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Chemical Retention Function of Thaulla Area of Small Reservoir; A Case Study in Ulankulama Tank, Anuradhapura, Sri Lanka

K. G. M. J. W. Gunapala, N. S. Abeysingha*

Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura, Sri Lanka

Abstract *Thaulla* is a term used to identify the upper peripheral region of small reservoirs /tanks located in Sri Lanka. This study was carried out to investigate the chemical retention function of the *thaulla* area of *Ulankulama* tank in North Central province of Sri Lanka. 13 soil and 15 tank water quality parameters were tested for this purpose. Soil samples were collected from 19 points in the *thaulla* area. Water samples were collected three times from the tank during the dry period. All soil and water samples were tested using standard methods. The results indicated that the *thaulla* area of the *Ulankulama* tank acts approximately as a wetland. It is evident by high accumulation of Fe (1819.65 ppm) and Al (1586.75 ppm) with a considerable retention of P (74.80 ppm), Ca (163.79 ppm) and Mg (203.67 ppm) in tested soil samples. This function was further corroborated with the observations of higher concentrations of P, Fe, and Al in the samples, which were higher than reference values of the Reddish Brown Earth soil found in the area. This phenomenon is supported by the evidence of low concentrations of Fe (1.40 ppm), Al (0.009 ppm) and P (0.095 ppm) in tank water during dry spell. N was found to be the limited nutrient in the *thaulla* area (0.073%) and it was identical to the wetlands. This study showed evidence for the chemical retention function of *thaulla* and suggests the restoring of the *thaulla* area of Dry Zone tanks in Sri Lanka.

Keywords Chemical retention, *Thaulla*, *Ulankulama* tank, Wetland

1. Introduction

The dry zone of Sri Lanka receives rainfall within a limited period of the year. In order to overcome the limited water availability for agriculture, the ancient communities developed their own water management system known as the Tank Cascade System (TCS). A cascade is a connected series of tanks organized within a meso catchment of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet (Madduma Bandara, 1985). Small manmade water storing structures, commonly known as '*wewa*' is the main element of TCS, which mainly supplies water for paddy cultivation. Water is continuously recycled in TCS and excess water from the upstream tank is captured in the downstream tanks. It supplies a water flow from upper tank to the lower tank through cultivated lands. The TCS of Sri Lanka are extensively considered as one of the unique water conveying and management systems among the ancient civilizations of the world and *has been recognized as a* Globally Important Agricultural Heritage Systems" (GIAHS) by the FAO (FAO, 2018).

The area situated just above the tank bed called as *Wew thaulla* through which runoff water enters into the tank. It covers with numerous types of plants and creepers. This micro-land region is partly covered with water and completely flooded during the rainy season (Abeysingha *et al*., 2018). *Thaulla* is a breeding and feeding ground for birds and also provides food for animals. This forest cover with waterloving trees, termed as *gassgommana* (upstream tree plantations) (Mahatantila *et al*., 2007) is a part of *thaula*. It acts as a wind barrier and reduces the occurrence of waves in the tank and evaporation of water. In addition, during high flood period, this area provides different habitats for fish and other aquatic species. It is hypothesized that the plants in the upper periphery of the tank may act as plants in constructed wetland and remove excessive nutrients, which drains to the tank (Mahatantila *et al*., 2010). At present the *thaulla* area of most of the tanks has been degraded, the land cover has changed and the intended function has been neglected. In addition, due to increased population pressure, *thaulla* areas have been increasingly encroached during the last decades (Bebermeier *et al*., 2017). This area and the adjacent reservation catchment

* Corresponding author:
nabeysingha@gmail.com (N. S. Abeysingha)
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were strictly protected by ancient farmers (Mahatantila *et al*., 2008). At present, it is very often not considered as one of the most important bio-engineering structure in TCS. Therefore, there is an urgent need to restore the tank *thaulla* area of all tanks in Sri Lanka. One way of understanding the importance of *thaulla* is scientifically convince its role. Therefore, Abeysingha *et al*. (2016), conducted a preliminary study to test the soil quality of *thaulla* area of *Ulankulama* tank analyzing only few parameters. The present study was extended to investigate the chemical retention function of *thaulla* area by taking *thaulla* area of *Ulankulama* tank in the Anuradhapura district as a case study so that researchers and policy makers can understand better the role of the *thaulla* area of TCS in Sri Lanka.

2. Methodology

2.1. Study Site

Ulankulama tank is situated in *Thirappane* Divisional Secretariat Division of the *Anuradhapura* district in Sri Lanka. It is located about 20 km south of *Anuradhapura* city, adjacent to the *Anuradhapura* - *Maradankadawala* - *Kekirawa* road. *Ulankulama* tank is located in the middle part of *Ulagalla* tank cascade (Fig. 1). The total average annual rainfall in the area is about 1,445 mm and the area receives more water from North East monsoon. The major soil group is reddish brown earth (Alfisols) comprising sandy-loam to sandy clay loam in texture. Gross area and net catchment area of the tank are 1523 ha and 904 ha, respectively. Tank capacity is 460,000 m^3 and water spread area at spill is 44.7 ha (Navaratne and Gunawardena, 1999). Farmers cultivate about 41 ha of paddy in the command area using the water of the *Ulankulama* tank. This tank has prominent *thaulla* area of about 0.43 km^2 (Fig. 1).

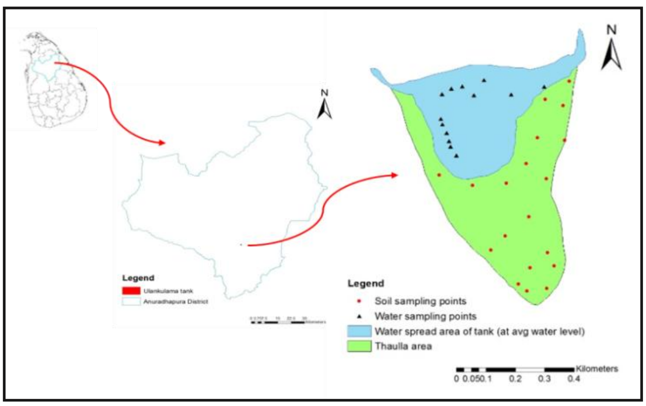

Figure 1. *Ulankulama* tank in Anuradhapura district in Sri Lanka

2.2. Soil Sampling and Analysis

Soil samples were collected from 19 randomly selected points in *thaulla* of *Ulankulama* tank to represent the entire *thaulla* area, from two depths as 0-15 cm and 15-30 cm using stainless steel soil augers at the beginning of the study. Global Positioning System (GPS) locations of sampling points in *thaulla* area were also recorded. The soil samples were analyzed for various physicochemical parameters i.e. pH, Electrical Conductivity (EC), total N, available P, total K, Na, Ca, Mg, Fe, Al, As, Cd and Pb contents in the laboratory by using standard laboratory methods. pH and EC were determined using the multi-parameter analyzer (HATCH, Sension 156) with the 1: 2.5 soil-water suspension method and 1: 5 soil-water suspension method respectively. Total N content of soil samples was determined by the Kjeldahl method (Bremmer and Muloaney, 1982). Available P content of soil samples was determined by UV- visible spectrophotometer with Olsen method (Olsen *et al*., 1954). Total K, Na, Ca, Mg, Fe, Al, As, Cd and Pb contents were measured using the Inductivity Couple Plasma Optical Emission Spectrophotometer (ICP-OES) procedure after acid digestion of soil samples (Martin *et al*., 1994).

2.3. Water Sampling and Analysis

Gilma is a folkloristic term used to denote a water collected area of a tank during a dry spell. Water samples were collected from the *gilma* area of *Ulankulama* tank during dry spell. Sampling was limited to three times (during October 2016, December 2017 and March 2017) due to drought condition during the dry spell. Sampling points were randomly selected to represent the entire water spread area and water spread areas varied during sampling periods. GPS locations of selected water sampling points in *Ulankulama* tank were recorded. Water samples were collected in a pre-clean sampling bottles in the early hours of the day.

The collected water samples were tested for physicochemical parameters such as water temperature, pH, EC, and Total Dissolved Solids (TDS), immediately using the multi-parameter analyzer (HATCH, Sension 156). Other parameters such as ammonium nitrogen ($NH4^+$ - N), nitrate nitrogen (NO_3^- - N), available P, total K, Na, Ca, Mg, Fe, Al, As, Cd and Pb were analyzed in the laboratory by using standard laboratory methods. Calibration of instruments was carried out before measurements using standard methods. NH_4^+ - N content of water samples was determined by UV – visible spectrophotometer with 4500 NH_3 F Phenate method (Solorzano, 1969). NO_3^- - N content of water samples was tested by UV – visible spectrophotometer with salicylic acid method (Cataldo *et al*., 1975). Available P content of water samples was determined by UV- visible spectrophotometer with ascorbic acid method (Olsen *et al*., 1954). Total K, Na, Ca, Mg, Fe, Al, As, Cd and Pb contents were measured by ICP-OES following the method of Martin *et al*. (1994).

2.4. Statistical Analysis and Interpolation of Data

The descriptive statistics were calculated for both the soil and the water of the *thaulla* area and water spread area of the tank, respectively using SPSS software. Point sample values of pH, EC, N, P, K, Na, Ca, Mg, Fe, Al, As, Cd and Pb contents of soil samples were interpolated to the *thaulla* area using the Kriging method of interpolation in Arc GIS 10.2 software.

3. Results and Discussion

Average soil properties at average depth (0-30 cm soil) of the *thaulla* area of *Ulankulama* tank are shown in table 1 with their standard deviation and maximum and minimum values while table 2 shows the average results of the physicochemical analysis carried out for water samples collected from *gilma* area of the *Ulankulama* tank during dry spell between September 2016 and April 2017.

Table 1. Average soil properties at average depth (0-30 cm soil) of *thaulla* area of *Ulankulama* tank

Parameter	Average Soil Properties		Maximum value	Minimum Value
	Value	SD		
pH	5.50	0.54	6.60	4.75
EC (μS/cm)	402.56	360.82	69.00	1317.00
Total N (%)	0.073	0.079	0.331	0.004
Available P (ppm)	74.80	64.12	317.78	28.14
Total K (ppm)	96.10	32.19	175.67	50.55
Total Na (ppm)	37.34	35.34	108.91	0.15
Total Ca (ppm)	163.79	83.40	370.44	61.28
Total Mg (ppm)	203.67	82.64	349.60	109.80
Total Fe (ppm)	1819.65	527.82	2669.40	980.20
Total Al (ppm)	1586.75	454.60	2295.20	898.60
Total As (ppm)	ND	-	-	-
Total Cd (ppm)	ND	-	-	-
Total Pb (ppm)	4.14	1.46	7.19	2.16

Table 2. Average soil properties at average depth (0-30 cm soil) of *thaulla* area of *Ulankulama* tank

Parameter	Average Water Quality		Maximum Value	Minimum Value
	Value	SD		
pH	7.16	0.98	9.14	6.26
EC (μS/cm)	613.54	355.29	1152.00	232.00
TDS (mg/l)	242.93	127.02	467.00	106.60
$NH4^+$ - N (ppm)	1.49	0.19	1.76	1.13
$NO3^-$ - N (ppm)	0.68	0.25	1.10	0.36
Available P (ppm)	0.095	0.023	0.14	0.06
Total K (ppm)	12.15	2.33	16.81	9.05
Total Na (ppm)	52.80	21.78	104.99	31.81
Total Ca (ppm)	29.22	8.70	40.81	18.28
Total Mg (ppm)	15.26	3.29	19.11	10.47
Total Fe (ppm)	1.40	1.48	5.01	0.01
Total Al (ppm)	0.009	0.010	0.034	0.001
Total As (ppm)	ND	-	-	-
Total Cd (ppm)	ND	-	-	-
Total Pb (ppm)	ND	-	-	-

Fig. 2 shows the spatial interpolated variation of pH, EC, total N and available P at soil depth 0-30 cm and fig. 3 shows the spatial interpolated variation of total K, Na, Ca, Mg, Fe, Al and Pb at average soil depth (0-30 cm) of the *thaulla* area of *Ulankulama* tank.

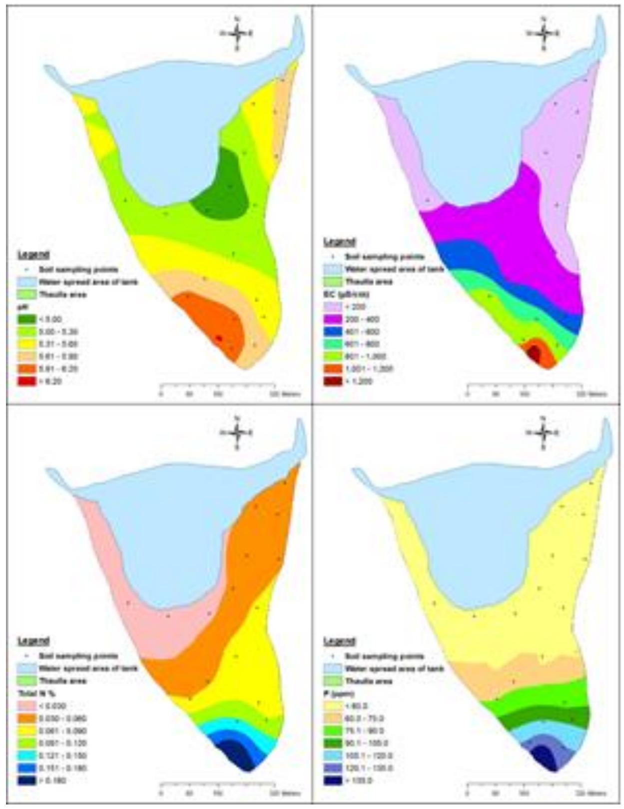

Figure 2. Variation of average pH, EC, total N and available P (0–30 cm soil) of *thaulla* area of *Ulankulama* tank

3.1. Soil pH of *thaulla* Area and Water pH at Low Water

pH affects the chemical reaction between water and soil minerals and pH determines the solubility and biological availability of some elements. The soil pH of the *thaulla* area at average depth (0-30 cm) ranged from 4.6 to 7.3 with an average of 5.5. It indicates that the soil condition of *thaulla* area varied from strongly acidic to slightly basic conditions. As an average (5.5), the soils of the area is slightly acidic in nature. The average pH (5.75) of 15-30 cm soil depth is higher than the average pH (5.25) of 0-15 cm soil depth indicating that surface soils were acidic than the subsurface soils (15-30 cm depth). Considering the interpolated pH in the *thaulla* area, there was no clear trend in the variation of pH of *thaulla* area (Fig. 2).

pH of the tank water at low water level ranged from slightly acidic (6.26) to strongly basic (9.14) and the average pH value of tank water during the study period was 7.16. The average pH value of tank water during low water level (7.16) was higher than the average pH of soils at *thaulla* area (5.5).

3.2. Variation of Electrical Conductivity (EC) of Soil and Water

Total nitrogen is the sum of nitrate, nitrite, organic nitrogen and ammonia nitrogen. The Total Kjeldahl Nitrogen (TKN) is only organic nitrogen and ammonia nitrogen. TKN was determined as total The EC of the soil in *thaulla* area at average depth (0-30 cm) during the sampling time ranged from 69 to 1317 μS/cm with an average of 402.56 μS/cm. It indicates that the EC of *thaulla* area varied from non-saline to strongly saline conditions. The average EC of tank water during dry spell (613.54 µS/cm) exceeded the average EC of *thaulla* area but tank water and soil of *thaulla* area were in moderately saline conditions when considering the average EC values. EC of Reddish Brown Earths (RBE) and Low Humic Gley (LHG) soil associations in the dry zone of Sri Lanka ranged from 0.3 to 0.6 dS/cm (30 – 60 µS/cm) (Vidyarathna *et al*., 2008). The average EC of soil in *thaulla* area at *Ulankulama* tank highly exceeded this range and this may be a result of higher dissolution of ions in water when water flows through the *thaulla* area. The average EC of 0-15 cm soil depth (516.36 µS/cm) is higher than the average EC of 15-30 cm soil depth (288.75 µS/cm) indicating that surface soils of *thaulla* area absorb more salts. Moreover, there was a decreasing trend in EC in 0-15, 15-30 cm and average depth (0-30 cm) (Fig. 2) towards the water spread area of the tank, especially though southwestern direction as the main water flow is from this direction. Abeysingha *et al*. (2016) also observed the same trend in EC in this *thaulla*. The reason may partly be the dilution effect of water closer to the water spread areas and the absorption of electrolyte by the plants in the *thaulla* area.

3.3. Total Nitrogen (N) in Soil in *thaulla* Area and Nitrogen (N) in Water

Total nitrogen is the sum of nitrate, nitrite, organic nitrogen and ammonia nitrogen. The Total Kjeldahl Nitrogen (TKN) is only organic nitrogen and ammonia nitrogen. TKN was determined as total nitrogen in this study. The observed values for total N of the *thaulla* area at average depth (0-30 cm) varied from 0.004% to 0.331% with average total N of 0.073%. The amount of prevailing total N extent for RBE and LHG soils are 11.6% and 23.22%, respectively (Nandasena, 2002). However, observed values of total N in *thaulla* area were lower than those values. Abeysingha *et al*., 2016 also observed the lower N concentration in same *thaulla* area. Nitrogen was shown to be the most limiting nutrient in wetlands and other aquatic systems. In wetlands, during the flooded period, anthropogenic nitrogen input is released from soil to the overlying water in the form of ammonia (Reddy and D'Angeolo, 1997). Similarly, when *thaulla* area is flooded during the heavy rainy period, nitrogen may release to the water from the soil. Moreover, total N in depth 0-30 cm (Fig. 2) was in a decreasing trend towards the water spread area of the tank. This decreasing trend can also be attributed to the releasing of nitrogen to the water by the soil processes where more water is available closer to the water spread areas.

It has been identified that major processes responsible for nitrogen removal in wetlands are denitrification (Tanner, 2004), uptake by plants, and subsequent nitrogen accumulation in the plant biomass (Borin and Toccheto, 2007), sedimentation (Borin and Toccheto, 2007), and volatilization (Vymazal, 2007). A similar process can happen in the *thaulla* area as there is growth of aquatic plants and grasses in the *thaulla* area, especially towards the water spread area of the tank, which may account for the loss of nitrogen.

Ammonium nitrogen concentration of the tank water during the dry spell ranged from 1.13 to 1.76 mg/l with an average of 1.49 mg/l. The nitrate-nitrogen concentration of the *Ulankulama* tank during the study period ranged from 0.36 to 1.10 mg/l with 0.68 mg/l of average nitrate concentration. The nitrate-nitrogen values observed in the waters of the tank at dry spell indicated lower values than permissible level of 10 mg/l for drinking (WHO, 1984). Nitrate-nitrogen in water may be absorbed by aquatic plants in the *thaulla* area and the water spread area of the tank. Wijesundara *et al*. (2012) showed that nitrate-nitrogen concentration of water at *Thirappane*, *Alisthana*, and *Meegasagama* tanks of the Anuradhapura district in Sri Lanka varied from 2.43 to 4.11 mg/l during the dry season (July, August, and September). Though these tanks are closer to the *Ulankulama* tank nitrate-nitrogen range is higher than that of *Ulankulama* tank during the dry period. The reasons may be the less prominent and unhealthy *thaulla* areas of those tanks when compared to the *thaulla* area of *Ulankulama* tank.

3.4. Available Phosphorous (P) Content in Soil in *thaulla* Area

Available P in soil is considered to be a fairly good measure of P supplying capacity of a soil. During the sampling time, available P concentration of the *thaulla* area at average depth (0-30 cm) varied from 28.14 to 317.78 ppm with average available P concentration of 74.80 ppm. The available P concentration of RBE soils in *Anuradhapura* district varied from 1.6 to 20 mg/kg (Karunadasa and Duminda, 2013). The average available P concentration of the *thaulla* area of *Ulankulama* tank exceeded this range and much higher concentration of P (1254ppm) was reported by Abeysingha *et al*. (2016) during 2015. These observations infer that there is P accumulation in the *thaulla* area. Just above the *thaulla* area and the upstream catchment area consists of paddy fields and chena lands, which can release a heavy load of P containing residues of chemical fertilizers through runoff during the rainy season leading to higher P concentration in the *thaulla* area of *Ulankulama* tank. The average available P of 0-15 cm soil depth (89.24 ppm) is higher than the average available P of 15-30 cm soil depth (60.36 ppm). It may indicate the adsorption of P and the accumulation of P in the upper layers of soil. Available P in average depth 0-30 cm (Fig. 2) is decreasing towards the water spread area of the tank, which is similar to the behavior of total nitrogen. Unlike nitrogen, phosphorous cannot be lost from wetlands through metabolic process thus phosphorus tends to accumulate in the system (Reddy and D'Angeolo, 1997). Thus, the accumulation of phosphorous in *thaulla* area resembles the similar function of a wetland. Further, the average available P concentration of tank water during dry spell (0.095 ppm) was lower than the available P concentration of *thaulla* area. It indicates that the *thaulla* area is functioning as a sink for P thus, reducing the overall P concentration in the tank water. This study tested the average texture of soil at the depth of 0 – 30 cm of *thaulla* area, and observed sand, silt and clay content as 32.95, 40.53 and 26.52 % respectively. Silt content is comparably higher than those of sand and clay. One reasons for higher concentration of P observed in *thaulla* area may be due to the P combine with the higher content of silt. Moreover, P can be retained by oxides and hydroxides of Fe and Al when the soil is acidic (Fisher and Acreman, 2004). It can be precipitated with Ca and Mg when the soil is basic (Reddy *et al.*, 2000). Hence, the medium acidic soils (average pH - 5.5) of and observed higher average Fe and Al concentrations (1819.65 and 1586.75 ppm) along *thaulla* area may be the reason for P retention in *thaulla* area. Also, the observed higher average Ca and Mg concentrations of *thaulla* area (163.79 and 203.67 ppm) suggest P precipitation with Ca and Mg in areas where pH is higher. This P retention with Fe, Al, and Ca and Mg further illustrate the function of *thaulla* similar to a wetland.

Available phosphorous concentration of the water at tank varied from 0.065 to 0.136 mg/l during the dry period and average available phosphorous concentration was 0.095 mg/l. These values recorded in low water level is very much lower than the soil P values.

3.5. Total Potassium (K) in Water and *thaulla* Soil

The average potassium concentration of *Ulankulama* tank water was 12.15 mg/l during the dry spell and it ranged from 9.05 to 16.81 mg/l. In general, surface water in Sri Lanka is rich in Na^+, Ca^{2+}, and Mg^{2+} but low in K^+ concentration (Dissanayake *et al*., 1982). The concentration of potassium, nitrate nitrogen and phosphate in tanks of the *Thirappane* cascade showed a bimodal pattern, which was coincided with the bimodal rainfall of the dry zone (Wijesundara *et al*., 2013). Their concentrations in surface water were higher in the dry *season* while relatively low during the wet season. Potassium fertilizers applied in the paddy field at the upstream catchment areas and the accumulated cow dung and other organic residues in the *thaulla* area may account for elevated concentration of potassium in water of the *Ulankulama* tank.

The soil potassium concentration of the *thaulla* area at average depth (0-30 cm) changed from 50.55 to 175.67 ppm with average K concentration of 96.10 ppm. However, the K concentration was observed to be increasing towards the water spread area of the tank without clear trend (Fig. 3). In addition, the average K concentration of tank water during the study period (12.15 ppm) was lower than the *thaulla* area. This behavior of K in the *thaulla* area is different from other elements such as Na, Ca, and Mg. Shen and Stucki (1994) indicate that when the Fe in smectites (a type of clay mineral) is reduced K fixation is increased and likely results in reduced K availability. They also showed that reduction of Fe in illites (a type of clay mineral) results in K release and increases in exchangeable K. Therefore, the clay soils with decreasing trend of Fe concentration toward the water spread area of the tank may affect on this behavior of increase in concentration towards the water spread area of K in the *thaulla* area. Though higher mud (silt and clay) content towards the water spread area was observed, further studies are needed to identify the clay mineralogy in *thaulla* area.

3.6. Variation of Total Sodium (Na), Calcium (Ca) and Magnesium (Mg)

The total Na, Ca and Mg concentrations of the soil in *thaulla* area at average depth (0-30 cm) varied from 0 to 108.91 ppm, 61.28 to 370.44 ppm and 109.80 to 349.60 ppm, respectively. Moreover, the average concentrations of Na, Ca and Mg were 37.34, 163.79 and 203.67 ppm, respectively in *thaulla* area. The concentration of these three elements apparently decreases towards the water spread area of the *Ulankulama* tank (Fig. 3). This behavior was clear, especially for Na concentration. This reducing trend of basic elements Na, Ca and Mg may be due to absorption of these ions by grasses and also dissolve in water. This uptake process of contaminants from soil or water by plant roots, their translocation and accumulation in aboveground biomass is known as phytoextraction (Kotrba *et al*., 2009). Also, higher Ca and Mg concentration were observed in the southwestern area of *thaulla* where there were abundant grasses. It indicates that the *thaulla* area plays a significant role in trapping basic cations like Ca, Mg and Na.

During the dry period, the sodium concentration of the tank water ranged from 31.81 to 104.99 mg/l and the average sodium concentration in the tank water was 52.80 mg/l. Calcium concentration of the *Ulankulama* tank water varied from 18.28 to 40.82 mg/l during the dry period. The average calcium concentration was 29.22 mg/l. Magnesium concentration of the tank ranged from 10.47 to 19.11 mg/l with an average of 15.26 mg/l during the dry period.

3.7. Variation in Total Iron (Fe) and Aluminum (Al)

Total iron and aluminum concentrations of the soils of *thaulla* area of *Ulankulama* tank at average depth (0-30 cm) changed from 980.2 to 2669.4 ppm and from 898.6 to 2295.2 ppm, respectively. The average concentrations of Fe and Al in soils were 1819.65 and 1586.75 ppm. There were high concentrations of Fe and Al but there was no clear trend for the spatial variation of Fe and Al concentrations in the *thaulla* area (Fig. 3). The average Fe and Al concentrations of tank water during the dry spell (1.4 and 0.009 ppm) were very low. The geochemistry of tank bed may also influence the variations in ion concentration. The observed high P, Fe and Al concentration of *thaulla* area may be due to the formation of various compounds of Fe and Al with P in the soil. Wetland soils are effective sinks for many trace metals through precipitation. Moreover, the solubility of Fe plays a major role in wetland environments (Reddy *et al.*, 2000). Yu *et al*. (2015) found that spatial distribution of Fe-P and Al-P showed a similar order in constructed wetlands. Other researchers have reported a significant relationship between extractable Fe and Al, and the P retention capacity of wetland soils (Lookman *et al*., 1995). Observed higher concentrations of P, Al, and Fe suggest that *thaulla* area act approximately as a wetland. Gambrell (1994) indicated that significant amounts of iron and aluminum oxides present in highly weathered and highly oxidized wetland soils are effective in adsorbing most trace metal cations. Therefore, *thaulla* area can have the ability to adsorb some other trace metals other than Ca, Mg and Na as influenced by higher concentration of Fe and Al.

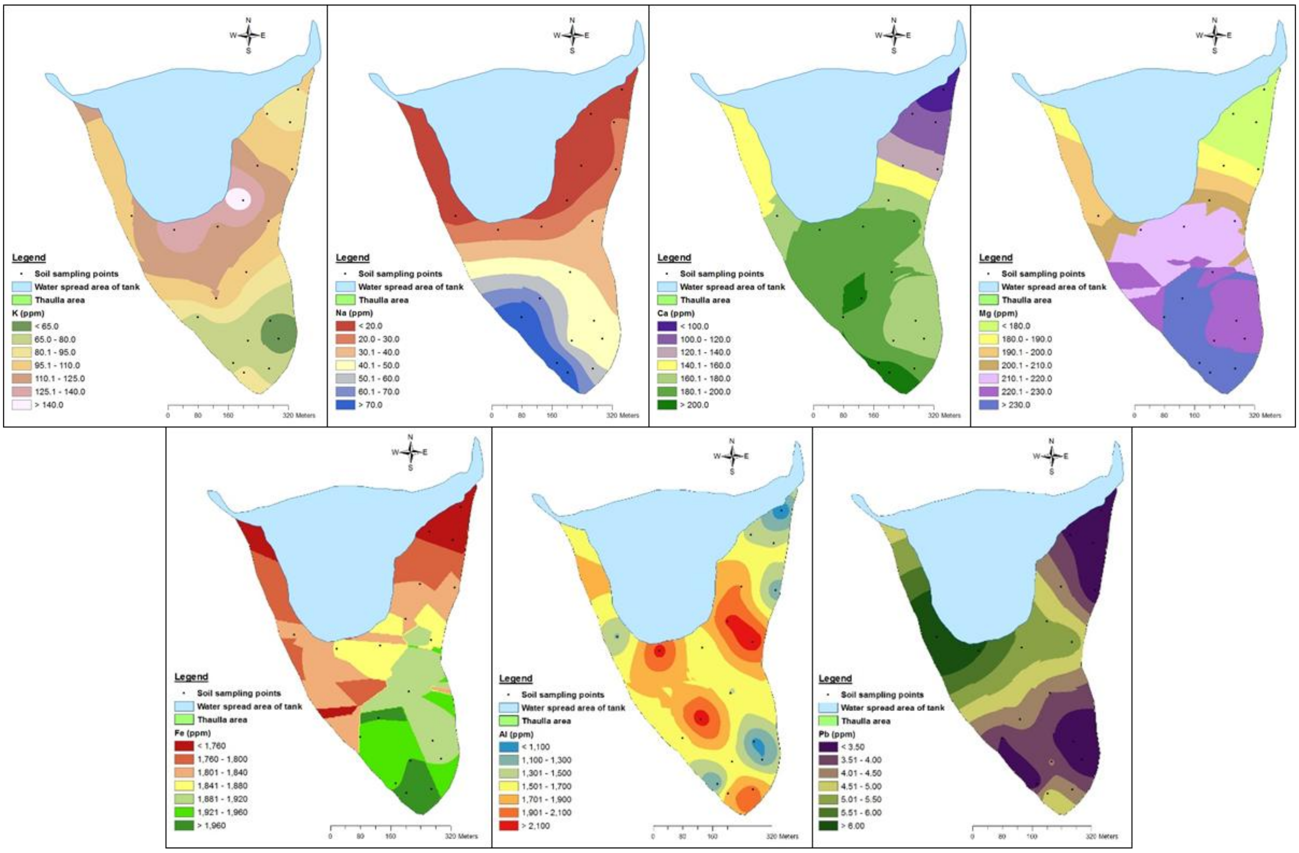

Figure 3. Variation of average total K, Na, Ca, Mg, Fe, Al and Pb (0–30 cm soil) of *thaulla* area of *Ulankulama* tank

3.8. Total Arsenic (As), Cadmium (Cd) and Lead (Pb) in *thaulla* Soil and Water in the Tank

Arsenic, cadmium, and lead concentrations of *Ulankulama* tank water during the study period were not in the detection range of the ICP-OES. Wijesundara *et al.* (2013) found that Cd^{2+} concentration in *Mahakanumulla* tank in Sri Lanka, which is closer to *Ulankulama* tank varied from 0.18 to 0.31 mg/l during a year. Cd^{2+} concentration elevated in the months of April and May in *Yala* season while relatively lower values were recorded for the *Maha* season (Wijesundara *et al*., 2013). With the chemical fertilizers such as triple superphosphate significant amount of Cd^{2+} could be added to the soil (Mclaughlin *et al*., 1996). It is also reported that Cd^{2+} concentration in buffalo and cattle dung varies 0.5 - 7.8 mg/l (Wijewardana and Gunarathna, 2004). During the rainy periods, dissolved heavy metals can reach the *thaulla* area of the tank with runoff water. Therefore, it can be suggested that grasses and other aquatic plants in the *thaulla* area of *Ulankulama* tank trap and absorb these heavy metals. Aquatic plants can accumulate elements through their roots, stems, and leaves (Jackson, 1998). Many plant species, especially aquatic macrophytes and some wetland plants have shown promising ability to uptake arsenic from soil and reduce it as metal chelates using specific high-affinity ligands (like oxygen-donor ligands, sulfur-donor ligands, and nitrogen-donor ligands). Bioaccumulation in stems and leaves through phytovolatilization is possible tolerance mechanisms of plants against arsenic contamination (Mirza *et al*., 2014).

The lead concentration of the soil at *thaulla* area at average depth (0-30 cm) changed from 2.16 to 7.19 ppm with average Pb concentration of 4.14 ppm of. The concentration of Pb apparently increases towards the water spread area of the tank similar to K variation in the *thaulla* area of *Ulankulama* tank (Fig. 3). But the average Pb concentration of tank water during the study period was not in the detection range of the ICP-OES (< 5 µg/l). This special behavior of Pb in the *thaulla* area is similar to K but different from other elements such as Na, Ca, Mg, Fe and Al. Pb tends to accumulate with clay minerals or get adsorbed onto Fe-oxide particles (Chandrajith *et al*., 2008). In wetlands, heavy metals are reduced effectively due to sorption processes in wetland systems (Yeh and Wu, 2009). In addition, it is shown that wetland can effectively remove heavy metals in water by acting as a matrix, facilitating interaction between microbes and plant/animal communities and performing functions such as filtration, adsorption, precipitation, ionic exchange, microbiological degradation, and biological uptake (Malaviya and Singh, 2012).

Water quality of the tank is affected by the hydro and geological processes of the immediate catchment and also the hydro geochemistry of the tank and its bed. Therefore, the variations of some physicochemical parameters along the *thaulla* area of *Ulankulama* tank are discussed in this study with the variation in water quality of the tank. The results of these findings suggest that the *thaulla* area of a tank acts as a small wetland and it plays a significant role in trapping pollutants. This study convinced that *thaulla* area plays a very important role in the retention of chemical pollutants. Otherwise that would flow directly into the tank and deteriorate the quality of water. This study helps to identify the role of *thaulla* area of a tank and claim to protect it for continuing its role for sustainable management of tank water for irrigation and other purposes. Moreover, this study shows the importance of the restoration of *thaulla* areas of dry zone tanks to keep up the good quality water of tanks in Sri Lanka. Further studies are needed to find out the relationships among nutrient retentions, especially P, Fe, Al, and the behavior of K along the *thaulla* area, with clay mineralogy, organic carbon and other soil quality parameters in *thaulla* area. Also, analysis of aquatic plants and grasses are needed to find out their functions in the *thaulla* area particularly the absorption of chemicals in *thaulla* area. Furthermore, analysis of water samples of the tank during low, medium and high flood levels and compare the results of variations in soil properties are needed to concrete understanding the behavior of *thaulla* area. Moreover, it is suggested to analyze the total suspended load in water in different water levels along with the runoff water as one of the main function of *thaulla* is trapping sediments.

4. Conclusions

The results of this study showed that the *thaulla* area of a tank acts approximately as a wetland, especially considering the chemical retention function. Soils in *thaulla* area play a very important role in chemical retention, which prevents flowing of such chemicals directly into the tank water, deteriorating the water quality. This function is evident by the high accumulation of Fe and Al with a considerable retention of P, Ca and Mg in the soil of *thaulla* area of the *Ulankulama* tank. The chemical precipitation function of *thaulla* was further corroborated by observing considerable higher concentrations of P, Fe, and Al than those of the reference values of the soils (Reddish Brown Earth) in the area. Moreover, this function was confirmed by the very low concentrations of Fe, Al, and P in tank water even during the dry season. *Thaulla* area is functioning as a sink for P as a wetland thus reducing the overall P concentration to the tank. P might retain by various compounds of Fe and Al in the soil similar way of a wetland. N was the limited nutrient in the *thaulla* area and it was also identical to the wetlands. EC, N, P, Na, Ca, and Mg concentrations decreased towards the water spread area. In contrast, K and Pb concentrations followed the opposite. The reason for this chemical precipitation may be due to the abundance of aquatic grasses and trees in the *thaulla* area of *Ulankulama* tank. These findings reconfirm the importance of ecological functions of *thaulla* area of tanks for sustainable use of tank water.

REFERENCES

[1] Abeysingha, N.S., Dassanayake, K.B. & Weerarathna, C.S., 2018, Will restoration of ecological functions of tank cascade system contribute to reduce CKDu in Sri Lanka? a Review. Journal of environment management and sustainable development, 7 (3). DOI: 10.5296/emsd.v7i3.13129.J.

[2] Abeysingha, N.S., Jayenethithi, J.P.H.U., Kosgollegedara, E.J. & Hammer, S., 2016, Variation in Soil Quality Parameters in the Thaulla Area of a Small Reservoir – A Case Study of Ulankulama Tank at Anuradhapura, Sri Lanka, Journal of Agricultural Physics, 2016 (1,2), 1-8.

[3] Bakacs, M., Yergeau, S. & Obropta, C., 2013, Assessment of car wash runoff treatment using bioretention mesocosms. Journal of Environmental Engineering 139, 1132–1136. DOI: http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000719.

[4] Bebermeier, W., Meister, J., Withanachchi, C.R., Middelhaufe, I. & Schütt, B., 2017, Tank cascade systems as a sustainable measure of watershed management in South Asia. Water 9(3), 231. DOI: https://doi.org/10.3390/w9030231 1-16.M.

[5] Borin, M. & Toccheto, D., 2007, Five years water and nitrogen balance for a constructed surface flow wetland treating agricultural drainage waters. Science of the Total Environment 380, 38–47. DOI: https://doi.org/10.1016/ j.scitotenv.2006.12.039.FLEXChip Signal Processor (MC68175/D), Motorola, 1996.

[6] Bremmer, J.M., & Muloaney, C.S., 1982, Methods of soil analysis, Part 2.2nd edition. Agronomy No.9, American Society of Agronomy, Madison, WI, USA.

[7] Cataldo, D. A., Maroon, M., Schrader, L. E. & Youngs, V. L., 1975, Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. Communications in Soil Science and Plant Analysis 6(1), 71-80. DOI: https://doi.org/10.1080/00103627509366547.

[8] Chandrajith, R., Mahatantila, K., Jayasena, H. A. H. & Tobschall, H. J., 2008, Geochemical characteristics of sediments from a reservoir (tank) ecosystem in Sri Lanka. Paddy Water Environment 6(4). DOI: https://doi.org/10.1007/s10333-008-0133-y.

[9] Dharmasena, P.B., 2010, Essential components of traditional village tank systems. In: Proceedings of the National Conference on Cascade Irrigation Systems for Rural Sustainability. Central Environmental Authority, Sri Lanka.

[10] Dissanayake, C.B., Weerasuriya, S.V.R. & Silva, S.G.H., 1982, The environmental chemistry of Mahaweli river, Sri Lanka. International Journal of Environmental Studies 78, 207-293.

[11] FAO, 2018, Globally Important Agricultural Heritage Systems combining agricultural biodiversity, resilient ecosystems, traditional farming practices and cultural identity, Retrieved from http://www.fao.org/3/BU612EN/bu612en.PDF.

[12] Fisher, J. & Acreman, M.C., 2004, Wetland nutrient removal – A review of the evidence. Hydrology and Earth System Sciences 8(4), 673-685. DOI: https://doi.org/10.5194/hess-8-673-2004.

[13] Gambrell, R.P., 1994, Trace and toxic metals in wetlands - A review. Journal of Environmental Quality 23(5), 883 – 891. DOI: http://dx.doi.org/10.2134/jeq1994.00472425002300050005x.

[14] Jackson, L.J., 1998, Paradigms of metal accumulation in rooted aquatic vascular plants. Science of the Total Environment 219(2-3), 223–231. DOI: http://dx.doi.org/10.1016/S0048-9697(98)00231-9.

[15] Jackson, M. L., 1958, Soil chemical analysis. Prentice Hall, Englewood Cliffs, NJ.

[16] Karunadasa, R.M.S.S.B. & Duminda, D.M.S., 2013, Soil fertility of major Maize (Zea mays L.) growing areas in Anuradhapura district. Undergraduate Research Symposium - July 2013, Department of Soil and Water Resources Management, Faculty of Agriculture, Rajarata University of Sri Lanka. Available at: http://repository.rjt.ac.lk:8080/ xmlui/handle/12345678 9/522, Accessed 14 June 2017.

[17] Kotrba, P., Najmanova, J., Macek, T. & Mackova, M., 2009, Genetically modified plants in phytoremediation of heavy metal and metalloid soil and sediment pollution. Biotechnology Advances 27(6), 799-810. DOI: https://doi.org/10.1016/j.biotechadv.2009.06.003.

[18] Lookman, R., Freese, D., Merck, R., Vlassak, K. & Riemsdijk, W.H., 1995, Long-term kinetics of phosphate release from soil. Environmental Science & Technology 29(6), 1569-1575. DOI: https://doi.org/10.1021/es00006a020.

[19] Madduma Bandara, C.M., 1985, Catchment ecosystems and village tank in the dry zone of Sri Lanka: A time-tested system of land and water management. In: Lundquist, J., Lohm, U. & Falkenmark, M. (Eds.), Strategies for river basin development. D. Reidel Publishing Company, Germany (1985), 99-103. Available at: https://link.springer.com/ chapter/10.1007/978-94-009-5458-8_11, Accessed 14 June 2017.

[20] Mahatantila, K., Chandrajith, R., Jayasena, H.A.H. & Marasinghe, S., 2010, Water quality variation in a tank cascade irrigation system: A case study from Malagane cascade, Sri Lanka. Reseachgate, 1345-1353. DOI: https://doi.org/10.1007/978-3-540-95991-5_126.

[21] Mahatantila, K., Chandrajith, R., Jayasena, H.A.H. & Ranawana, K.B., 2008, Spatial and temporal changes of hydrogeochemistry in ancient tank cascade systems in Sri Lanka: evidence for a constructed wetland. Water and Environment Journal 22(1), 17-24. DOI: https://doi.org/10.1111/j.1747-6593.2007.00077.x.

[22] Malaviya, P. & Singh, A., 2012, A Constructed wetlands for management of urban stormwater runoff. Critical Reviews in Environmental Science and Technology 42(20), 2153–2214. DOI: https://doi.org/10.1080/10643389.2011.574107.

[23] Martin, T.D., Brockhoff, C.A. & Creed J.T., 1994, EMMC methods work group - Method 200.7, Determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry, Revision 4.4, U. S. Environmental Protection Agency, Cincinnati, Ohio. Available at: https://www.epa.gov/sites/production/files/ 2015-08/documents/method_200-7_rev_4-4_1994.pdf, Accessed 20 May 2017.

[24] Mclaughlin, M.J., Tiler, K.G., Naidu, R. & Stevens, D.P., 1996, The behaviour and environmental impacts of contaminants in fertilizers. Australian Journal of Soil Research 34(1), 1-54. DOI: https://doi.org/10.1071/SR9960001.

[25] Mirza, N., Mahmood, Q., Shah, M.M., Pervez, A. & Sultan, S., 2014, Plants as useful vectors to reduce environmental toxic Arsenic content. The Scientific World Journal 2014 (ID 921581), 1-11. DOI: http://dx.doi.org/10.1155/2014/921581.

[26] Nandasena, K.A., 2002, Nitrogen status and its supplying capacity of tropical soils of Sri Lanka. Sri Lanka Journal of Agricultural Science 39, 116-126. DOI: https://doi.org/10.31357/fesympo.v0i0.1438.

[27] Navaratne, W.M.U. & Gunawardena, E.R.N., 1999, Verification of design parameters for operational studies of minor tanks in the dry zone. Tropical Agricultural Research 11, 1-18. Available at: https://www.researchgate.net/profile/ ERN_Gunawardena/publication/317174953_Verification_of _Design_Parameters_for_Operational_Studies_of_Minor_Tanks_in_the_Dryzone/links/5929274a458515e3d4676c6b/Verification-of-Design-Parameters-for-Operational-Studies-of-Minor-Tanks-in-the Dryzone.pdf, Accessed 18 July 2017.

[28] Olsen, S.R., Cole, C.V., Watanabe, F.S. & Dean, L.A., 1954, Estimation of available phosphorus in soil by extraction with sodium bicarbonate, Volume No. 939. U.S. Department of Agriculture, National Agricultural Library, Washington.

[29] Reddy, K.R. & D'Angelo, E.M., 1997, Biogeochemical indicators to evaluate pollutant removal efficiency in constructed wetlands. Water Science and Technology 35(5), 1-10. DOI: https://doi.org/10.1016/S0273-1223(97)00046-2.

[30] Reddy, K.R., D'Angelo, E.M. & Harries, W.G., 2000, Biogeochemistry of wetlands. Handbook of Soil Science (M.E. Summer, Ed), G89-G119. CRC Press, Boca Raton.

[31] Shen, S. & Stucki, J.W., 1994, Effects of iron oxidation state on the fate and behavior of potassium in soils. Soil testing: Prospects for improving nutrient recommendations (eds: Havlin, J.L., J. Jacobsen., P. Fixen & G. Hergert), Chapter 10, 173-185. SSSA special publication 40, Soil Science Society of America, Madison, Wisconsin.

[32] Solorzano, L., 1969, Determination of ammonia in natural waters by the phenol hypochlorite method 1 1 This research was fully supported by U.S. Atomic Energy Commission Contract No. ATS (11-1) GEN 10, P.A. 20. Limnology and Oceanography 14(5), 799-801. DOI: https://doi.org/10.4319/lo.1969.14.5.0799.

[33] Tanner, C.C., 2004, Nitrogen removal processes in constructed wetlands. Development in ecosystems (eds. Wong M.H.), 1, 331–346. Elsevier, Amsterdam. DOI: https://doi.org/10.1016/S15727.

[34] Vidyarathna, D.D., Duminda, D.M.S., Amarasekara, M.G.T.S. & Jinadasa, D.M., 2008, Characterization of some of soil fertility parameters along an undulating terrain of Reddish Brown Earth and Low Humic Gley soils. Undergraduate Research Symposium - July 2008, Volume 2, Department of Soil and Water Resources Management, Faculty of Agriculture, Rajarata University of Sri Lanka. Available at: http://repository.rjt.ac.lk:8080/xmlui/bitstream/handle/123456789/618/5758.pdf?sequence=1&isAllowed=y, Accessed 20 July 2017.

[35] Vymazal, J., 2007, Removal of nutrients in various types of constructed wetlands. Science of the Total Environment 380(1-3), 48–65. DOI: https://doi.org/10.1016/j.scitotenv.2006.09.014.

[36] WHO (World Health Organization), 1984, Guidelines for drinking water quality, Volume 1, WHO, Geneva. Available at: http://apps.who.int/iris/bitstream/handle/10665/252072/9241541687-eng.pdf?sequence=1, Accessed 22 August 2017.

[37] Wijesundara, W.M.G.D., Nandasena, K.A. & Jayakody, A.N., 2012, Spatial and temporal changes in Nitrogen, Phosphorus and Potassium concentration in water in the Thirappane tank cascade in dry zone of Sri Lanka. Journal of Environmental Professionals Sri Lanka 1(1), 70-81. DOI: http://dx.doi.org/10.4038/jepsl.v1i1.5143.

[38] Wijesundara, W.M.G.D., Nandasena, K.A. & Jayakody, A.N., 2013, Seasonal and spatial variations of N, P, K and Cd concentrations in water of the Mahakanumulla cascade in the dry zone of Sri Lanka. Tropical Agricultural Research 24(3), 279–288. DOI: http://doi.org/10.4038/tar.v24i3.8013.

[39] Wijewardana, J.D.H. & Gunarathna, S.P., 2004, Heavy metal contents in commonly used animal manures. In: Annals of the Sri Lanka Department of Agriculture, Department of Agriculture, 6, 245-253.

[40] Yeh, T.Y. & Wu, C.H., 2009, Pollutant removal within hybrid constructed wetland systems in tropical regions. Water Science & Technology 59(2), 233-240. DOI: https://doi.org/10.2166/wst.2009.846.

[41] Yu, G., Tan, M., Chong, Y. & Long, X., 2015, Spatial variation of Phosphorous retention capacity in subsurface flow constructed wetlands: Effect of wetland type and inflow loading. PLOS ONE, 10(7), e0134010. DOI: https://doi.org/10.1371/jurnal.phone.0134010.