{1f} AER

DL_{2a} Agro-ecological region

Ampara and Moneragala districts mainly come under this AER with an annual rainfall of over 1,300 mm. DL_{2a} has a very clear uni-modal rainfall distribution pattern having only a prominent *Maha* season and no good *Yala* season rainfall (Figure 11).

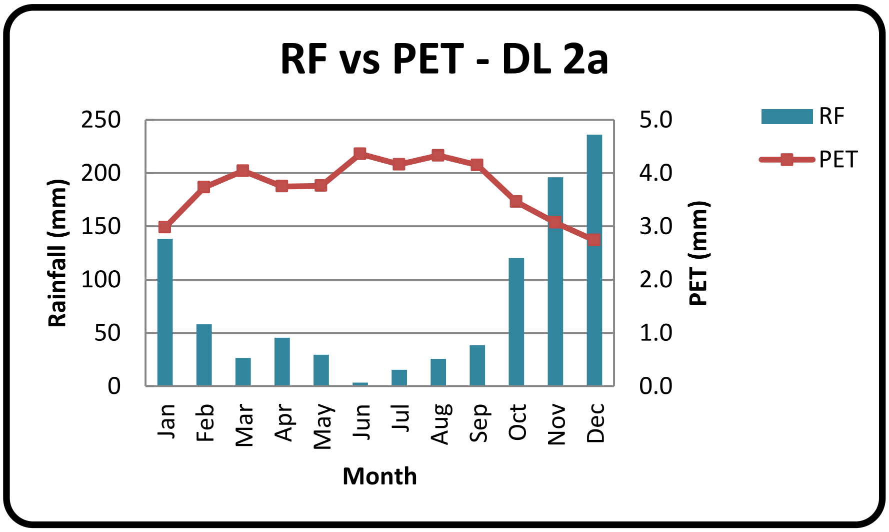

Figure 11. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{2a} AER

DL_{2b} Agro-ecological region

A part of eastern costal area belongs to DL_{2b} AER. The annual rainfall is over 1,100 mm. Rainfall distribution pattern is uni-modal having only a good *Maha* season (Figure 12).

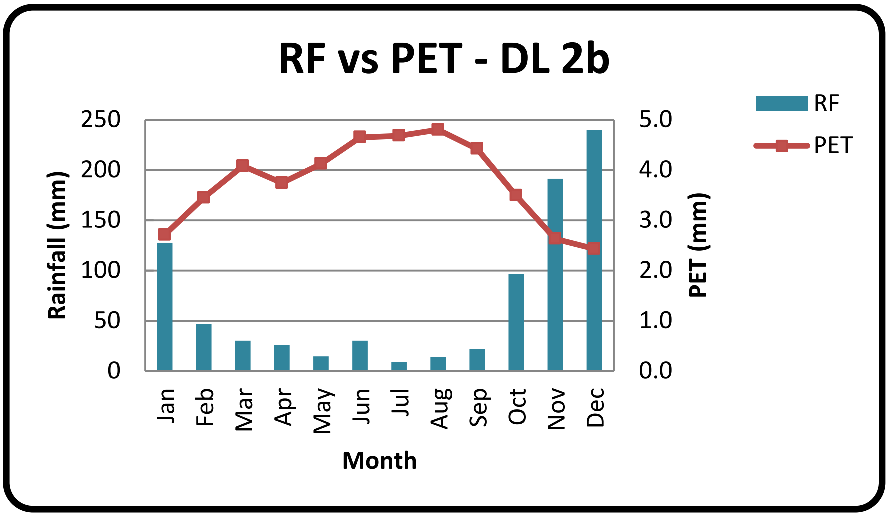

Figure 12. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_{2b} AER

DL_3 Agro-ecological region

Annual rainfall of this AER is over 800 mm and limited to October to December. Red-Yellow Latosol is the main soil type in this area. Due to the depth, porosity and the underlain calcified parental material of this soil, this region has the highest groundwater availability in the country (Figure 13).

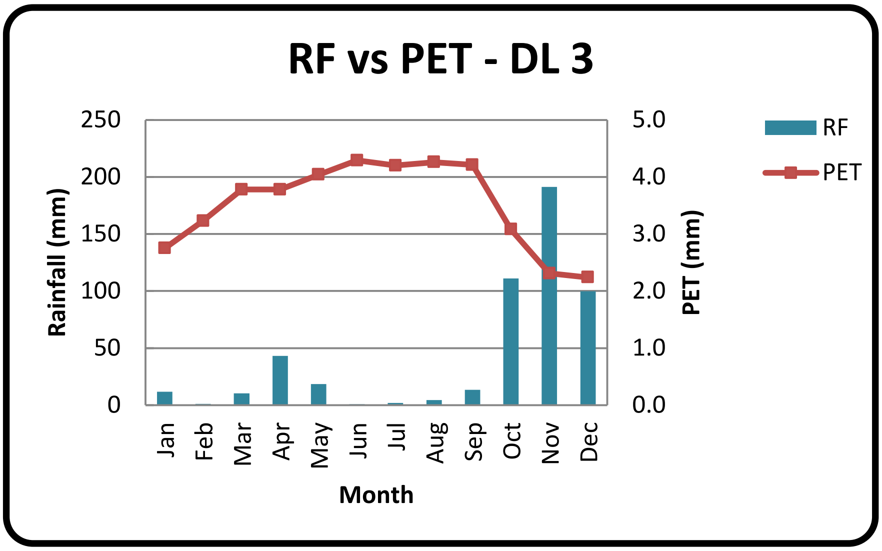

Figure 13. Rainfall and Potential Evapotranspiration (PET) distribution pattern in the DL_3 AER

DL_4 Agro-ecological region

The coastal area of the Mannar district is considered as DL_4 AER. The annual rainfall is over 750 mm and limited only to the last three months of a year. Only the month November receives rainfall in excess of PET (Figure 14).

DL_5 Agro-ecological region

The DL_5 AER receives the lowest rainfall of over 650 mm. Mainly Hambantota and parts of Moneragala and Ampara districts belong to this region. Although this area exhibit bi-modal rainfall distribution, due to the insufficient amount of rainfall, saline soil and higher evaporation rates, even *Maha* season cannot be considered as a successful growing season (Figure 15).

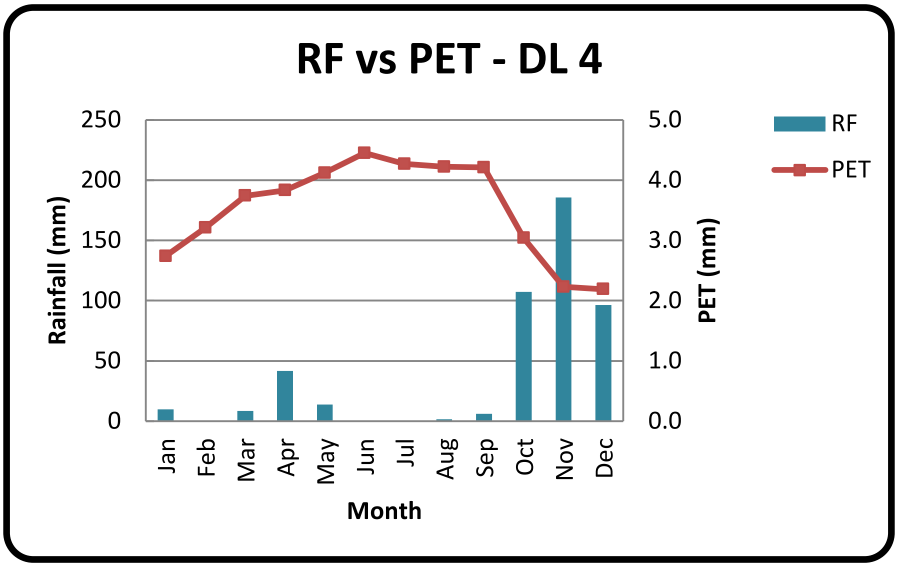

Figure 14. Rainfall (RF) and Potential Evapotranspiration (PET) distribution pattern in the DL_4 AER

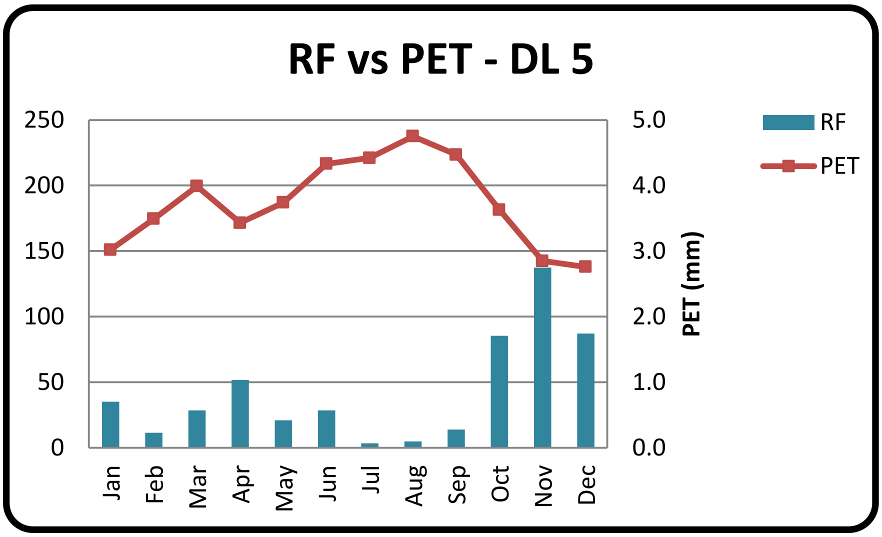

Figure 15. Rainfall and Potential Evapotranspiration distribution pattern in the DL_5 AER

VULNERABILITY OF SRI LANKA TO CLIMATE CHANGE

District level Climate Change induced vulnerability of Sri Lanka has been studied by Punyawardena *et al.* (2013) to find out the vulnerability of each district to Climate Change using a composite index of three major components of vulnerability, namely, exposure, sensitivity and adaptive capacity to Climate Change (Figure 16).

According to this categorization, northern and north-western parts of Dry Zone are considered as very highly vulnerable to climate change and south-eastern sector including Batticaloa, Monaragala and Hambantota and north-central part of the Dry Zone are considered as highly vulnerable to climate change. Most of these districts are characterized by subsistence rainfed agriculture under rainfed conditions with the use of groundwater for supplementary irrigation (Punyawardena *et al.*, 2013). Moreover, Anuradhapura, Vavuniya, Kurunegala and Hambantota districts which are either very highly or highly vulnerable to climate change are the main districts of the Dry Zone where cascade of village tanks are highly concentrated. Being either highly or very highly vulnerable to climate change, frequent drought conditions may likely to occur in these districts in the Dry Zone which may definitely pose threats to the groundwater resources.

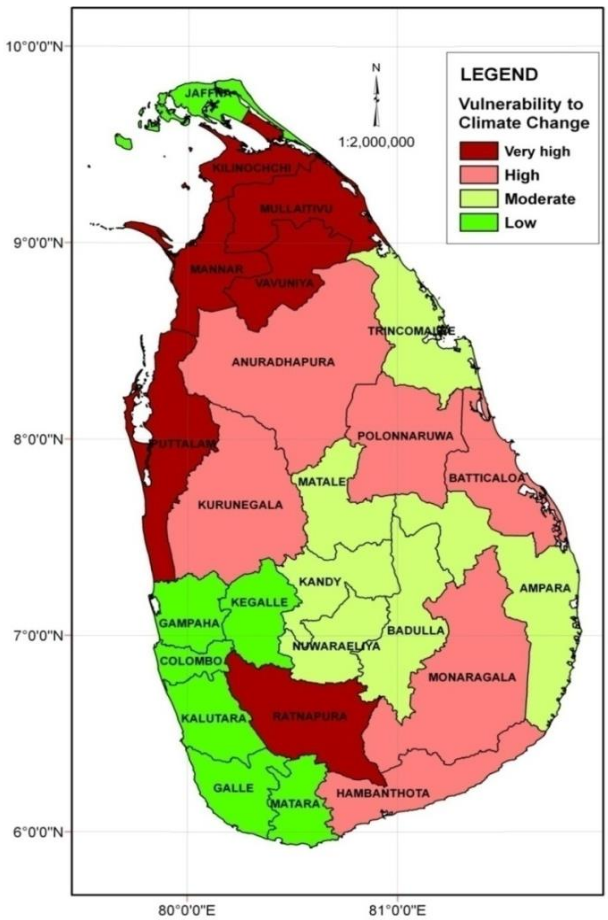

Figure 16. Vulnerability of Sri Lanka to Climate Change (Punyawardena *et al.*, 2013)

METEOROLOGICAL TRENDS IN DRY ZONE

Variability of seasonal rainfall

Tables 9 and 10 indicate a statistical comparison of seasonal rainfall variation of standard period of 1991-2000 verses 2001-2010 in the *Maha* season and the *Yala* season, respectively. It is clear that, co-efficient of variance has considerably increased in recent 10 years in most cases. It reveals that pattern of rainfall intensity, duration, spatial variability and the amount had been changing during this period. This rainfall variation may directly affects the groundwater storage and surface water collection of water bodies in the Dry Zone.

Table 9. Variability of *Maha* season rainfall in the Dry Zone

Station	CV(1991-2000)	CV(2001-2010)
Ampara tank	0.23	0.27
Anuradhapura	0.37	0.24
Batticaloa	0.35	0.36
Hambantota	0.31	0.34
Trincomalee	0.33	0.26

Table 10. Variability of *Yala* season rainfall in the Dry Zone

Station	CV(1991-2000)	CV(2001-2010)
Ampara tank	0.35	0.51
Anuradhapura	0.39	0.26
Batticaloa	0.37	0.52
Hambantota	0.30	0.39
Trincomalee	0.39	0.47

Variability of temperature

A trend analysis was done considering the cold days, cold nights, warm days and warm night in the selected stations in the Dry Zone (Table 11 and Table 12). The result reveals that there is a significant decreasing trend in occurrence of both cold days and cold nights. At the same time there is a significant increasing trend in occurrence of warm days and warm nights.

From the study it can be concluded that the temperature of the Dry Zone is increasing. With the increasing temperature, evaporation rates also increases. This situation leads to decrease the availability of groundwater and reduce the water level of the Dry Zone tanks.

Table 11. Trend of number of cold days and cold nights in the Dry Zone

No. of Cold Days			
	Trend	**R^2**	**P-Value**
Anuradhapura	-0.233	0.41	0.00
Maha-Illuppallama	-0.099	0.09	0.027
Batticaloa	-0.249	0.55	0.00
Hambantota	-0.255	0.54	0.00
Mannar	-0.208	0.21	0.004

No. of Cold Night			
	Trend	**R^2**	**P-Value**
Anuradhapura	-0.295	0.47	0.00
Maha-illuppallama	-0.224	0.26	0.00
Batticaloa	-0.062	0.01	0.253
Hambantota	-0.112	0.13	0.008
Mannar	-0.159	0.26	0.001

Table 12. Trend of number of warm days and warm nights in the Dry Zone

No. of Warm Days			
	Trend	R^2	P-Value
Anuradhapura	0.395	0.27	0.00
Maha-Illuppallama	0.025	0.00	0.774
Batticaloa	0.548	0.53	0.00
Hambantota	0.547	0.56	0.00
Mannar	0.336	0.12	0.027

No of Warm Nights			
	Trend	R^2	P-Value
Anuradhapura	0.63	0.55	0.00
Mah-Illuppallama	0.187	0.13	0.009
Batticaloa	0.15	0.10	0.032
Hambantota	0.247	0.17	0.003
Mannar	0.523	0.48	0.00

Trends of annual number of rainy days in north-central province of Dry Zone

Analysis of trend of number of rainy days in a year in the North Central part of the Dry Zone has revealed that almost all selected locations in the region indicate a negative trend and this decreasing trend is significant in most cases. This is an alarming situation for groundwater resource of the north central part of the Dry Zone where usual replenishment of it may not happen as in the case of past (Table 13).

Table 13. Annual number of rainy days in North Central Province of Dry Zone (1960- 2013)

Station	m (Slope)	c (Intercept)	R^2	P
Bakamuna	0.027	17.1	0.000	0.867
Kaudulla tank	-0.056	181.6	0.003	0.681
Maha- Illuppallama	-0.189	463.4	0.045	0.123
Angamedilla	-0.317	702.5	0.102	0.019
Anuradhapura	-0.321	724.7	0.122	0.009
Giritale	-0.373	806.2	0.086	0.031
Minneriya tank	-0.574	1208.0	0.346	0.000
Kalawewa tank	-0.743	1546.0	0.304	0.000

Trends of extreme positive rainfall anomalies in the Dry Zone

A study on the occurrence of heavy and very heavy rainfall events in the Dry Zone considering a standard period of 30 year using a pentad analysis for the period of 1991-2014 has clearly showed that in all major agro-ecological regions of the Dry Zone, occurrence of heavy rainfall events during NEM season has dramatically increased during the most recent pentad, 2010-2014 at almost all locations of the study. The same is true for the occurrence of very high rainfall events too, except for a few instances (Figure 17) (Abeysekera *et al.*, 2015). This may result in several negative impacts on the environment including accelerated soil erosion in catchment of village tanks with subsequent siltation, damages to water related infrastructure and reduced replenishment of groundwater.

CONCLUSION

Agro-ecology of the Dry Zone varies substantially across the country. It is therefore, suggested to consider the site specific characteristics in managing and regulating the use of groundwater in the Dry Zone of Sri Lanka.

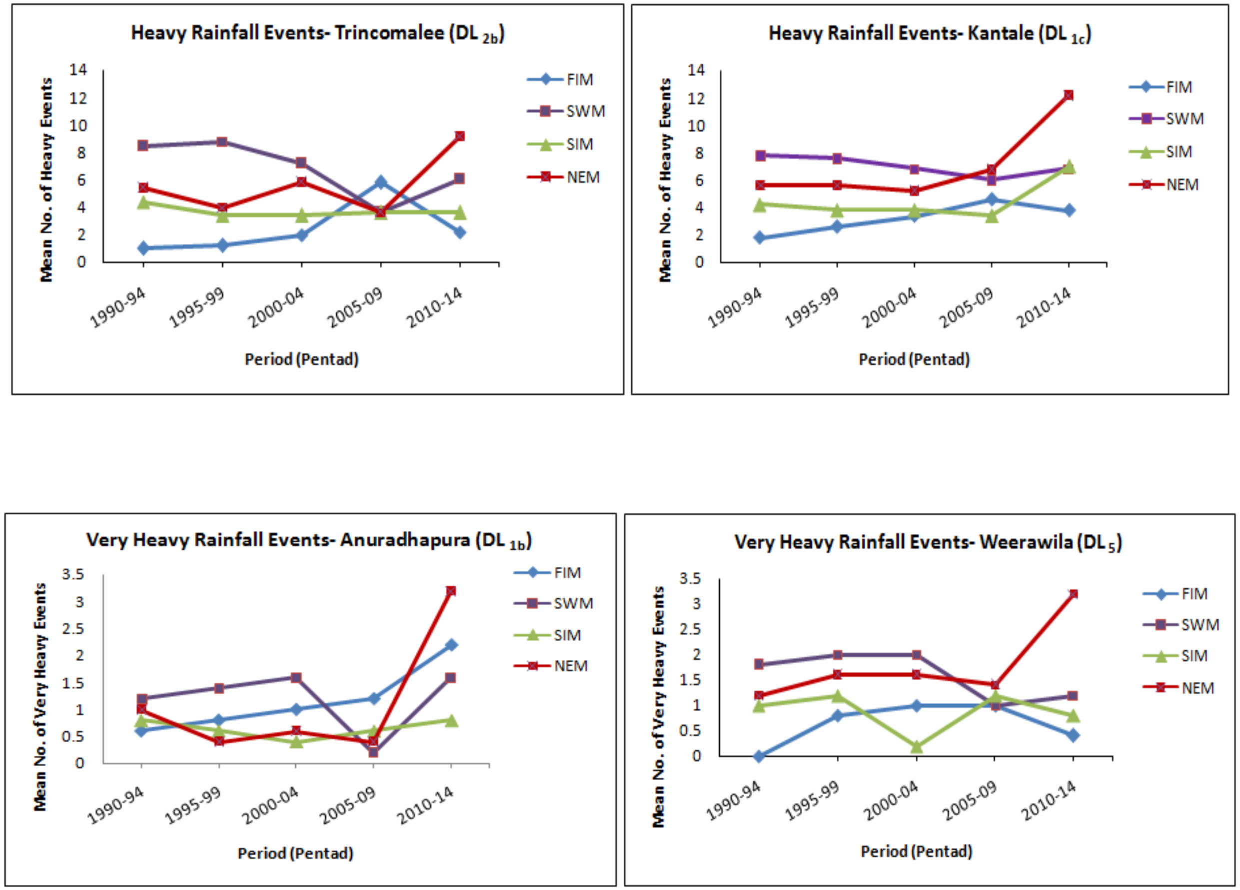

Figure 17. Extreme positive rainfall anomalies in the Dry Zone (Abeysekera *et al.*, 2015)

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Resilience and prosperity through agro-well driven cultivation in the north central province, Sri Lanka: A case study on its evolution, structure and impacts

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ABSTRACT

Agricultural practices are changing at an unprecedented rate in small pockets of the dry zone of Sri Lanka. Commercial vegetable production is flourishing underwritten by groundwater accessed via agro-wells, increased market access and new business opportunities. Since the early 1990s, small-holder farmers have been excavating agro-wells for highland field irrigation and reaping unprecedented returns. Highland fields were previously subject to rain-fed shifting cultivation with long fallow periods. Water from agro-wells with the addition of chemical inputs, along with the advent of mobile phones, reliable road transport, new markets, greater access to credit and a more secure post-conflict environment, have now made frequent highland cropping viable and profitable. This has ignited the entrepreneurial spirit of farmers whose financial inputs and investments and labour is bringing rapid socio-economic transformation. In a country where the dry zone constitutes roughly a third of the land area, and where many dry zone households lack surface water for dry season cropping, these pockets of groundwater driven dry season production may pose a way out of poverty. While acknowledging the significant impact of agro-well-based farming in lifting farmers out of poverty, the paper ends on a cautionary note. This type of agricultural intensification is predicated on a social-ecological system linked to a specific institutional architecture and an aquifer with highly variable water availability. Current success in poverty alleviation masks an inherent fragility and risk that warrants further investigation before attempts are made to scale out groundwater based dry season farming to other parts of the dry zone.

INTRODUCTION

Sri Lanka's dry zone is renowned for its irrigation systems threaded through a landscape that is a visual mosaic of tanks (reservoirs), rice fields and forests. At the national level there is something of a preoccupation with ancient and contemporary irrigation. Globally, Sri Lanka's dry zone can proudly demonstrate the longest history of irrigation dating back at least 2000 years. The dominance of surface irrigation is part of a national trajectory that has seen uninterrupted state sponsorship since the era of royal rule in the ancient cities of Anuradhapura and Polonnaruwa between the 4th century BC and 11th century AD (Bandaragoda, 2006). Thus, even in the middle of the 20th century Leach identified that for agrarian society in the dry zone '… the basic valuable is scarce water rather than scarce land…' (1959). However, recent agricultural expansion based on groundwater extraction from agro-wells is altering this dynamic in some areas of the dry zone including parts of the North-Central Province (NCP).

Although tank irrigated paddy continues to dominate national policy, institutional orientation and fiscal spending, and remains culturally indispensable, paddy has failed to generate the economic gains required to move large numbers of farmers out of poverty in the context of an increasingly monetized society. In contrast, Shah *et al*. (2013) found farmers making 10-15 times more money with an acre of agro-well irrigated vegetables than an acre of irrigated paddy. This warranted more in depth research to investigate the evolution, structure and impacts of this production system and implications it may have for future agriculture and water management policy.

Groundwater from agro-wells is taken typically with diesel pumps, and the driver for digging an agro-well is the high value cash crops grown during the dry season. A review of existing literature suggests that research focussed specifically on this agro-well driven agrarian change has been sporadic and largely sectoral (Ariyabandu, 1992; Brow, 1992; Hettige, 1992; Dharmasena, 2003; de Silva, 2003; Karunaratne and Pathmarajah, 2003; Panabokke, 2003; Pathmarajah, 2003; Jayakody, 2006). This paper seeks to further advance this body of work through an analysis of agrarian driven social, economic, and institutional change in four villages in Thirappane Divisional Secretariat, Anuradhapura District, North-Central Province (NCP). In particular, it explains the success of this cultivation through a culmination of social, institutional and technological developments that have enabled high economic values to be realized from groundwater. The paper however cautions against viewing agro-wells as the solution for other parts of the NCP in view of the fragmented nature of the aquifer that may not support a spatially uniform up-scaling of this system. Instead, better knowledge of water distribution in the aquifer could facilitate a more spatially targeted approach to minimize adoption risks for farmers. It also recognizes that uncertainty exists over the future stability of this system in view of the intensity of water and land use and the volatility of key commodity prices, which warrants further investigation of these aspects as well.

Geographical and hydrogeological characteristics

The island of Sri Lanka has six major types of aquifer systems across a variety of geological and hydrogeological settings. This together with the overall rainfall regimes and topography has to a large extent influenced the options for groundwater use (Villholth and Rajasooriyar, 2010). Extraction of groundwater for agriculture in Sri Lanka was previously confined to the northern and eastern provinces which lack perennial surface water resources. The rapid expansion of shallow groundwater extraction for agriculture in North Central, North Western and North Eastern provinces is predicated on groundwater found in limited quantities in the shallow regolith aquifer generally thought to be a maximum of 10 m deep (Panabokke and Perera, 2005). This is linked to the presence of small or minor tank[1] cascade systems[2] throughout this region, and underpins the emergence of agro-wells as the new engines of dry zone farming expansion and intensification in this area. Particularly advantaged are villages in the lower aspects of shallow inland valleys which receive groundwater flows through seepage from village tanks upstream. While occurring in relatively small quantities, this aquifer represents a highly renewable groundwater supply due to an abundance of small tanks throughout this landscape (Panabokke and Perera, 2005). This goes some way to explaining how it has continued to support intensification and the expansion of cropping area. It must be noted this is also due to the reduction of groundwater abstraction in the rainy season which is critical in allowing time for aquifer recharge. The same authors suggest a recharge of around 100 mm in this aquifer during this season.

The North Central Province (NCP) is situated in the dry zone with an average annual rainfall of 1500 mm. A third of this rain falls during March to August which is considered as the dry or *Yala* season, while the remaining two-thirds fall between September and February, considered as the wet or *Maha* season.

METHODOLOGY

The research team sought a location in Anuradhapura District with a high number of agro-wells to best exemplify changes associated with increased groundwater extraction. The spread and density of agro-wells over time was estimated super-imposing satellite images covering the study area with Google Earth maps from September 2002 (the earliest available satellite images for Thirappane) and 2012. These were zoomed until the wells were identifiable. The resulting values are considered as estimates only as some wells may be obscured by surrounding tall grass and trees, and others that are identified may be abandoned or unused. In conjunction with these results and unpublished 2010 Ministry of Agriculture data, Thirappane Divisional Secretariat (DS)[3] was identified as having the highest number of agro-wells (1,258) in the District. At

[1] Defined by the Agrarian Services Act No. 58 of 1979 as an irrigation infrastructure serving up to 80 ha of irrigable land.

[2] "… a connected series of tanks (irrigation reservoirs) organized within a micro-catchment of the Dry Zone landscape, storing, conveying and utilizing water from an ephemeral rivulet" (Madduma Bandara, 1985)

[3] There are 13 DS Divisions in the Anuradhapura District.

the DS level three adjacent villages were identified as having a high concentration of agro-wells; Mawathawewa, Puliyankulama, and Pandiketuwewa. A fourth adjacent village, Kuttikulama[4] with much fewer wells was also included.

A combination of quantitative and qualitative data was collected from October 2013 to October 2014. Primary data collection consisted of field observation and semi-structured interviews with government bureaucrats, female and male farmers (hereafter glossed as 'farmers' unless specified), village elders, and other residents comprising a sample size of 120 individuals. Data collection spanned the spatial evolution of each village prior to and after the introduction of agro-wells in relation to: living conditions; household and agricultural assets; employment; changes in land cover and agricultural practices; current cropping practices and their production and economies; local institutions and interactions with local government; social change including the position of women in society; and gender relations linked to altered agricultural practices. The results of data analysis were verified through a meeting in each study village where results were presented and discussed in the local Sinhala language.

HIGHLAND CULTIVATION AND AGRO-WELLS: EVOLUTION, IMPACTS AND ENABLING FACTORS

Previously highland crops were planted on forest land cleared near the village in the wet season followed by a fallow period of between 3-11 years to regenerate soil fertility and organic matter. Given the absence of water especially in the dry season, highland farming primarily met basic household food security needs through small quantities of drought tolerant food items such as finger millet, traditional varieties of chilli, tomato, cucumber, pumpkin, mustard, and black and horse gram. Nevertheless, it performed a vital function particularly for poorer farmers for whom these crops provided a diversified range of nutrition.

Highland swidden cultivation lay outside the general paddy-centric conception of agriculture in Sri Lanka until the 1980s as it was viewed as a marginal practice. However, the government did recognize the subsistence value of this cultivation in the 1940s, issuing temporary user permits for shifting cultivation on farmer encroached crown forest land. Encroachment and the clearing of highland fields increased in the mid-1970s when farmers began changing their ploughing techniques. Fallow periods became rare with double or triple cropping becoming commonplace. The latest innovation has come in the form of large-scale machinery; ride-on tractors and bulldozers which are now available for hire or purchase and financially within the reach of many farmers. Highland areas that were previously prepared with controlled burning can now

[4] Each village in this study corresponds to the smallest administrative unit *Grama Nilhadari* (GN), with the exception of Pandiketuwewa which along with Puliyankulama constitutes the Puliyankulama GN Division.

be subject to wholesale mechanized clearing. Access to groundwater by digging agro-wells is directly linked to the clearance and enclosure of land.

Passing references to the use of agro-wells in the region to irrigate highland crops appear in the literature since the 1950s (Kikuchi *et al*. 2003). Between 1953 and 1983 in Kukulewa village (north of Thirappane) commercial production was already increasing with wage labour becoming common place hence bringing changes in the social relations of production and incorporation in larger economic and political systems (Brow, 1992; Hettige, 1992). This however appears to be an exceptional case as agro-well adoption generally started to gain momentum from the mid- to late 1980s, and quickly became a trigger to increase highland cropping. This was also the case in Thirappane. However, the appearance of agro-wells as early as the 1950s means recent developments in groundwater extraction can be plotted on a continuum of change in agriculture over the last 60 years.

The sharp increase in agro-well adoption from the 1980s is linked to government and international aid programs to assist farmers to construct agro-wells to irrigate 0.5 to 1.0 acre plots of chilli, onions and vegetables (Panabokke, 2003b). According to Ariyabandu (1992) the first concerted effort by the State to utilize groundwater to alleviate rural poverty in the dry zone resulted from a Cabinet Memorandum in 1986 which recommended providing subsidies for large diameter agro-wells to promote crop diversification. These wells were to provide supplementary irrigation to farmers during the *Maha* season and be the primary irrigation source during the *Yala* season. Underlying this initiative was a growing concern at the inability of existing production systems to improve rural living standards in the dry zone, particularly in areas not served by large irrigation schemes and hence dependent on seasonal availability of water in village-scale minor irrigation tanks that limited farmers to a single cultivation season. Agro-wells were thus seen as a means to emancipate the dry zone farmer from climatic constraints, and in so doing, also alleviate the financial burden borne by the state in operating welfare schemes to maintain a minimum standard of living of these farmer households. Agro-wells, with a maximum irrigation capacity to cover one hectare, were well suited for supporting other field crops (OFCs) such as vegetables, onion, chilli, green gram, and soya beans, and were thus expected to also facilitate the government's agriculture diversification objective.

Thus the National Agro-well Program was launched in 1989 through the Provincial Departments of Agriculture (PDA) and Agricultural Development Authority (ADA) (Pathmarajah, 2003) whereby farmers received a subsidy[5] for digging and lining wells, and purchasing water pumps. A total of 12,000 agro-wells were subsidized, while a number of non-governmental organizations

[5] Set originally at LKR 15,000/well out of a total cost of LKR.50,000, this was increased to LKR 20,000 in 1997 and 30,00 in 1999 (Karunaratne and Pathmarajah, 2003).

(NGOs) concurrently also promoted agro-wells. The wells were also free of the operation and maintenance challenges faced by canal-based irrigation schemes where securing farmer participation was a major challenge (Ariyabandu, 1992). The wells and pumps required far less maintenance and this brought their management within the capacities of individual farmer households. Other advantages include flexibility in the selection of crops and cultivation periods, as well as greater individual control over irrigation (Pathmarajah, 2003) which enable them to capitalize on market opportunities such as high prices. Agro-well farmers also gained greater control over when to sow crops or plant seedling based on their own meteorological understandings or to capitalize on market availability and prices.

In 2000, the ADA commenced a subsidy program with the ambitious goal of doubling the extent of land cultivated under agro-wells for increasing irrigation efficiency and cropping intensity by 300 % and improving the quality of produce. This program included providing farmer training on agronomical, technical and financial aspects related to agro-wells, micro-irrigation and water pump maintenance. The success of agro-well irrigation without heavy capital investment prompted other organizations like provincial ministries, NGOs and private individuals to invest in agro-wells construction (Karunaratne and Pathmarajah, 2003). Kikuchi *et al*. (2003) estimated that in 2000, 65 % of the approximately 50,000 agro-wells had been dug in minor irrigation schemes, with the highest density in Anuradhapura District. These wells were found in equal numbers in the command area of irrigation schemes and in highlands where the cropping intensity in the dry season had increased from 20 % to 80 %. The same authors also note that by this time, the private investments being made in agro-wells and pumps exceeded the total public expenditure for the operation and maintenance of all existing major irrigation schemes in the country. Kikuchi *et al.* (2003) estimated the private internal rate of return on the investment in a lined well of 6.15 m (20 ft) deep to be 37 %[6] (enough to induce farmer investment), while a subsidy further increased this rate to 49 %. This expansion has continued ever since, as illustrated in Table 1 which contrasts the number of agro-wells in 2002 and 2012 in our study sites.

Table 1. Agro-wells by Grama Niladhari Division.

Grama Nilhadari Division	**Agro-wells**		**% Change**
	2002	**2012**	
Mawathawewa	74	139	88
Kuttikulama	43	120	179
Puliyankulama (includes Pandiketuwewa village)	101	166	64

[6] The rate of return for unlined wells is estimated at over 100 % Kikuchi *et al*. (2003).

In Puliyankulama village, interviewees reported that wells were first introduced between 1988 and 1990. The first two wells were dug with manual labour and financial support from the ADA to gauge water availability and its impact on production. Agro-well adoption escalated after 1996 after farmers had observed the benefits derived from groundwater irrigation. Some farmers received government subsidies but many others sold or pawned belongings to finance agro-wells, suggesting that this phase of expansion was more farmer driven rather than a response to external interventions. The increase in agro-wells is paralleled by an expansion of highland area brought under farmers' control over a similar timespan. In Puliyankulama in the 1940s, each farmer worked 0.25-0.5 acres of shifting highland cultivation, aggregating to not more than 3 acres in the village. When the first agro-wells were introduced in the late 1980s a farmer's average highland holdings had increased to an acre with a village total of approximately 100 acres due to population growth. Water continued to be scarce, while considerable forestland remained. The scenario began to change from around 1998 which corresponds to the acceleration of agro-well adoption. By 2012, official statistics (Thirappane Divisional Secretory Division, 2012) indicate the extent of maize cropping alone to be 470 acres in Puliyankulama (compared to 295 acres of paddy), with similar expansions recorded for Mawathawewa (275 acres) and Kuttikulama (420 acres)

This period also witnessed a change from shifting cultivation to permanent highland plots along with a shift in crop choices. In the wet seasons farmers changed to firstly soya and now to maize, and in the dry season from maize, mustard, chilli, finger millet, green gram, sesame seed and vegetables to chilli and onions. Prior to the use of agro-wells for commercial production approximately 80 % of non-paddy produce was for home consumption. This ratio has now been inverted. Farmers with agro-wells can now be engaged in agriculture for much of the year. Previously there were distinct periods when crops did not need tending in the wet and dry season cultivation cycle which left time for other social-cultural activities. These activities meshed with the cooperation and coordination required for tank irrigation among paddy farmers and interdependence cantered on the tank. While economic independence is undoubtedly on the rise, interdependence is still evident in the sharing and coordination of transporting produce to market, and after a short hiatus, a revival in reciprocal labour exchanges (*attam*) as labour supply from surrounding villages diminished. In practice we found both daily wage labourers and *attam* groups working in the fields.

Lifting farmer households out of poverty

The net seasonal and annual income from primary crops calculated using gross income, production cost and cropping area data collected from farmers are presented in Table 2. That chilli and onions account for over 93 % of agricultural income in the dry season and 86.3 % of annual agricultural income, makes clear the impact of agro-well production has been nothing short of transformatory. Since average cropping area is approximately 0.5 acres, the net income scenario in the *Yala* season has changed from approximately LKR 35,000 from paddy to up to LKR 752,500 for the average farmer in these villages. The significantly higher per acre net income generated from chilli and onions from a relatively small cropping area also illustrates the potential for substantial returns even where land is scarce, which also means such gains are available to smaller-scale farmers in other areas, subject to other production factors being within their means.

Table 2. Average net income per acre from paddy and highland cultivation (LKR) as a percentage of net annual agricultural income

Season	**Low land**	**Highland**			**Annual**
	Paddy	**Maize**	**Chilli**	**Onion**	
Maha (wet)	75,600	81,000	N/A	N/A	156,600
Yala (dry)	70,000	N/A	620,000	815,000	1,505,000
Annual	145,600	81,000	620,000	815,000	1,661,600
Contribution to net annual agricultural income	8.8%	4.9%	37.3%	49.%	100%

The impact of this infusion of income on peoples' well-being has been significant. The Resource Profile 2012 of Thirappane Divisional Secretory Division (Thirappane Divisional Secretory Division, 2012) and dialogues with farmers indicate significant improvements in household assets (Figures 2 and 3) which indicate the virtual disappearance of low-quality housing and increasing agricultural assets. To confirm such changes in well-being can be attributed to this additional agricultural income, the authors sought verification by the farmers themselves and official employment statistics (Thirappane Divisional Secretory Division 2012). Accounts by especially older people of village life prior to agro-well adoption confirmed that most houses were semi-permanent mud and wattle constructions and the only mechanized asset was a bicycle owned by a few households. Respondents from a wider age range also attribute this change to the agro-well driven farming. The government data corroborates this attribution by confirming that only 16 % of the population between 18-60 years of age are employed outside of farming in public or private employment. In fact, even all public sector employees in local government living in the study villages who were interviewed were also farmers, using labour in their households, and taking leave during the planting and harvesting periods. Remittances from family members employed overseas (a significant contributor to rural household income in Sri Lanka) was also ruled out by the farmer interviews and government statistics.

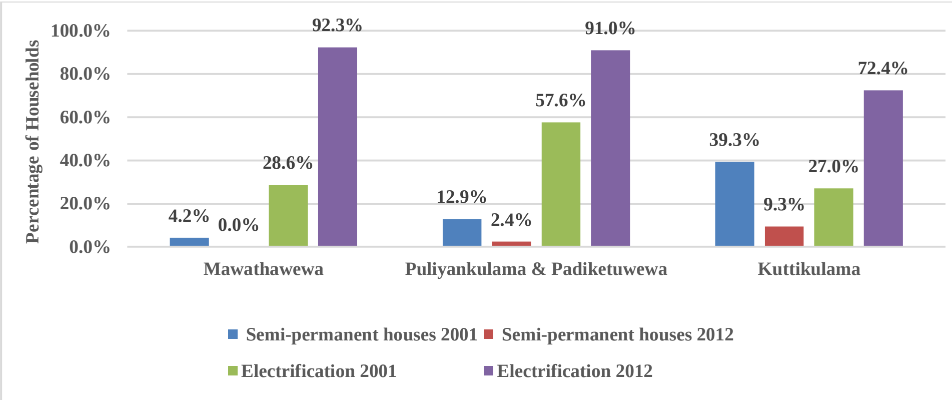

Figure 2. Comparison of housing and electrification 2001 and 2012 using Grama Nilidhari level data (Thirappane Divisional Secretory Division, 2012)

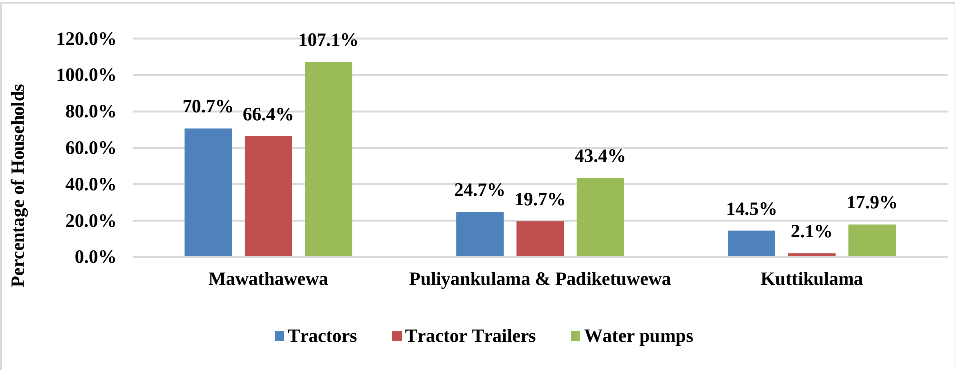

Figure 3. Agricultural assets by household 2012 using Grama Niladhari level data (Thirappane Divisional Secretory Division, 2012)

In contrast to the virtually full household engagement in the study villages in agriculture, Gamage and Damayanthi (2012) found that in the smallholder agriculture sector overall, while 35.2 % of farmers who focused on paddy were 'unemployed',[7] this percentage was only 0.2 % for households that also cultivated chilli. Furthermore, of the 'unemployed', the highest percentage (34.4 %) was found to be from the major surface irrigation areas while the lowest of 18 % was amongst farming households who had agro-wells. This may be seen as an emphatic statement of just how significant agro-wells, along with the rise of supportive institutions, can become in Sri Lanka's dry zone.

A range of factors have spurred on the commercialization of agriculture underwritten by access to reliable groundwater resources including formal forward contracts for soya and maize and informal agreements for chilli; a

[7] Defined by the authors as: "…persons who are not employed and were available and/or looking for work, and had taken specific steps to find employment during previous three months of the survey period" (footnote 12, p.24).

sympathetic official approach to continued forest encroachment (though this has changed in recent times); attractive prices for chilli and onion due to advantageous demand-supply scenarios for these crops; increased post-conflict security; societal changes to gender relations with greater mobility amongst women; intermittent state support and political patronage primarily through subsidies for farm equipment; development of local markets especially for maize; higher profits from non-paddy crops; the construction of a dedicated vegetable market complex in the Central Province; improved roads and road access; and access to diverse sources of credit and affordable and reliable communication technology.

Forward contracts for maize

The impetus to dig agro-wells and expand cropping has been spurred on by the arrival of private sector buyers of first soya and now maize through forward contracts. Individual farmers sign contracts with companies requiring maize as a core ingredient in the production of Samaposha, a popular breakfast cereal, and also for animal fodder. A minimum price per kilogram is agreed before planting. This gives farmers greater financial security and the opportunity to plan their finances based on projected crop yields. The minimum prices (LKR 34-36 per kg in the 2013-14 *Maha* season) are almost double what farmers used to receive at farm gate from local traders who have been largely displaced by commercial companies. The price this rain fed crop now commands has driven an expansion of cropping area (ranging from 2–10 acres per household) with profits contributing to endogenous investment in, and expansion of, agro-wells.

Agricultural encroachment of State forest

The increase in highland cropping of maize and groundwater irrigated crops has only been curtailed by the exhaustion of convertible forest land and stricter forestry rule enforcement since 2008. Villages have transitioned from being unbounded to bounded (Vitebsky, 1984;1992) over time. For example, by 2000 there was no more convertible land in Puliyankulama which induced an intensification of cropping each season. In our study locations much of the converted forest belonged to the Divisional Secretariat (DS) which has discretion over whether such conversion would be allowed. Given the poverty of these villages in the early 1990s, interviews with DS staff indicate that a conscious choice was made to view forest conversion as a necessary condition for enabling livelihood improvement. The situation has however changed since 2008 when, according to interviews with Forest Department officers, stricter rule enforcement was prompted by the loss of forests and an escalation of conflicts between people and wildlife and to ensure the supply of groundwater.

Supportive commodity prices and government policy

While the farm gate price of maize was raised with forward contracts, the prices of fresh chilli and large onions - the two primary dry season highland crops –

are characterized by sharp price fluctuations due to annual domestic production deficits. This is especially the case for chilli where domestic production remains below 50 % of the national requirement (Sri Lanka Government, 2008), while this figure is approximately 64 % for large onions (Chandrasiri and Bamunuarachchi, 2013). Price spikes occur either due to reduced domestic production or fiscal interventions by the government that seeks to make Sri Lanka self-sufficient in both crops, thereby making considerable foreign exchange savings (Ministry of Agricultural Development and Agrarian Services, 2008). The former scenario was aptly demonstrated during the 2014 dry season when prolonged dry conditions caused farmers in many areas of the country to abandon cultivation, sending fresh chilli prices soaring to LKR 600/kg at farm gate. The fact that farmers in the study villages were able to supply the market at these prices and reap profits multiple times their production cost is also testament to the crucial advantage provided by their agro-wells in terms of access to irrigation. In previous years when drought was not a factor, fresh chilli prices had yet surpassed or come close to LKR 100/kg (profitable) at the beginning (May-June) and end (October-November) of the dry season in several years (HARTI, 2012), with much higher short-term price spikes (e.g. LKR 350-700/kg in 2011). Here too, agro-wells are at the centre of a farmer strategy of planting the first chilli crop immediately after harvesting the wet season maize to take advantage of the high pre-*yala* season chilli prices that reflect low domestic production through the *Maha* season. This is only possible due to the flexibility agro-wells bring to irrigation. In the case of large onions local production is incentivized through a commodity levy on imported onions towards the end of the dry season to discourage further onion imports. This creates conditions of scarcity and inflates domestic onion prices to coincide with domestic harvests.

Dividends of the secession of civil conflict and altered gender roles

Until the end of the civil war in 2009, these developments have occurred under the spectre of personal insecurity which curtailed cropping in NCP. Following the conflict's cessation, farmers are more confident to invest in permanent farming inputs such as agro-wells on land at a distance from the village. A more secure environment was also a prerequisite for societal change that has seen increased female mobility and independence. While women were always active farmers, until as recently as the mid-2000s it was rare to see a woman riding a motorbike or operating agricultural equipment. This is now commonplace as the demands and practicalities of commercial highland cultivation requires both women and men to be mobile and able to work independently. In addition to personal autonomy, economic opportunities for women have been greatly enhanced. A number of widows in this area have successful highland cultivations based on agro-well irrigation.

Improved infrastructure

Reliable bitumen roads connect farmers with the Dambulla Dedicated Economic Centre built in 1999. The Centre is the premier collection and distribution site for agricultural produce across Sri Lanka. Approximately 55 km by road from Thirappane, it effectively links farmers to virtually the entire country's demand for produce. Farmers use mobile phones to negotiate prices with traders in the Centre prior to organizing transport of the harvest via lorry. There is also the option to authorize the lorry driver to negotiate the price on arrival in Dambulla. The driver will take a commission for the sale by either taking a cut from the price per kilo or straight off the top of produce sold. A third option is to sell directly to traders at the farm gate which generally attracts a price lower than buyers at Dambulla, but saves on transport costs and the risk of damaged produce.

DISCUSSION: STRENGTHS AND EMERGING ISSUES FOR GROUNDWATER DRIVEN CULTIVATION

Extant and emerging issues as a result of the increase in groundwater extraction include the finite nature of the water resource, market volatility and absorptive capacity, chemical use, soil health and land availability. Studies such as that by Senaratne (1996) suggest there is a limit beyond which the exploitation of the regolith aquifer would result in an irreversible degradation of this limited resource. Moreover, at least 25 % of the potential should be reserved to meet environmental requirements in areas where there is intensive agro-well farming (Panabokke and Perera, 2005). While wells can be spaced as close as 100 m, it is the well density which has to be emphasized. Whereas well density should not exceed 7-8 wells per 100 ha according to Panabokke and Perera (2005), the average density of agro-wells in the study villages is significantly higher at an estimated 30 wells per 100 ha according to the well count presented in Table 1. Although systematic well monitoring was not undertaken as part of this research, it is nevertheless interesting to note that farmers consider water levels in the agro-wells to be sufficient in the dry season when there is what is considered to be 'average' rainfall, where water recharges fully within 3 days of pumping. This had been the case until the drought that commenced in late 2013 and continued till October 2014. One reason for the continued supply of groundwater despite the density of agro-wells may be the combination of the wet season rains which deposit up to 63 % (about 693mm) of Anuradhapura District's annual rainfall between October and December (Gunaratne and Kumari, 2013), and the 4-5 small irrigation tanks in each village which collect this rainfall and facilitate aquifer recharge well into the dry season. Another critical factor in the currently stable use of groundwater is farmers' observed willingness to adjust cropping area according to their perception of climatic conditions. This was evident in numerous farmers' decision to halve their cropping area for *Yala* 2014 given failure of the late 2013/early 2014 monsoon that had in previous years recharged the aquifer fully after the previous dry season. This suggests a globally rare capacity to self-regulate abstraction in the absence of any formal groundwater governance framework.

Farmers seek to mitigate the risks posed by inter- and intra-seasonal fluctuations in the price of chilli, onions and maize by growing all three cash crops each year. The low price for one crop can potentially be compensated for by a high price for another crop. Crop diversification made possible by agro-wells has thus added a new level of economic resilience to the farming system. Prior to the agro-well boom farmers had little capacity to offset any *Maha* season losses. Moreover, having followed the fortunes of these farmers throughout both the 2013-14 *Maha* and 2014 *Yala* seasons in a year marked by drought, the combination of highland crops grown during a cropping calendar (maize in *Maha* season; chilli and onion in *Yala* season), combined with agro-wells appears to provide considerable drought proofing. For example, while much of the paddy crop was lost when the 2013-14 *Maha* season monsoon failed, the maize grown concurrently on the highland plots yielded an additional 500 kg/acre in the dryer conditions that partially off-set financial loss linked to the paddy crop. Meanwhile in the *Yala* season that followed, access to groundwater via agro-wells along with voluntary reductions in cropping area enabled farmers to not only withstand drought, but to thrive as chilli prices soared as cultivation was abandoned in other parts of the dry zone.

It is clear that hitherto high inter-seasonal commodity prices have been important to this agrarian change in Thirappane and other adjacent areas. The resulting profits have swelled farmer's confidence to invest in agro-wells and other farming assets needed for lateral expansion as well as intensification. Whether these market conditions will continue however, is unclear. On the one hand, the government's drive for self-sufficiency by encouraging chilli and onion cultivation in other areas of the country (Sri Lanka Government, 2008) suggests domestic production could rise in the coming years. On the other hand, the demand-domestic supply statistics noted earlier suggest significant capacity for the market to absorb future increases in production. Many factors will determine how successful the government's initiatives will be, not least the availability of irrigation in the *Yala* season.

Gamage and Damayanthi (2012) found that non-paddy crops (OFCs) provide significantly higher profits with paddy contributing only 12.7 % to total household income. This is reflected in our study where its contribution ranged from 10.7 % to 14.1 %. While the enthusiastic adoption of agro-well driven production can be easily understood in light of these significant economic benefits this generates compared to paddy cultivation, we argue that this does not represent a wholesale shift in farmers' focus away from paddy, but rather the diversification of livelihood strategies. Highland commercial crops complement paddy cultivation which has both food security as well as cultural and spiritual value which are central components of traditional agrarian identities. There are also political economy factors at play, especially since the formal Farmer Organizations (FOs) are by far the largest and most politically linked local institutions. FO membership is predicated on the cultivation of paddy and is a pre-requisite for accessing the substantial state-sponsored subsidy on fertilizer. Therefore, paddy and non-paddy crops appear to provide different contributions and meaning in the overall agrarian system. Nevertheless, it is clear that access to groundwater along with new market opportunities for several high value crops, has enabled low income agrarian communities to become far more empowered participants in the increasing monetization that characterizes Sri Lankan society in the 21st Century. These innovations, however, have in fact occurred in spite of state policy which has historically largely excluded highland cultivation from its formal agriculture policy and fiscal frameworks (Weeramundra and Damayanthi, 2011). A logical next step is to investigate and analyse to what extent this has scope for poverty reduction in other areas of the dry zone. This would include addressing concerns over sustainability in addition to the availability of groundwater if it was to be scaled out.

An obvious starting point would be the capacity of the aquifer and distribution of water in it since water in the regolith aquifer that characterizes the NCP exists not as a continuous body of water, but in pockets (Panabokke, 2003a). Any attempt to replicate the agro-well based production in our study sites without knowledge of where these groundwater pockets may be located may consequently be a hit-or-miss affair with significant financial risks for farmers. Research on the impacts of intensification of highland cropping in relation to groundwater availability and the interplay of ground and surface water is thus strongly recommended to effectively manage resources and guide policy. Furthermore, land clearing and intensification of cropping has greatly altered customary practices based on traditional ecological knowledge, where highland areas were left fallow to allow for soil regeneration. Intensification has virtually eliminated fallow periods, while chemical applications have intensified. To what extent changes in soil characteristics will impact productivity and vulnerability to disease therefore also demands investigation. The long-term impacts on soil quality and use of chemicals also require examination to inform how to mitigate any potential negative consequences of the new farming regimes.

CONCLUSION

We see that the vibrancy and innovation represented in the expansion of highland cultivation is for the most part endogenous to the communities in response to initial infusions of new technologies (agro-wells); emerging market opportunities; increased security; and a mainly private-sector driven enabling institutional environment. Despite the state's early role in initiating agro-well adoption in these villages, agrarian change in these instances aligns with the observations that these innovations have in fact occurred in spite of state policy which has historically largely excluded highland cultivation from its formal agriculture policy and fiscal frameworks. This may however be changing with the government's focus on expanding production of key high value crops such as onions and chilli which are the mainstay of highland agro-well based production.

There is clear and considerable economic potential in agro-wells in the current contexts when linked to high value markets and other enabling factors, and it thus presents a tempting option for linking poverty alleviation with addressing the seasonal water scarcity that characterizes Sri Lanka's dry zone. However, the medium and long term viability of these farming practices with regard to water and soil quality and groundwater availability is yet to be assessed. Last but not least, the maturity of the farmer communities in the study area and their specialist knowledge on both groundwater behaviour and the OFCs they grow, may be challenging to replicate given such knowledge has co-evolved along with the structural changes to the production system.

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Present status of groundwater quality and quantity related issues and need for a groundwater monitoring system for Sri Lanka

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ABSTRACT

Demand for groundwater has grown rapidly as a result of population increase and economic development of the country. A wide variety of users such as small-scale irrigators, households and housing development schemes, industries and industrial promotion zones, hotels, shrimp farms are now tapping groundwater in large quantities. The unlimited groundwater extraction cause depletion of the regional groundwater table and drying out surrounding wells located in the shallow aquifers. The groundwater pollution due to application of excess fertilizer and use of pesticides and other agrochemicals in agricultural areas and emission of wastes from the industries leads to contaminate groundwater sources considerably.

Recently, the environmental issues related to groundwater depletion and groundwater pollution is considerably increased in many parts of the country. These areas includes Kalpitiya, Jaffna Peninsula, CKDu prevailing areas in Anuradhapura, Polonnaruwa, Kurunegala, Monaragala, Badulla and Hambantota districts, areas where groundwater based water bottling schemes established and many other coastal areas. Water Resources Board has engaged with research work on groundwater quality and quantity related issues of the above areas and found interesting results. The occurrence of excess amounts of Nitrates, iron, fluorides, phosphates and High EC values in groundwater are the main issues identified in those areas.

The paper discuss the current status of groundwater in Sri Lanka with respect to those issues and propose to establish a groundwater monitoring network to manage this valuable resource of the country for future generations.

INTRODUCTION

Groundwater is a limited and strategic water resource, widely used for domestic, small-scale irrigation, industrial and commercial and other purposes. Groundwater conditions vary considerably throughout the country. In some areas there are shallow aquifers which are replenished quickly during rainy seasons or from nearby surface water sources. This form of groundwater can be easily tapped and is susceptible to over use by numerous small users.

Demand for groundwater has grown rapidly as a result of population increases and economic development. A wide variety of users such as small-scale irrigators, households and housing development schemes, industries and industrial promotion zones, hotels, shrimp farms are now tapping groundwater to an unprecedented extent. Subsidies have been introduced for shallow wells in some areas and groundwater exploitation is being actively promoted by some politicians, often without adequate knowledge of the availability of the resource. Well drilling and pumping technologies have spread, increasing the risk of over-extraction and groundwater contamination. Groundwater is also, by nature, a hidden resource. Users often have little or no understanding of its location or quantity and a few incentives exist to protect groundwater supply and quality.

Groundwater in most shallow aquifers is closely connected to surface water. It is replenished directly from rainfall and infiltration from surface water bodies such as rivers, streams, tanks and ponds. Groundwater is also the source of river flow and other surface water during the periods of low precipitation or drought. During these periods shallow groundwater is slowly released through springs and other seepage pathways, providing more stable surface water supply. Groundwater replenishment and flows are normally slow, relative to surface water. As a result, groundwater is often a more localized resource than surface water and in some cases is relatively slow to recover from depletion or contamination.

OBJECTIVES

The main objective of the study is to collect data regarding the groundwater pollution, and other groundwater related issues through studies conducted by the Water Resources Board (WRB) and data available with other stakeholder agencies. This information would enable the Water Resources Board to introduce a mechanism to address the groundwater issues and manage groundwater resources of the country.

METHODOLOGY

This study was conducted under the Dam Safety and Water Resources Planning Project of Sri Lanka to identify groundwater related issues in selected

Divisional Secretary Divisions (DSD's) of seven districts as listed in Table 1. After carrying out field activities in the pilot areas, groundwater monitoring networks for each pilot area were developed and the hydro geological and geochemical maps were prepared. The maps were analysed and the groundwater related issues were identified in each pilot area. In addition, studies were conducted to gather information whenever there were serious issues of groundwater related problems reported by the public.

Table 1. Districts and respective Divisional Secretariat Divisions selected for the study

District	Selected Divisional Secretariat Divisions
Jaffna	Jaffna, Nallur, Chavakachcheri, Pachchalipallai
Puttalam	Kalpitiya, Puttalam, Vanathawillu
Anuradhapura	Medawachchiya, NuwaragamPalatha (central), Padaviya, Kebithigollewa, Rambewa, Horowpathana, Kahatagasdigiliya, Galanbindunuwewa
Gampaha	Gampaha, Wattala, JaEla, Wattala, Biyagama, Katana
Ampara	Sammanthurai, Kalmunai, Ninthavur, Adallachchenai
Matale	Dambulla, Galewela, Laggala, Pallegama, Na Ula, Pallepola
Badulla	Mainly southern part of the district

(Source: Water Resources Board)

The information collected is presented in graphical forms for each of the pilot study under the results and discussion.

RESULTS

Groundwater monitoring results from pilot areas

Puttalam pilot area

In the Puttalam district pilot area, zones with excess Nitrate and high Salinity zones were identified (Figure 1 and Figure 2). The Nitrate map indicates that Nitrate concentration of the groundwater in Puttalam pilot area varies from 0.0 to 34 mg/l. A sizable proportion of Kalpitiya peninsula has *Nitrate* concentration exceeding 10 mg/l, which is the permissible level according to the Sri Lankan drinking water standards. The Electrical Conductivity (EC) of groundwater varies from 750 - 7200 µs/cm. According to the Sri Lankan drinking water standards the maximum permissible level for *EC* is 3500 µs/cm.

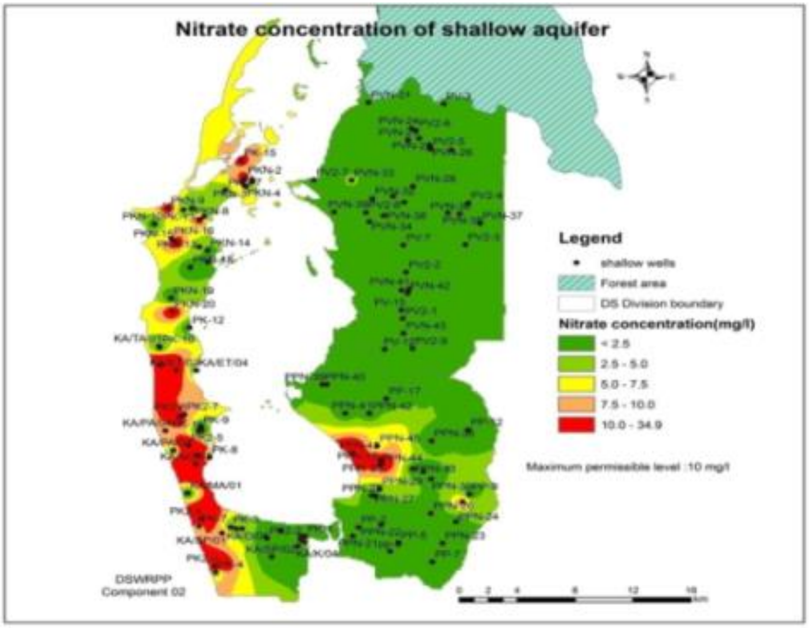

Figure 1. Nitrate map of Puttalam pilot area

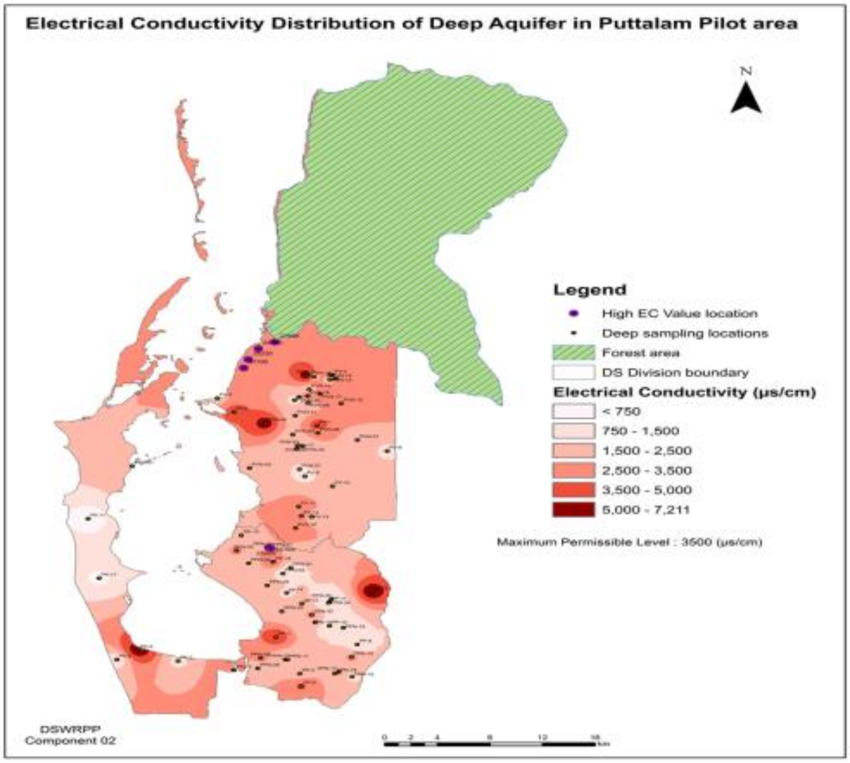

Figure 2. Electrical conductivity map of Puttalam pilot area

Jaffna pilot area

The data collected in Jaffna pilot area and rest of the peninsula were used to develop the water quality map for the entire peninsula. The maps clearly indicate the presence of zones with excess Nitrate and high salinity (Figure 3 and Figure 4). As in the case of Puttalam area, there are areas of more than 10 mg/l of *Nitrate* and 3500 µs/cm of Electrical Conductivity (EC) respectively.

Ampara pilot area

The *Phosphate* concentration of groundwater in Ampara pilot area varies from 0 – 6 mg/l as shown in Figure 5. According to the Sri Lankan drinking water standards the Phosphate concentration should be less than 2 mg/l. Therefore, zones with excess Phosphates were observed in eastern and central part of the pilot area which coincides with agricultural lands.

Anuradhapura pilot area

The zones with high concentration of Fluoride were observed in Anuradhapura pilot Area (Figure 6 and Figure 7). The Fluoride concentration of deep and shallow groundwater varies from 0 to 2.5 mg/l. According to the Sri Lankan drinking water standards the Fluoride level should be less than 1.5 mg/l. The occurrence of high fluorides is primarily connected to the geology of the area.

Figures 8 and 9 show the Arsenic concentration found in groundwater sources in Medawachchiya DSD. The values range from 2.6 ppb to 10.2 ppb. Only a small fraction of the area exceeds the permissible level of 10 ppb for drinking water.

Gampaha pilot area

The *pH* values of the groundwater in Gampaha pilot area varies from 3.8 – 8.5 as shown by Figure 10. In general, the groundwater appears to be more acidic.

Matale pilot area

The groundwater levels of the agro-wells in the selected DSD's of the *Matale* pilot area were monitored for two years. Figure 11 indicate groundwater flow map of the Matale Pilot area. The water level depletion was observed due to heavy pumping of groundwater for agriculture.

There was considerable fluctuation of the water levels both in wet and dry seasons. Figure 12 indicate the groundwater level fluctuation of the selected agro-wells in the pilot area, which shows different behaviour of the agro-wells. In some wells, the water level fluctuations were considerably high.

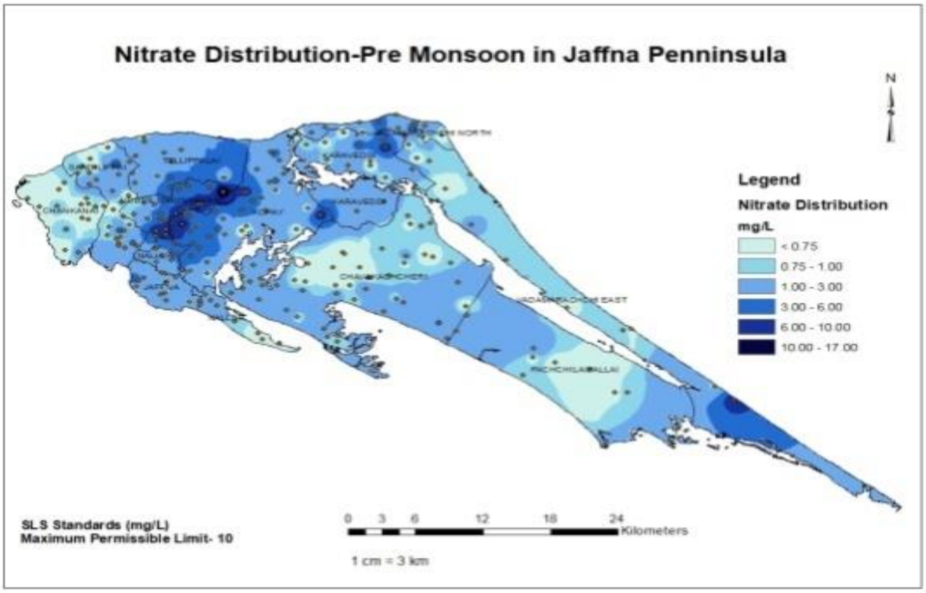

Figure 3. Nitrate map of Jaffna Peninsula

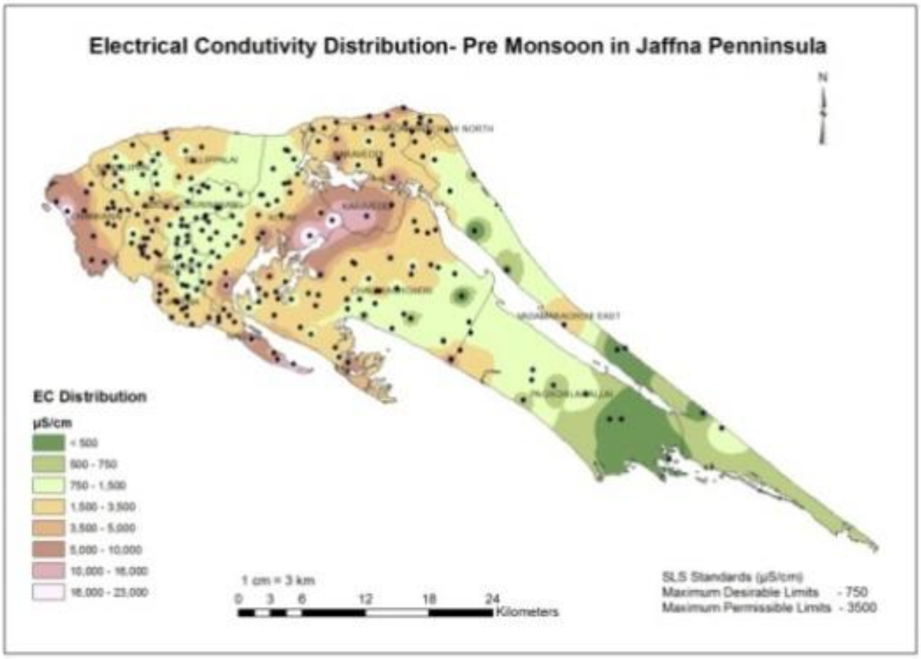

Figure 4. Electrical conductivity map of Jaffna Peninsula

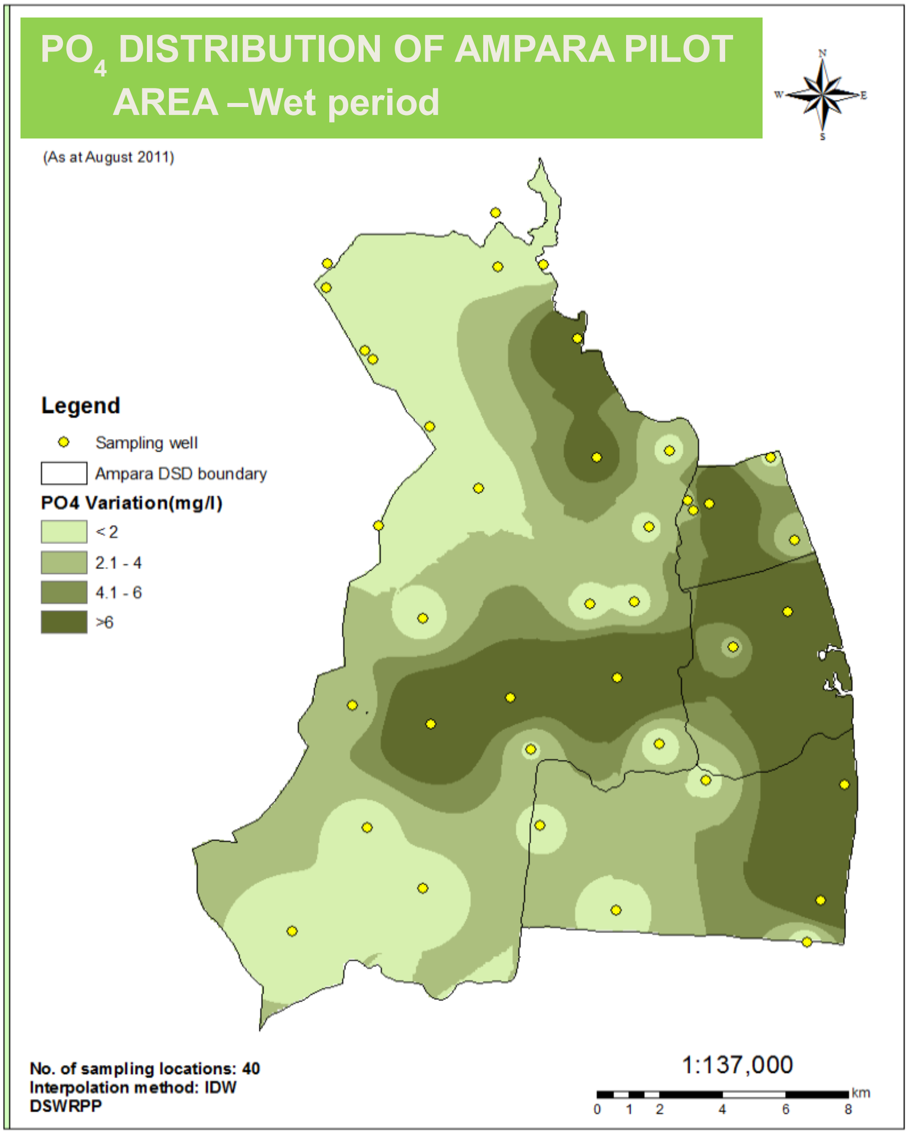

Figure 5. Phosphate map of Ampara pilot area

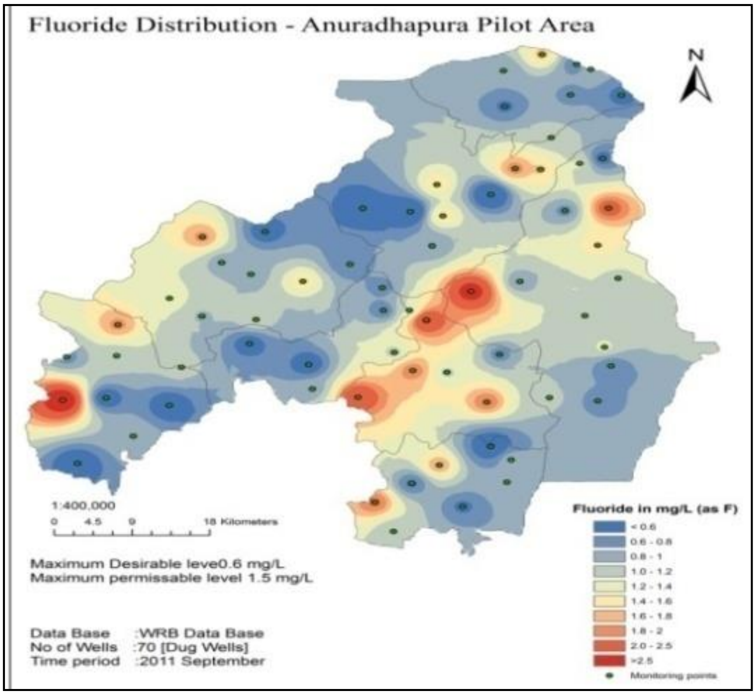

Figure 6. Fluoride in shallow groundwater of Anuradhapura pilot area

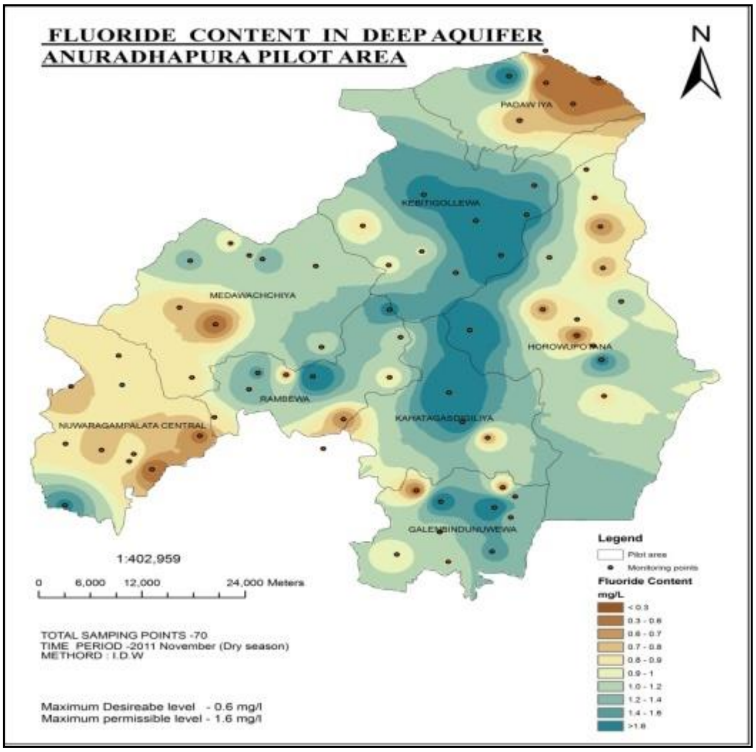

Figure 7. Fluoride in deep groundwater of Anuradhapura pilot area

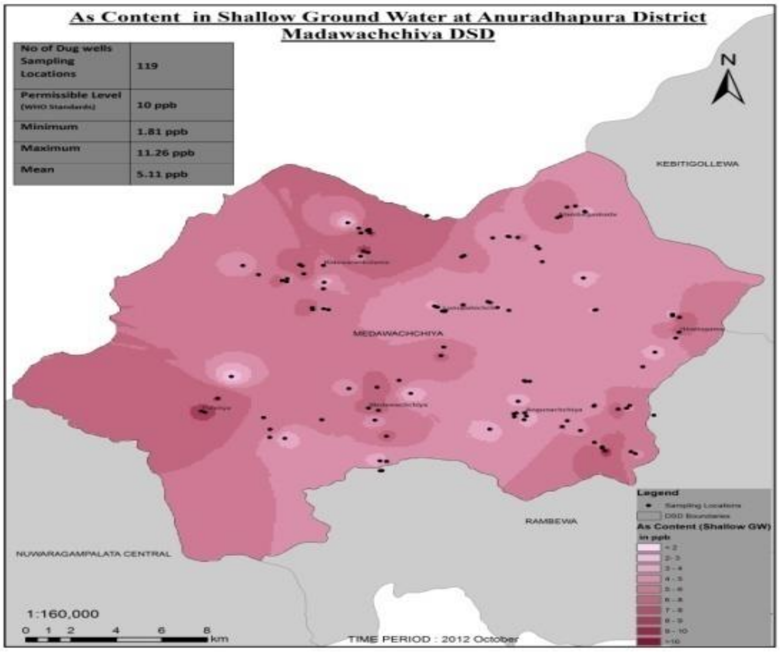

Figure 8. Arsenic in shallow groundwater of Medawachchiya DSD

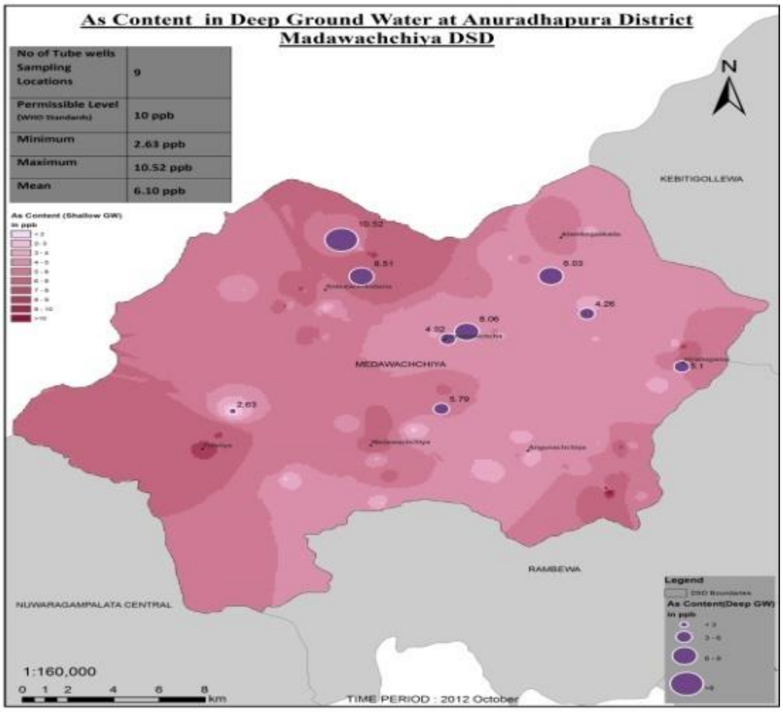

Figure 9. Arsenic in deep groundwater of Medawachchiya DSD

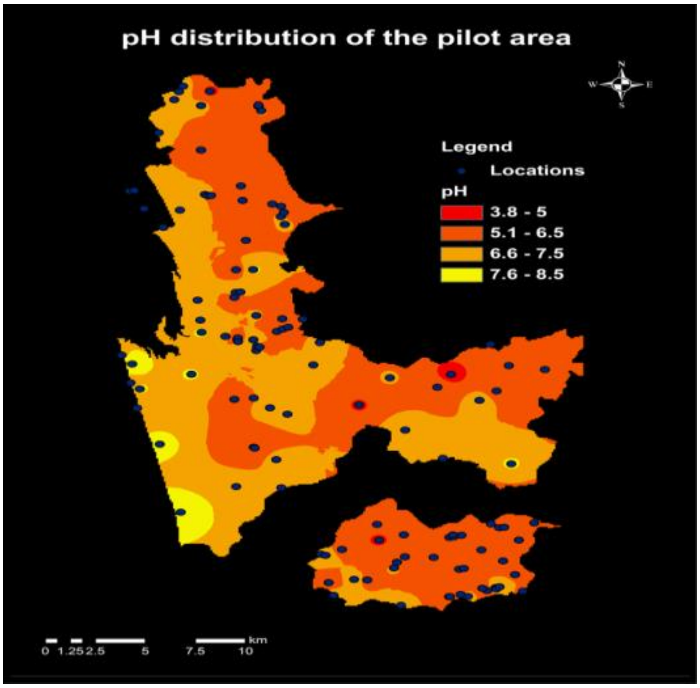

Figure 10. pH values of Gampaha pilot area.

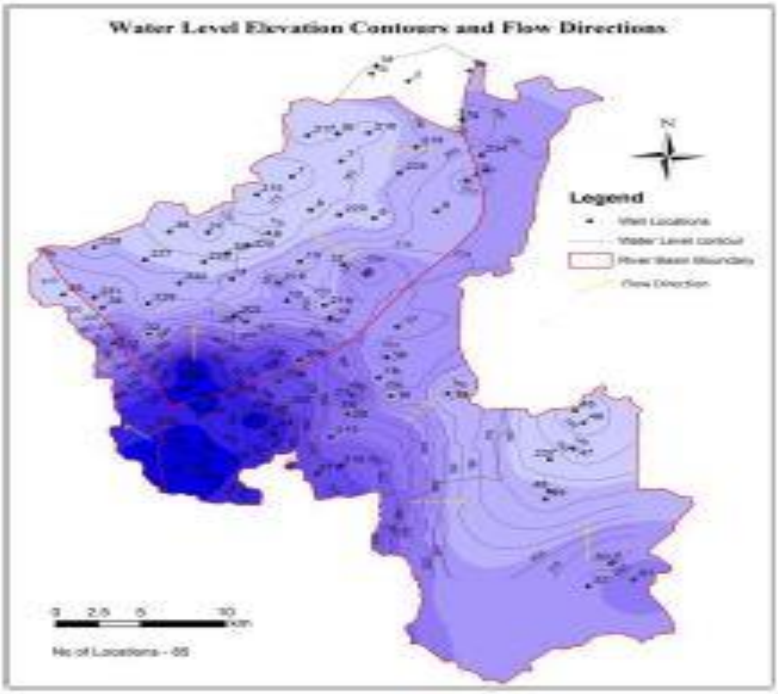

Figure 11. Groundwater flow map of Matale pilot area

Badulla pilot area

As shown in Figure 13, there is only localized Nitrate concentrations, which exceed the permissible limit of 10 mg/l in Badulla pilot area.

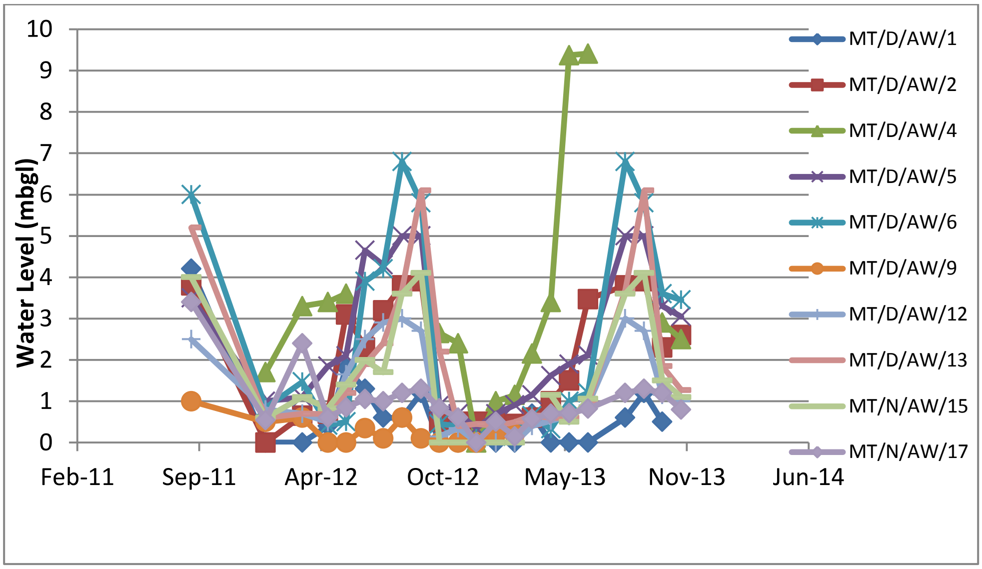

Figure 12. Water level fluctuation in selected agro-wells of Matale pilot area (2011 –2014)

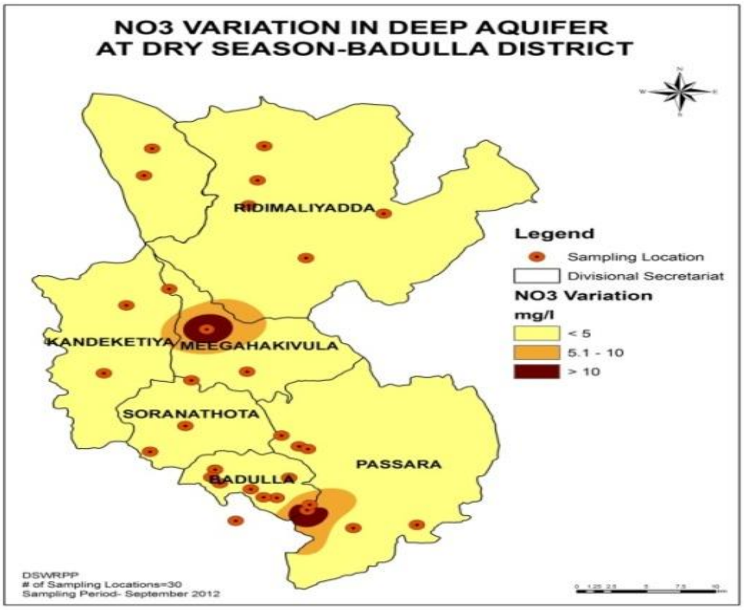

Figure 13. Nitrate map of Badulla pilot area

Results from significant groundwater issues reported in Sri Lanka

Low pH problem in Rathupaswela

In 2013, a serious problem was reported in Ratupaswela in Gampaha district due to low pH in the well water around Rathupaswela area. It was suspected that the emission of effluents from a nearby factory could be the reason for the incident. A study was conducted by the Water Resources Board through a groundwater monitoring network covering the entire area. The groundwater flow maps were prepared and analyzed to determine the pattern of groundwater contamination. In addition to the low pH, Nitrate and Sulphate contamination was also noted in close by dug wells in the area. Figure 14 indicates the groundwater flow map and the pH distribution of the study area indicating a possible connection.

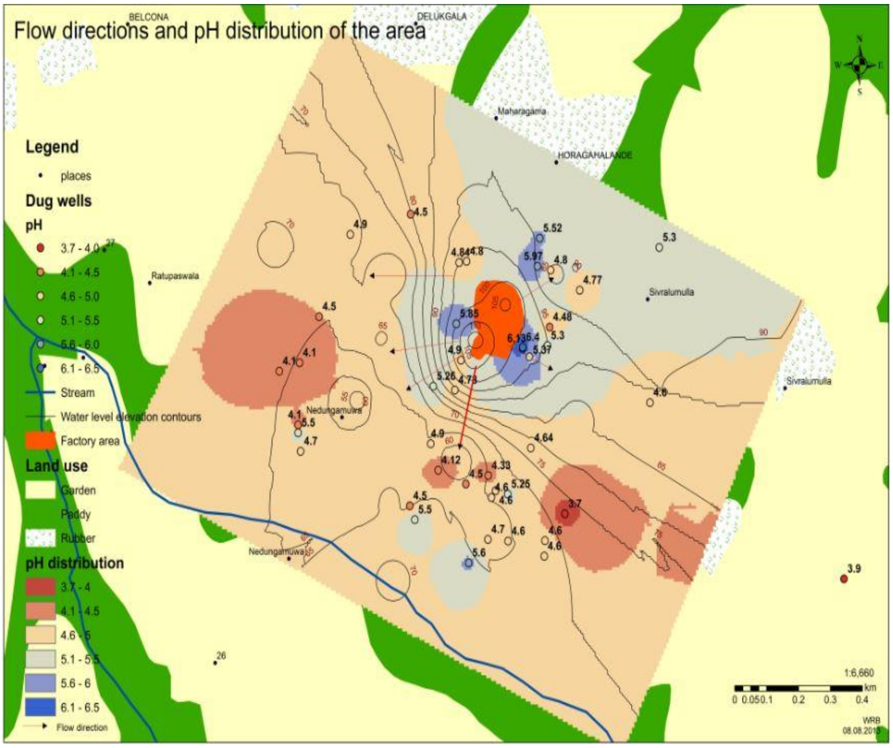

Figure 14. Groundwater flow direction and pH distribution in the well water, Rathupaswela

Contamination of groundwater due to dumping of oil and grease at Chunnakkam, Jaffna.

Groundwater contamination was reported in Chunnakkam, Jaffna due to dumping of oil and grease into the ground in an unprotected manner. Location of the site is indicated in Figure 15. The photographs in Figure 16 show the oil and grease contamination in surrounding areas of the Chunnakkam site.

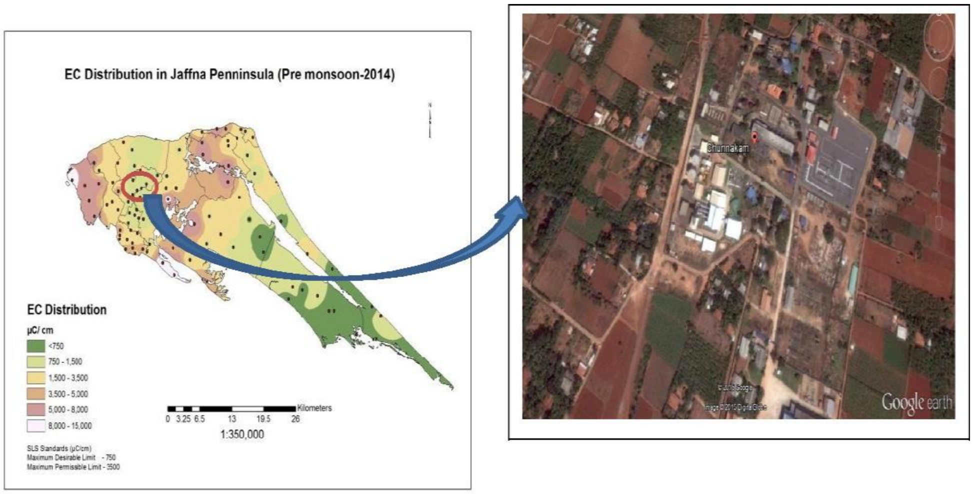

Figure 15. Location of the Chunnakkam site

Figure 16. Oil and grease Contamination in Chunnakkam area (Source: National Water Supply and Drainage Board)

E- coli contamination in Baduwatta, Katana

The residents of Baduwatta area complained to the Central Environmental Authority regarding the contamination of their wells due to the activity of a mill located close by to their village. The officers of the Central Environmental Authority checked three representative water samples from the wells in the village area. Their results are indicated in table 2. Comparison of these observed values with the Sri Lankan Standards, given in Table 3 shows that the water in this area is contaminated with E-Coli whilst the pH is also below the accepted standards.

Table 2. The analytical results of the well water, Baduwatta –Katana (Source: Central Environmental Authority)

Sample	**pH**	**Colour (NTU)**	**Chloride (mg/l)**	**Tcoli MPN/100 ml**	**Ecoli MPN/100 ml**
Sample no 839/14/LS	5	7	271	800	130
Sample no 840/14/LS	4.5	4	187	1100	170
Sample no 841/14/LS	5.8	12	21	170	60

Table 3. Sri Lankan Standards

	pH	**Colour (NTU)**	**Chloride (mg/l)**	**Tcoli MPN/100ml**	**Ecoli MPN/100ml**
Standard values	6.5 – 8.5	2	250	10	0

DISCUSSION

The results presented above clearly indicate that the groundwater contamination and the groundwater depletion are happening in many parts of the country due to various human activities, incorrect agricultural and industrial activities. In addition to the cases reported above, data on many other groundwater related issues are available in the data bank of the Water Resources Board. If a proper groundwater monitoring system is established in the country, it would be possible to issue a warning before the incident happened. The availability and the accuracy of monitoring data would enable the authorities to manage groundwater system of the country in a sustainable manner. The management always depends on monitoring and the availability of reliable real time data. The diagram shown in Figure 17 clearly indicates the role of monitoring data in the water management.

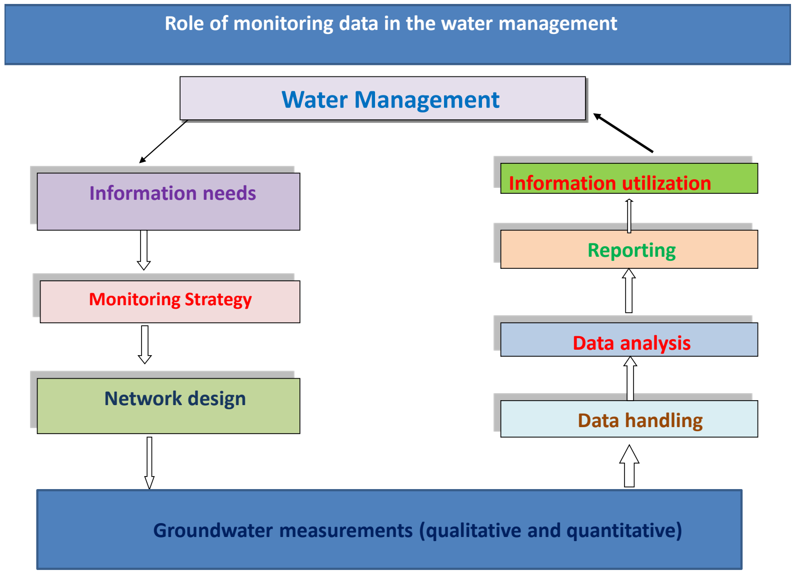

Figure 17. The role of monitoring data in the water management

There are many areas which require special attention due to the characteristics of aquifers and the type of groundwater use. A brief introduction of those identified areas is given below.

Community water supply schemes

There are many community based water supply schemes in Sri Lanka, especially in the dry zone. For an example the majority of community water supply schemes in Anuradhapura district use shallow or deep groundwater as their source. Figure 18 indicates the community water supply schemes in *Anuradhapura*. It is very important to monitor the groundwater quality of these wells in view of the prevailing CKDu problem in the area.

Groundwater in Jaffna peninsula

Groundwater is the main available source of water for the people in Jaffna Peninsula. Studies conducted in the peninsula indicate that the Nitrate concentration of groundwater in some of the water supply wells is above the recommended levels.

A case is point with regard to high concentration of *Nitrate* in groundwater comes from the water supply well at Kondavil, Jaffna. Figure 19 indicate the Nitrate concentration of this particular well. Water Resources Board continuously monitored the *Nitrate* concentration of this particular well during the last 4 years and observed that from January to December of each year the *Nitrate* levels are changing from 7 mg/l – 25mg/l. This well is located in the

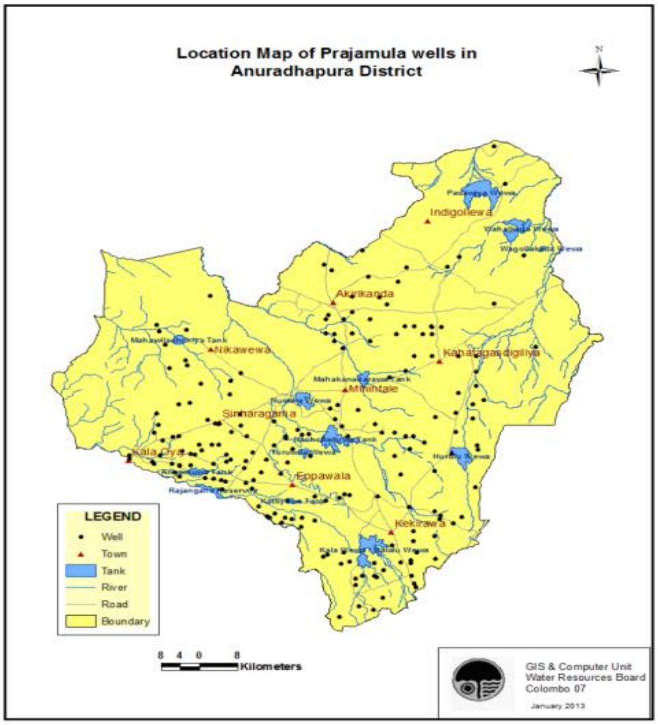

Figure 18.Cummunity based water supply schemes in Anuradhapura district (Data collected from NWSDB, Anuradhapura)

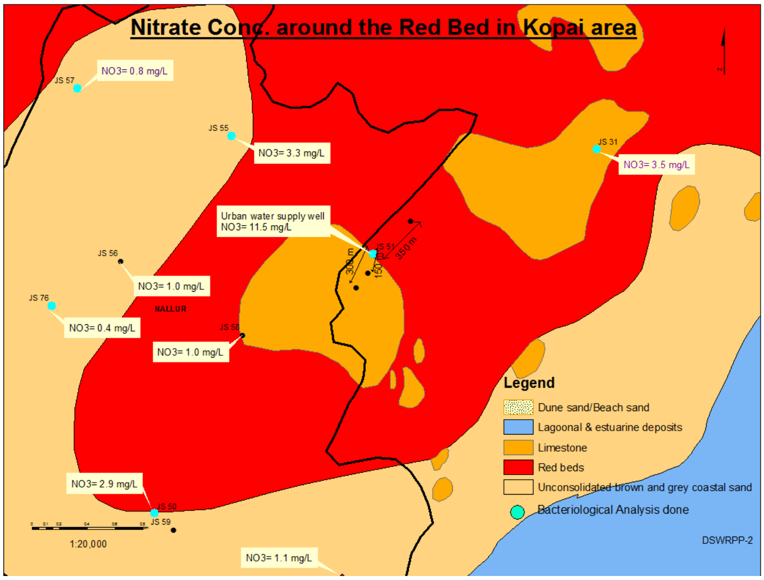

Figure 19. Nitrate map of Kondavil area

agricultural area and Nitrates may come from inorganic fertilizers applied for various crops by the farmers.

Mannar limestone aquifer

Mannar Limestone aquifer has very high groundwater potential and a large amount of groundwater is used for irrigation purposes. These wells are also threatened with the increase of chemical contents in water and hence needs to be monitored.

Coastal sandy aquifer

Many hotels and industries use groundwater from coastal aquifers. For instance, Industries in the Board of Investment zone of Katunayake use 3000 cubic meters of water on daily basis from 33wells constructed in the coastal aquifer extending from Colombo to Negombo. Therefore, this aquifer should be closely monitored qualitatively and quantitatively.

Alluvial aquifers

The alluvial deposits along major rivers are considered to be very good shallow aquifers. The main beverage companies like Coca Cola, Ceylon Cold Stores and other water bottling industries are situated along the river terrace of Kelani and they use considerable amounts of groundwater from shallow wells. As a result of these heavy groundwater extractions, the groundwater level fluctuation and water quality changes could be expected in this aquifer system. This aquifer system also needs more attention in future.

Laterite aquifer

This is the main aquifer in western and south western part of the county. The groundwater in this particular aquifer shows low pH values within the range of 4 – 6. Many people use this water for their day to day activities. Many industries are located within this area and activities of these industries may be affecting water quality of the wells (e.g. Rathupaswela). Therefore, attention must be focused on this aquifer system too.

As stated earlier the development activities of the county with the population increase would increase the demand for groundwater considerably in future. Therefore, a groundwater management system through a proper groundwater monitoring network is essential for the country.

GROUNDWATER MONITORING SYSTEM

The paper contain only very limited issues identified or reported to the Water Resources Board. There are some court cases regarding the groundwater issues. Therefore, it is recommended to establish a proper groundwater monitoring system for the country covering all the aquifer systems and the sensitive areas already identified by the Water Resources Board, as shown in Figure 20.

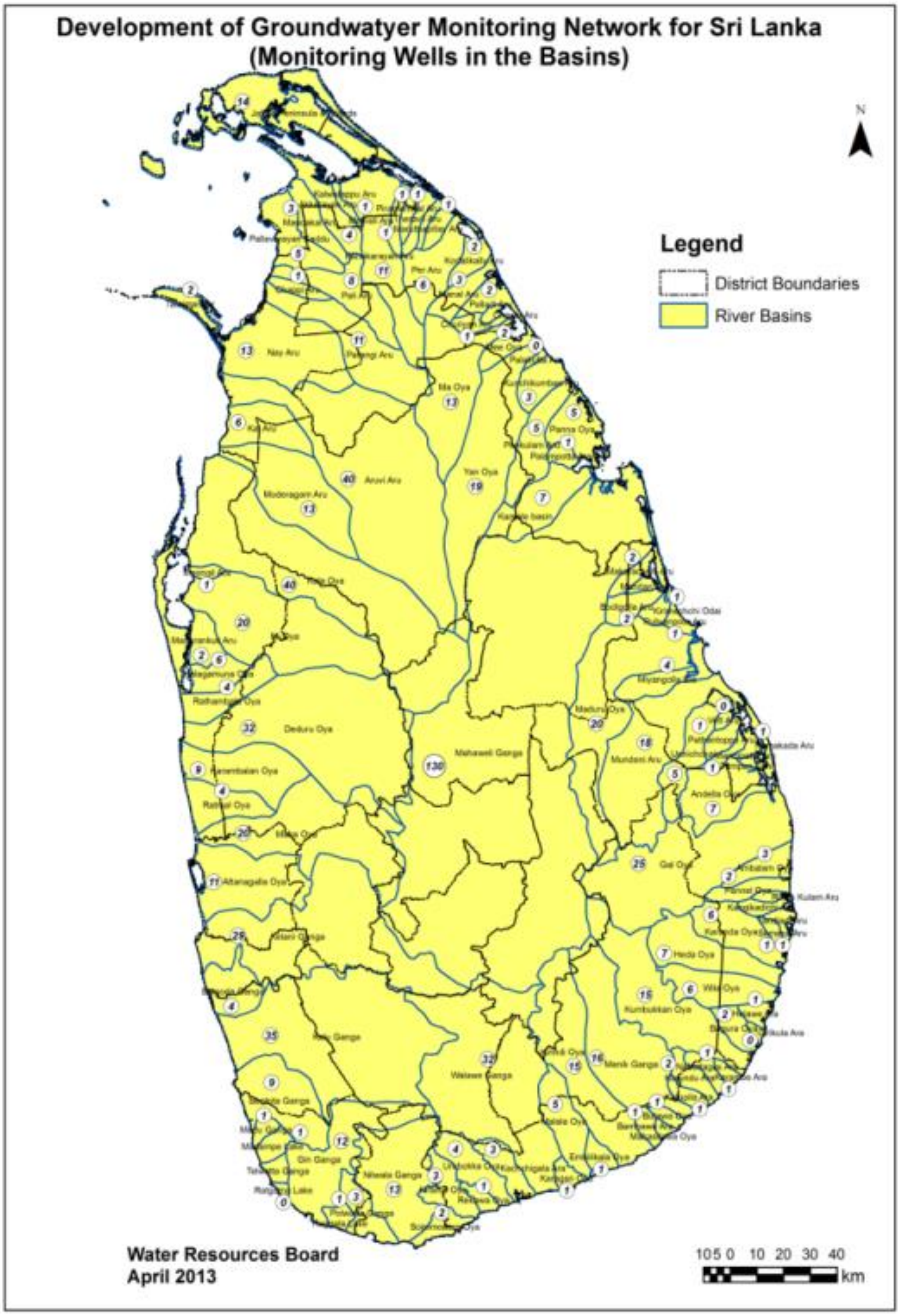

Figure 20. The groundwater monitoring network already designed by the Water Resources Board

The well monitoring system should be designed as follows:

a) The system should have at least 1030 observation wells.
b) Install the wells with data loggers to monitor Water levels, Electrical conductivity, *pH* and Chemical parameters (*Nitrate*)
c) Collect real time data
d) Data analysis

The following benefits could be accrued from a groundwater monitoring network.

- Develop real time groundwater data base for Sri Lanka.
- Maintain a proper groundwater management system for the country.
- The possibility of taking quick action to the groundwater related issues.
- Ability to forecast groundwater related issues.
- Share data with decision makers, researches, stakeholder agencies and general public.
- Periodical evaluation to examine the changing trends to assess the improvement of water quality.
- Conducting awareness programmes on mitigation.

CONCLUSION

The government of Sri Lanka should pay more attention to the protection of groundwater resources of the country by implementing groundwater monitoring system with immediate effect.

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Groundwater assessment study in Thirappane cascade system in Anuradhapura district, Sri Lanka

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ABSTRACT

A study was carried out to quantify the recharge of the groundwater from a cascade tank system and to assess how far this recharge quantity would benefit the farmers during the Maha season for cultivation of different type of crops. It has been noticed that surface water is discharged during the Maha season for cultivation without considering the enhanced groundwater potential due to the presence of the cascade system. This can be used in conjunction with tank water for better and effective water management.

Thirappane Tank Cascade System considered for this study composed of seven tanks of which five are located in the main branch while two are on a tributary is about 18.5 km^2 in extent. During the study, variation of groundwater level over a hydrologic year due to the rainfall and seepage and percolation from the tanks of the cascade system were measured. In addition, a detailed study on the available data such as geology, geomorphology, soil types, land use and drainage basins was carried out to compile information for the acquirement of basic knowledge on the study area prior to commence the field work. Dug wells which are accessible for monitoring were selected for the monitoring network. Monitoring gaps were identified and new test wells were constructed after conducting hydrogeological investigations together with geophysical resistivity surveys followed by the pumping tests that provided the aquifer parameters of the subsurface formations in the area.

(a

Monitoring of water levels of the network was carried out at monthly intervals since 2013 and these data was used to prepare hydrographs and estimate the annual recharge during a hydrologic year. Specific yield of the unconfined aquifer, i.e. regolith was computed by analysing the data obtained from pumping tests that were conducted for some wells located within the project domain. The average recharge during the hydrologic year of 2014 - 2015 from rainfall and seepage and percolation from the cascade system was approximately 4.09 x 10^5 m^3. The water type as per the piper diagram falls within the group of Sodium-Potassium Bicarbonate and seems to be uniform in the whole study area.

INTRODUCTION

North-Central province of Sri Lanka consists of large number of small irrigation tanks that are distributed across the hard rock undulating landscape of the dry zone and found to occur in the form of distinct cascades that are positioned within well-defined small watersheds. The type of aquifer present in these areas is shallow regolith aquifer which is underlain by crystalline basement rock (Panabokke *et al*., 2007). The province experiences North-West monsoon, i.e. October – March and the rainfall events are found to be of high intensity resulting in rapid runoff. The major agricultural activities in the area are dependent on the tank storage of the cascades which is often inadequate to store water to cultivate paddy in both *Maha* (wet season) and *Yala* (dry season) seasons (Sakthivadivel and Panabokke, 1996). Therefore, the use of groundwater for agricultural activities in conjunction with surface water is important.

Objectives of the study

The objectives of the study are;

- to quantify the groundwater recharge over a hydrologic year due to rainfall and seepage and percolation from the tanks of a cascade system, and
- assess the seepage loss from the tank system that can be used in conjunction with surface water, enabling the farmers to carryout effective water management during the *Yala* season where field crops are cultivated with water from wells and tanks.

METHODOLOGY

Description of the study area

Thirappane tank cascade system which is located in the dry zone in the North-Central province of Sri Lanka was selected for this study. The cascade is about 18.5 km^2 in extent and situated 20 km away from the nearest city of Anuradhapura. The system is composed of seven tanks of which five are located in the main branch while two are on a tributary. Thirappane Tank, Allisthana Tank, Meegassegama Tank, Vendrankulama Tank and Gulupatthawewa Tank are in the main system and Bulankulama Tank and Badugama Tank are in the tributary (Figure 1).

Desk study

A detailed study on the available data such as geology, geomorphology, soil types and land use at drainage basins level was carried out by using topographic, geology and structural maps as well as aerial and satellite images to collect information prior to the commencement of the field work. Available rainfall and temperature data were collected from the Department of Meteorology and the Department of Irrigation.

Selection of dug wells for monitoring network

Dug wells for the monitoring *network* were selected covering the whole study area where access was possible, and depending on the depth and diameter of the dug well. Most of the selected dug wells were fully penetrating the regolith aquifer.

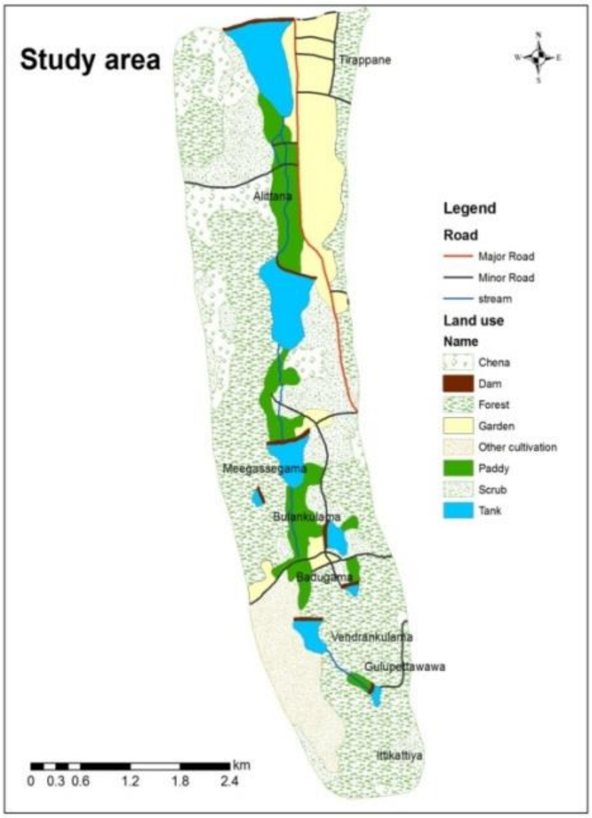


Figure 1. Thirappane tank cascade system

Monitoring of water levels of dug wells

Water level monitoring was carried out in selected dug wells in each tank system to prepare hydrographs in order to calculate the recharge of the area. The water levels of each and every selected dug well were measured on every Month using Dip Meter (Water Level Recorder) to obtain regular pattern of data on water level fluctuations. The monitoring points are shown Figure 2.

Geophysical survey

Geophysical Resistivity Surveys were carried out in the study area to determine the subsurface of the area. Resistivity method which is one of the most prominent survey techniques on the groundwater development activities was applied to carry out the geophysical investigations to determine the subsurface conditions. The instrument called as “ABEM SAS 300 Terrameter” was used to obtain the apparent resistivity values of the subsurface formations. Ten (10) numbers of different Vertical Electrical Soundings (VES) were carried out in order to determine the sub surficial conditions. The result is plotted in Figure 3.

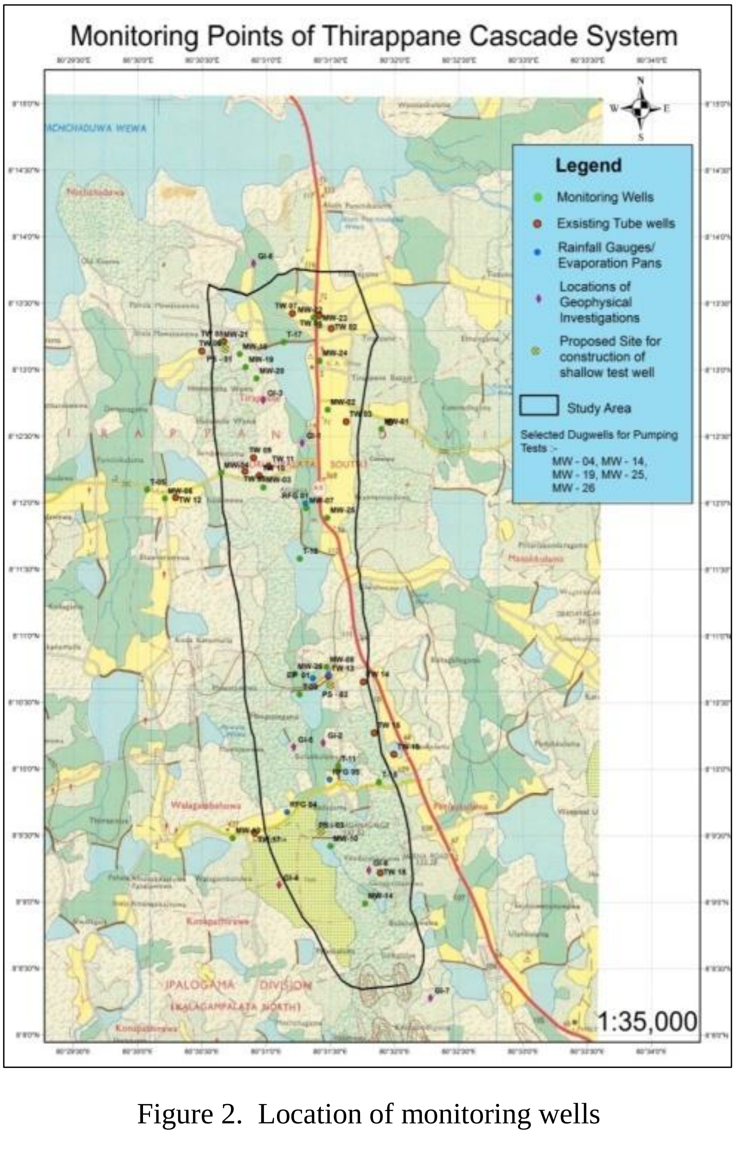


Figure 2. Location of monitoring wells

N	ρ	h	d	Alt
1	26.2	0.838	2.46	-0.8381
2	3.67	2.36	10.83	-3.195
3	1531			

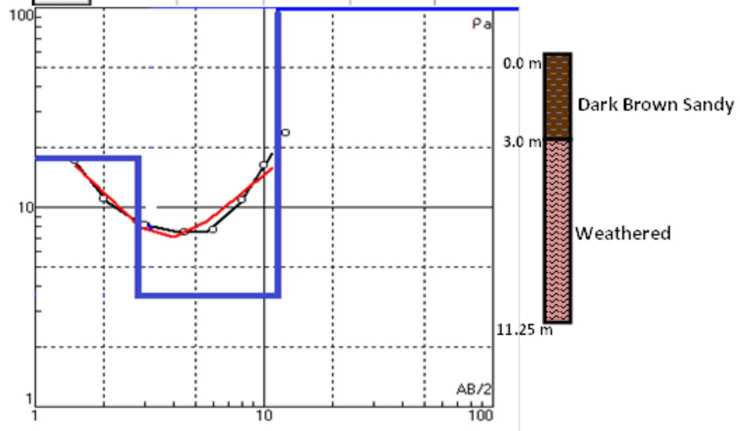


Figure 3. Plotted curve of geophysical survey

Drilling test bore holes

Test bore holes were drilled at selected sites depending on the survey results and the water samples from the *overburden* of the drilled test bore holes were analysed for chemical and physical parameters. Soil samples collected at 2 m depth in each of the test boreholes were also tested

Pumping tests

Detailed pumping tests were carried out in the constructed test wells including Calibration Test, Step Test and 24 –Hour Constant Rate Test to determine the Transmissivity (T, m^2/day) and Storativity (S) of the aquifer. In addition, 24 hour constant rate pumping tests were carried out in four (04) selected dug wells to compare the variation of aquifer characteristics on different hydraulic structures.

Levelling of dug wells

(a

Levelling of 18 selected dug wells was done using Differential Global Positioning System (DGPS) for the *preparation* of water elevation contour lines to identify groundwater flow direction of the study area.

Chemical analysis of water samples

The collected water samples were analysed for chemical parameters such as pH, Electrical Conductivity (EC), Total Hardness, Total Alkalinity, TDS, Sulphate (SO_4), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Fluoride (F), Salinity, Nitrate (NO_3), Nitrite (NO_2) and Total Phosphate (PO_4), and three physical parameters namely Temperature, Colour and Turbidity. The anions and cations were measured using APHA method, EDTA titration and Flame Photometer method.

Preparation of hydrographs

Groundwater hydrographs that show the water level readings were converted to water levels below ground surface. The water levels against their corresponding time were prepared for all the dug wells in the monitoring network together with the rainfall data over a hydrologic year which helps to estimate the annual groundwater recharge from rainfall.

Calculation of groundwater recharge

Estimation of groundwater recharge was done using water level data of the monitored dug wells in accordance to the following equation.

$Q = Sy\ \Delta y/\ \Delta t$

Where: Q = Total recharge
Sy = Specific yield
Δy = Annual rise in water level
Δt = Period of time of annual rise

RESULTS AND DISCUSSION

The piper diagram indicates a uniform water type within the cascade which is Sodium-Potassium-Bicarbonate type. There are consequent variations in the Na^{+}/ K^{+} ion concentrations in some samples which are the causatives of the identical anomalies in the Piper *Diagram*. The variations may be due to the ions released from the weathered formation in which the wells are dug through (Figures 4 and 5).

Isopach thickness in the area varies from 3.1 m – 12.5 m. For the preparation of iso-pach the data were collected from dug well survey and from the 1d resistivity surveys (Figure 6).

The results of the pumping tests were manually analysed using standard methods of pumping test data *analysis* for unconfined aquifers in the steady state conditions such as Theis's method, and Jacob's method. Logan's method (Figure 7; Tables 1 and 2).

The average recharge during the hydrologic year of 2014 - 2015 from rainfall and seepage from the *cascade* system was approximately $4.09 \times 10^{5}\ m^{3}$.

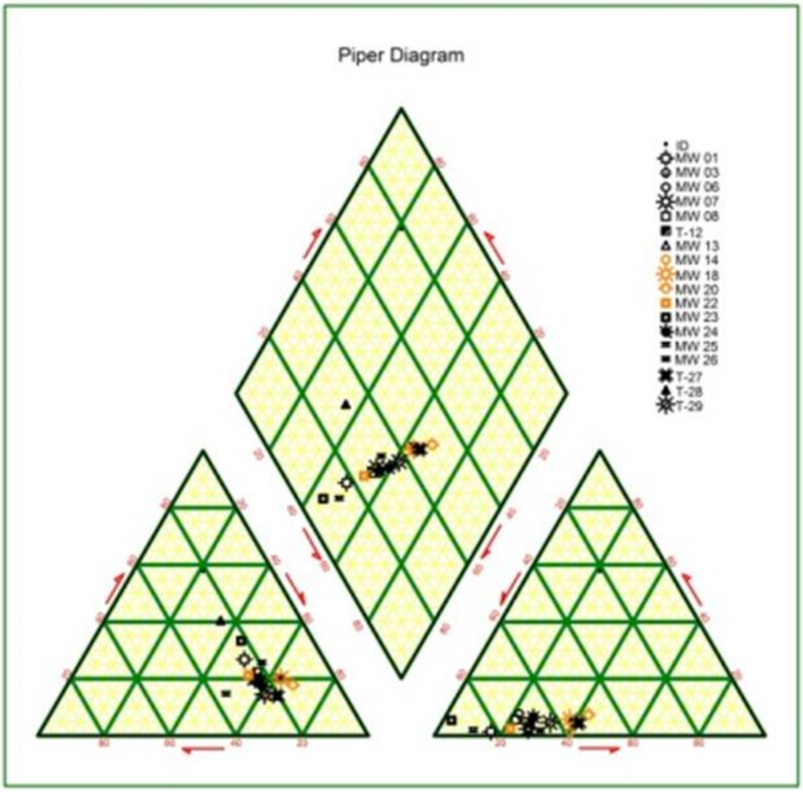
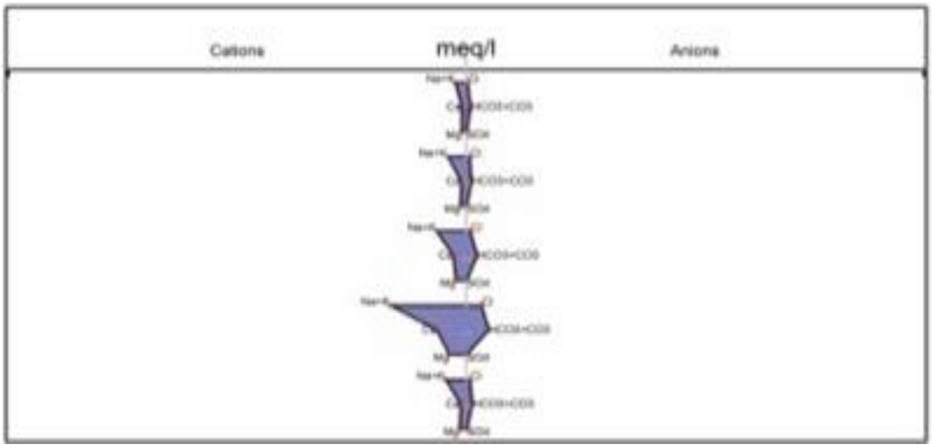
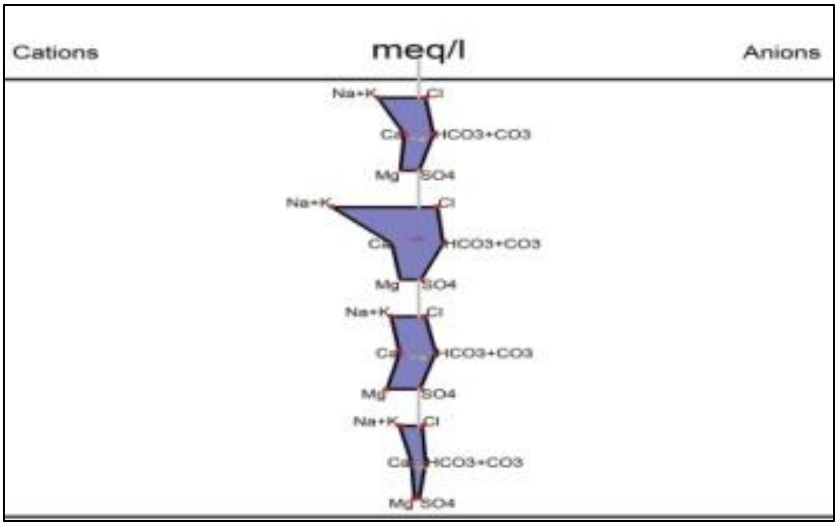


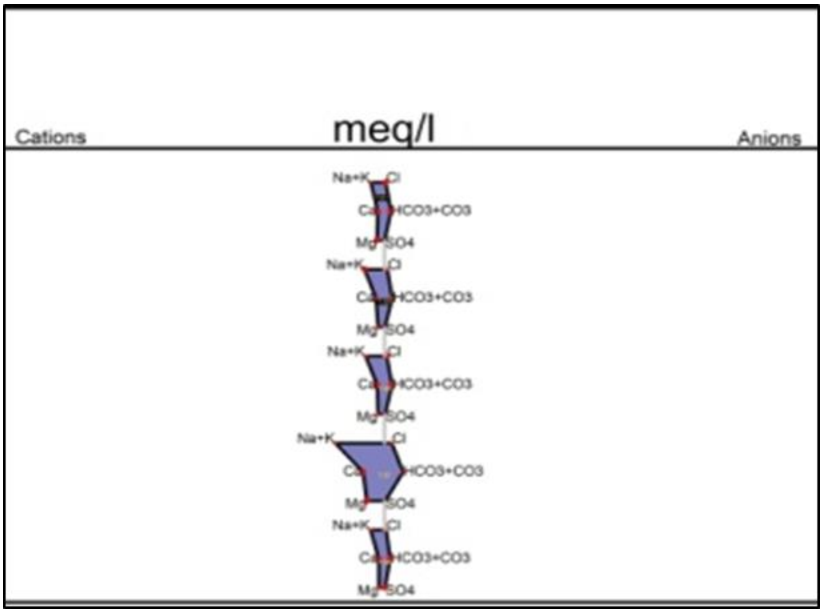
Figure 4. Piper diagram indicating the water quality of the sampling wells



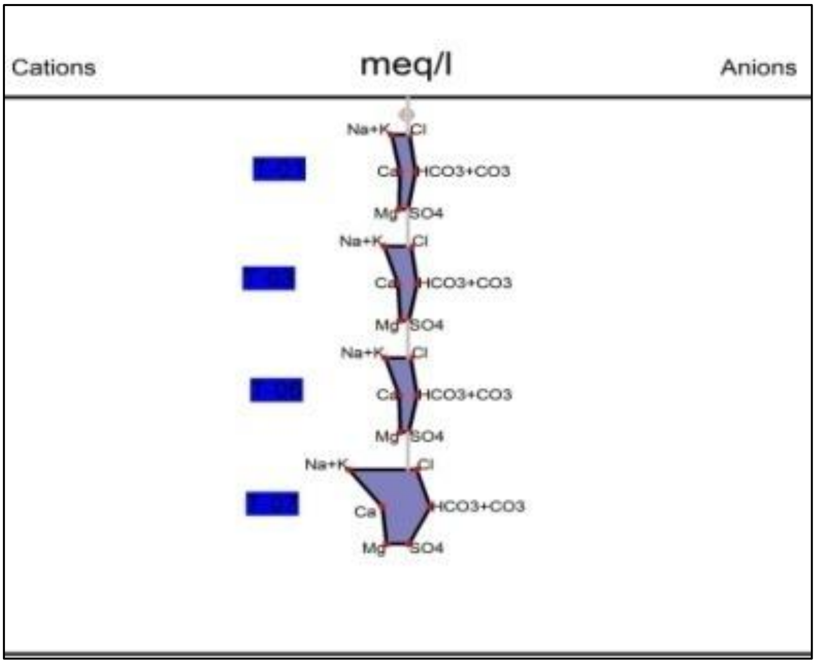
(a) MW 01, MW 02, MW 03, MW 04, MW 06



(b) MW 07, MW 08, MW 10, MW 13



(c) MW 14, MW 18, MW 19, MW 20, MW 22



(d) MW 23, MW 24, MW 25, MW 26

Figure 5. Stiff diagrams (a, b, c and d) indicating the water quality of the sampling wells

Table 1. Aquifer parameters obtained through Theis' and Jacob's methods

Location	Theis's Method		Jacob's method	
	T(m^2/day)	S	T(m^2/day)	S
Allistan	161.71	0.0049	207.99	0.0036
Bulankulama	19.64	0.0026	50.58	0.0019

Table 2. Aquifer parameters obtained through Logan's method

Location	Well No.	Logan's Method T(m^2/day)
Allistan	MW 07	146.78
Bulankulama	MW 10	30.82
Thirappane	MW 02	38.98
Meegassegama	MW 26	258.35

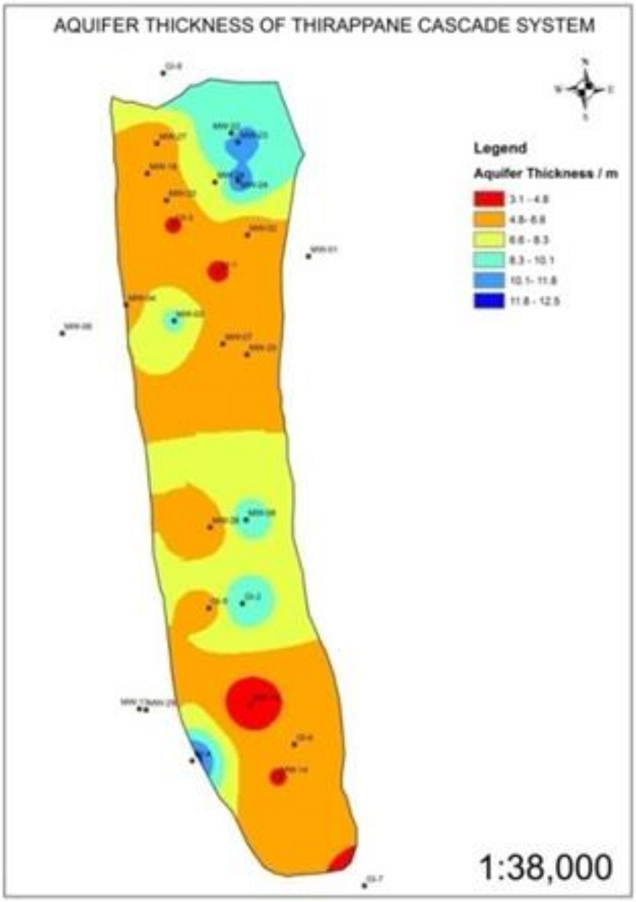


Figure 6. Aquifer thickness

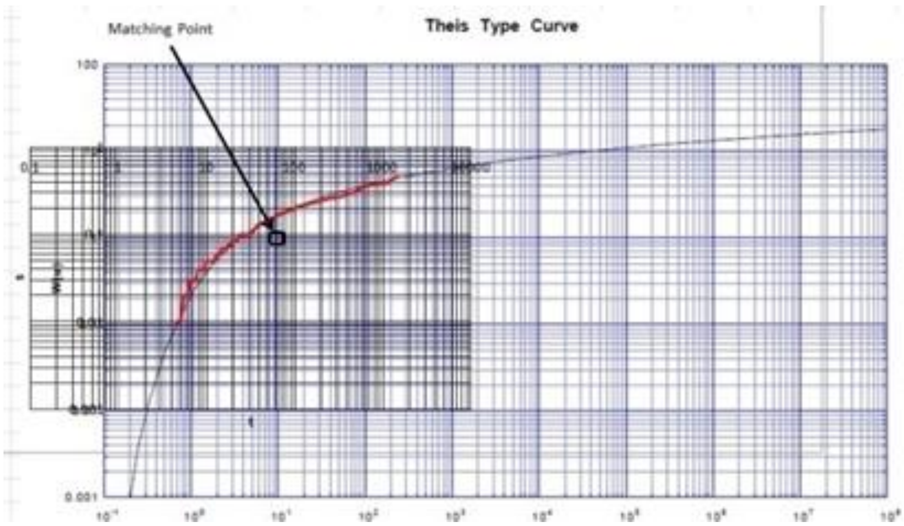


Figure 7. Analysis of aquifer characteristic

Contour maps which were prepared using the results of levelling procedures reveal an existence of an elevation gradient towards the downstream of the cascade resulting in a surface water flow direction. On the other hand, the water level contour map also shows an elevation gradient towards the downstream of the cascade with some differences (Figure 7).

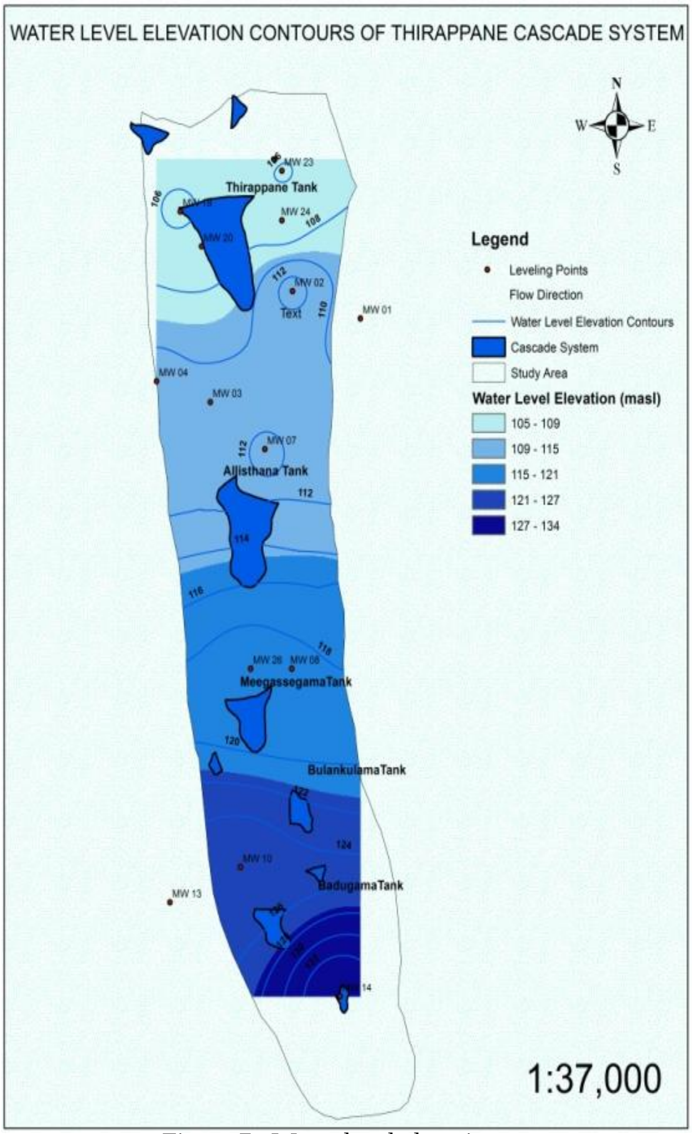


Figure 7. Water level elevation map

CONCLUSIONS

The average recharge during the hydrologic year of 2014 - 2015 from rainfall and seepage from the *cascade* system is approximately 4.09 x 10^5 m^3. Some of the wells in the monitoring network are not fully penetrated into the aquifer, therefore, this has an impact to the water level measured in certain wells. This could be rectified during the future monitoring programme by selecting wells which are fully penetrated.

A unique water type of Sodium-Potassium Bicarbonate type can be identified within the area of Thirappane Cascade System. Lateral variation of chemical parameters was not identified.

Overburden depth in the cascade varies from 3.1 m to 12.5 m which is very important as an unconfined regolith aquifer for the extraction of groundwater in the region.

Some wells located in Thirappane (MW 02, MW 20), Allistana (MW 03, MW 07), Vendrankulama (MW 10) and Meegassegama (MW 26) show a slight variation in the water level fluctuation. Those tank systems can be identified as high potential areas for groundwater recharge that can be used as the sources of water for agriculture.

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Groundwater quality in the dry zone of Sri Lanka: Conditions, trends and community Issues

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ABSTRACT

Since ancient times, dry zone communities have mainly used rain and surface water for their daily needs and few decades back, limited availability of such water has compelled people to exploit groundwater in the area. All the above water sources show diverse quality and community issues related to human uses. The significant issues in the use of groundwater include excessive salt uptake by plants, excessive salt intake by human through drinking water, enhanced eutrophication caused by nitrate and phosphate, potential for blue baby syndrome in infants and gastric cancer in adults by nitrate, dental and skeletal fluorosis and some kind of kidney diseases. Further, toxic metallic elements cause many health problems in general but presently available data are not adequate to understand the status of the elements in groundwater, temporal and spatial variations and long term trends. Further, it is suspected that the causal factor of the chronic kidney disease with unknown aetiology (CKDu) is associated with drinking water; groundwater sources in particular. This paper suggests to seriously consider the quality aspects of groundwater when using it, particularly for drinking purposes. In this regard, expansion of water testing and purification facility in an area, supply of good quality water for adversely affected areas and making the community aware of water quality aspects are some of the steps to be taken to mitigate the above issues.

INTRODUCTION

The dry zone of Sri Lanka has been characterized as the principal area for seasonal food crop production, greater fraction of people being involved in subsistence level of farming for food and income, bimodal rainfall with a dry climate (NRMC, 2003), abundance of salt rich Alfisols (Panabokke, 1996), flat to undulating landscape (Dimantha, 1992), coastal and inland regions based on geographic features, abundance of man-made structures for rainwater harvesting (NARESA, 1991) and abundance of rural communities being existed in a cascade array. Since ancient times, dry zone communities have used rain and surface water sources for various types of their daily needs. Use of groundwater particularly for agriculture has been confined traditionally to the Northern and Eastern provinces where limestone and sand-layered aquifers are found, especially in the coastal belt. Few decades back in the inland dry zone, limited availability of surface water against expanded population has compelled people to exploit all available groundwater sources (shallow and deep groundwater) in the area, in addition. Further, an increasing trend has been observed in the exploitation of groundwater since then.

All above water sources show diverse qualities related to human use depending on its inherent characteristics. Further, water has an ability to dissolve almost any substance and provides sustenance to all living beings. In contrast, the same property brings a large number of substances into solution in concentrations that are extremely harmful to life. Community issues have emerged due to the diversity in quality and specific features of water. The significant issues include contamination of water by sediment, organic debris and faecal matter; excessive salt uptake by plants; excessive salt intake by human through drinking water; enhanced eutrophication leading to water pollution, potential for blue baby syndrome in infants and gastric cancer in adults, dental and skeletal fluorosis and kidney diseases confined to dry zone settlements. Dissolved solids, nitrates, phosphates, fluoride, toxic metallic elements and faecal matter in water have been identified as major causal factors for some of significant community problems in the area. This paper discusses conditions and trends in groundwater quality, community issues emerged related to water quality and possible steps to be taken towards mitigating community issues.

Characterization of groundwater quality

Water has multiple uses and community issues emerge accordingly. Some of the major uses include drinking, food preparation, bathing, washing, recreation, aesthetic purposes, home gardening, irrigation, industry, power generation, navigation, livestock rearing, fish rearing, maintaining the stability of ecosystems and preserving the quality of the environment (Amarasiri, 2015). The groundwater in the dry zone of Sri Lanka has most of the above uses with few exceptions. Although many water quality parameters have been identified, in practice, few significant parameters are widely used in the dry zone to address community issues. The quality parameters are pH, total dissolved solids (TDS) or electrical conductivity (EC), major cations (sodium, potassium, calcium and magnesium), major anions (nitrate, phosphate, sulphate, chloride, carbonate and bicarbonate), nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P), fluoride (F), toxic metallic elements (cadmium, arsenic, chromium, mercury, lead, nickel, molybdenum, copper, manganese and zinc) and Escherichia Coli (E.Coli) count. Number of pathogenic organisms extremely harmful to human health may be present in water that is contaminated with human faecal matter. The presence of such organisms is extremely difficult to assess because of the limitations of available laboratory techniques. On the other hand, E.Coli, a non-pathogenic bacterium that is found in very large numbers in human faeces is easily detectable. It is for this reason that E.Coli is used as an indicator organism for the possible presence of human fecal matter in water. The permissible qualitative and quantitative conditions of above parameters in groundwater depend on the particular use and therefore water quality guidelines have been developed based on the use.

Spatial and temporal variability in groundwater quality

Groundwater quality significantly varies from the wet zone to dry zone in Sri Lanka. Transect studies (Nandasena *et al.*, 2005) conducted from Gannoruwa to Puttalam and Maradankadawala using 72 domestic wells situated along the two transects at 10 km intervals sampled for every 20 days intervals in *Maha* season starting from October 2002 to January 2003 showed significant changes in groundwater quality towards the dry zone. The pH and EC of groundwater showed a spatial variation with the climatic variation from wet to dry. The pH of wet, intermediate and dry zones was ranged from 6.38 to 6.58, 6.32 to 6.97 and 6.97 to 7.40, respectively while EC ranged from 0.04 to 0.44, 0.05 to 2.94 and 0.24 to 3.10 dS/m, respectively. The F concentration did not show a spatial variation with climatic variation and it ranged from 0 to 1.9 mg/L in all three climatic zones. However, some wells situated in the dry zone villages namely Aulagama, Nikaweratiya and Mirisgoniaoya in the study area had high F concentrations of 1.8, 1.9 and 1.5 mg/L exceeding the WHO guidelines for F in drinking water. There was no difference in NO_3-N concentrations in three climatic zones. In all three climatic zones, NO_3-N concentration ranged from 0.005 to 3.86 mg/L. The NH_4-N concentration also did not show any significant spatial variation from wet to dry climatic zones and ranged from 0.06 to 0.41 mg/L. The PO_4-P concentration also did not show a significant variation against climatic zones and ranged from 0.005 to 0.680 mg/L. According to the above study, pH and EC showed an increasing trend towards the dry zone. The other groundwater quality parameters investigated namely F, NO_3-N, NH_4-N and PO_4-P did not show any significant spatial variation from wet to dry climatic zones. Except F, the other quality parameters did not exceed the WHO guidelines for drinking water and also has not contributed to groundwater pollution in the dry zone. Based on exceptionally high values of F observed scattered in groundwater in the dry zone, proposals may have been put forwarded by scientists as it is the possible causal factor for Chronic Kidney Disease with unknown aetiology (CKDu) in the dry zone communities.

Groundwater quality related community issues

There are large number of groundwater quality related community issues, including excessive salt uptake by plants, excessive salt intake by human through drinking water, enhanced eutrophication leading to water pollution, potential for blue baby syndrome in infants and gastric cancer in adults, dental and skeletal fluorosis and kidney diseases exists in the dry zone settlements.

Contamination of groundwater by sediment, organic debris and faecal matter

As the soil column serves as a filter, compared to surface water bodies, contamination of groundwater by sediment, organic debris and faecal matter has not been reported as a community issue in the dry zone. In contrast, all surface water bodies in the form of village tanks and major reservoirs are fed by rain water captured by immediate tank catchments or drainage water diverted from central highlands in the country. Water drained off from immediate tank catchments has a potential for getting contaminated by sediment detached and transported from upland farming systems, organic debris from shrub jungles and faecal matter from village settlements, domestic animal herds and wild animals. Ancient tank villages had several man-made structures to mitigate contamination of tank water by sediment and organic debris. A meadow was developed to filters the sediment flow coming from upstream shifting chena lands (slash and burn cultivation) and an upstream soil ridge was constructed either side of the tank bund to prevent eroded soil or sediment entering from the upper land slopes. A water hole was constructed to trap sediment and providing water to wild animals and a small tank was constructed above relatively large reservoirs only to trap sediment and not for irrigation (Dharmasena, 2004). Further, it provides water to wild animals. In the recent past, such valuable structures have been subject to disappearance from existing tank villages and in the construction of new tanks and reservoirs such structures or suitable alternatives have not been accommodated in most cases. Further, since recent past, it has been a common practice that the washing of the body of farm implements, land vehicles and even vehicles being used for public transport taking them into tanks and reservoirs. Water diverted from central highlands may contain soil eroded from agricultural lands and disposed from urban earth excavations, industrial disposals and urban wastes. All above recent developments collectively discourage the use of surface water for drinking purpose in dry zone settlements and pushing people to extract groundwater for drinking purpose. As a result, new developments in water quality related issues have been appeared in the dry zone particularly during past 4 decades.

Soluble salts in groundwater

At present, groundwater in the dry zone is widely used for irrigation and drinking purpose. Hence, soluble salts in groundwater can have adverse effects on crop productivity due to excessive salt uptake by plants and human health due to excessive salt intake through drinking water.

Excessive salt uptake by plants

As a result of geological and ecological contribution, groundwater in dry zone contains considerable quantities of soluble salts (Kendaragama, 1994; Kendaragama, 1997 and Kendaragama, *et al*., 1998) leading to excessive salt uptake by plants. In contrast, a research conducted (Kumari *et al*., 2016) during April to June 2015 showed that water diverted from wet zone has low salinity water (Table 1). Irrigation water has been classified based on EC as shown in Table 2. Ancient people in dry zone communities practiced rain-fed upland farming and irrigated rice farming using water in village tanks. A study conducted (Kendaragama *et al*., 1998) during October to December 1997 using representative different water sources in six villages (Paindikulama, marikaragama, Mawathawewa, Walagambahuwa, Mahakanumulla and Sivalagala) in the Mahakanumulla cascade in the inland dry zone showed that rain water, village tank water and reservoir water contained low salinity water compared to groundwater (Table 3). Further studies related to groundwater salinity in inland areas in the dry zone (Kendaragama, 2000) using 17 agro-wells in Paindikulama and Ihala Puliyankulama areas in the Anuradapura district during March to June 1997 showed that mean EC was 1.49 dS/m indicating presence of more salts in groundwater. Among the major cations, Na, Ca and Mg contributed more for water salinity. This study also revealed that 69.9, 21.6, 4.5 and 4.5 % wells contained low, medium, high and very high sodium concentration in water, respectively. The situation may be different in the coastal area and more sodium rich groundwater may be expected due to sea water intrusion but information is scare regarding groundwater quality and related community issues in the coastal dry zone.

With the introduction of agro-well farming in 1980s, salt rich groundwater came into irrigation. Therefore, water quality related issues were appeared particularly in agro-well farming sector. Agro-well farming sector has given significant economic enhancement to people and therefore, it is not possible to discourage the sector. As a result, guidelines were formulated by mandatory authorities in order to mitigate problems appeared while practicing agro-well farming. The guidelines include subject areas such as selection of a suitable location for establishment of an agro-well, optimum well densities for cascade system, permissible limits for groundwater extraction and application of water for irrigation purpose.

Table 1. Total dissolved solids in water diverted from central highlands

Water source	EC (dS/m)
Ulhitiya reservoir	0.26
Rathkinda Reservoir	0.24
Mahaweli Ganga at Mahiyanganaya	0.11
Minipe Ela at Hasalaka	0.12

Source: Adapted from Kumari *et al.* (2016)

Table 2. Classification of water for irrigation purpose based on EC

Electrical Conductivity (dS/m)	Class
< 0.25	Low salinity
0.25 – 0.75	Medium salinity
0.75 – 2.25	High salinity
2.25 <	Very high salinity

Source: USDA (1954)

Excessive salt intake by human through drinking water

People in ancient hamlets in the dry zone mostly depended on tank water for drinking but with the expansion of hamlets to ribbon type of settlements on village road sides, they went to dug-wells having salt rich water. This was possibly a turning point for excessive salt intake into human body in dry zone settlements. Research information is scare regarding health issues due to excessive salt intake by humans in the dry zone.

Table 3. EC in water sources in the Mahakanumula cascade in the dry zone

Water source	Electrical Conductivity (dS/m)
Rain	0.05
Village tank	0.28
Domestic well	1.11
Agro-well	1.6
Tube well	1.6

Source: adapted from Kendaragama *et al.* (1998)

Enhanced eutrophication in groundwater

Eutrophication may be defined as the enrichment of water by plant nutrients particularly nitrogen and phosphorus. In the dry zone in ancient time, eutrophication has not been a major issue in village tanks as the catchment areas have been occupied by natural forest with few land parcels allocated to chena farming. With the gradual increase of population pressure, most of such natural forest lands have been converted to sedentary type of farming and thereby commercial scale farming with crops such as hybrid maize, chilli and onion for which excessive levels of nitrogen and phosphorus have been added in the form of chemical fertilizers. A potential exists for a similar threat for groundwater in agro-wells due to excessive use of chemical fertilizer, nitrogen and phosphorus in particular and organic manure, animal dung and green manure in particular, in commercial crops under such dug wells. It can cause many issues as listed below.

- Disagreeable colour, unpleasant odour and unacceptable taste and the need of special treatments prior to using for drinking purpose.
- Making hindrance to community activities such as bathing, washing clothes and various uses for domestic animals.
- Production of algal toxins during their degradation.
- Difficulties in operation of micro irrigation systems.

Potential for blue baby syndrome in infants and gastric cancer in adults

The blue baby syndrome in infants and gastric cancer in adults have been major community issues by contamination of water with nitrates. Permissible level of 10 mg/L for NO_3-N has been recommended for potable water (SLSI, 2013). Excessive levels of nitrates have been reported from groundwater in many areas in the coastal dry zone of Sri Lanka such as Kalpitiya peninsula (Kuruppuarachchi, 1995) and Jaffna peninsula (Nagarajah *et al.,* 1988; Sutharsiny *et al*., 2014) but similar elevated levels of nitrates have not been reported from inland dry zone (Kendaragama, 1999 and Nandasena *et al.,* 2005). Low levels of NO3-N has been reported from a study conducted during October to December 1997 using representative different water sources in six villages (Paindikulama, marikaragama, Mawathawewa, Walagambahuwa, Mahakanumulla and Sivalagala) in the Mahakanumulla cascade in the inland dry zone (Table 4). However, blue baby syndrome in infants and gastric cancer in adults have not yet been reported as major community issues both in the coastal and inland dry zones of Sri Lanka.

Table 4. NO_3-N in EC in water sources in the Mahakanumulla cascade in the dry zone

Water source	**NO3- N (mg/L)**
Rain	0.05
Village tank	0.40
Domestic well	4.52
Agro-well	2.20
Tube well	1.44

Source: adapted from Samaraweera (1997)

Dental and skeletal fluorosis

Excessive levels of fluoride in drinking water causes dental and skeletal fluorosis. Groundwater in most areas of dry zone settlements usually contains small amounts of fluoride, but in some areas, groundwater contains high amount of fluoride mainly from geogenic sources. This significant spatial variation in fluoride in groundwater is mainly determined by factors such as the amount of rainfall, degree of land irrigation and composition of rock minerals. When rain and irrigation water percolates through soil, it leaches out fluoride to the groundwater. Further, groundwater continuously interacts with fluoride rich rock minerals within saturated zone and is contaminated with high fluoride. The above process has been accelerated by major irrigation schemes established in the past in the dry zone.

The Sri Lanka Standards for potable water (SLSI, 2013) recommends a maximum permissible level of 1.0 mg/L for F in drinking water for both dry and wet zones of Sri Lanka. Compared to groundwater in the wet zone, a possibility exists for having relatively higher levels of F in groundwater in the dry zone and therefore it is suggested to develop two separate recommendations for maximum permissible levels of F in drinking water in dry and wet zones of Sri Lanka.

Health related problems caused by toxic metallic elements

High concentrations of toxic metallic elements can be harmful in the short and long term. The toxic metallic elements are classed as extremely poisonous (cadmium, arsenic, chromium and mercury), moderately poisonous (lead, nickel and molybdenum) and low in toxicity (copper, manganese and zinc) (Brady, 2000). Different types of health problems are associated with the element present in water at excessive levels (Table 5). Therefore, drinking water standards for selected toxic metallic elements have been formulated for safety purpose (SLSI, 2013). The interest for accelerating research related to the status of toxic metallic elements in groundwater in the dry zone was created with the identification of chronic kidney disease with unknown aetiology (CKDu) in dry done communities. Concentration of toxic metallic elements in groundwater results from geologic, climatic and anthropogenic contributions. Adequate research data are not available for status of toxic metallic elements in groundwater and fractionation based on the contributory source. Presently available research findings, for example Bandara *et al.* (2010) and Dissanayake and Chandrajith (2009) provide information on specific elements or subject areas. Therefore, it is suggested to generate a comprehensive set of water quality data in order to understand the status of toxic metallic elements in groundwater, possible health problems and to identify steps to address them.

Table 5. Health related problems caused by toxic metallic elements

Category	**Element**	**Possible health problems**
Extremely poisonous	Cadmium	Decalcification of bones, protein and sugar in urine and kidney damage.
	Arsenic	Skin, bladder and lung cancer
	Chromium	Kidney problem, lung cancer and skin diseases
	Mercury	Affects kidney, nervous system and causes brain damages.
Moderately poisonous	Lead	Muscular paralysis, damage to nervous system, liver and kidney.
	Nickel	Nickel allergy
	Molybdenum	Not common in human
Low in toxicity	Copper	Cellular damage
	Manganese	Unpleasant taste
	Zinc	Unpleasant taste

Kidney diseases in the dry zone settlements

Kidney diseases have emerged as an important public health problem in some parts of Sri Lanka. Situations such as diabetes, hypertension, genetics, snake poisons contribute for this kidney disease burden. However, a significant portion of cases of kidney disease that occur in the North central and Uva Provinces in Sri Lanka are caused by a hitherto undetermined cause (Chronic Kidney Disease of Unknown aetiology – CKDu). Based on the available information, it is estimated that the affected area covers approximately 17,000 km^2 with a population of approximately 2.5 million, in which, more than 95 % live in rural areas (Noble *et al.*, 2014). It has resulted in the death of a considerable number of people in dry zone communities.

Possible causal factor of CKDu

At present, investigations are in progress in several directions and several hypotheses have been put forward. For example some of them are fluoride or fluoride conjointly with aluminium from cooking utensils (Illeperuma *et al*., 2009; Kulatunga and Illeperuma, 2013), cadmium (Bandara *et al.*, 2008), arsenic (Jayasumana *et al*., 2013) and iconicity (Dharma-wardana, *et al.*, 2014). Some of the published and unpublished hypotheses can be categorised as below.

1. Hardness and/or high content of fluorides in drinking water.
2. Use of cheap aluminium cookware which is easily solubilized by the fluoride in water.
3. Excessive use of agrochemicals containing nephrotoxic chemicals, such as compounds of heavy metals like cadmium and arsenic, and even plant nutrients like phosphate.
4. Consumption of food items such as lotus roots and smoking tobacco, which have high Cadmium (Cd) levels.
5. Algal and herbal toxins in the drinking water supply.
6. High ionic concentration in groundwater aquifers supplying the wells from which people draw their drinking water.
7. Nephrotoxic ingredients (e.g. *Sapsanda*) in widely used ayurvedic herbal medicines.
8. Excessive dehydration in the work environment of farmers.
9. Genetic predisposition of the affected population to kidney damage from normally harmless levels of nephrotoxins.
10. Groundwater ionicity.
11. Multi-factorial causes.

Causal situation of CKDu

A study (Jayasekara *et al.,* 2013) showed the occurrence of the CKDu is confined to certain geographic situations. A review study (Noble *et al.*, 2014) reported that the majority of the patients diagnosed with CKDu are farmers suggesting the possibility of water resources being the major contributor to development of the disease. Therefore, till the causal factor is found, it is possible to find the causal situation. Then the dry zone community can be made aware on the causal situation in order to get possible precautionary measures.

A research conducted (Kumari *et al.,* 2016) in CKDu recorded 8 villages (Bathalayaya, Aluththarama, Galporuyaya, Agalayaya, Belaganwewa, Teldeniyaya, Hebarawa and Divulpelessa) in the Girandurukotte area during April to June 2015 showed the superiority of surface water in village tanks and reservoirs over groundwater extracted from dug wells for drinking purpose with respect to concerned water quality parameters (Table 6). Compared to surface water, groundwater shows 2.4 fold high in F, Mg and total dissolved solids. Similarly, an increase has shown in Ca, Na, Cl, PO_4-P and NO_3-N in groundwater. Among the water quality parameters studied, only K showed relatively low concentrations in groundwater.

Ancient people in the dry zone hamlets also mainly depended on water collected from village tanks for drinking purpose. Similarly, CKDu has not been reported from areas such as Anuradapura metropolitan area where people receive good quality surface water through water purification schemes. Further, investigations conducted in the recent past showed that majority of CKDu patients have used water extracted from dug-wells for drinking purpose. All above factors collectively suggest shift back to surface water for drinking purpose as a tentative attempt till the causal factor is established.

Table 6. Selected quality parameters of surface and groundwater in CKDu recorded farming settlements in Girandurukotte area

Character	**Water quality in Girandurukotte area**		**(G/S)**
	Groundwater from domestic wells (G) (mg/L)	**Surface water from irrigation canals (S) (mg/L)**	
Total dissolved solids (TDS)	135	59	2.4
Sodium (Na^+)	24.5	11.5	2.1
Potassium (K^+)	1.5	2.6	0.58
Calcium (Ca^{++})	13.7	11.4	1.2
Magnesium (Mg^{++})	9.5	3.9	2.4
Chloride (Cl^-)	30.9	15.4	2.0
Fluoride (F^-)	0.81	0.34	2.4
Phosphate ($PO4^-$)	0.19	0.09	2.1
Nitrate ($NO3^-$)	0.28	0.23	1.2

Source: adapted from Kumari *et al.* (2016).

Groundwater quality testing and purification facility

Though the causal factor of CKDu is not known yet, it is strongly suspected that the causal factor is linked with drinking water. Hence, providing good quality water for drinking purpose can be considered as a tentative measure to mitigate the disease. Most of people in the dry zone communities use water for various uses such as drinking, other domestic and agricultural without proper understanding the quality characteristics of water. Hence, it is suggested to expand existing water quality testing and purification facility in the area. The expansion includes establishment of water quality testing laboratories and purification plants, providing the water quality testing service to private water source owners at an affordable cost and making community people aware on the importance of considering qualitative aspects of water in day to day activities.

Further, if water purification facility is not feasible in certain localities in the area, it is suggested to establish a system to supply good quality water brought from outside at a reasonable cost particularly for drinking purpose.

CONCLUSIONS

Different water sources show diverse qualities issues related to human uses and different community issues have emerged due to this diversity. Among the water sources, groundwater shows consistently high in ionic contents. The significant issues in the use of groundwater include excessive salt uptake by plants, excessive salt intake by human through drinking water, enhanced eutrophication caused by nitrate and phosphate, potential for blue baby syndrome in infants and gastric cancer in adults by nitrate, dental and skeletal fluorosis and some of kidney diseases. In this context, expansion of water testing and purification facility in the potentially vulnerable areas, supply of good quality water for adversely affected areas and making the community aware on qualitative aspects of water use are some of the steps to be taken to address the above community issues.

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Meeting water deficit through conjunctive use of surface and groundwater: A case study in Huruluwewa irrigation scheme in Sri Lanka

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ABSTRACT

Two types of Irrigation systems are in operation in Sri Lanka to make use of surface water for irrigation, namely Diversion Systems and Reservoirs. Irrigation reservoirs are primarily located in the dry zone where the rainfall is received seasonally during the North East (NE) monsoon period from October to February. There are nearly 13 major reservoirs and 75 medium reservoirs in Anuradhapura District, out of which five are augmented by Mahaweli Diversions. In order to cultivate the two main cropping seasons, Yala and Maha, these reservoirs are needed to be replenished at least twice a year to fulfill the water demand. Hurulu wewa is one of the major reservoirs in Anuradhapura district with a capacity of 68 MCM and 4,300 ha of irrigable area which is augmented through the Mahaweli trans-basin canal called Hurulu wewa Kandalama Feeder Canal (KHFC). KHFC was designed to convey the supplementary issues to Hurulu wewa, as the yield of its own catchment cannot cope up with the water demand. From this intake point up to Hurulu wewa, Yan oya acts as a feeder canal which consists of diversions to Sigiriya Mort, three minor reservoirs called Hiriwaduna, Habarana and Thalkote and large number of illicit tapping. Therefore it is very difficult to divert required quantity within a limited period of time to start the cultivation in Hurulu wewa scheme on agreed date, and in some occasions to complete the cultivations successfully. In the recent past it was observed that the impact of climate change has resulted long dry spells during later part of NE monsoon, particularly in 2014, which resulted in less storages for Yala season. Therefore conjunctive use of groundwater was introduced as the solution to sustain the cultivations. Irrigation Department was able to support the community for groundwater extractions during the subsequent dry spell, which is an unconventional gesture. This paper narrates the challenges faced by irrigation officials during 2014 Yala season and how conjunctive use of groundwater was successful in Hurulu wewa scheme ensuring the uninterrupted cultivation. As added benefits, farmers received increased income from OFC cultivation while being able to use the renovated and newly constructed agro-wells during subsequent seasons as an adaptation measure to water deficit.

INTRODUCTION

The Irrigation Department (ID) with over a century of experience as a pioneer organization responsible for development of new water resources schemes and for operation and maintenance of majority of irrigation and flood protection schemes in Sri Lanka. ID is the only department which carries out the planning, designing and construction of water resources related infrastructures without having the outside consultations. The Department is currently providing irrigation facilities to 288,000 ha of lands for cultivation under 340 irrigation schemes. In addition, ID is maintaining 21 drainage and flood schemes.

The Irrigation Department is operating and maintaining 73 major reservoirs and 160 medium reservoirs which are having total capacity of 3755 million cubic meters. Total canal length of the water conveying systems of ID is about 8000 km of which 2550 km is recorded as main canal length.

Paddy production of Sri Lanka in year 2014/15 *Maha* and 2015 *Yala* season is 4,818,000 t Out of that, 2,037,255 t (42 %) came from the schemes under ID. In addition to the paddy production, these irrigation systems contribute for other field crop productions and inland fishery industry. Main objective of the irrigation systems are to increase the income of farming community through properly managed irrigated agriculture. Major and medium reservoirs under ID contribute for the drinking water supply service too. ID reservoirs and conveying systems give Indirect effects and benefits to the environment such as fulfilling water requirements of flora and fauna surrounding the systems, maintain groundwater table and fulfilling water related domestic requirements of villages.

Traditionally, several Wet Zone river basins were classified as flood-prone, and Dry Zone river basins as drought-prone. However, an increasing incidence of floods in the Dry Zone is observed in the recent past.

Hurulu wewa irrigation scheme

Hurulu wewa was an ancient tank which is situated in Anuradhapura District. It was rehabilitated during 1949-1954 to irrigate 3489 ha of lands to cultivate paddy. Later this extend was increased to 3867 ha without any augmentation of water. With encroachments, the present command area is approximately 4300 ha.

The catchment area of the Hurulu wewa tank is 66.0 km^2 and anticipated yield from the natural catchment is 32.5 million cubic meter (MCM) during the North East monsoon and 3.4 MCM during the south west monsoon according to the 150 yield curves of the Irrigation Department. The capacity of the tank is 68 MCM and therefore the gross inadequacy of the tank yield to fill up the tank is evident according to normal design criteria. In order to meet the water shortage at Hurulu wewa, there is a proposal under North Central Province canal (NCP

Canal) to construct a parallel canal to the existing feeder canal to augment the capacity of Hurulu wewa in order to supply a bulk quantity of water during a shorter duration. Figure 1 shows the schematic diagram of Kandalama – Hurulu wewa feeder canal with bifurcations at Lenadora to Kala Wewa and Kandalama.

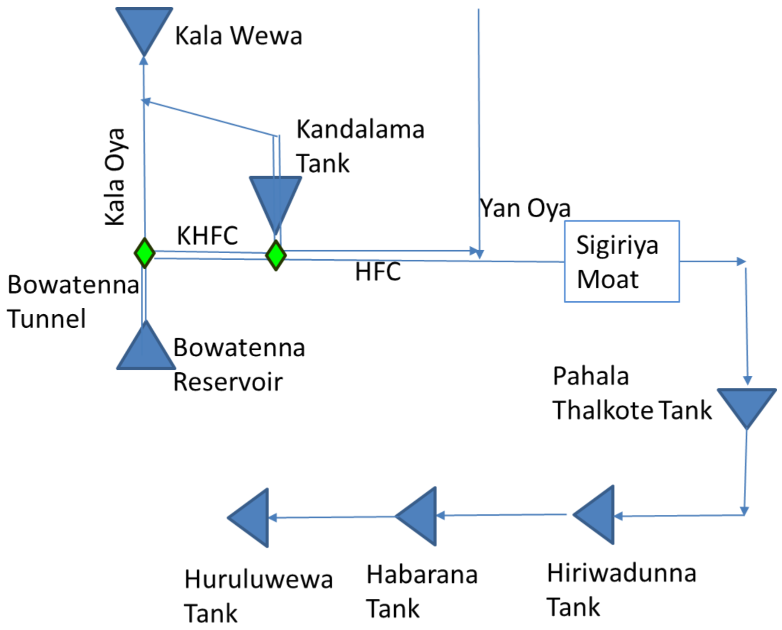

Figure 1. Schematic diagram of Kandalama – Hurulu wewa feeder canal

In order to meet the deficiency of water in Hurulu wewa, this tank was augmented with a feeder canal from Kala Wewa - Kandalama under the Mahaweli project in order to release water from Bowatenna reservoir. Hurulu wewa feeder canal was constructed by Mahaweli Authority of Sri Lanka and commissioned in 1976. The feeder canal takes off from Bowatenna reservoir with a designed discharge capacity of 28.3 cumecs (1000 cusecs). Then it bifurcates to two branches at Lenadora. One canal goes to Kalawewa (700 cusec) and other goes to Kandalama and Hurulu wewa (300 cusecs). Then water bifurcates to Kandalama (200 cusecs) and to Hurulu wewa (150 cusecs) at Kandalama bifurcation.

There are three minor tanks called Pahala Thalkote, Hiriwaduna and Habarana wewa across Yan Oya and there are considered as an integral component of the major irrigation conveyance system. It is also necessary to emphasize that feeder canal water has to go through this minor tanks before reaching Hurulu wewa. However no specific and formal guide lines and operational rules available regarding the water releases to Hurulu wewa from these tanks. Due to absence of enforcement of any regulations, each tank has to spill over to convey water to Hurulu wewa. Final tank called Habarana can divert only 80 cusecs through the sluice to Hurulu wewa feeder canal.

Legal and illicit tapping and water losses in the feeder canal

There are illicit cultivators along the feeder canal and these encroachers take water by pumping and siphoning. Illicit and legal farmers in and around Hurulu wewa feeder canal cultivate paddy during *Maha* and vegetables and OFC during *Yala*. Therefore most of the water released at Kandalama off take is lost due to illicit tapping and normal conveyance losses.

A study done by the International Water Management Institute (IWMI) has identified the canal efficiency as 56 % implying that when 150 cusec is released, only 60 cusec reach the Hurulu wewa. During *Yala*, 80 % of the water diverted at Kandalama is utilized by illicit farmers under the feeder canal. The conveyance losses due to canal seepage have been estimated as 44 % for 25 km long canal. (about 2% for each km).

Illicit cultivation in an around the feeder canal is very productive even though there is no government intervention. This has to be regularized and bring to the main stream of water management by Mahaweli Authority to stop wastage due to syphoning. Therefore even though it is illicit, by considering the contribution to the economy, it is not suggested to study the ways and means of stopping this cultivation.

This paper narrates the challenges faced by irrigation officials during 2014 Yala (a below normal season) and how conjunctive use of groundwater was successfully implemented in Hurulu wewa scheme to ensure uninterrupted cultivation.

METHODOLOGY

This analysis is based on the two factors; increasing the land, water and crop productivity and climate change adaptation measures in the water sector. These two areas has now become very important areas to address the growing challenges in water sector due to increasing water demand in the expanding communities and expanding service sectors.

Having understood the national and regional issues which depend on the natural resources management against upcoming disasters it was intended to discuss to maximize the resource utilization in a sustainable manner in water sector to increase the land, water and crop productivity.

Past performance of Hurulu wewa

Normally Hurulu wewa farmers cultivating paddy in *Maha* season and other field crops such as Maize, Soya Beans in *Yala* seasons. Figure 2 indicates Cropping intensity of Hurulu wewa scheme during past 20 years. It shows the annual performance of Hurulu wewa which was able to cultivate full extent only 5 years during the last twenty two years.

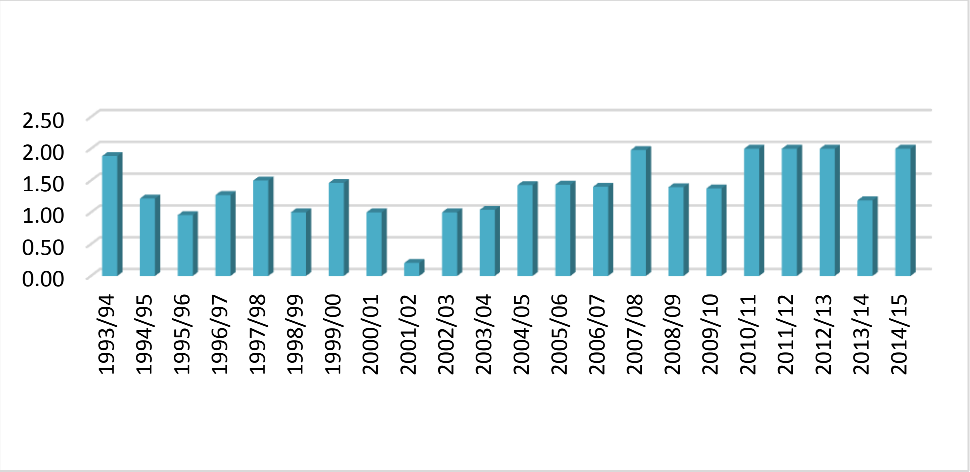

Figure 2. Annual Cropping Intensity of Huru Wewa from 1993 - 2015

(Source: Internal Documents of Irrigation Department, Water Management Branch, 2012-2015)

Issues related to climate change

In the recent years, particularly the Dry Zone of Sri Lanka, experienced a cycle of alternating droughts and floods. The drought of 2012 has been one of the worst in the past 20 years and substantially affected crop production (CBSL, 2012). Dry Zone farmers have traditionally coped with drought and water deficiencies by building storage reservoirs to cultivate the dry season and ensure sufficient groundwater recharge, farmer-managed arrangements to share land during droughts, and sharing water among different users. Village irrigation systems are perceived as one of the most appropriate adaptation strategy for climate variability and change in the Dry Zone (Abeysekera *et al.,* 2015).

Seasonal forecast for SW monsoon in Year 2014

Country's cropping calendar is decided depending on the monsoonal period since ancient times. Department of Meteorology given the outlook for South West Monsoon (May to September) which is preparing based on forecast from different empirical and dynamic climate models, probabilistic forecast from climate predictability tool and the various prevailing global climate conditions.

Based on the prevailing climate conditions and forecast from various statistical and dynamical models with the sea surface temperature as one tool suggested that the 2014 South West Monsoon (May to September) rainfall for Sri Lanka is likely to be below normal (Web site of South Asian Climate Outlook forum, 2014).

Interventions

With the adverse weather forecasted and the conditions prevailed, the challenges anticipated by the Ministry of Irrigation and Water Resources Management (M/IWRM) and Irrigation Department (ID) were as follows:

- Low storages in reservoirs
- Less rainfall and unexpected severe drought
- Need to pay attention for livelihood of farming community
- Need solutions for alternative crops
- Need solutions for alternative water sources

Joint discussions were carried out by M/IWRM and ID to find out area specific alternative solutions. Finally conclusion came up to use groundwater as an alternative for Hurulu wewa. Available statistics indicates that there are around 800 abandoned groundwater wells available within the irrigable area. Necessary arrangements such as machinery and financial support were given by M/IWRM and ID to clean, desilt and deepen the existing wells to meet the irrigation requirement for cultivating at least half an acre of OFCs by each farm family. Farmers requested to construct new wells for the areas which need additional wells to cultivate selected extent. Following table gives the details about intervention including cost.

Table 1: Detail of existing wells and new wells

Scheme	**New wells**		**Existing wells**		**Cost (Rs M)**
	Planned	**Actual**	**Planned**	**Actual**	
Hurulu wewa	30	30	800	930	5.745

Figure 3 shows the deepened existing wells and construction of new wells during *Yala* 2014 to cultivate big onions, Chillies, Maize, Green gram, Finger Millets, Soya Beans, Vegetables and Water Mellon (Figure 4). Total area cultivated during *Yala* season was 2600 ac (1182 ha).

Figure 3. An improved existing well and construction of a new well

Figure 4. Other field crops cultivation in *Yala* 2014

Benefits to the community

It was a great achievement to support the livelihood of farming community. Following observations were made by field officers and Irrigation Engineers who contributed to the success of this effort. The benefits derived were:

- High income through OFC cultivation
- Family labour sharing
- Income sharing with other sectors
- Use of these wells for future water shortages (these wells used to cultivate other field crops during Yala 2016 too)
- Increasing the land, water and crop productivity
- Climate change adaptation measures in the water sector

Draw backs of the activities

In Dry Zone, over-exploitation of groundwater has contributed to depletion of groundwater table and led to deterioration of groundwater quality. Leaching of salts from agriculture to the groundwater table is identified as a cause of water pollution. It is noted that most of the paddy farmers in the Dry Zone of Sri Lanka are heavily exposed to pesticides and fertilizers. Decreasing quality and availability of groundwater, unsafe agricultural practices have contributed to pollution of surface water bodies and groundwater. Unavailability of protection wall is the main problem of these types of groundwater wells.

CONCLUSION AND RECOMMENDATION

Use of groundwater as an alternative source during drought period is a very good solution for food security, to increase the croppy intensity and income generation for farming community. But as a non-renewable resource, sustainability is the main issue with current climate change impacts. Thus, urgent measures to augment groundwater recharge have to be initiated. Some of the measures which could aid groundwater recharging are increasing the vegetation on the land, soil and moisture conservation measures, proper land use practices and building appropriate structures such as check dams across streams during dry periods.

Therefore it is necessary to introduce monitoring mechanism for groundwater abstraction and also need to monitor the water quality throughout the year. Dissemination of these information and achievements among farmers through farmer awareness can minimise drawbacks. Continuous monitoring system and a proper maintenance system are needed to control detrition of groundwater quality. It is very important to encourage the farmers to construct protection walls to ensure the safety and prevent groundwater pollution.

ACKNOWLEDGEMENTS

Authors wish to express gratitude to Eng Ivan de Silva, former Secretary, Ministry of Irrigation and Water Resources Management; Eng Badra Kamaladase, former Director General of Irrigation; Eng Lalith de Alwis, former Director of Irrigation (Anuradhapura) and Eng Athula Weerawardena , Divisional Irrigation Engineer (Hurulu wewa) for their fullest support to implement this programme successfully during *Yala* 2014.

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Development of a reverse osmosis system with integrated pre-treatment to suit source water in the dry zone of Sri Lanka

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ABSTRACT

A field survey was conducted to gather data and to identify operational problems of reverse osmosis (RO) systems used in Anuradhapura District. Inadequate pretreatment to condition poor quality source water was identified as the primary cause of difficulties. A RO system with integrated pretreatment was developed to address this issue with emphasis on lowering initial and operating cost. Pump characteristic curves were derived for a diaphragm pump and a rotary vane pump by conducting trials. The vane pump generated higher pressure and flow rate (1,700 kPa and 5 lpm) compared to the diaphragm pump (800 kPa and 2 lpm). Performance characteristics of series, parallel and tapered arrays were evaluated using Filmtec TW30-1812-75 membranes. Inlet and outlet pressures, flow rates, and total dissolved solids of feed, permeate and retentate were measured. A tapered array of three membranes with a diaphragm was found to be the most suitable. A sand filter with backwash capability was constructed. An antiscalant injector was assembled to pump antiscalant solution at a rate of 4 mL/min. An online total dissolved solids monitoring unit was made by connecting a TDS meter to electrodes fixed in pipeline. A 1,600 lpd RO system was assembled using two diaphragm pumps each connected to three Filmtec TW30-1812-75 membranes in tapered 2-1 array. The pretreatment train included two sand filters, two 5 µm cartridge filters and an antiscalant injection unit. The developed membrane system reduces the initial cost by 60 % compared to available systems. The sand filter lowers the initial cost by 75 %. The antiscalant injection system is 90 % lower in initial cost, 80 % lower in operating cost, and minimizes the adverse environmental impact due to salt discharge compared to softeners. The RO system with integrated pretreatment developed in this study reduces the water production cost by 40 %. It also reduces the feed water volume by 40 %. The new integrated system is more compact compared to available systems.

INTRODUCTION

Sri Lanka is rich in water resources. It receives a considerable amount of rainfall due to northeast and southwest monsoons and inter monsoonal conventional rains. Rainfall is the main source of surface and groundwater. The water availability has divided Sri Lanka into two regions namely the wet zone where the water is abundant and the dry zone where there is a deficiency of water. Quality of the water in the two regions is significantly different. Drinking water quality of dry zone is poor compared to the wet zone. High fluoride content and high hardness of groundwater is recorded in some areas of the dry zone. People living in these areas face difficulty because of the poor quality of water.

A major health issue reported during last few decades is chronic kidney disease of unknown aetiology (CKDu) in several areas of Sri Lanka. North Central, parts of North Western and Uva provinces are the most affected areas where many patients are identified. In order to reduce the occurrence of this disease it is crucial to determine its causal factors. According to separate studies carried out by a number of scientists, CKDu is attributed to high levels of different constituents in drinking water. Among these constituents are fluoride, cadmium, arsenic, hardness, toxins released by blue green algae, chemical fertilizers and pesticides in agriculture. The use of aluminium utensils instead of clay pots for cooking is also mentioned as a cause.

In CKDu affected areas, majority use groundwater obtained from tube wells, and dug wells. These water sources are satisfactory for general purposes such as bathing, washing of clothes and utensils etc. However it may not be suitable for drinking and cooking purposes. Only few areas have surface water based pipe water supply.

According to the literature, providing safe drinking water is a good method for control of this disease. There were many projects carried out by government and NGOs to provide safe drinking water to affected areas. Conservation of natural springs, distribution of purified drinking water using bowsers and providing reverse osmosis (RO) systems are some projects conducted by National Water Supply and Drainage Board. In addition, some private venders sell drinking water purified using commercially available reverse osmosis systems.

Majority of commercially available RO systems are imported from USA, China and India. These systems are designed according to their source water quality parameters. Hence such filtering systems are not ideally suited for local source water quality in Sri Lanka, especially in North Central Province. As a result of this, private venders are faced with difficulties during long term operation of these RO systems. Some of the problems are membrane fouling within a short period of time; prefilters requiring frequent replacement, low filter output, etc. Other disadvantages are, difficulty in identifying correct membrane replacement stage in RO systems, need to install costly pretreatment systems.

The objective of this study was to design and develop a RO system with integrated prefiltation to provide long membrane life, low cost pre-filtration, low operation and maintaining cost, high efficiency, to suit for local water sources in North Central Province in Sri Lanka.

MATERIALS AND METHODS

A survey of available commercial reverse osmosis (RO) systems in Anuradhapura district was conducted as the first step of the study. The survey covered 25 RO water venders in Eppawala, Thalawa, Thambuththegama, Mahabulankulama, Ulukkulama, Dahaiyagama, Wijayapura, Parasangaswewa, Saliyapura, Nachchaduwa areas using a questionnaire. Gathered information during the survey were brand and model of the RO system, capacity, membrane model, number of membranes in the system, membranes life, number of membrane discarded per year, volume of water produced per month, water source and water quality parameter (TDS) in source water. The problems associated with RO systems were identified through discussions with vendors, observing the RO system and collecting survey data. After identifying the problems of the available RO system, a new RO system to overcome those issues was developed in the Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya.

Pump characteristics

In the RO technology an important part is the pump. According to the survey results, most of the RO systems (400GPD, 500GPD) have diaphragm pumps with 130 psi maximum pressure. During the development process two pumps, a vane pump (Procon, USA) and a diaphragm pump (E-Chen, China), were evaluated according to their performance to select the best pump that gives required performance to the system. The flow rate vs. pressure and power consumption of pumps were measured with both pumps using experimental setup shown in Figure 1.

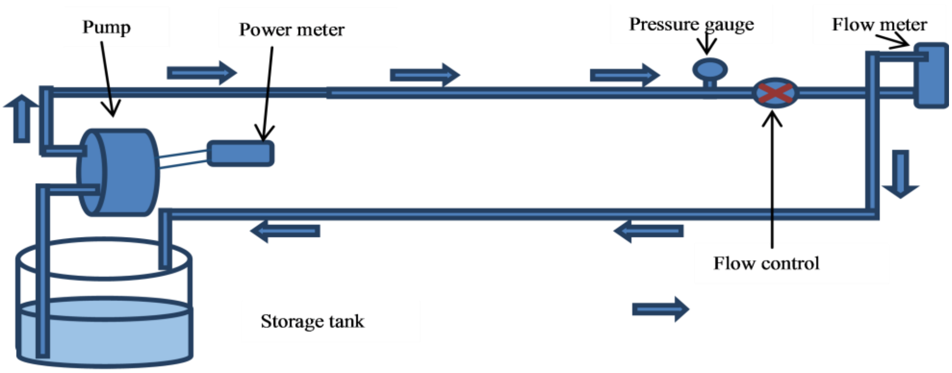

Figure 1 Experimental setup to evaluate pumps performance.

Figure 1. Experimental setup to evaluate the pump performance

The pump pressurizes water and the pressurized water goes through the flow meter via flow control valve. The pressure gauge indicates the line water pressure. The line water pressure and flow rate were changed using the valve. The flow rate was measured under different pressures and flow rate vs pressure curves were developed for both pumps. Also the power consumption of pumps at different pressures was measured using a power meter. Then power vs pressure curves were developed for both pumps.

Membrane characteristics

Membranes arrangement is another important factor that influences the RO system's performance. Most of the systems observed in the survey used parallel membrane arrangement. To find the performance of different membrane arrangements the experiment setup shown in Figure 2 was developed. This measured pressure of feed and retentate, flow rate of permeate and retentate. Samples were used to measure TDS of the feed, permeate and retentate. Trials were conducted with different membrane arrangements using both pumps.

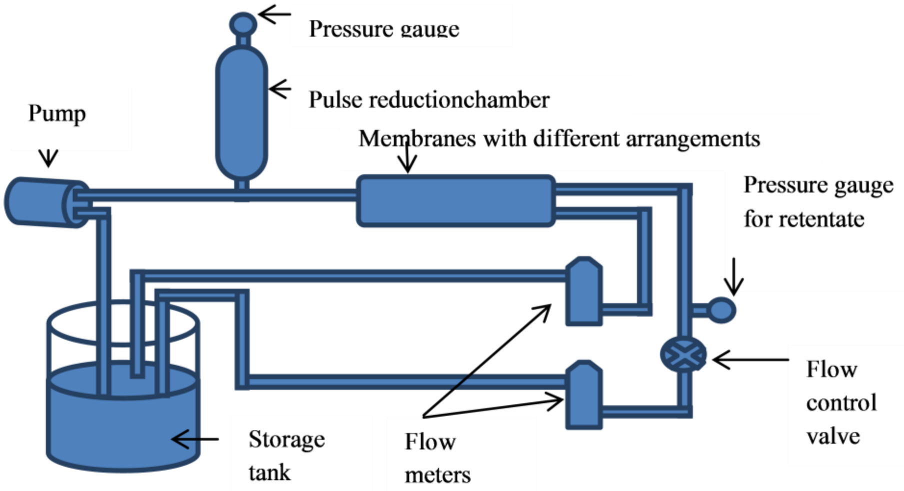

Figure 2. Experimental setup to evaluate the membrane performance

Sand filter

A low cost sand filter with backwashing capability was developed by modifying a transparent cartridge filter housing with 5" diameter and 20" length. A 20 cm high column of fine sand of 1 mm - 2.5 mm particle size was used as the filtration media as shown in Figure 3.

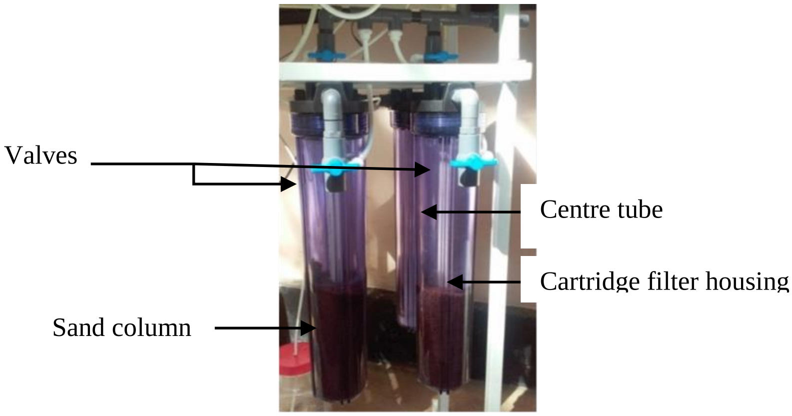

Figure 3. Sand filters

Antiscalant injector

An inkjet pump (24V/7W) was used to pump antiscalent solution to feed water. A timer was used to control the injection rate of antiscalant solution. Antiscalant solution with 1,250 ppm concentration was prepared by dissolving 5 ml of PA-100 (Pure Aqua, USA) antiscalant in 4 L of permeate. The feed water flow rate was about 3 L/min and the inkjet pump flow rate was about 300 mL/min. Operating the ink jet pump in a 2 seconds on – 58 seconds off cycle would result in 4 ppm antiscalant concentration in the feed.

Online Total Dissolved Solids (TDS) monitor

Online TDS meters were developed to measure the TDS value of permeate line and retentate line. Laboratory experiment was conducted to find out the distance between two probes that gives most accurate TDS readings. TDS-3 model type two TDS meters were used to measure the TDS value in permeate and retentate flows.

Figure 4. Calibration of online TDS monitor

Two probes in TDS meter was connected to the 1/2" PVC pipe using the two brass electrodes as shown in Figure 4. There were five holes in the PVC tube with distance of 1 cm to insert the electrodes. Three different concentrations of salt solutions were prepared. Its TDS was measured with another identical TDS meter. Then the solution was poured in to the pipe. After changing the two copper electrodes distance get indirect solution TDS reading. Then a graph of indirect TDS reading vs. the difference distance between two electrodes was plotted. Three graphs were plotted for the three different salt solutions. The distance that that gives the same TDS reading as the direct reading was determined from the graphs.

Reverse osmosis system

The 1,600 lpd reverse osmosis system was developed based on the results obtained from the experiments. The RO system consisted of two 20" sand filters connected in parallel, two 20" cartridge filters (5 micron) in series, six RO membranes (*DOW Filmtec^{TM} TW30-1812-75,USA*), two diaphragm pumps (*E-Chen, China*), and an antiscalant injector. The instrument panel included two flow meters, four pressure gauges and two online TDS meters. Flow diagram and the RO system are shown in Figures 5 and 6, respectively.

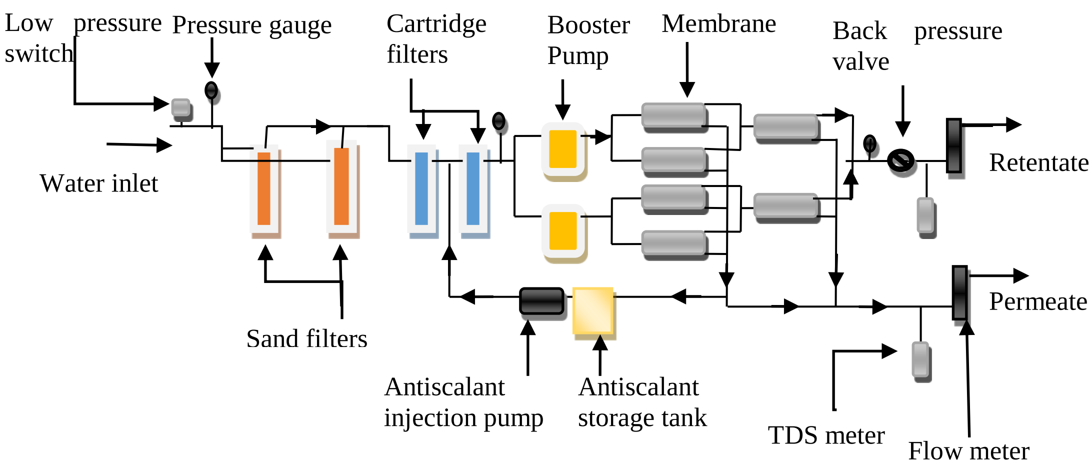

Figure 5. Flow diagram of the system

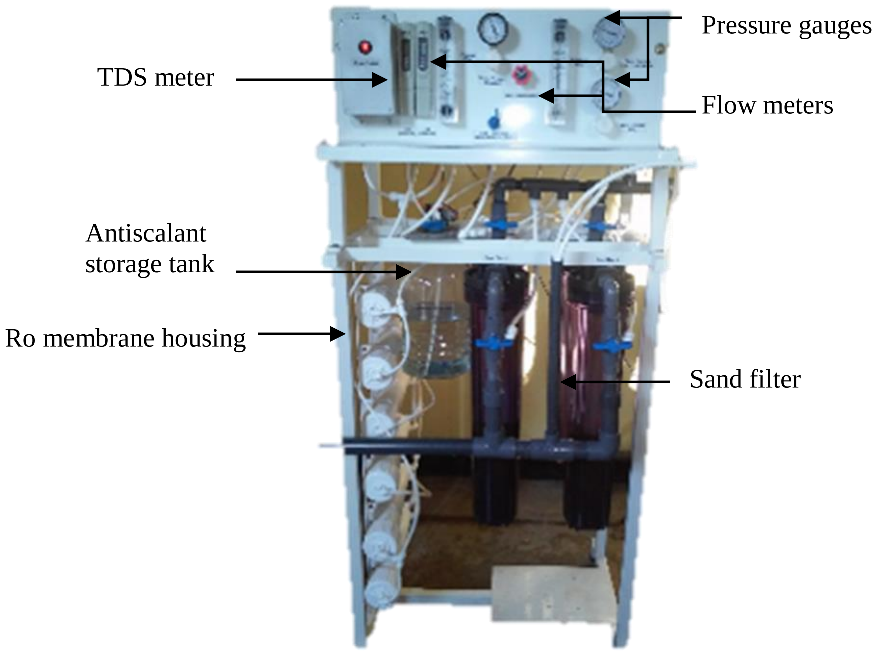

Figure 6. Reverse osmosis system

The frame was fabricated using steel box iron (1”×1”). Lower section was 36” height, 24” length, and 18” width. Upper section was 15” height, 24” length, and 18” width. Zinc coated 1.2 mm metal sheet was bend to L shape and attached to the upper section to mount the instrumentation. Zinc coated 1.2 mm thickness 24”×6” size metal sheets were bent to U shape and holes were drilled to attach sand filters and cartridge filter housings. Then the two U shape metal sheets were welded to the lower section of the frame. The six membranes were mounted on two 1” wide 30” high flat iron bars welded to the lower frame. Two pumps were mounted on a 9”×24” metal sheet on the frame. Antiscalant injector was placed in between the two metal sheets supporting the sand filters and cartridge filters. A five liter plastic bottle was used as the antiscalant storage.

Installation of reverse osmosis system

The fabricated RO system was installed in Mahailuppallama University Sub-campus for drinking and cooking purposes of about 250 users. System performance was recorded daily when operating the system. Flow rate of retentate and permeate, water pressure before prefiltration, after prefiltration, and TDS of permeate and retentate were recorded.

RESULTS AND DISCUSSION

Survey of reverse osmosis systems in Anuradhapura

The survey results indicated that several makes of RO systems imported from USA, China, and India were in use by RO water vendors. Some of these makes were, Purepro (USA), Kent (India), Aura (Taiwan), Triwin (Taiwan)

The sources of the water that used for the system were well water and tap water. It was observed that the TDS of the source water was normally above the 500 ppm, especially in well water. Some of the TDS values that measured during survey are given in Table 1.

Table 1 TDS Content of source water in several locations in Anuradhapura

Location	TDS (ppm)	Water source
Anuradhapura city	375	Tap water*
Mahabulankulama	767	Well water
Thambuththegama	245	Tap water**
Ulukkulama	1,230	Well water
Pahamunegama	881	Well water

*Turuwila water purification plant
**Thambuttagama water purification plant

High hardness of source water caused rapid fouling of RO membranes and required frequent replacement of membranes. Muddy water fouled prefilters and required frequent replacement. Both contributed to high operation cost. To overcome these weaknesses RO water vendors have begun to use sand filters and softeners as pretreatment.

Sand filters are used to trap the suspended solid particles which come with feed water. It can trap down to 25 micron size particles from feed water. There were different sizes of sand filters used by vendors. Those were 8”×44’’, 10”×55”, 12”×56” and most popular one was 8”×44”. The backwash of sand filters is practiced once per week. The cost of the commercially available sand filters was around Rs 30,000 to 38,000. RO water venders used at least one sand filter in the system.

Softeners were used to remove the agents that create hardness of the water. Size of the softener was 8”×44”. The cost of softener was around Rs 35,000. It uses 6 kg of salt for regeneration every 4 days. It creates lot of operating cost and the waste water coming from regenerating the softener will create lot of environment impact in the future.

Pump characteristics

Flow and power consumption of two pumps with respect to the pressure are shown in Figure 7 and Figure 8, respectively.

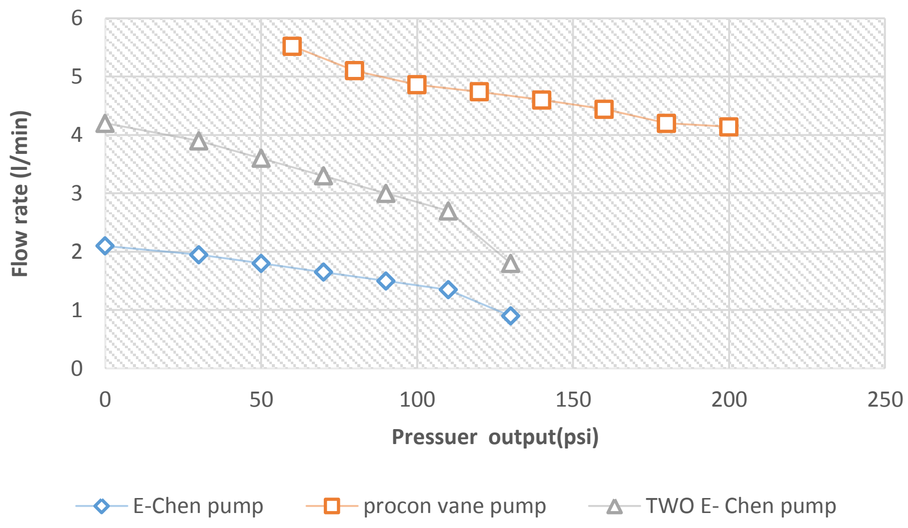

Figure 7. Relationship of flow vs. pressure

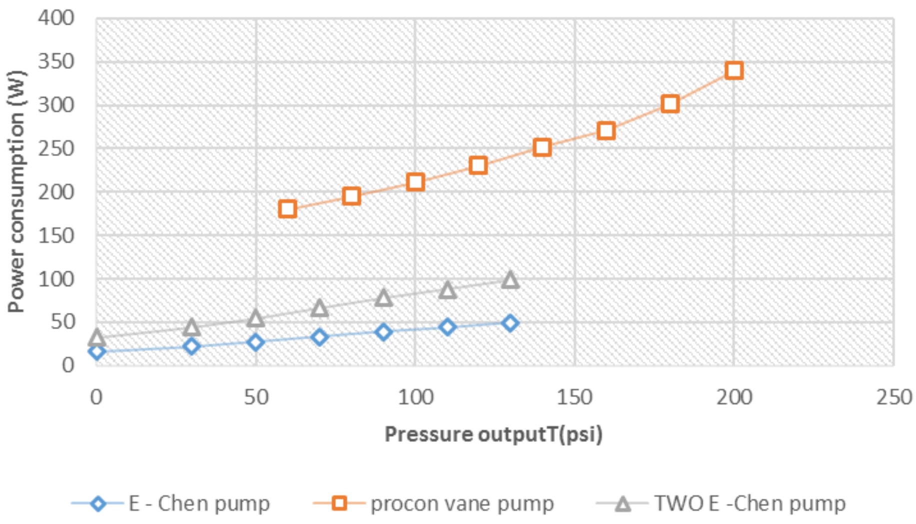

Figure 8. Relationship of power consumption vs. pressure

The maximum operational pressure of diaphragm pump was 120 psi but vane pump was 250 psi. Also low flow rate was observed with diaphragm pump than the vane pump. The power consumption of the diaphragm pump was also lower than that of the vane pump due to the low pressure of the diaphragm pump.

The required flow rate for the designed 1600 lpd RO system was 3 L/min assuming that, it was operated at 50 % recovery rate. Considering power consumption and availability of pumps, two diaphragm pumps were selected to run the RO system. The use of two diaphragm pumps saves considerable amount of electric power.

Membrane characteristics

Several membrane arrangements were tested with both pumps to identify the performance of the membrane arrangements. Parallel membrane arrangement had low pressure drop but recovery rate of water was very low. Series membrane arrangement had high recovery rate but high pressure drop thought the membranes. Tapered arrangement had considerably high recovery and low pressure drop through the membranes. Therefore, (2:1 array) tapered arrangement was selected as the membrane arrangement of the designed RO system.

Sand filter performance

A 20 cm height sand column was used in the sand filter. Sand used was 1 mm-2.5 mm particle size of find sand. To obtain the required flow rate of feed water to the system and to reduce the pressure drop, two sand filters were used in parallel arrangement. When operating the sand filters it shows 0.5 psi pressure drop during 17 psi inlet water pressure of the sand filter. At this pressure it maintains average 2.85 l/min water out flow. When operating the system, back wash of sand filter is necessary for about five minutes daily. The designed sand filter has lowered the initial cost by 75 % compared to the currently available sand filters.

Online TDS monitoring

According to Figure 9, indirect TDS value of the TDS meter decreased with the distance of two probes. Calculating the X value of the three graphs gives the average value as the distance of two probes. The value was found to be 1.12 cm. This is the distance of probes that gives actual TDS value of the solution through the online TDS meter. This setup was installed in the final RO system. Its gives online TDS reading of permeate and retentate in the designed RO system.

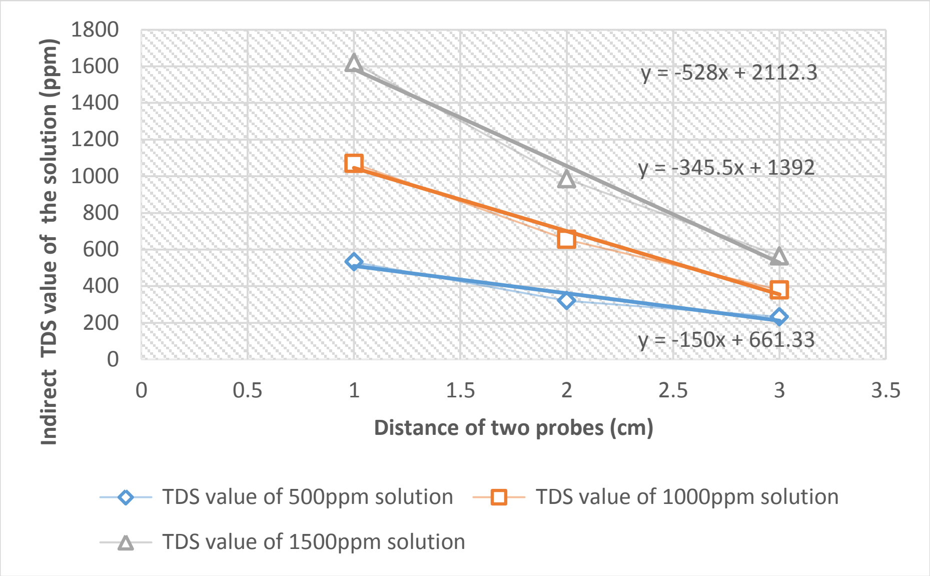

Figure 9. Indirect TDS value vs. distance of two probes

Cost analysis

Significant reduction of cost can be seen in designed RO system than the available systems. There is no need of external per filters to the designed RO system. Therefore, it reduced the cost for external sand filter and softener that need for most of the available RO systems in the market. Also antiscalant injection system totally replaced softener and it totally reduced the salt requirement also. Because of the high water recovery in the designed system, it reduced considerable amount of source water requirement to produced good quality water. Also high membrane lifetime in the designed system reduced the operational cost also. Some cost comparisons of the two systems is shown in the Table 2 and 3.

Table 2. Initial cost comparisons of developed and available RO systems.

Item	Cost (Rs.)	
	System developed in this work	Systems in the market
Two sand filters	9,000	35,000
Antiscalant injector	3,000	-
Softener	-	35,000
Cartridge filters	8,000	-
RO system	106,000	265,000
Total initial cost	126,000	335,000

Table 3. Operating cost comparisons of developed and available RO systems.

Item	**Cost (Rs.)**	
	System developed in this work	**Systems in the market**
Electricity (per day)	72	48
Feed water (per day)	80	90
Antiscalant (per day)	25	-
Regeneration salt (per day)	-	90
Operating cost (per day)	177	228
Water output (liters/day)	1,600	1,200
Unit operating cost (Rs/liter)	0.11	0.19

CONCLUSIONS

The project was conducted to develop a RO system with integrated pretreatment to suit source water in the dry zone of Sri Lanka. The developed RO system has many advantages compared to commercially available RO systems in the dry zone in Sri Lanka. The developed membrane system reduces the initial cost by 60 % compared to available systems. The sand filter lowers the initial cost by 75 %. The antiscalant injection system is 90 % lower in initial cost, 80 % lower in operating cost, and minimizes the adverse environmental impact due to salt discharge compared to softeners. The RO system with integrated pretreatment developed in this study reduces the water production cost by 40 %. It also reduces the feed water volume by 40 %. The new integrated system is more compact compared to available systems.

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Groundwater development through sprinkler irrigation: Consequences of a lack of a governance structure in Kalpitiya, Sri Lanka

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ABSTRACT

Groundwater provides nearly 100 % of the water supplies in some districts of Sri Lanka and is a major source of domestic water in all other districts. However, the resource remains largely neglected and invisible to society and policymakers. Groundwater offers the advantage of being a more reliable and readily available resource for agriculture, and offers the basis for a 'silent revolution' in many areas. A groundwater-supported agricultural boom has, while imparting a large number of benefits, created its own set of obstinate problems, including over-exploitation and depletion of groundwater resources. In some districts, over-exploitation is putting the livelihoods of farmers that have come to depend on groundwater resources in jeopardy.

Micro-irrigation technologies have been widely promoted as a means of reducing water demand by enhancing farm-level water-use efficiency. These technologies are proven to improve irrigation uniformity; increase irrigation application efficiency, by reducing soil evaporation and seepage losses; and increase crop productivity. It is assumed that using these technologies will enable water to be reallocated for other uses. The Government of Sri Lanka has made repeated attempts to promote micro-irrigation as a means of improving irrigation performance to minimize water scarcity in areas of the Dry Zone. These attempts have involved providing substantial heavy subsidies, but have met with little success in terms of adoption of 'professionally designed' installations. However, in Kalpitiya, farmers have adopted a locally designed sprinkler technology within a short period of time without subsidies and professional design inputs.

This paper reviews the evolving agricultural boom as a result of groundwater and sprinkler irrigation that has occurred on the Kalpitiya peninsula. The development of a farmer-led sprinkler technology is assessed with reference to improving livelihoods of the people, and the potential consequences on sustainable management of groundwater resources. The experiences in

Kalpitiya show that, in the absence of effective groundwater governance and policies, supported with appropriate institutions, micro-irrigation has enabled the expansion of the cultivated area and crop intensification. This has increased, rather than decreased, net water use on the peninsula. The estimated increase in water withdrawals is 14,490 m^3/ha /y. This indicates that promoting efficient technologies alone is not sufficient to achieve water savings, which requires control of overall abstractions and recharge levels to stabilize aquifer storage. In the absence of an appropriate regulatory framework and lack of political will to manage groundwater, it is recommended that the social framework and community governance arrangements are developed and strengthened to enable sustainable use of groundwater resources.

INTRODUCTION

Groundwater is expected to play an important role in efforts to address water scarcity in area in the Dry Zone of Sri Lanka. Exploitation of groundwater resources for development has been taking place very rapidly in some areas during the last few decades. As nearly 90 % of the country’s land mass is underlain by a shallow regolith aquifer in the hard rock region, the utilization and management of groundwater resources has to be undertaken cautiously. Extracting groundwater for the cultivation of high-value crops in the highland areas has become popular within a short time span. In some areas, the construction of agro-wells has exceeded the carrying capacity of the underlying aquifers (Panabokke, 2002). In recent years, the use of groundwater for agriculture in some locations has become the cornerstone of agricultural intensification, and an important factor in providing water supplies for local food baskets.

Groundwater is a cheap and easy-to-access source of water for irrigation for farmers, which is controlled by the users themselves. In contrast to surface irrigation, which is an extensively regulated public good, groundwater resources are under the control of the landowner. Groundwater offers the advantage of being a more reliable and readily available resource, which can increase drought resilience and ensure year-round income. The availability of groundwater allows farmers to grow more crops, minimize the damage caused by droughts, and achieve enhanced incomes from higher cropping intensities and the cultivation of high-value crops. Therefore, extraction of groundwater for cash crop cultivation has been increasing rapidly during the last two decades in the Dry Zone areas of Sri Lanka (IWMI, 2003; Athukorala and Wilson, 2012). Farmers do not pay for the use of water resources (only the costs of abstraction), and do not internalize external environmental costs associated with irrigation, such as diffuse water pollution and habitat degradation. Studies have shown that excessive groundwater extraction is likely to impact negatively on overall agricultural production with serious long-term effects (IWMI, 2003; Kikuchi *et al*., 2003). Further, over-exploitation and misuse of groundwater resources have adversely affected the quality of water in several places (Lawrence and

Kuruppuarachchi, 1986; Kuruppuarachchi and Fernando, 1990; Kuruppuarachchi, and Fernando, 1999; Mathara Arachchi *et al*., 2014; Melvani *et al*., 2006).

In the absence of the means for direct governance to regulate groundwater abstraction, such as command and control methods or market instruments, a common strategy is the adoption of demand management. In Sri Lanka, the government has attempted to indirectly regulate groundwater use through the promotion of micro-irrigation technologies. Various incentive mechanisms have been initiated to promote drip and sprinkler irrigation systems by the government, with support from donors and nongovernmental organizations (NGOs) since the late 1990s. However, these efforts and interventions have not led to much success. Despite the general and repeated failure of formal promotion of micro-irrigation across the country, this was not the case in the Kalpitiya Peninsula, where the sprinkler technology has been adopted and spread quickly in this groundwater-based agricultural economy during a short period of 10 years. It continues to expand and be adopted.

The major drivers of the technological shift (adoption of the sprinkler technology) in Kalpitiya are (i) significant reduction in the cost of irrigation due to low labour and fuel costs, and (ii) user-friendliness and affordability of the farmer-cantered technology, which is relatively simple to maintain with locally available spare parts. The irrigation technologies are supported by increased markets for high-value cash crops, expanded cultivation with available labour, and the use of cellular technology to obtain market information (Aheeyar *et al*., 2016). Absence of mechanisms to control groundwater abstraction has thus far allowed farmers to expand groundwater irrigation without any limitations.

The objective of this paper is to assess the consequences of the agricultural boom in Kalpitiya, which has occurred as a result of adoption of the groundwater-based sprinkler irrigation technology, on agrarian transition and sustainability of resource use in the context of a lack of measures to govern the use of groundwater resources.

Description of the study area

Kalpitiya is a low-lying, sandy peninsula situated in the Puttalam District in the Northwestern Province of Sri Lanka. It is located between 79° 40’ - 79° 50’ Eastern longitude and 8° 20’ - 8° 90’ Northern latitude. The total land area of the peninsula is about 160 km^2 with a population of 86,019 (Department of Census and Statistics, 2011). The entire peninsula is an economically hyperactive zone with a coal power plant, wind power, agriculture, fisheries, prawn farming, salterns, and religious and ecotourism activities.

The area is classified as being a part of the Dry Lowland (DL3) agro-ecological zone, which receives an average annual rainfall of about 900 mm. A thinner layer of freshwater occurs as a lens floating over the brackish water at 1-3 m depth. The sandy aquifer is recharged by both direct infiltration from rainfall during the northeast monsoon and return irrigation flows. As the soil is extremely permeable, there are no problems of drainage or waterlogging.

Due to low water-holding capacity, farmers tend to apply more water and/or irrigate more frequently. These water application practices unintentionally pollute the aquifer with irrigation return flows carrying agricultural chemicals such as fertilizer and pesticide residues to the groundwater. The level of nitrate in the groundwater below intensively cultivated areas of Kalpitiya (Lawrence and Kuruppuarachchi, 1986; Kuruppuarachchi and Fernando, 1990; Kuruppuarachchi, and Fernando, 1999; Mathara Arachchi *et al*., 2014), and in the vegetables grown in Kalpitiya Peninsula (Liyanage, *et al.*, 2000), has been recorded as being beyond the safe limits of the World Health Organization (WHO). The water in over 50 % of the wells constructed by the National Water Supply and Drainage Board (NWSDB) to supply potable water for the people in the Kalpitiya Peninsula were found to be contaminated and unsuitable for human consumption due to high levels of nitrate, nitrite, chloride and potassium (Melvani *et al.*, 2006). Continued over-extraction from this shallow coastal aquifer may be expected to result in saline water intrusion, particularly during the dry months.

Institutional context of groundwater development

Private sector involvement in the area, by providing the sprinkler technology, was quite distinct from the traditional approach of the marketing of expensive proprietary irrigation packages. A private micro irrigation distribution company was ready to market the different components of sprinkler products separately, enabling the farmers to select the required components. The company conducted a number of successful demonstration plots in farmers' fields; following up on arranging visits for farmers living in the neighbouring villages in the pilot areas for dissemination of the technology. Some entrepreneur farmers were innovative enough to develop simple sprinkler layouts within the existing layout of the main and sub-main lines previously used for drag hose irrigation. The cost of these farmer-designed systems is about 25 % less than sophisticated packaged systems available in the market, and they are also considered to be easier to operate and maintain.

In the absence of groundwater regulating authorities, and with the lack of an active government extension service and other supporting line agencies, farmers developed their own irrigated agricultural systems based on experience and personal networks for input supply, pest and disease management, and output marketing. Most of the farmers own, at least, a motorcycle, which they use to transport agricultural produce to markets near and far. There are no community-based organizations (CBOs) or formally organized Water Users' Associations as in surface irrigation schemes. With this lack of grassroots institutional arrangements and support services, farmers have demonstrated their capacity to be self-dependent, free decision makers, able to make rational decisions and be innovative for their individual development. However, with reference to sustainable management of the common property resource the system depends on, the groundwater, there is no system of accountability or joint management.

Impacts of the sprinkler technology on farming practices and livelihoods groundwater development and utilization

Farmers in Kalpitiya are completely dependent on groundwater, as there is no surface irrigation or rainfed cultivation. In 2010, there were over 1,500 farmers using more than 4,500 tube wells/agro-wells (Hydrosult Inc, 2010). Before the 1980s, shallow dug wells (agro-wells) were the main source of irrigation water. Each well cost approximately LKR 50,000-75,000 (USD 394-590[8]) per well. Groundwater use was effectively self-regulated as farmers used to irrigate manually with buckets, and changes in the water level were visible in the open dug wells. Manual irrigation required four to five person days to irrigate one acre (0.4 ha), which limited the extent cultivated by a farmer (from 0.1 ha to 1 ha). However, the introduction of energized water pumps in the mid-1980s triggered substantial shifts in cultivation patterns and crop intensification. Farmers in Kalpitiya adopted drag hose and water pump technology quickly, which reduced labour demand for irrigation by over 50 % (two person days per acre or five labour per ha). The labour saved enabled extensification (expanded area) of cultivation.

With the adoption of sprinkler irrigation, crop intensification and commercialization of cultivation further expanded in the area since 2000. The technology quickly reduced the labour requirement to 0.5 person days per acre (1.25 persons days per ha). Achievement of the farmer-cantered initiative was very promising as the labour-saving technology and reducing cost of cultivation. Almost all the farmers involved in cash crop cultivation have adopted the technology and have been motivated to expand the area cultivated over the years. To support the sprinkler irrigation systems, farmers needed two to three extra wells per hectare to irrigate the expanded land. The construction of additional wells was simplified with the introduction of the cost-effective and easy-to-construct tube well technology. The construction cost of a 10.5 m deep and 15 cm diameter tube well was only LKR 12,500-15,000 (USD 98-118), which is about 20 % of the cost of constructing an agro-well. Two or three tube wells located about 8 m apart are connected to a single centrifugal pump to irrigate one hectare area. These well arrangements are similar to the skimming of wells used in Pakistan to draw water from relatively shallow, freshwater lenses overlaying saline water at greater depths, thereby avoiding saltwater intrusion (Sufi *et al*., 1998; Saeed *et al*., 2002; Saeed and Ashraf, 2005). In Kalpitiya, the group of wells reduces drawdown and enables the pump to

[8] USD 1 = LKR 127 at 2012 prices.

maintain adequate water pressure to operate the sprinklers. Shah (2009) described the unregulated proliferation of wells, such as that seen in Kalpitiya, as ‘anarchy’. An unfortunate side-effect of the transition from agro-wells to tube wells is that the water table has become invisible to the users, eroding an important component of the earlier self-regulation.

Cropping system

Prior to the introduction of micro-irrigation, cultivation was generally limited to two seasons: *Maha* and *Yala*. The adoption of sprinkler irrigation enabled the majority of farmers to cultivate three or more crops each year, resulting in an increase in the net sown area, net irrigated area, cropping intensity and irrigation intensity**.**

Sprinkler technology has also enabled about 65 % of the farmers to change the types of crops that they cultivate, as high-value and short-duration crops were difficult to cultivate previously due to mechanical damage to the crop caused by drag hose irrigation. There are three distinguished cropping seasons in Kalpitiya (i) *Maha* season (first season - mid-September to mid-January), (ii) Mid-season (third season - mid-January to mid-April), and (iii) Yala season (second season - mid-April to mid-September). Figure 1 shows the percentage of farmers cultivating different crops, and Figure 2 shows the percentage of total land area under different crops, in the three seasons. Volatile prices for cash crops are a major risk faced by farmers; however, according to farmers, tobacco prices are relatively constant throughout the year. Farmers are practicing crop rotation to minimize soil degradation, and to manage pest and disease problems. Farmers with larger landholdings practice crop rotation by splitting the land, and smallholders rotate crops seasonally.

Cropping intensity

Sprinkler irrigation has facilitated farmers to cultivate year-round cultivation. Findings of the study show that cropping intensity in the area during the 2012/2013 cultivation year was 300 % or more for 80 % of the farmers. This includes 46 % of the farmers with 300 % cropping intensity, and 35 % with more than 300 % or continuous year-round cultivation of crops of differing life spans and a 10-15 day fallow period in between.

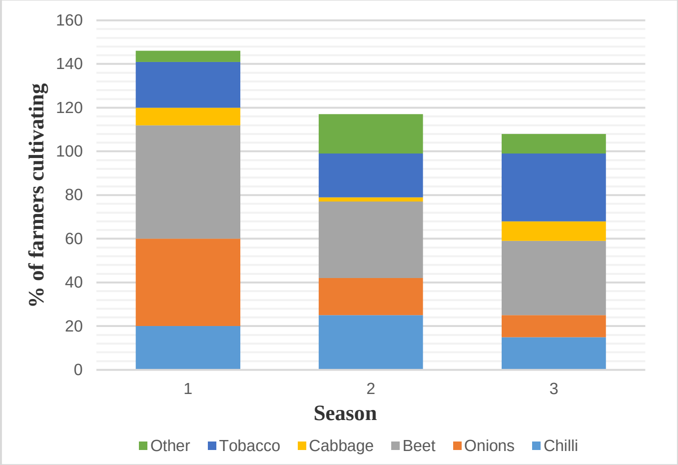

Figure 1: Percentage of farmers cultivating different crops during the three seasons

Source: Authors' survey data, 2013
Note: 1. Season 1- *Maha*, Season 2- *Yala*, and Season 3- Mid
2. Due to the cultivation of multiple crops, the percentage sums to more than 100.

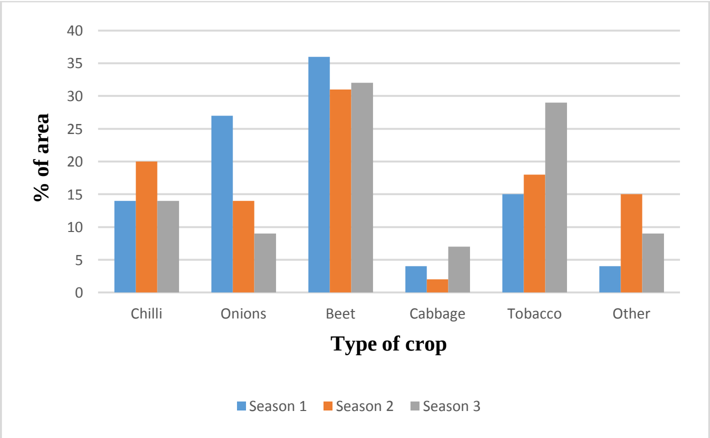

Figure 2: Percentage of land area under different crops during the three seasons

Source: Authors' survey data, 2013
Note: Season 1- *Maha*, Season 2- *Yala*, and Season 3- Mid

Extent of cultivation

In general, Padmajani *et al*., (2013), and Samarakoon and Shamil, (2010) found that, in Sri Lanka, cash crops are cultivated on smallholdings of less than 0.4 ha (1 acre), which is largely due to high capital requirement and the associated investment risks. However, in Kalpitiya, farmers are cultivating relatively large extents (up to 10 ha) of cash crops, which is an uncommon phenomenon compared to other parts of the country. Only 4 % of the farmers had cultivated less than 0.4 ha (1 acre), while about 32 % of the farmers had cultivated more than1 hectare (2.5 acres) of land (Figure 3). This indicates the dominance of relatively large landowners involved in commercial cultivation, with the land expansion that has taken place with the technology shift. Land expansion has occurred with the accumulation of wealth and the related agricultural development taking place in the area. These land plots are scattered, indicating that they have been purchased over time.

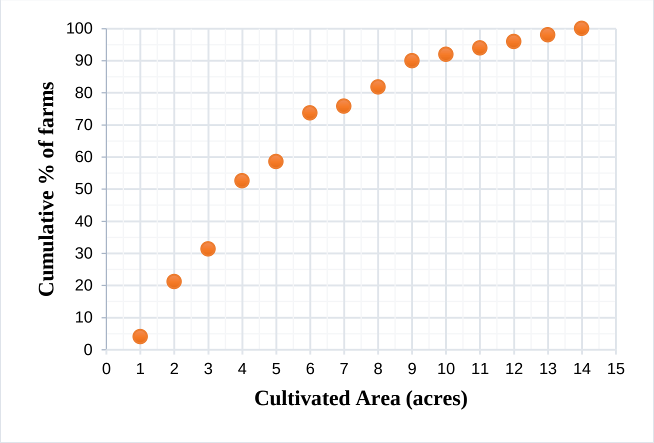

Figure 3: Percentage of farmers owning different sizes of landholdings.

Source: Authors' survey data, 2013

Increase in income and changes in livelihood

The assured availability of water for irrigation has changed cropping patterns, leading to better incomes and enhanced livelihoods. Crop intensification, land expansion and crop commercialization accomplished through the groundwater-based sprinkler irrigation technology has increased agricultural income substantially, providing a net income per season in the range of LKR 300,000 (USD 2,360) to LKR 1,000,000 (USD 7,875) from a 1 ha area of cultivation. Enhanced income levels have brought huge benefits in development and improvements for people in the area. The changes achieved have enabled farmers, including those that are not so educated, to adopt improved irrigation methods and to gain higher incomes. This has provided avenues for their children to achieve more educational opportunities, enabling them to exit agriculture and gain employment in the industrial and service sectors. Land values in the area have escalated, and all the shrubland and thorny jungles have been cleared for cultivation. Although the sprinkler technology reduced the labour required for irrigation, area expansion has increased the labour demand for other activities related to cultivation.

Changes in annual water demand

Farmers in Kalpitiya generally irrigate one to three times per day using sprinklers. The frequency of irrigation during a day varies between and within the seasons depending on the dryness and availability of groundwater, but appears to be irrespective of the type of crop cultivated (Table 1). Almost half of the farmers apply two irrigation rotations per day throughout the year. Two rotations include a 20 minute application in the morning and a 10 minute application in the evening to each plot. About 15-20 % of the farmers only irrigate once a day for 20 minutes in the both the *Maha* and Mid seasons, but the number of farmers in this category increases to 30 % during the *Yala* season, indicating water scarcity. Inadequacy of available water for irrigation has been reported by 40 % and 34 % of the farmers during the second (*Yala*) and third (Mid) seasons, respectively (Table 2). Total annual water demand has increased due to expansion in the cultivated area and crop intensification supported by the tube well sprinkler technology.

According to Melvani *et al*., (2006), the daily water requirement for drag hose irrigation is around 185 m^3/ha. Evaluation of sprinkler irrigation in the Kalpitiya area showed that approximately 177 m^3 of water is required to irrigate a 1 ha land area for 25 minutes. If we assume two seasons of cultivation per year under drag hose irrigation, the average total annual water withdrawals for 6 months is 33,300 m^3. However, farmers practicing sprinkler irrigation cultivate a minimum of three seasons per year. Thus, if we assume that the cultivation period is 9 months with 25 minutes of irrigation per day, the total annual water withdrawals under sprinkler irrigation is 47,790 m^3. This would be a net annual increase of 14,490 m^3/ha for cultivation during the three seasons. The estimated net increase would be higher to the farmers cultivating more than three seasons (continuous cultivation throughout the year).

A common measure adopted by farmers to overcome water scarcity is to increase the depth of wells and enable the extraction of more water. Typically, initial well depth was 25 feet (7.7 m), which is then increased to 30 feet (9.2 m). In 2012, the common depth for new wells was 35 feet (10.7 m). Silva (2015) predicted that groundwater recharge in Kalpitiya is likely to decrease by 20 % due to the possible effects of climate change, which would put further pressure on groundwater resources in the absence of adequate regulatory arrangements.

Table 1: Frequency of irrigation per day (percentage of farmers)

Season	**Once (%)**	**Twice (%)**	**Thrice (%)**
First season (*Maha*)	19	51	30
Second season (*Yala*)	16	55	29
Third season (Mid)	30	49	21

Source: Authors' survey data, 2013

Table 2: Adequacy of irrigation water (percentage of farmers)

Season	**Adequate to pump continuously (%)**	**Inadequate to pump continuously (%)**
First season (*Maha*)	82	18
Second season (*Yala*)	60	40
Third season (Mid)	66	34

Source: Authors' survey data, 2013

It is a common phenomenon that excessive pumping from coastal sand aquifers makes the groundwater resource vulnerable to seawater intrusion and upconing[9] of saline water. None of the farmers interviewed had any idea about the possibility of upconing due to groundwater over-extraction, although 5 % of the farmers reported problems of seasonal salinity. About 90 % of the farmers had not yet experienced the problems of seasonal salinity. The use of multiple wells (skimming wells) with one pump is a farmer innovation that is reducing the chances of upconing.

CONCLUDING REMARKS

Exploitation of the Kalpitiya aquifer by hundreds of individual users, each acting completely independently, has become the norm of the day. As in the rest of the country, there is no regulating authorities and governance arrangements for the use and management of groundwater resources. Although groundwater resources are a common property resource, in practice, it is currently developed and managed as a private resource. Unlike in surface irrigation systems, there are no beneficiary organizations to ensure sharing of benefits of the resource. Therefore, farmers are free to increase well depths and the number of wells per unit area, enabling the abstraction of more water for expansion of the cultivated areas and to increase cropping intensity. The cost of pumping is too low, relative to a potential increase in income and profit, to discipline individual users to regulate resource use. Introduction of the groundwater-based sprinkler irrigation technology has further reduced irrigation costs, promoting a further increase in groundwater use which may, ultimately, undermine the sustainability of this vital resource. Over-exploitation and misuse of groundwater resources have already adversely affected the quality of water in several places.

Groundwater users in Kalpitiya have provided endless opportunities and development changes to the farmers in the area. In the absence of any formal regulation from government agencies or self-regulation of abstraction, use of this common property resource for individual benefit is causing considerable damage to the groundwater asset base. Attempts to indirectly regulate

[9] 'Upconing' of saline water may occur when a pumping well is installed in a freshwater lens that is underlain by a layer containing saline water.

groundwater use through the introduction of micro-irrigation technologies have produced substantial benefits to individuals by increasing production and income. However, sustainability of these benefits is at risk as a result of the negative consequences of over-extraction and pollution of the resource, which are occurring due to the absence of effective governance arrangements to regulate use of the aquifers.

Farmers have experienced the benefits offered by micro-irrigation technologies, which led to increases in cropping intensity, cultivated land area and water abstraction without considering the sustainability of limited groundwater resources. This is a consequence of the lack of knowledge of the aquifer and the risks involved in over-exploiting groundwater resources. Therefore, creating awareness of this fragile groundwater resource, characteristic features and its sustainable management are urgently required. A concerted effort is required to help communities assess and monitor the status of groundwater regularly at the village level. Agencies must use relevant knowledge and scientific principles to help estimate the available water for each crop season. The most critical aspects of community-led groundwater governance are (i) local leadership, (ii) community mobilization, and (iii) political will to provide necessary facilitation. Components required to underpin good groundwater governance are: (i) proper management of data and information, and (ii) mechanisms for effective stakeholder participation. Although the transaction costs to mobilize individual farmers in sufficient number to accomplish community-led groundwater management is high, there are some success stories of small-scale institutional innovations being able to provide sustainable solutions to groundwater management in different parts of India (Reddy *et al*., 2012). We recommend that local and national government agencies act to facilitate community-led governance of groundwater use in Kalpitiya to avoid further deterioration of the aquifer and potential collapse of the agricultural system.

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A framework for groundwater policy for Sri Lanka

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ABSTRACT

Except in Jaffna peninsula groundwater has never been used on a large scale in the past. From late 1970's, various government and non-government agencies have been involved in groundwater development. In 1989 with a subsidy scheme, financial aid was given to farmers for construction of agro-wells leading to expansion of the use of groundwater for irrigation. In addition, groundwater has been exploited by industries in the recent past as well.

As at present intensive irrigation practices and the over use of agrochemicals has caused deterioration of groundwater quality in many parts of the country. Water quantity issues have arisen with uncontrolled digging of wells, over abstraction and construction of agro-wells without following the recommendations. There are numbers of existing regulations and recommendations to address the issues regarding the sustainable groundwater usage in Sri Lanka. Some recommendations are suggested and some are already applied. But those problems still remains unsolved primarily due to inconsistent and ad-hoc approach which does not address the problem in a coordinated manner. When consider other countries and the way they deal with issues of groundwater, implementing of a coherent policy can be a better option. Before developing a policy it is necessary to identify how other countries address each of their major groundwater issues through such policies. In this respect, groundwater policies of South Africa, Goa and Tamil Nadu in India, California, Scotland, New South Wales in Australia and China were reviewed in addition to the existing groundwater regulation in Sri Lanka. Based on the review, a framework for groundwater policy for Sri Lanka was drafted.

Groundwater use in Sri Lanka

In the past groundwater has been used on a large scale only in Jaffna peninsula. This is due to the absence of perennial rivers or major water supply schemes to the peninsula and short duration of seasonal rainfall. As the single water source, groundwater fulfils domestic, industrial and agricultural water requirements of the peninsula. In the rest of the country, groundwater from dug wells, usually situated in the back garden, were used for drinking purposes and household chores (Senarath, 1990). Before 1960, water was drawn from wells using traditional water-lifting devices. But at present small electric or lift pumps are used (Rajasooriyar *et al*., 2002, Mikunthan *et al*., 2013).

Farmers in dry zone mainly depend on seasonal rainfall and irrigation water from reservoirs for cultivation. With the rapid increase of rural farmer population and intensive agriculture practices, the available water resources could not meet the increased water demand from traditional sources (Wijesinghe and Kodithuwakku, 1990). Under these circumstances groundwater as a supplementary source of irrigation came into focus. Scientific surveys in locating groundwater had been practiced in late 1960's in Sri Lanka, though up to late 1970's, the rate of groundwater development was slow. After 1978 there had been a very high rate of development, and by the end of 1980's there were over 12,000 deep bore holes within the country (Senarath, 1990; Ranasinghe and Wijesekara, 1990). Since then, the diffusion of groundwater extraction wells has been very rapid in minor irrigation schemes situated in the north central and north western part of the dry zone.

With the introduction of large diameter (3-5 m), shallow (about 10 m) wells, called "agro-wells" along with a subsidy scheme by the Government in 1989, it gained popularity since farmers were able to select crops and time of cultivation with flexibility. According to an estimate, there were about 50,000 agro-wells in the dry zone by the end of 2000basin. A heavy concentration of agro-wells (about 80 %) is found in the northwest dry zone. About 65 % of agro-wells are located in minor irrigation schemes. *Malwathu Oya* basin and *Kala Oya* basin has the highest density of lined dug wells, while unlined dug wells are found in *Deduru Oya* basin (Kikuchi *et al*., 2003).

Small pumps operated by diesel or kerosene engines and electricity are used to abstract water from agro-wells. As a result, farmers have the full control over the irrigation. When using agro-wells they can irrigate on on-demand basis (Pathmarajah, 2003). Access to water irrespective of the season, maintenance of crops with supplementary irrigation during *Maha* season, ability to cultivate short duration crops just after *Maha,* maintain crops during *Yala season,* little or low maintenance and no additional infrastructure are the other advantages. An agro-well can irrigate about 0.2 to 0.8ha of land, with 20 % to 80 % increase of yield. The risk of crop failure due to water shortage is minimal. Therefore, an agro-well is like an insurance and life time investment for the farmer (Peiris, 1990).

Groundwater availability in Sri Lanka

The information on the availability of groundwater resource within the country, along with the groundwater use and issues are important in formulating a policy. In this respects, the following sections briefly describe the availability of groundwater and groundwater issues in Sri Lanka at present.

From the studies carried out by the Water Resources Board (WRB) and the National Water Supply and Drainage Board (NWS&DB), six main types of groundwater aquifers in Sri Lanka have been identified and mapped as shown in Figure 1 (Panabokke and Perera, 2005). The geomorphic perspectives of these aquifers are described in detail by Panabokke (2007).

These aquifers are,

1. Shallow Karstic Aquifer of Jaffna Peninsula
2. Deep Confined Aquifers
3. Coastal Sand Aquifers
4. Alluvial Aquifers
5. Shallow Regolith Aquifer of the Hard Rock Region
6. South Western Lateritic (Cabook) Aquifer

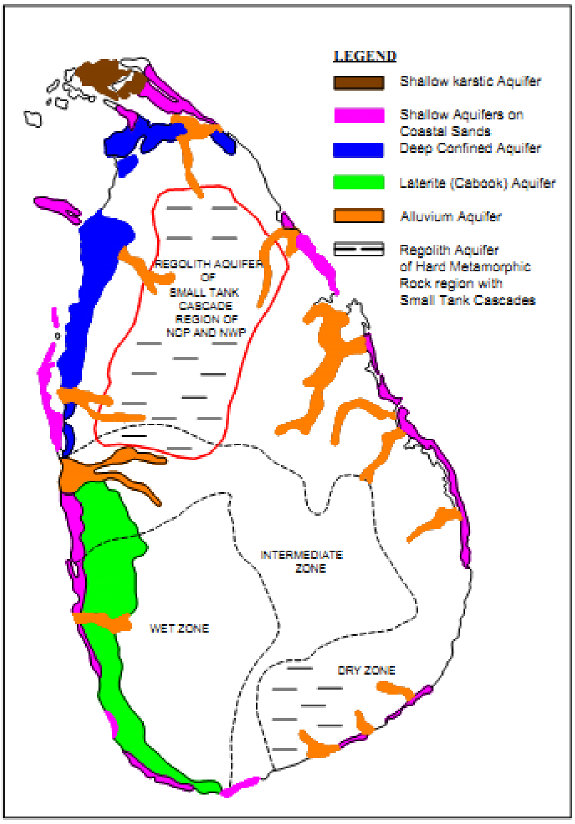

Figure 1: Different types of aquifers in Sri Lanka (Panabokke and Perera, 2005)

Shallow karstic aquifer of Jaffna Peninsula

This aquifer occurs in the channels and cavities (karsts) of the Miocene Limestone which underlain the peninsula. This is the most studied and the most intensively used aquifertype of Sri Lanka. The aquifer gets recharged through the infiltration of rainfall. Therefore, during the North East monsoon it gets fully recharged and with less rainfall water level drops rapidly. In other words aquifer boundary, expands and contracts through the wet and dry seasons respectively.

Deep confined aquifers

This aquifer is not yet adequately studied and the least utilized one. There are seven identified distinct aquifer basins within this deep confined aquifers region, located in northwest coastal plain. Deep confined aquifers occur within the sedimentary limestone and sandstone formations of this region. These are more than 60m deep aquifers with relatively high discharge rates.

Coastal sand aquifers

The shallow coastal sand aquifers expand along a total extent of approximately 125,000 ha of the coastal beaches and spits. Three main types of coastal sand aquifers have been recognized and characterized in Sri Lanka.

1. Shallow aquifers on coastal spits and bars
   e.g. Kalpitiya, Pooneryn and Mannar Island
2. Shallow aquifers on raised beaches
   e.g. Pulmuddai, Nilaveli, and Kalkudah
3. Moderately deep aquifers on old red and yellow sands of prior beach plains
   e.g. Katunayake, Chilaw.

It constitutes a limited groundwater supply but highly used in intensive agriculture and flourishing tourist industry. These aquifers are recharged and expands mainly during wet season and contracts during the dry season, and accordingly brackish and saline boundaries are fluctuating.

Alluvial aquifers

The alluvial aquifers occur on coastal and inland flood plains, inland river valley sand old buried river beds. These aquifers are fully used throughout the year and a reliable volume of groundwater can be extracted from them. Because they are deeper and have a wider alluvial fill they do not get significantly reduced even in extremes conditions.

Shallow regolith aquifer of the hard rock region

Although having a groundwater storage capacity, low yield and transmisivity, these aquifers provided the basic minimum water needs for village settlements over centuries. Agro-well farming in the north central provinces wholly depend on this shallow groundwater. Shallow regolith aquifer does not occur as a continuous body of groundwater with a single water table, but as separate pockets of groundwater. In the north central and north western provinces aquifer recharge is about 100mm during the *Maha* season. In the southern province the amount of recharge is not significant.

South western lateritic (cabook) aquifer

This is a laterite formation or cabook with a considerable water holding capacity depending on the depth of the cabook formation. Cabook aquifers can be found in south western Sri Lanka. These vesicular laterities support relatively shallow aquifers and easily accessible to dug wells and shallow ‘tube’ wells. This aquifer gets recharged very rapidly with the first rains.

Groundwater issues in Sri Lanka

Though, many researchers have documented the groundwater issues in Sri Lanka through their own studies, the proceeding of the national workshop on “Challenges in groundwater management in Sri Lanka” held on the 15th March 2011, is considered as one of the comprehensive compilation of the groundwater issues that the country is facing as at present (WRB, 2011). The following brief description is given in order to indicate that the issues are different with respect to types and locations of aquifers, hence require specific interventions in formulating a groundwater policy.

Issues on water quality

Water pollution has been identified as the major issue facing groundwater use and management in Sri Lanka (WRB, 2011). Agricultural practices are increasingly dependent on chemical fertilizers and pesticides for increased food production. The possibility of groundwater pollution is high with the overuse of chemicals and intensive irrigation practices. High concentrations of nitrates, chlorides, sulphate, heavy metals and hardness have been identified in groundwater resources of several regions.

According to a study carried out between August 1997 and February 1998, nitrate levels exceeded the WHO standard due to intensive agricultural practices and the improper construction of latrine soak away pits in the Jaffna peninsula (Rajasooriyar *et al*., 2002). Several studies have found out that 80 % of the wells in the peninsula are affected by high nitrate concentrations. In some cases Cd was exceeding the WHO limits for drinking water standards (Mikunthan *et al*., 2013). Chunnagam, Kopay and Kondavil areas (red bed areas) are also identified with high nitrate content, as well as high numbers of stomach cancer patients. The usage of excess amount of nitrogen fertilizer, insecticides, weedicides, and high population density and shallow groundwater table are identified as major reasons for this higher nitrate concentration. In these areas, the wells located very near to the lagoon are totally contaminated by salt water, due to the over extraction of groundwater which creates salt water intrusions (Hidayathulla and Karunaratna, 2013). Reason for the high chloride concentrations in Valigamam area is the excessive extraction of groundwater that results in saline water intrusion from the sea or lagoonal areas (Rajasooriyar *et al*., 2002).

Similar to Jaffna peninsula, Kalpitiya area also experiences similar issues due to sea water intrusion and agricultural activities. From a study conducted in eight selected districts of Sri Lanka, Puttalam (Kalpitiya area) was found as the area with most polluted groundwater by nitrate (39.8 ±88 mgl^{-1} as NO^{-3}). The mean nitrate levels of all the different categories of waters in the Kalpitiya peninsula were significantly higher than the nitrate content of waters of the North Western Province and the domestic wells in Jaffna (Liyanage *et al.*, 2000). Researchers have found out a clear correlation between groundwater quality and land use in Kalpitiya area. According to them NO_3 in groundwater within the intensively cultivated area was in the range of 10 -15 mg/l, while it is 0.2 mg/l within the non-cultivated areas. With excessive rainfall and irrigation, the nitrate applied to the soil is washed down to the groundwater table. Electrical Conductivity levels are also very high, exceeding the standards. As a result, groundwater in the area could not be recommended for domestic consumptions at least during the dry season (Liyanage *et al*., 2000; Mathara Arachchi *et al*., 2014).

Water quality issues are not limited to coastal areas, but are equally applicable to the interior part of the country. Area around Nuwara Eliya is well known for intensive agricultural activities where root crops and vegetables are cultivated up to four times per year. This is with high rates of fertilizers and without proper soil conservation practices. It was found that, in some occasion, the fertilizer and pesticide rates applied by the farmers are about 10 times higher than the rates recommended by the Department of Agriculture. Beet crop receives an over application rate of Muriate of Potash (MOP) which is about 16 times more than the recommended rate and carrot crop receives Triple Supper Phosphate (TSP) of about five times higher than the recommended rate (Henegama *et al.*, 2013).

Several studies have revealed that shallow groundwater has been contaminated with leached nutrients and heavy metals released from fertilizer and agro-chemicals. Values of NO^{3-} N concentrations in upcountry well water are found to be 2-3 times higher than the WHO standards of 10 mg/l (Rajakaruna *et al.*, 2005). According to Watawala *et al.* (2009) groundwater in Nuwar Eliya area has an extremely high risk of contamination by fungicides. In Welimada and Bandarawela areas a high risk of groundwater pollution by Mancozeb and a medium risk by Propineb have been identified. This is due to application of higher doses of pesticides than recommended, and not using recommended mechanisms to measure pesticide volumes during the preparation of pesticide mixes (Watawala *et al*.,n.d.). As in the Jaffna peninsula, groundwater is also contaminated by sewerage. A study conducted in Rothschild estate, Pussallawa reported that the average E.coli count is more than double in wells closer to line houses in the estate, compared to distantly located houses from the line houses (Rajapakshe *et al*., 2008). In general, there is evidence that groundwater is contaminated with agricultural pollution and leakage from sewerage pits in most part of the country. Intensive agriculture and construction of houses with water supply wells and toilet at close spacing due to population growth were the main reasons for the above observations.

Chronic Kidney Disease of Unknown aetiology (CKDu) has been a major issue in the hard rock areas of the dry zone. Water has been identified as a major cause though there is no conclusive evidence.

Issues on water quantity

Construction of wells without any supervision or regulation of responsible authorities' control has led to many groundwater management issues. Studies indicated that the number of wells had already exceeded the upper limit in certain areas. Within a period of 10 years from 1992 to 2002, the Agricultural Development Authority (ADA) has provided subsidies for construction of about 18,000 Agro-wells. Several Non-Governmental Organizations and individual farmers also engaged in agro-well constructions (Jayakody, 2006). Within Jaffna peninsula there are over 100,000 dug wells of which 17,860 are agricultural wells (Mikunthan *et al.*, 2013). Heavy extraction of fresh water had led to problems associated with lowering of the groundwater level, drying up of agro-wells and in worst cases farmers have abandoned a considerable number of agro-wells. There is no assessment of the hydro-geological properties, spacing between agro-wells, safe yield, recharge potential and a rational methodology for proper siting and spacing of agro-wells. A study conducted on 50 cascades within the Anuradhapura district showed that in five cascades the number of agro-wells had already exceeded the upper limit of the optimum number of agro-wells that could be safely accommodated (Panabokke, 2002).Even the conjunctive use of the groundwater as a secondary source has also reached the threshold level, as a result of unregulated exploitation (De Silva, 2002). Over extraction causes depletion of groundwater resources. Over exploitation creates problems such as drying of wells in midseason, low recovery rates, interference between wells and build-up of salinity.

In Jaffna Peninsula rainfall is the major source of groundwater recharge (no perennial rivers or any other external recharge sources). Groundwater is very limited in this area, due to short seasonal rainfall, high evapotranspiration loss during the dry season and high runoff losses during the wet season (Mikunthan *et al*., 2013). In 1997, a large part of the Jaffna Peninsula had negative water level elevations in both the wet and dry seasons. Excessive extraction of groundwater from wells, particularly from agricultural wells using high capacity electrical pumps for prolonged periods, has caused the reduction in groundwater elevations (Rajasooriyar *et al*., 2002).

Drilling of wells close to water bodies throughout the country is another issue which has been seriously neglected. Large industries, hotels and other similar institutions have excavated wells closer to streams, rivers and catchment areas of tanks. This will cause draw down of water level of these resources.

Other issues

In addition to most obvious water quality and quantity issues, there are many important issues that determine the sustainability of groundwater resources in the country such as, lack of legal and political commitment, poor integration between different sectors, non-availability of a proper institutional arrangement, lack of updated information on groundwater resources and use and unawareness of common people on the availability and use of groundwater. To make it effective, a comprehensive groundwater policy is needs to address all these issues.

Attempt to address the groundwater issues

The regulation enacted by the government to mandate the WRB as the institution responsible to develop, control and manage the groundwater resources in the country has been the major strategy. Proposed mechanism for implementation of Water Resources Board Act No 29 of 1964 and the amendment made in 1999 to the above Act for the replacement of section 12 provide the details (WRB, 2016). A workshop organized with the support of Food and Agricultural Organization by the Natural Resources Management Centre of the Department of Agriculture has come out with the recommendation to sustain the agro-wells (NRMC, 1997). There were also technical guidelines developed to determine the number of agro-wells to be constructed in a given area (Fernando, 1996). It is also reported that the WRB has recently develop regulations and is in the process of forwarding them to the cabinet for approval and follow up action. However, none of the above strategies have addressed the groundwater issues in a holistic manner. This demands a comprehensive groundwater policy for Sri Lanka.

Salient features of groundwater policies in other countries

As mentioned above there are numbers of regulations and recommendations to address the issues regarding the sustainable groundwater usage in Sri Lanka. Some recommendations are suggested and some are already applied. But the problems still remain unsolved primarily due to inconsistent and ad-hoc approach which does not address the problem in a coordinated manner. When consider other countries and the way they deal with issues of groundwater, implementing of a policy can be a better option. Before developing a policy, it is necessary to identify how other countries address each of their major groundwater issues through such policies.

Out of the policy documents studied, South Africa (Department of Water Affairs and Forestry, 2000) provides a very interesting legal background to anchor the groundwater policy of Sri Lanka. It says that "National Government, acting through the Minister, is the public trustee of the country's water resources. The Minister, through the Department, is responsible for implementing the National Water Act. Surface and groundwater quality management are both important parts of this responsibility". This is very much similar to the public trust doctrine on which the legal system of Sri Lanka is based (Gunawardena and Silva, 2014). Regulation governing registering and licensing groundwater development and abstraction are covered in almost all the policy documents referred. It is to be noted that some of these regulations are included in the WRB ACT NO 29 and amendments of 1999. Though, regulations governing groundwater quality management are included in all policy documents perused, the most detail account is given in the groundwater policy of California (ACWA, 2011).More emphasis on environmental and ecosystems management are included in the groundwater policy of New South Wales (Department of Land and Water Conservation, 1997) which states the importance of maintaining the intrinsic environmental value, particularly where groundwater dependent ecosystems support threatened species, populations and communities, or critical habitat. It also advocates conservation of special or representative areas.

Scotland (SEPA, 2009) provides directions on groundwater restoration which states that “groundwater bodies which are at poor status because of over-abstraction or pollution where it is technically feasible and would not entail disproportionate cost should be restored”. Countries/States with scares water resources, such as Australia, California and Tamil Nadu, have included regulations to promote conjunctive use of groundwater resources with surface water (ARMCANZ, 1996; ACWA, 2011).

Groundwater policy is not complete without addressing pricing and cost recovery of groundwater use. China advocates stricter water use quotas in combination with differential water pricing for high water consumption industries and the service industry (COWI, 2013). All the policies identify institutional arrangements for better coordination. One of the salient features of the South African policy is to “facilitate community participation through Catchment Management Agencies and Water User Associations”. This provision is very much applicable to Sri Lanka as well.

Research and development with awareness are also important in managing the groundwater resources for sustainability. South Africa identifies the need for research and development through the Institute of Water Quality Studies and the Water Research Commission while encouraging other organizations, also to play an important role in water-related research.

Australia promotes opportunities for increasing public awareness of the value of groundwater, its vulnerability to over-use and damage through other activities and the need for groundwater management. It also encourages the States to develop appropriate awareness programs. Groundwater officers are expected to conduct village level camps in a phased manner at *panchayat*-wise in Goa to educate the citizens on the importance and judicious use of groundwater.

Proposed groundwater policy

Given below is the frame work for a groundwater policy for Sri Lanka. Based on the past negative experience of taxing well users (included in the first draft of the Water Act) during the formulation of water policy, this proposed groundwater policy should exclude users of Domestic Purpose ("Domestic Purpose" in relation to a well means extraction of groundwater from such a well for the purpose of drinking, cooking, bathing, washing, livestock or sanitary, by using manual, mechanical, or electrical device not exceeding one horse power).

Policy goals

Sustainability" and "equity" are the two primary policy principles underlined in the Groundwater Policy

Legal basis

Follow "Public Trust Doctrine" which also complies with the historical and cultural background of Sri Lankan as well as the Roman Dutch Law practiced in Sri Lanka. Accordingly, the Government of Sri Lanka, as a trustee, shall have the responsibility to manage the groundwater, as a common resource, for its citizens. On behalf of the government, the Water Resources Board, is identified as the main institution mandated for the above purpose.

Policy principles

The main policy principles are discussed under the followings;

1. Groundwater Development
2. Registering and Licensing
3. Groundwater Abstraction
4. Water Quality Management
5. Pricing and Cost Recovery
6. Groundwater Restoration
7. Conjunctive Use
8. Institutional Arrangement
9. Integration with other Policies
10. Environmental/Social Values
11. Awareness
12. Research and Capacity Building

1. Groundwater Development

- The WRB (or a delegated authority by the WRB) shall have the power to develop, control, regulate and administer the groundwater resource.
- Employ the principles of ecologically sustainable development and should be directed at achieving sustainable use of the resource.
- Develop an agreed nationally consistent definition and approach to sustainable groundwater yield.

- Activities should be compatible with the long-term protection of water resources. This will ensure the protection of dependent ecosystems and the availability of good quality groundwater.
- A national classification system for water resources, including groundwater and determine a management class for each resource.
- Determine the "Reserve," which includes the basic human needs reserve (water for drinking, food preparation and personal hygiene) and the ecological reserve, which must be determined for all or part of any significant water resource such as rivers, streams, wetlands, lakes, estuaries, as well as groundwater.
- Set resource-quality objectives which represent the desired level of protection of a water resource.

2. *Registering and Licensing*

- Register all the existing wells and get permissions for new wells from an authorized agency.
- All the bore wells will be drilled through bore well agencies registered with the Water Resources Board.
- Local Authorities, delegated by the WRB, have the authority for issuing approvals, including licenses for groundwater extractions (in granting licenses or permits consider the impacts of those developments on the associated groundwater resource).
- Licensing of all high yielding wells (specified in the Act) will be undertaken by the WRB.
- Registering of wells of subsistent or small farmers (Subsistent or Small Farmer means a farmer who holds lands less than 1 ha) needs to be undertaken by the Agrarian Development Department in liaison with the WRB.

3. *Groundwater Abstraction*

- All the withdrawals of the groundwater from "high yielding wells "should be metered.
- The meters and withdrawals will be checked periodically.
- Monitor the groundwater levels, especially in highly sensitive areas identified by the WRB.
- Maintain a sustainable balance between abstraction, the water needs of dependent ecosystems and surface waters and the recharge of groundwater.
- Non-sustainable resource uses should be phased out and should not be permitted to continue.
- Encourage the efficient use of groundwater to improve preservation of the available resource.
- Prevent changes in flow direction of groundwater resulting from groundwater abstractions.

- Ensure that new abstractions do not compromise the resources available to existing abstractors.
- The agencies should develop strategies to reduce abstractions to sustainable levels within time frames that minimize permanent damage to the resource.
- All the transportation carriers, especially the tankers should be registered by the authorized officers (a permit will be issued).

4. *Water Quality Management*

- Policy principle of "Groundwater quality management is integral to optimizing groundwater resources. It must be science-based and include improved data management, basin assessments, monitoring, reporting, protection and, where appropriate, remediation.
- Water quality of groundwater should be assessed and monitored on a regular basis.
- Water should be checked by the owners, at regular intervals (preferably twice a year), with the help from laboratories registered with the WRB.
- All the parameters should be within the prescribed limits.
- The protection of groundwater from contamination is primarily governed by the National Environmental Act.
- Maintain the quality of groundwater such that there is, no harm to human health, including harm by pathogens, no harm to the quality of aquatic ecosystems or terrestrial ecosystems dependent on groundwater, no impairment or interference with amenities or other legitimate uses of the environment, no deterioration in status of the water environment and no significant damage to aquatic ecosystems.
- Encourage a progressive reduction of discharges of contaminated groundwater via base flow of groundwater into surface waters of priority substances and cessation or phasing out of discharges of priority hazardous substances into surface waters via the groundwater pathway.
- Standards to regulate the quality of waste discharges to water resources (end-of-pipe quality, already identified by the Central Environment Authority (CEA)).
- Requirements for on-site management practices (e.g. to minimize waste at source and to control diffuse pollution (already identified by the CEA)

5. *Pricing and Cost Recovery*

- The cost of direct management activities should be recovered from users.
- Explore means for meeting the indirect costs of groundwater management.

- Stricter water use quotas in combination with differential water pricing for high water consumption industries and the service industry.
- Management costs from domestic users and marginal farmers shall be borne by the State.

6. Groundwater Restoration

- Secure restoration of groundwater bodies which are at poor status because of over-abstraction or pollution.

7. Conjunctive Use

- Where appropriate, the management of surface and groundwater resources should be integrated.
- In canals or flow irrigation, conjunctive use of groundwater along with surface water resources should be adopted to prevent wastage and conserve water.

8. Institutional Arrangement

- Water Resources Board is the main institution responsible for implementing the Groundwater Act and manages the resource as per the stated policy.
- The WRB shall liaise with relevant institution in implementing the Groundwater Act
- The responsibilities of the WRB shall be delegated to the local and provincial government authorities.
- WRB, line ministries, local authorities should develop and implement organizational arrangements and processes which specifically eliminate conflict of interest situations in groundwater assessment and management.
- Mechanism should be developed to facilitate community participation, such as Water User Associations (WUAs), Community Based Organizations (CBOs) etc.

9. Integration with other Policies

- Groundwater management should be integrated with the wider environmental and resource management framework, and also with other policies dealing with human activities and land use, such as urban development, agriculture, industry, mining, energy, transport and tourism.

10. Environmental/Social Values

- Maintenance of intrinsic environmental value, particularly where groundwater dependent ecosystems support threatened species, populations and communities, or critical habitat.
- Conservation of special areas.
- Maintain unique social or recreational amenity. Where village/town water supplies are wholly or partially derived from groundwater, strategies may be required to ensure other land use activities do not adversely affect the quality of the groundwater.
- Environmentally degrading processes and practices should be replaced with more efficient and ecologically sustainable alternatives.
- Where possible, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.
- Groundwater management should be adaptive, to account for both increasing understanding of resource dynamics and changing community attitudes and needs.

11. Awareness

- Assess the opportunities for increasing public awareness of the value of groundwater, its vulnerability to over-use and damage through other activities and the need for groundwater management.
- Encourage the development of appropriate awareness programs through various organizations including schools and universities.

12. Research and Capacity Building

- The state should promote and sustain groundwater research by allocation of funds.
- The collaborative research among line ministries and universities should be encouraged and promoted.

CONCLUDING REMARKS

In the past, there have been many workshops and discussions on formulating a groundwater resources policy for Sri Lanka. However, no proper documentation and follow up action has been taken to date to consolidate the outcomes which would finally lead to formulate a policy document. In this respect, this paper provides a basis for formulating a groundwater policy, which is also shaped by the contributions and insights of those who are working in the water sector in Sri Lanka. Therefore, many would agree to some of these policy principles whilst some may have critical comments. It is anticipated to carry this activity of formulating a groundwater policy forward with a wider consultation in future to find gaps, narrow down disagreements and build consensus so that an acceptable groundwater policy could be forwarded to decision makers at the highest level.

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Groundwater policy for Sri Lanka: The way forward

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ABSTRACT

Groundwater is a vast area where related issues are inter-sectoral. Therefore, clear guidelines have to be stipulated for the coordinated and sustainable use of the resource by diverse stakeholders. Unfortunately, the expert panels formulated time to time to formulate a national water resources policy could not arrive at an outcome that is agreeable to all the interest groups. However, the idea of formulating a water policy; groundwater policy in particular, has been in the agendas of many forums. The aim of this paper is to summarize the outcome of the panel discussion held in the current symposium as a supplementary resource to already existing groundwater policy guidelines.

INTRODUCTION

One of the earliest attempts at developing a national water resources policy was the establishment of the Water Resources Board in 1964 (Act No. 29 of 1964). Despite its mandate, the Water Resources Board has not functioned as an overall policy formulator, instead it engaging in hydrogeological investigations and the groundwater development (Nanayakkara, 2009).

With the increasing demand for water in non-agricultural sectors, water management faced critical challenges, including a lack of policy clarity on resource development and allocation, and the presence of many overlapping institutions and laws in the sector. Policy reforms for water resource management in Sri Lanka have been attempted during the past decades with the involvement of external actors. The ADB-funded Comprehensive Water Resources Management (CWRM) project began in 1992. It proposed to development a single overarching policy and law to govern water resources and institute a single apex body to coordinate water-related activities. However, despite intensive efforts, the apex body was never established and the policy development process collapsed. This failure is largely attributable to a lack of understanding of the political system and the strong cultural values attached to water, suspicion of water privatisation and misrepresentations in the media depicting the policy as commodification of water resources. A lack of stakeholder consultation and poor communication of the policy also helped to undermine the process. Thus the process was completely suspended in 2004 (Ariyabandu, 2008). Since then many formal and informal attempts have been made to come out with a home-made national water resources policy. The latest was the draft National Policy on Protection and Conservation of Water Sources, their Catchments and Reservations in Sri Lanka by the Ministry of Land and Land Development in 2014.

The commonality in all these attempts was that the inadequate attention given to the management of groundwater resources. Therefore, concurrent attempts have been made to formulate a groundwater resource management policy since 1990s. The readers are referred to the policy guidelines proposed for groundwater use by Nagarajah and Gamage (1998). A draft framework for a National Water Resources Policy with Special Reference to Groundwater has been proposed by de Alwis (n.d.) as an outcome of a series of workshops organised by the National Academy of Sciences of Sri Lanka (NASSL) during 2008 to 2010. Other two relevant materials that provide substantial lessons and guidelines are Ariyabandu (2008) and Nanayakkara (2009). In addition, in this publication, Gunawardena and Pabasara (pp 128-145) present a framework for groundwater policy for Sri Lanka.

The aim of this paper is to summarize the outcome of the panel discussion held in the current symposium as a supplementary resource to already existing groundwater policy guidelines.

POLICY ISSUES

Need for a home-made policy

Groundwater policies adopted in developed countries cannot be copied as Sri Lanka does not have the necessary infrastructure to support similar policies. Also, the socio-political setup is highly sensitive to water related issues and will not accept radical changes even if those are beneficial. Unfortunately, in the absence of a policy, the users and mangers of groundwater take the liberty to exploit the resource in an unregulated manner.

Demarcation of ownership and responsibilities

Traditionally, water resources in Sri Lanka are treated as public goods and the state played the role of custodian. With the creation of Provincial Councils under the 13th amendment to constitution (Act No. 42 of 1987), the responsibility of managing the surface water bodies have been devolved to the provincial administration to certain extent. However, similar arrangement has not been made in managing groundwater. Unlike other mineral resources, there is ambiguity in the ownership when comes to groundwater. Land owners feel that they own the groundwater below their land and they can exploit it as much as they want. This notion is no longer acceptable with the increasing demand for groundwater (a common underground reservoir) that needs to be allocated equitably among different uses. Therefore, the government must device a mechanism to devolve the responsibilities and regulate the use of groundwater at state and regional levels. Also, the responsibilities of different institutions in using and managing groundwater have to be clearly demarcated.

Assessing groundwater resources and balancing the demand in a sustainable manner

No serious attempts have been made to assess the capacities of different aquifers and regulate the use of groundwater. It appears that no single institution is mandated to perform this task despite the authority vested on the Water Resources Board (WRB). Haphazard siting of agro-wells in the hard-rock areas is the classic example. No one is clear who or which institution should undertake this responsibility.

Demand for groundwater by various uses including the ecosystem needs must be estimated and entitlements in some form have to be stipulated to distribute this resource equitably among the uses.

Conjunctive use of groundwater

At present, Irrigation Department (ID), Mahaweli Authority of Sri Lanka (MASL) and Department of Agrarian Development (DoAD) are responsible for managing surface water resources of the country for irrigation. With recent phenomena of climate change that resulted in recurrent dry spells in the command areas, these agencies were successful in exploiting groundwater as a supplementary source of water for crops including paddy. In the process, they encountered difficulty as there is no guideline exists for them to regulate the use of groundwater. In Mannar for example, farmers in the command areas use deep groundwater heavily to irrigate their *Yala* rice crop in an unregulated manner. With climate change, dependency on groundwater is increasing in domestic and industrial sectors as well. Therefore, while promoting conjunctive use of surface and groundwater, it has to be regulated to ensure equitable benefit among the users.

Groundwater pollution

Majority of the fruits and vegetables consumed in the country come from groundwater irrigated areas in the dry zone. Therefore, the use of groundwater for agriculture is vital to sustain food supply particularly during the off seasons. Meantime, water pollution resulting from intensive agriculture has to be arrested.

There are increasing evidences that activities like agriculture and industries are polluting the groundwater and making it unsuitable for human consumption and other uses. Nitrate pollution resulting from agriculture in Kalpitiya and oil pollution resulting from an industrial activity in Jaffna are typical examples. Therefore, appropriate regulation to impose controlled disposal of effluents is essential. Violation of such regulations must be considered punishable. Like in the case of land and surface water bodies, the Central Environmental Authority (CEA) can monitor and regulate groundwater pollution by commercial users.

Department of Agriculture (DoA) is now promoting good agricultural practices (GAP) as a viable alternative to organic farming. Local supermarket chains are also looking for GAP certified food items as those items fetch higher prices. Further, countries importing agricultural products expect us to ensure the maximum residual limits (MRL) of agricultural chemicals including heavy metals. However, the dilemma is that the GAP standards require the use of good quality water for irrigation which is often not found in groundwater irrigated areas. This will be a serious issue for commercial farmers, particularly when the groundwater is suspected to contain heavy metals. With the current level of management of irrigation and chemical application, it is almost impossible to maintain MRL for export market.

The extension arm of the DoA must ensure that the farmers are using the right amount of fertilizer or at least not exceeding the maximum limits. The DoA must be empowered to take regulatory measurers at ground level.

Monitoring and early warning of water pollution and seawater intrusion

Lack of accurate and up-to-date information on spatial and temporal changes in quantity and quality of groundwater is a limitation for groundwater management, regulation and issuing early warning on water pollution and seawater intrusion. Unlike surface water, in groundwater studies, emphasis has been more on the quality than quantity. At present, there are about 4000 tube wells that are abstracting water from deep aquifers all over the country. But, only a general estimation of the availability of groundwater is available. Assessing or taking a stock of available groundwater quantity and metering the users (at least heavy users or exploiters) are essential before or in parallel to formulation of a groundwater policy.

Monitoring activities undertaken at present are ad hog and often project based. Apart from absence of regular monitoring, there is no mechanism to make the relevant information on climate, groundwater levels, groundwater quality, etc. available to relevant individuals and organizations. Therefore, an institutional arrangement is needed for monitoring and information sharing. Based on the information, early warning systems have to be established in vulnerable areas. This is particularly essential in coastal areas where groundwater dependent urban and economic centres are being established. Similar to agricultural areas, these centres not only use groundwater but also pollute the groundwater resources. Further, these areas face the risk of salt water intrusion resulting from sea level rise that is apparent due to climate change.

The spatial variability of groundwater availability is drastic. Further, the availability of water in the deep aquifer system in this country is also not adequately known. Therefore, availability has to be mapped with high resolution. WRB is capable of doing it as they have the equipment and trained personals. By metering and having a network among the explorers, drillers and user, WRB can have a very good data base which can always help the researchers, managers and policy makers.

With the emerging issues of frequent floods and droughts, it is essential to earmark and preserve wells for emergency use for drinking purposes.

Community participation

Shallow aquifers in the hard rock areas have limited quantity of water. Therefore, it is essential to have an institutional arrangement to monitor and regulate the use of this aquifer. For example, MASL, ID and DoAD can do this within their command areas. However, formulation of new Community Based Organizations (CBOs) or the use of existing CBOs is essential for areas that are falling outside the command areas like in Anuradhapura, Jaffna, Kalpittiya and other coastal areas. WRB can advise, monitor, regulate and coordinate all relevant activities starting from well siting. Monitoring the wells can be easily accomplished by involving the users in the process. It should be made mandatory for the users in the vulnerable areas to monitor and report the water quality of their own wells at least once in six months.

Performance based subsidies to promote efficient water management and good practices

Use of sprinkler and drip irrigation has to be promoted among groundwater users to increase the water use efficiency and to reduce water pollution while serving the energy on pumping. Use of solar energy (green energy) for pumping can also be promoted.

Subsidy schemes in the form of materials and/or money have proved to be ineffective in the past. Therefore, subsidies or incentives have to be performance based. Meantime, farmers have to be educated of good agricultural practices including efficient irrigation techniques. In the long run, it has to be made mandatory for the groundwater users in sensitive areas to use sprinkler or drip irrigation.

Promotion of artificial recharge

Shallow aquifers of the hard rock areas and the karstic aquifer of the Jaffna peninsula are being exploited in an unsustainable manner. Therefore, facilitation of artificial recharge through rehabilitation and maintenance of minor tanks and ponds and promotion of other rainwater water harvesting means while identifying and protecting the natural recharge areas is essential.

Institutional arrangement

Institutions that are widely involved in groundwater use and management are Water Resources Board (WRB), National Water Supply and Drainage Board (NWS&DB), Department of Agrarian Development (DoAD), Irrigation Department (ID), Department of Agriculture (DoA), Central Environment Authority (CEA) and Mahawali Authority of Sri Lanka (MASL).

Though, many institutions and individuals are using or promoting the use of groundwater for various activities, according to the act, Water Resources Board (WRB) is the custodian of the groundwater resources of the country and mandated to prepare the regulations. At present, WRB is not empowered to act as a coordinating body. Therefore, WRB has initiated the process of drafting a policy document in consultation with stakeholder agencies in 2012 and managed to prepare a draft which is now submitted for internal approval before it could be forwarded for the approval of the Cabinet.

Implementation of policies and guidelines

Even if a policy is formulated, enabling an institutional mechanism to implement the policies might take considerable time. Therefore, it is not wise to wait for the policy to be approved, acts are formed and guidelines are prescribed. Instead, like in the management of surface water resources, it is time that mechanisms are established to manage, regulate and monitor groundwater resource for its sustainable use. As prescribed in the act, WRB can act as the umbrella organization in coordinating the activities.

CONCLUSIONS AND RECOMMENDATIONS

- Groundwater is a common resource and needs to be shared equitably among all users. In line with this, each user must be made aware of his/her groundwater entitlement.
- Like in the case of surface water bodies, responsibility of managing the groundwater resources also have to be devolved to appropriate institutions through provincial and local authorities.
- Groundwater availability in different aquifer systems in the country has to be assessed and safe extraction limits have to be stipulated considering the recharge capacities and the existing number of wells.
- Present and future demand, including ecosystem demand for groundwater has to be assessed, managed and regulated to match the groundwater availability.
- Land right and groundwater right has to be detached to avoid land owners exploiting the resource beyond their entitlement.

- Guidelines have to be stipulated to facilitate the conjunctive use of surface water and groundwater.
- Good agricultural practices have to be promoted and rewarded to contain agricultural pollution. The Department of Agriculture (DoA) must be empowered to take regulatory measures.
- Use of groundwater for commercial purposes has to be monitored and regulated by the Water Resources Board (WRB) while the Central Environmental Authority (CEA) monitors and regulates the waste disposal by the commercial users.
- WRB together with the support of the well owners must devise a mechanism to regularly monitor the groundwater levels and water qualities all over the island and make this data/information readily available to other interest groups.
- Based on the monitoring, sensitive areas have to be identified and early warning on water level depletion, water quality deterioration, saline water intrusion, etc. have to be issued.
- Management of the use of groundwater in the command areas can come under the purview of Irrigation Department (ID), Mahaweli Authority of Sri Lanka (MASL) and Department of Agrarian Development (DoAD) while DoAD with the assistance of Community Based Organizations (CBOs) manages the use of groundwater in other areas. WRB has to be empowered to function as the advisory and regulatory body.
- A home-made policy considering the traditional values and cultural norms associated with groundwater will likely face the least resistant.

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APPENDIX I

List of panellists

The following eminent groundwater professionals five different institutions represented the panel:

Dr. Herath Manthrithilake (Chair)
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Eng. (Ms.) Janaki Meegastanna
Director, Water Management Unit, Irrigation Department

Prof. Atula Senaratne
Former Vice-chancellor, University of Peradeniya
Former Chairman, Water Recourses Board (WRB)

Mr. R.S. Wijesekera
General Manager, Water Resources Board

Mr. R.S. Wijesekera
Director/Extension and Training, Department of Agriculture (DoA)

APPENDIX II

List of participants

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