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Water quality and microbial contamination status of Madawachchiya, Padaviya and Kebithigollewa areas in Anuradhapura District, Sri Lanka

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Abstract

Typhoid or enteric fever is a worldwide infection caused by the bacterium *Salmonella enterica.* In Sri Lanka, 12,823 *Salmonella* positive cases were recorded and 133 cases were recorded from Anuradhapura district during 2005 to 2014. Therefore, the study was carried out to identify the microbiological and chemical contamination status of forty-four water sources in Anuradhapura area during October 2016. The study was focused to determine total coliform, faecal coliform, *Salmonella* spp. and *Shigella* spp. contamination along with some physico-chemical parameters of both ground and surface water. Sampling, transportation, and analysis were performed following standard protocols. Results of the study revealed that almost all sampling locations were contaminated with both total and *E. coli* bacteria and the values were not within the World Health Organization and Sri Lanka Standards drinking water quality standards. Around 32% of sampling locations were positive for *Salmonella* spp. and among them, 2 spring sampling locations are being highly used to extract water for drinking. However, *Shigella* spp. was not recorded during the study period. Majority of the sampling points were not within the Sri Lanka drinking water standards for COD and 25% sampling locations were recorded greater than 750 $\mu S \cdot cm^{-1}$ conductivity. Also, 55% of locations recorded very hard water where the highest values were recorded in Padaviya. The tested other water quality parameters: NO_2-N, NH_3-N, and total phosphate (TP) concentrations were found within the Sri Lanka drinking water standards. PCA analysis revealed that sampling locations were grouped into three groups such as; well water, tank water and springs.

Key words: *chronic disease of unknown etiology prevalence areas, ground and surface water, Salmonella spp., Shigella spp., water-borne diseasses, enteric diseases, water quality*

INTRODUCTION

Water is a major natural source and basic human need for life. In recent decades, groundwater has become an essential resource due to its purity and availability [VERMA *et al.* 2013]. The water requirement in Sri Lanka is gradually increasing, mainly to the development of industrial sector and demand for agriculture [IGES 2007]. In Sri Lanka, the dry and wet zones are the main climatic divisions and the majority of people depend on groundwater for their domestic consumption [JAYAWARDANA *et al.* 2010]. The physical and chemical parameters of water quality are closely related to the climatic changes and accordingly, quality of water varies with regions of the country. In Sri Lanka usually, groundwater is extracted from shallow dug wells for drinking. More than 60% of the rural drinking water supply depends on protected and unprotected groundwater sources by means of dug wells and tube wells. Dug wells are distributed all over the rural and semi-urban areas, mostly as private wells associated with single family homesteads [VILLHOLTH, RAJASOORIYAR 2010]. Further, Sri Lanka's surface waters can describe as both natural and anthropogenic. A large number of man-made surface water bodies which include irrigation tanks that are located in the dry zone in order to trap rainwater for irrigation purposes. Urban, suburban and rural area of Sri Lanka has practices to consume ground and surface water with or without treatment [MAHAGAMAGE, MANAGE 2016].

In Kebithigollewa area around 17% population use springs for drinking purposes where around 24% of the population in Padaviya area facilitated with pipe born water and rural water supply projects. Considering the sanitation facilities, around 5% population has no proper toilet facilities in Kebethigollewa area [Department of Census and Statistics… 2013]. Therefore, determination of faecal bacteria in drinking water is timely important.

World Health Organization (WHO) 1993 documented that 80% of pathogenic diseases in human beings are caused by contaminated water and the valuation of water quality in developing countries has become a critical problem in last few years [CABRAL 2010]. The water-borne and enteric diseases, including acute gastrointestinal disease, cholera, dysentery, hepatitis-A and typhoid was estimated to be about 66% during a year [ABRAHAM 2011]. Therefore, drinking water can be contaminated with these pathogenic bacteria and this is an issue of great concern [CABRAL 2010].

Salmonella and *Shigella* are the causative pathogens for Salmonellosis and Shigellosis. They are the most common and widely distributed waterborne diseases in worldwide. Further, it causes the acute onset of fever, diarrhea, abdominal pain, nausea and vomiting [CABRAL 2010]. Accordingly, WHO has estimated that tens of millions of human cases occur worldwide every year and these diseases result in more than hundred thousand deaths [WHO 2016]. Number of resent studies have shown that presence of *Salmonella* and *Shigella* in sewage effluents, irrigation water, freshwater and marine waters globally [CABRAL 2010; LIU *et al*. 2018; ODJADJARE, OLANIRAN 2015] and limited numbers of published research information on human pathogenic bacteria in both ground and surface water are available in Sri Lanka [MAHAGAMAGE *et al*. 2016; 2019; MANNAPPERUMA *et al.* 2013].

According to PALIHAWADANA [2015], 12,823 typhoid fever incidences were recorded from 2005 to 2014 in Sri Lanka and Anuradhapura district was ranked as the twentieth district which was recorded only 133 cases during that period. Though there fewer incidences were recorded, the determinations of microbiological quality in these areas are important because the study area has identified as high prevalence of chronic kidney disease of unknown etiology (CKDu). Therefore, the scope of this study was to investigate pathogenic microbes along with physico-chemical properties of ground and surface water in Padawiya, Kebithigollewa and Medawachchiya area in Sri Lanka.

MATERIALS AND METHODS

STUDY AREA

Majority of households in the Anuradhapura district use protected well water and around 4% of households get water from unprotected wells. Further, 24.5% of households are using pipe born water and the rest use other sources like rural water supply projects, tube wells, bottled water, tank and river water [Environmental and Social Development Division 2014]. According to Department of Census and Statistics [2013] around 93,000 individuals were recorded within the study area (Padaviya, Kebithigollewa and Medawachchiya). Tables 1, 2 and 3 describes the population, housing, drinking water sources and sanitary facilities of the study area.

Table 1. Population and housing information of the study area

Area	Population	Population density	Number of household
Padaviya	23 197	0.967	6 203
Kebithigollewa	22 519	0.366	5 991
Medawachchi	47 309	0.982	12 560

Source: Department of Census and Statistics [2013].

Table 2. Drinking water sources of the study area

Area	Drinking water (%)						
	protected well	unprotected well	piped born water	rural water supply project	tube well	bottled water	river/ tank/ stream/ springs
Padaviya	60.13	9.93	10.41	13.61	1.76	0.42	3.74
Kebithigollewa	66.47	2.80	6.11	5.26	2.25	0.07	17.04
Medawachchi	61.86	3.24	11.54	9.63	6.21	2.68	4.83

Source: Department of Census and Statistics [2011].

Table 3. Sanitation facilities of the study area

Area	Toilet facilities (%)		
	exclusively for the household	public toilet	not using a toilet
Padaviya	86.28	0.05	2.33
Kebithigollewa	79.85	0.02	5.29
Medawachchi	39.21	0.04	1.26

Source: Department of Census and Statistics [2011]

In Anuradhapura district, around 54% of the total population is engaging in agricultural practices where paddy is the main agricultural crop (100,598 ha). Chena cultivation is also practiced with crops such as maize, green gram, sorghum, cow pea, ground nuts, kurakkan, sweet potatoes and mustard are the most common crops utilize mainly ground water through agricultural wells [Department of Census and Statistics 2013].

Rainy period occurs during the November to February when the North-East monsoon time. Where, the period from May to September (South-West monsoon) is generally dry. The annual average temperature lies around 25–27.5°C [Environmental and Social Development Division

2014]. Present study samples were collected during the 2nd intermonsoon period.

SAMPLING

Out of 44 water samples three springs, nine tanks and thirty two well water samples were collected from Anuradhapura district during October 2016 (Fig. 1, Tab. 4). Precleaned polypropylene bottles and ambour color sterile glass bottles were used to collect water samples for chemical and microbial analysis respectively [APHA 1999; Ministry of Health Public Health Services 2010]. Water samples were transported to the laboratory in cold condition using ice boxes within 24 h after collection and stored in cold room. Microbial and chemical analysis were carried-out within 24 h after collection of sampling. The GPS coordinates were recorded at each site by the GPS (Handheld Garmin eTrex 30 GPS receiver).

PHYSICO-CHEMICAL ANALYSIS

Water temperature, pH and dissolved oxygen (DO) were measured using HQD portable multi meter (HACH – HQ 40D) and total dissolved solids (TDS), electrical conductivity (*EC*) and salinity were recorded using the portable conductivity meter (HACH – Sension EC5) at the site itself. Closed reflux method was employed to determination of chemical oxygen demand (COD) where ammonia (as NH_3-N), nitrates (as NO_3-N), nitrite (as NO_2-N) and total phosphate (TP) concentrations were measured by

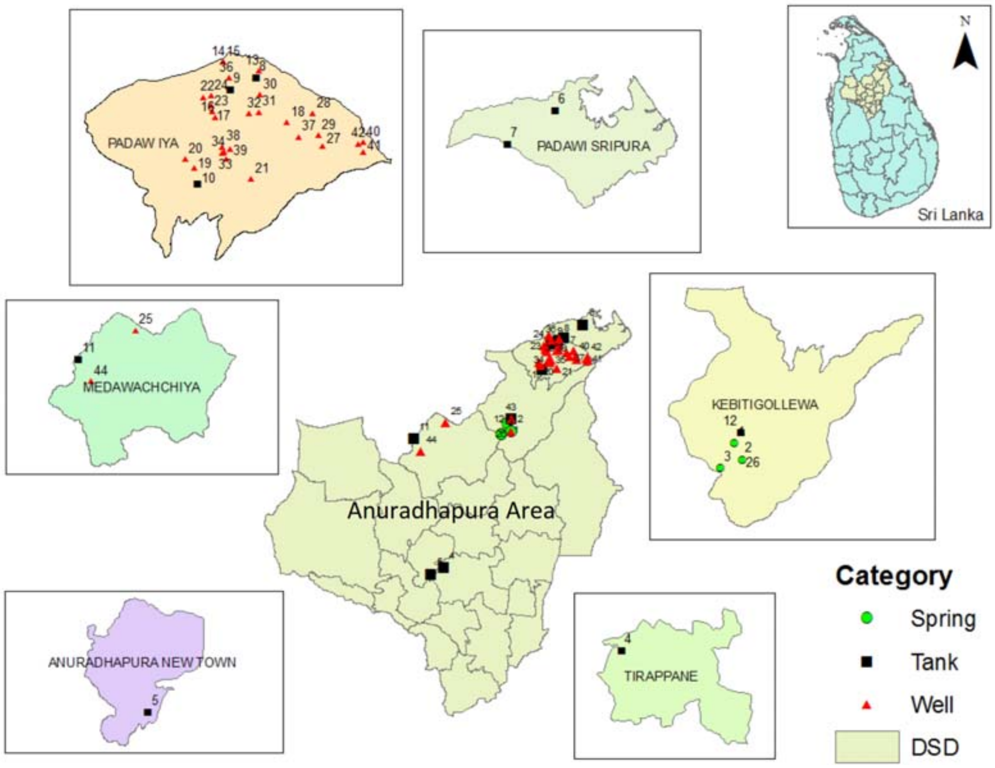

Fig. 1. Sampling locations map of the Anuradhapura area; source: own elaboration

Table 4. Spring, tank and well water sampling locations in the Anuradhapura area during the study

Ref. No.	Location	Ref. No.	Location	Ref. No.	Location
1	Kunchuttuwa (S)	16	B yaya 1 (W)	31	Mithreepura 2 (W)
2	Kebithigollewa (S)	17	B yaya 2 (W)	32	Mithreepura 3 (W)
3	Gonameriyawa (S)	18	Balayawewa (W)	33	Padaviya 1 (W)
4	Nachchaduwa tank (T)	19	Bisokotuwa 1 (W)	34	Padaviya 2 (W)
5	Thuruwila tank (T)	20	Bisokotuwa 2 (W)	35	Padaviya Town (W)
6	Sinhapura tank (T)	21	Bogaswewa (W)	36	Parakramapura (W)
7	Jayanthi tank (T)	22	Buddangala 1 (W)	37	Ruwanpura (W)
8	Galkulama tank (T)	23	Buddangala 2 (W)	38	Sudarshanagama 1 (W)
9	Thonigala tank (T)	24	Buddangala 3 (W)	39	Sudarshanagama 2 (W)
10	Padaviya tank (T)	25	Galkandegama (W)	40	Urewa 1 (W)
11	Mudaliyamkulam tank (T)	26	Kebithigollewa (W)	41	Urewa 2 (W)
12	Wiharahalmillewa tank (T)	27	Kubukwewa (W)	42	Urewa 3 (W)
13	Abayapura (W)	28	Mahasenpura 1 (W)	43	Wiharahalmillewa (W)
14	Alikimbulagala 1 (W)	29	Mahasenpura 2 (W)	44	Yakawewa (W)
15	Alikimbulagala 2 (W)	30	Mithreepura 1 (W)		

Explanations: S = spring water, T = tank water, W = well water.
Source: own elaboration.

Spectrophotometric (Spectro UV-VIS Double UVD 2960) methods [APHA 1999]. Total hardness was determined by titrimetric method with EDTA following standard protocole.

MICROBIOLOGICAL ANALYSIS

- **Total coliform and *E. coli* bacteria (membrane filtration method)**

Membrane lactose glucuronide agar (MLGA) plate method was performed to determine the total coliform (TC) and *E. coli* count per 100 cm^3 of water sample. 100 cm^3 of water samples were filtered through 0.45 μm filter papers and the filter disks were kept on the MLGA plates and incubated at 37°C ± 1°C for 22 h ± 2 h [SLSI 2013].

- **Identification of *Salmonella* spp. and *Shigella* spp.**

38 samples were subjected for identification of pathogenic *Salmonella* spp. and *Shigella* spp. 1 dm^3 sample was filtered through 0.45 μm filter papers (Whatman Cat No: 7001 0004, D-47 mm) and then the filter paper was dipped in the sterile 90 cm^3 buffered peptone water and incubated at 37°C for 18 ± 2 h. After incubation, enriched broth (BPW) was inoculated to selective enrichment media. 0.1 cm^3 of enrichment broth was added into 10 cm^3 of Rappaport Vassiliadis soya peptone broth (RVS) and incubation was followed at 41.5°C for 24 ± 3 h and 1 cm^3 of enrichment broth into 10 cm^3 of selenite cystine broth (SCB) was incubated at 37°C for 24 ± 3 h. After the selective enrichment, bacteria colonies were isolated by streak plating onto *Salmonella-Shigella* agar (SSA) and xylose lysine deoxycholate agar (XLD) then the plates were incubated at 37°C for 24 ± 3 h. Suspected colonies of *Salmonella* spp. and *Shigella* spp. were identified by using colony appearances. Further, identification of suspected colonies of *Salmonella* spp. and *Shigella* spp. were performed by biochemical tests; Kligler iron agar (KIA) test, urea test, lysine decarboxylation test, indole test and motility test following standard protocol [HPA 2006; 2007; KARUNARATNE 2011; MAHAGAMAGE *et al*. 2019].

STATISTICAL ANALYSIS AND SPATIAL MAP PREPARATION

Data set was processed using Minitab version 15 statistical software. Principal component analyses (PCA) and Pearson correlation tests were carried out for 14 physicochemical and microbiological parameters for 44 sampling locations. PCA is a nonparametric method of classification, which generally used for reducing the dimensions of multivariate problems without loss of information given by the study which was developed by HOTELLING [1933]. Arc GIS 10.0 was used to create the spatial distribution maps for selected water quality parameters in Padaviya area.

RESULTS AND DISCUSSION

Electrical conductivity (*EC*), total dissolved solids (TDS) and salinity are comprised of inorganic salts (principally calcium, magnesium, bicarbonates, chlorides, potassium, sodium, nitrates, and sulfates) and small amounts of organic matters that are dissolved in water [NAS, BERKTAY 2010]. Electrical conductivity values in springs, tanks, and well water were varied between 79.00 to 106.33 $\mu S \cdot cm^{-1}$, 340.00 to 719.00 $\mu S \cdot cm^{-1}$ and 77.60 to 1303.00 $\mu S \cdot cm^{-1}$ respectively (Fig. 2e). The spring and tank water

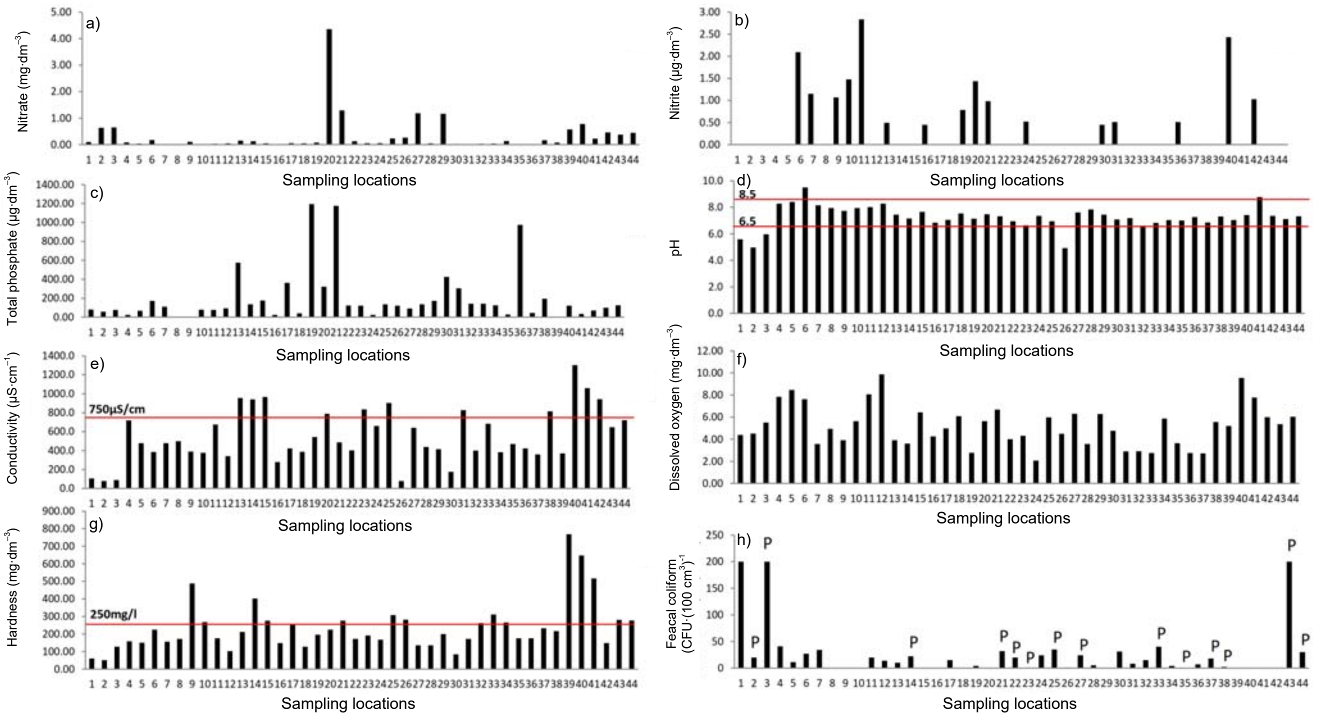

Fig. 2. Water quality variation and microbial contamination status in 44 sampling locations in Anuradhapura study area: a) nitrate, b) nitrite, c) total phosphate, d) pH, e) conductivity, f) dissolved oxygen, g) hardness, h) *E. coli*; P = *Salmonella* spp. positive, horizontal line = SLS drinking water guideline value; source: own study

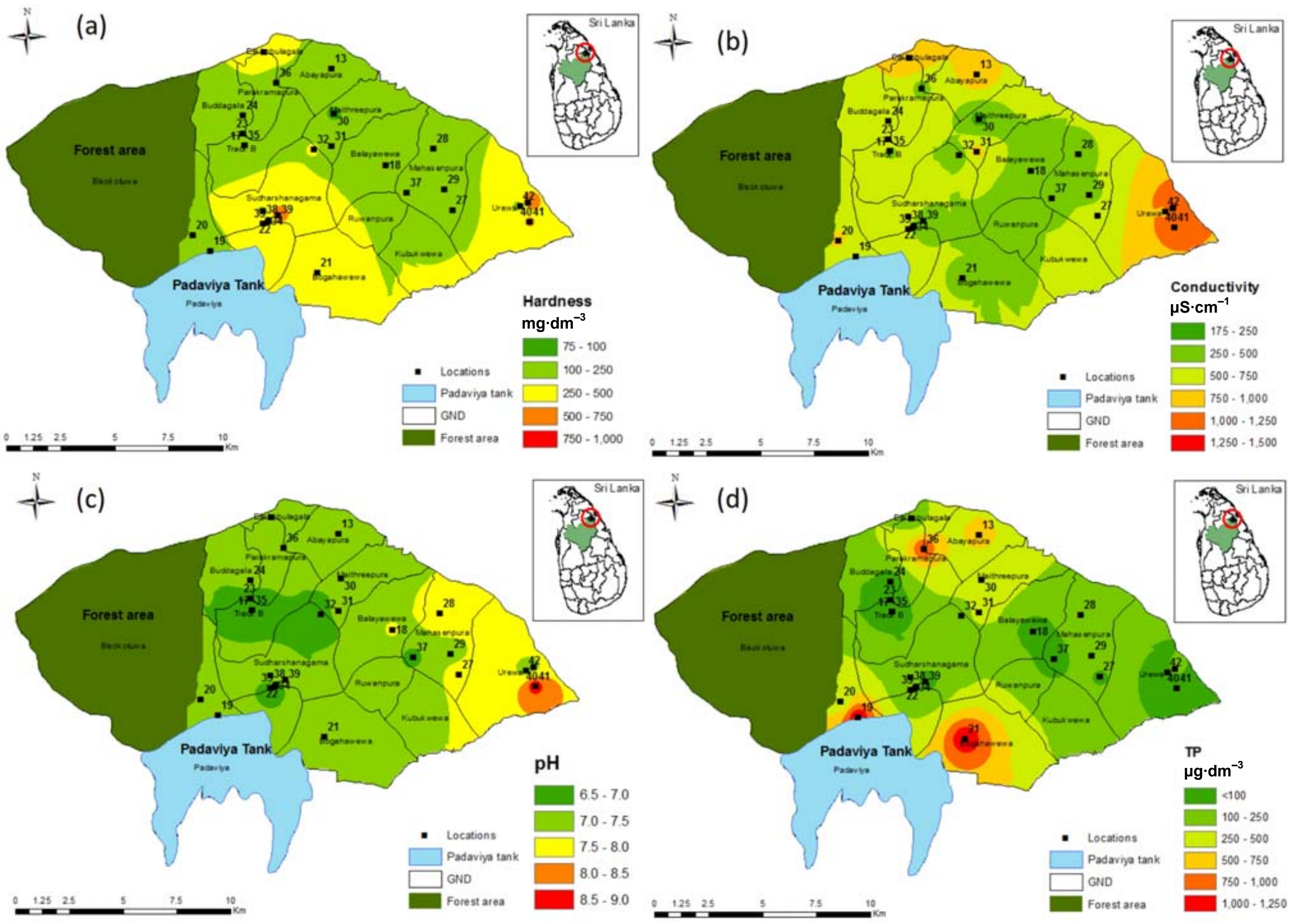

Fig. 3. Spatial variation of: a) hardness, b) conductivity, c) pH, d) total phosphate in Padaviya area; source: own study

conductivity values remained within the Sri Lankan Standards for drinking water (750.0 µS·cm^{-1} – SLSI [1983]) where ten wells in Padaviya and one well from Medawachchiya showed greater conductivity more than 750.0 µS·cm^{-1} [SLSI 1983]. In Padaviya area, the highest conductivity values were recorded from Urewa, Elikimbulagala and Abayapura GN divisions (Fig. 3b). In the present study, TDS values in springs, tanks and wells were recorded between 49.77 to 66.99 mg·dm^{-3}, 214.20 to 453.00 mg·dm^{-3} and 48.90 to 807.80 mg·dm^{-3} respectively. According to JOHNSON *et al.* [2012], the lowest TDS (56.4 mg·dm^{-3}) was recorded from in spring water collected from Kebithigollewa where DHANAPALA *et al.* [2015] documented similar results from Padaviya area for both surface and spring water and the values were not exceeded the level of 500 mg·dm^{-3} given by SLS [1983]. Accordingly, the present results were more or less within the range of the TDS recorded from previous studies except some wells. However, WHO [2016] has not given health-based guideline value for TDS as possible health effects associated with the ingestion of TDS in drinking water are not recorded. However, JOHNSON *et al.* [2012] recorded that samples were collected from Medawachchiya and Kebithigollewa areas in Anuradhapura district exceeded the maximum desirable level given by SLSI.

pH is one of the most important water quality parameter and the required pH in drinking water often being in the highest desirable between 7.0 and 8.5 and the maximum permissible level is 6.5–8.5 [SLS 1983]. The minimum and maximum values of pH in springs were remained between 4.97 and 5.97 and the values were well below the WHO and SLS drinking water quality guideline values (Fig. 2d). LIYANAGE [2009] documented that there are some perennial springs yielding numerous flow of clean water, which can be used for pipe-borne water supply schemes for the benefit of larger community in rural areas such as Padaviya, Kebithigollewa and, Medawachchiya where chronic kidney disease of unknown etiology (CKDu) is prevailing. Further, Kunchuttuwa spring is used by around 100–150 families in the area and they are extracting nearly 30,000–35,000 dm^3 of water per day. CHUAN *et al.* [1996] documented that metal solubility was greater when water pH less than 5.0. Thus, there is a risk with heavy metals contamination in spring water at Kebithigollewa. In the present study, Urewa (Padaviya) sampling location showed the highest pH (8.77) at Padaviya area and other sampling locations were–remained within the SLS maximum permissible levels (Fig. 3c).

It was found that the total hardness was ranged between 50.60–768.0 mg·dm^{-3} (Fig. 2g) and 16 sampling locations were recorded greater hardness than the highest desirable level of 250 mg·dm^{-3}. USGS [2016] documented general guidelines for classification of waters are considered as: soft (0 to 60 mg·dm^{-3}); moderately hard (61 to 120 mg·dm^{-3}); hard (121 to 180 mg·dm^{-3}) and, very hard (more than 180 mg·dm^{-3}) based on concentration of calcium carbonate. Therefore, findings of the present study showed that two springs namely, Kunchuttuwa and Kebithigollewa having soft water nature where Mithreepura 1 well and Wiharahalmillewa tank falls under the category of moderate hard. Gonameriyawa spring and five tanks namely, Jayanthi, Thuruwila, Mudaliyamkulam, Galkulama and Nachchaduwa, 10 wells which are located in Padaviya area are having hard water. Sinhapura, Padaviya and Thonigala tanks and 19 wells in Padaviya, 2 wells from Medawachchiya and 2 wells from Kebithigollewa are categorized as very hard water based on the concentration of calcium carbonate [USGS 2016]. In Padaviya area, very hard water found in Sudharshanagama, Bogahawewa, Urewa, Elikimbulagala and Padaviya new town Grama Niladari divisions (Fig. 3a). PARANAGAMA [2013] recorded the similar hardness values in Anuradhapura area and the low value of hardness was recorded in Gonameriyawa sampling location (9 mg·dm^{-3}). However, present study recorded much higher hardness in the same sampling location (128 mg·dm^{-3}). Further, FONSEKA *et al.* [2012] and DHANAPALA *et al.* [2015] have documented more or less similar hardness values in Anuradhapura area.

Nitrite, ammonia and nitrate, can be used as an important chemical indicator for the organic pollution of water and it can enter to the environment as a result of leaching from the soils containing nitrogenous fertilizer [BURAKHAM *et al*. 2004]. Nitrate in groundwater is normally low but it can reach high levels due to leaching or runoff from agricultural lands or human and animal wastes as a consequence of the oxidation of ammonia and similar sources [WHO 2004]. During recent years, water contamination by nitrogen has been documented all over the world [BENRABAH *et al.* 2016; BURAKHAM *et al.* 2004; GAO *et al.* 2012; MAHAGAMAGE, MANAGE 2014]. Anthropogenic activities are the main causes to have high ammonia, nitrate and nitrite concentrations in water of the study area and the recorded ranges were <1.00–4.41 μg·dm^{-3}, <0.10–4.35 mg·dm^{-3} and <1.00–2.83 μg·dm^{-3} respectively (Fig. 2a, b). However, the recorded values were less than the WHO and SLSI drinking water quality standards. The highest nitrate was recorded from groundwater source in Bisokotuwa (4.36 mg·dm^{-3}). Nitrate in groundwater may release from many sources including: nitrate minerals, nitrogen in soils, plant debris, animal wastes and synthetic fertilizers. However, Kebithigollewa and Gonameriyawa spring water reached high nitrate concentration compare to some well and tank water since these two springs surrounded with scrub forests in the study area. Therefore, plant debris and nitrogen in soils may be the reason for nitrogen in water. The highest ammonia and nitrite was recorded from Padaviya, Thonigala, Jayanthi, Sinhapura and Mudaliyamkulam tanks may due to surface water runoff from agricultural areas and animal manure the nearby area.

MAHAGAMAGE and MANAGE [2015] documented that high organic pollution directed to very high COD load in the water and this may due to untreated domestic waste water and fertilizer from agricultural areas. In the study COD in spring water was ranging from 8.98 to 66.35 mg·dm^{-3}. Groundwater and tank water was ranged between 8.98 and 98.72 mg·dm^{-3}, 43.40 and 257.57 mg·dm^{-3} respectively. The recorded high COD values from tank water may due to organic matter contamination from the agricultural water runoff and domestic effluent water. The present study revealed that all sampling locations were not within the guidelines value (10 mg·dm^{-3}) given by SLS and WHO for drinking water.

Normally groundwater contains only a minimum phosphorus level because of the low solubility of native phosphate minerals and the ability of soils to retain phosphate [MAHAGAMAGE, MANAGE 2015]. It was found that total phosphate (TP) in well water varied from 24.20 μg·dm^{-3} to 1194.72 μg·dm^{-3} (Fig. 2c, 3d). PARANAGAMA [2013] has reported similar phosphate concentrations in well water in the present study area. However, DHANAPALA *et al.* [2015] documented that the organic phosphorous in well water varied from 0.1 to 0.39 mg·dm^{-3}. The results of the present study showed, spring water and tank water phosphate values were ranged between 57.21 and 81.41 μg·dm^{-3}, and 22.74 to 171.62 μg·dm^{-3} respectively. As phosphate is a limiting factor for the growth of plankton and aquatic plants, thus law TP concentration was detected in tank water [IDROOS, MANAGE 2015]. However, most of the sampling locations recorded less than the values (2000 μg·dm^{-3}) proposed by SLS and WHO guideline.

It is important to note that almost all the sampling locations were contaminated with both Total coliform (TC) and *E. coli* bacteria during the study period. However, this may not cause illness and it can be used as one of the indicators of pathogenic contamination [MAHAGAMAGE, MANAGE 2016]. Therefore, the coliform count is used as an indicator of treatment efficiency, sanitation and the reliability of the water supply systems. *E. coli*, is one species of the coliform group, is always found in faeces [WHO 2004]. Therefore, the presence of TC and *E. coli* count is evaluating the quality of water for human consumption as a critical factor. All spring sampling locations recorded TC count was greater than 200 CFU·(100 cm^3)$^{-1}$ and except Kebithigollewa spring, other two springs recorded *E. coli* count was greater than 200 CFU·(100 cm^3)$^{-1}$ and the recorded values were not within the SLS and WHO drinking water guidelines (Fig. 2h; Tab. 5). However, people in the study area are depending on the spring's water for their domestic water requirements specially for drinking. PACHEPSKY *et al.* [2011] documented that most sources of water was contaminated with TC and such contamination will be influenced by weather patterns, the presence of animals, poor water management, and agricultural practices in the study area. In the presence study 62.5% of wells were contaminated greater than 200 CFU·(100 cm^3)$^{-1}$ for total coliform and one sampling location exceed the 200 CFU·(100 cm^3)$^{-1}$ for *E. coli* bacteria. This may due to poor sanitary conditions in the vicinity of the area or low distance between toilet pit and well [MAHAGAMAGE, MANAGE 2016]. According to the Central Bank [CBSL 2010], currently around 36% of people in the island have access to pipe-borne water but still rural populations depend on well water for their drinking, cooking, washing and bathing where others use water from tanks for daily requirement. Therefore, people in the area consume water without

Table 5. Contamination status of total coliform, *E. coli* and occurrence of *Salmonella* spp. in spring, well and tank water samples collected from Anuradhapura area

Sample No	Total coliform	*E. coli*	*Pseudomonas* spp.	*Salmonella* spp.	Category
	CFU·(100 cm^3)$^{-1}$				
1	>200	>200	0		spring
2	>200	20	0	P	spring
3	>200	>200	0	P	spring
4	>200	41	0		tank
5	20	11	0		tank
6	>200	27	>200		tank
7	100	34	0		tank
8	0	0	>200		tank
9	0	0	>200		tank
10	0	0	>200		tank
11	>200	20	0		tank
12	>200	14	0		tank
13	10	10	>200		well
14	>200	22	0	P	well
15	0	0	>200		well
16	0	0	0		well
17	15	15	0		well
18	>200	0	>200		well
19	>200	4	0		well
20	2	0	>200		well
21	>200	32	0	P	well
22	>200	20	0	P	well
23	5	1	0	P	well
24	>200	24	0		well
25	>200	35	0	P	well
26	2	1	0		well
27	>200	24	0	P	well
28	>200	5	>200		well
29	0	0	0		well
30	>200	31	0		well
31	>200	8	0		well
32	20	15	0		well
33	>200	40	0	P	well
34	5	4	0		well
35	>200	0	0	P	well
36	>200	7	>200		well
37	>200	18	0	P	well
38	>200	2	0	P	well
39	>200	0	0		well
40	0	0	0		well
41	0	0	0		well
42	0	0	0		well
43	>200	>200	0	P	well
44	>200	30	0	P	well

Explanations: P = *Salmonella* spp. positive.
Source: own elaboration.

any treatment is risk as these bacteria may course diseases such as, Shigellosis, Salmonellosis, diarrhea and gastroenteritis [MAHAGAMAGE *et al.* 2016].

Enteric fever is caused by faecal oral transmission of *Salmonella enterica*. CRUMP *et al.* [2004] documented about 27 million people suffer from enteric fever each year, among them around 200 000 died, almost exclusively in the developing world. This could be happen through the contaminated water.

Anuradhapura district is divided into 19 Medical Officer of Health (MOH) divisions. PALIHAWADANA [2015] recorded that more than half of cases relates to enteric fever (51%) are from 5 districts in Sri Lanka (Jaffna, Colombo, Vavuniya, Nuwara-Eliya, and Badulla). In 2013, 100 incidences were recorded for dysentery cases, 59 food poisoning cases and 23 typhus fever from Anuradhapura district. The results of the present study revealed that 37% sampling locations were positive for *Salmonella* spp. and *Shigella* spp. contamination was not recorded. Among them, 2 sampling locations were springs which are strictly used for drinking and rest were well water sources are being used for drinking.

Kebithigollewa and Gonameriyawa springs are surrounded by forest cover and protected by concrete rings but outer water can flow through the spring and microbial contamination is possible. Outer water can be contaminated by people who come to collect water for their drinking requirement and animal manure from the forest area. Groundwater contamination of pathogenic bacteria may due to the distance between toilet pits.

The results of this present study revealed that the majority of the homes in the Anuradhapura area have their toilet pits close to the wells and selected wells have only a minimum distance between the toilet pit and the groundwater source was less than 30 feet, which is below the recommended distance (50 feet) given by the Public Health Inspector (PHI) manual, Sri Lanka [WERELLAGAMA, HETTIARACHCHI 2004]. MAHAGAMAGE and MANAGE [2015] also recorded the relationship between the distance of toilet pit and *E. coli* contamination in groundwater sources in Sri Lanka.

STATISTICAL ANALYSIS

PCA is a nonparametric method of classification, which can use for reducing the data without loss of information given by the study [MAHAGAMAGE *et al.* 2015]. It is one of the most widely used multivariate statistical methods in natural sciences, which was developed by HOTELLING [1933]. To determine the correlation between springs, wells and, tanks, PCA analysis was done. Results of the study showed that three different types of water sources (spring, well and tank) grouped into three groups (Fig. 4).

Accordingly, the high concentration of total coliform and *E. coli* count and low values for conductivity, TDS and salinity were recorded from springs (Fig. 4) where, tank water showed high concentration of DO, COD, nitrite, pH and ammonia. High values for conductivity, TDS, salinity, TP, and hardness were recorded from the groundwater sampling locations where well water sampling locations of Padaviya recorded the highest values. Padaviya and Padavi Sripura tanks were shown similar water quality characteristics such as high amount of ammonia, nitrite and COD (Fig. 4). Mudaliyamkulam tank and Nachchaduwa tank were recorded similar water quality values.

According to Pearson correlation, a low correlation was observed in conductivity, TDS, salinity, ammonia, DO and COD with pH. Further, it was revealed that less correlation of conductivity, TDS, and salinity with hardness (Tab. 6).

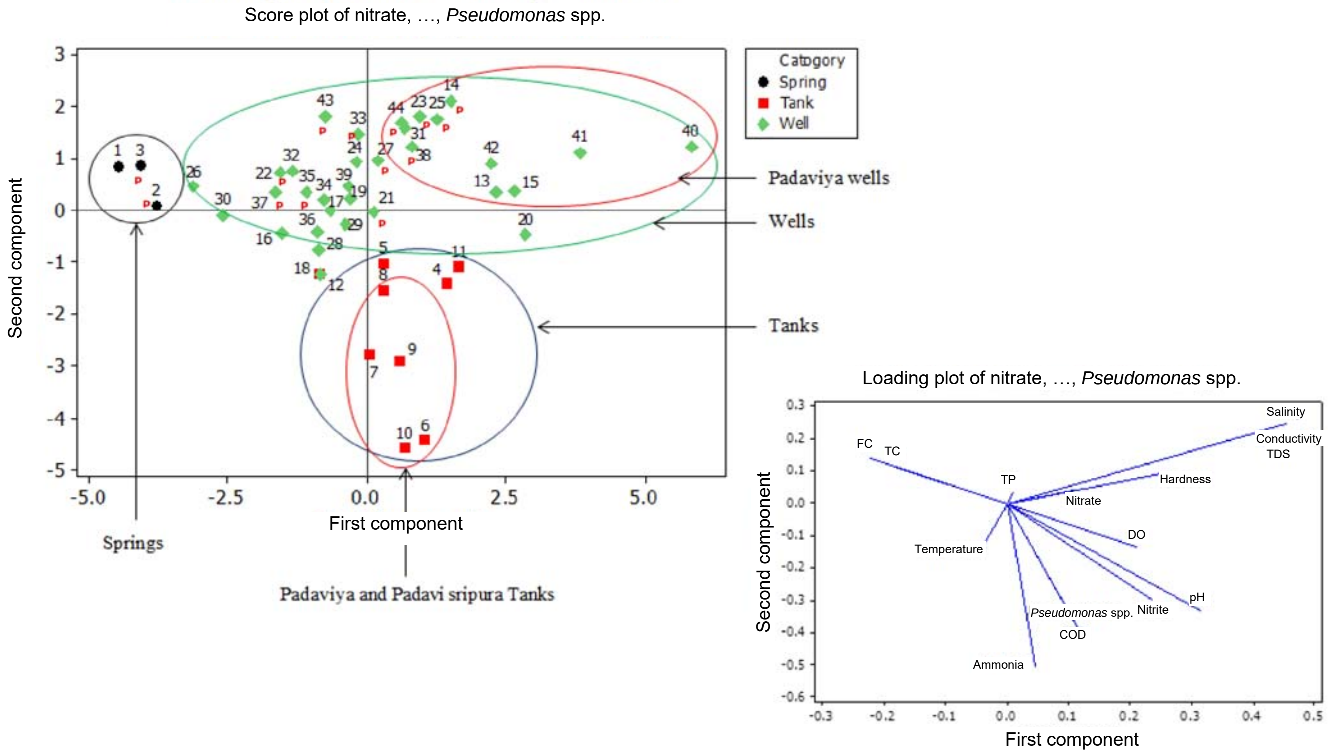

Fig. 4. Score plot and loading plot derived from PCA analysis; P = *Salmonella* spp. positive; source: own study

Table 6. Pearson correlation values for tested water quality parameters

	Nitrate	Nitrite	TP	pH	Conductivity	TDS	Salinity	Ammonia	DO	Temperature	COD	Hardness	TC
Nitrate													
Nitrite	0.217												
	0.158												
TP	0.137	0.156											
	0.375	0.312											
pH	–0.037	0.372	–0.018										
	0.812	0.013	0.910										
Conductivity	0.129	0.231	0.020	**0.394**									
	0.404	0.132	0.898	**0.008**									
TDS	0.126	0.227	0.016	**0.391**	**1**								
	0.416	0.139	0.916	**0.009**	**0**								
Salinity	0.129	0.231	0.020	**0.394**	**1**	**1**							
	0.404	0.132	0.898	**0.008**	**0**	**0**							
Ammonia	–0.129	**0.429**	–0.129	**0.394**	–0.164	–0.166	–0.164						
	0.404	**0.004**	0.405	**0.008**	0.288	0.282	0.288						
DO	0.176	0.288	–0.188	**0.457**	0.233	0.235	0.233	0.028					
	0.254	0.058	0.221	**0.002**	0.127	0.125	0.127	0.859					
Temperature	–0.28	–0.112	–0.269	0.190	–0.130	–0.130	–0.130	–0.028	**0.340**				
	0.065	0.469	0.077	0.218	0.401	0.400	0.401	0.856	**0.024**				
COD	0.031	0.261	0.051	**0.416**	0.028	0.028	0.028	**0.323**	0.187	0.009			
	0.842	0.087	0.741	**0.005**	0.855	0.859	0.855	**0.032**	0.223	0.952			
Hardness	0.082	0.166	–0.075	0.128	**0.396**	**0.395**	**0.396**	0.058	0.156	–0.013	–0.047		
	0.595	0.282	0.629	0.409	**0.008**	**0.008**	**0.008**	0.708	0.310	0.935	0.762		
TC	–0.217	0.029	0.010	0.112	–0.053	–0.053	–0.053	–0.103	0.006	0.206	0.083	–0.054	
	0.210	0.869	0.955	0.523	0.761	0.761	0.761	0.554	0.974	0.235	0.634	0.758	
E. coli	0.211	–0.132	–0.194	–0.277	–0.281	–0.277	–0.281	–0.042	0.055	–0.096	–0.155	–0.164	0.276
	0.256	0.480	0.296	0.131	0.126	0.132	0.126	0.822	0.770	0.608	0.406	0.379	0.133

Explanations: cell contents: top cells for every parameter Pearson correlation, bottom cells for every parameter – *p*-value; TP = total phosphate, TDS = total dissolved solids, DO = dissolved oxygen, COD = chemical oxygen demand, TC = total coliform.
Source: own elaboration.

CONCLUSIONS

Thirty-seven percent sampling locations were positive for *Salmonella* spp. and almost all sampling locations were contaminated with both total coliform and, *E. coli* bacteria. Chemical oxygen demand, conductivity, total coliform and *E. coli* were not within the drinking water guideline values given by Sri Lanka Standards Institution (SLSI) where 36% wells in the study area recorded greater than the SLSI desirable value for hardness. The recorded pH values in spring water was less than the WHO and SLSI water quality standards. The highest ammonia and nitrite was recorded from Padaviya tank, Thuruwila tank and Mudaliyamkulam tank may due to receiving of agricultural and animal manure via surface water runoff. PCA analysis clearly grouped the sampling locations of well water, tank water and springs. Overall results showed that rural societies in Anuradhapura district are facing major problems on lack of safe water for drinking. Further, the present study revealed that, freshwater from springs offers a huge potential as an alternative water source, it should be treated before drinking and public awareness programs are needed to aware water consumers on the present status of ground water quality in the area.

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Jakość i zanieczyszczenie mikrobiologiczne wody na terenach Madawachchiya, Padaviya i Kebathigollewa w dystrykcie Anuradhapura, Sri Lanka

STRESZCZENIE

Dur brzuszny jest chorobą o zasięgu światowym wywoływaną przez bakterie *Salmonella enterica.* W latach 2005–2014 na Sri Lance zanotowano 12 823 przypadki zakażenia salmonellą, w tym 133 przypadki na terenie dystryktu Anuradhapura. Dlatego podjęto badania celem zidentyfikowania stanu zanieczyszczenia mikrobiologicznego i chemicznego 44 źródeł wody na terenie Anuradhapura w październiku 2016 r. Oznaczono całkowitą liczbę bakterii grupy coli, *Escherichia coli*, *Salmonella* spp. i *Shigella* spp. oraz niektóre fizyczne i chemiczne parametry wód gruntowych i powierzchniowych. Pobieranie próbek, transport i analizy wykonywano według standardowych procedur. Wyniki analiz wykazały, że niemal wszystkie stanowiska były zanieczyszczone zarówno bakteriami *E. coli* jak i bakteriami grupy coli, a ich liczebność przekraczała normy WHO i Sri Lanki. W około 32% stanowisk stwierdzono obecność *Salmonella* spp., wśród nich 2 źródła, które są intensywnie eksploatowane na cele spożywcze. W okresie badań nie stwierdzono obecności *Shigella spp.* Wody większości stanowisk nie spełniały norm Sri Lanki, pod względem poziomu ChZT, a w 25% stanowisk przewodnictwo wody przekraczało 750 $\mu S \cdot cm^{-1}$. Wody 55% stanowisk wykazywały dużą twardość z najwyższymi wartościami notowanymi w Padaviya. Inne parametry chemiczne takie jak: NO_2-N, NH_3-N i fosfor całkowity mieściły się w normach jakości wody pitnej w Sri Lance. Za pomocą analizy PCA zagregowano badane źródła w trzy grupy: wody ze studni, wody ze zbiorników i wody źródlane.

Słowa kluczowe: *choroby przenoszone drogą wodną, chroniczna choroba nerek o nieznanej etiologii, dur brzuszny, jakość wody, obszary przeważające, Salmonella spp., Shigella spp., wody powierzchniowe i gruntowe*