ASSESSMENT OF SURFACE WATER QUALITY IN TANK CASCADE SYSTEM: A CASE STUDY IN ULAGALLA CASCADE, SRI LANKA

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Abstract - Analysis and interpretation of the spatial and temporal variation of surface water quality is critical component in the assessment process. Multivariate analysis such as cluster analysis (CA) and principal component analysis (PCA) were used to evaluate the spatial/temporal variation and the interpretation of large complex water quality data set to identify the latent sources of water pollution in Ulagalla cascade, Sri Lanka. The data set included water quality data on 16 parameters for 11 different tanks over a year monitoring period (2016-2017). Based on the spatial variation of water quality along the main water way, all of the agricultural (pesticides, insecticide and excess fertilizer) and domestic pollutants were accumulated in the end member of the cascade as water is passing from one tank to another in downstream while it is utilized. Hierarchical agglomerative clustering was performed to the experimental data standardized through z -scale transformation to minimize the effect of differences in measurement units. Accordingly, eleven tanks grouped into three clusters based on their similarities, corresponding to tanks of less polluted (LP), moderately polluted (MP) and polluted (P). PCA performed on water quality data of eleven tanks indicates that the parameters responsible for water quality variation are primarily related to mineral dissolution (natural) and factors related agricultural activities as well as livestock. It can be recommended that multivariate statistical techniques can be successfully used to identify the most important water quality parameters and sites. Henceforth the results can be effectively use in management of surface water resources in tank cascade systems.

Index Terms - Cluster analysis, mineral dissolution, principal component analysis, Ulagalla cascade, water quality

I. INTRODUCTION

Water is a unique natural resource essential for drinking, domestic, industrial and agricultural purposes. Natural processes like precipitation, weathering of rocks and minerals, erosion, and anthropogenic activities like industrial and agricultural practices affect on the quality of water resources (Carpenter et al., 1998 and Zang Y et al., 2009). The quality of surface water is a major factor affecting human health as it can be easily contaminated with excessive loadings of contaminants releases from both natural and anthropogenic activities (Qudir et al., 2008). However the, the degree of contamination by each water quality parameter is unclear. It is necessary to identify spatial and temporal variation in water quality as well as the latent pollutant sources to reduce the uncertainty caused during policy planning processes (Wang et al., 2008).

Recently, multivariate statistical techniques such as cluster analysis (CA) and principal component analysis (PCA) has become popular for better understanding of water quality variation of a large volume of data set without losing the original information (Liu et al., 2011; Shrestha and Kazama,2007: Vega et al., 1998). These techniques are capable to assess temporal and spatial variations in river water quality and to identify potential sources of contamination (Phung et al., 2015). The village tank cascade systems (TCSs) in the dry zone of Sri Lanka is considered as one of the most efficient traditional water management system in the world since 3rd century BC and still act as essential elements of water management for agriculture in the dry zone of Sri Lanka. The main principle behind the TCSs is recycling and reuse of water through a connected series of tanks (Madduma Bandara, 1985). The main advantages of TCSs are collection of rainwater, maintain the soil moisture and groundwater, control the soil erosion and maintain the ecological balance (Panabokke, 2002).

A tank cascade is defined as an interconnected series of tanks organized within the micro-catchments of the dry zone to landscape, storing, conveying and utilizing water from an ephemeral rivulet (Madduma Bandara, 1985). The main elements of TCSs are the watershed boundary of the meso- catchment (the whole catchment area of the cascade), the micro-catchment (catchment area of individual tank within the cascade), the main valley, side valleys, axis of the main valley and irrigated paddy lands.
As water is passing from one tank to another in downstream while it is utilized, all the agricultural (pesticides, insecticide and excess fertilizer) and domestic pollutants get accumulated in the end member of the cascade. The use of grazing cattle

during the dry season

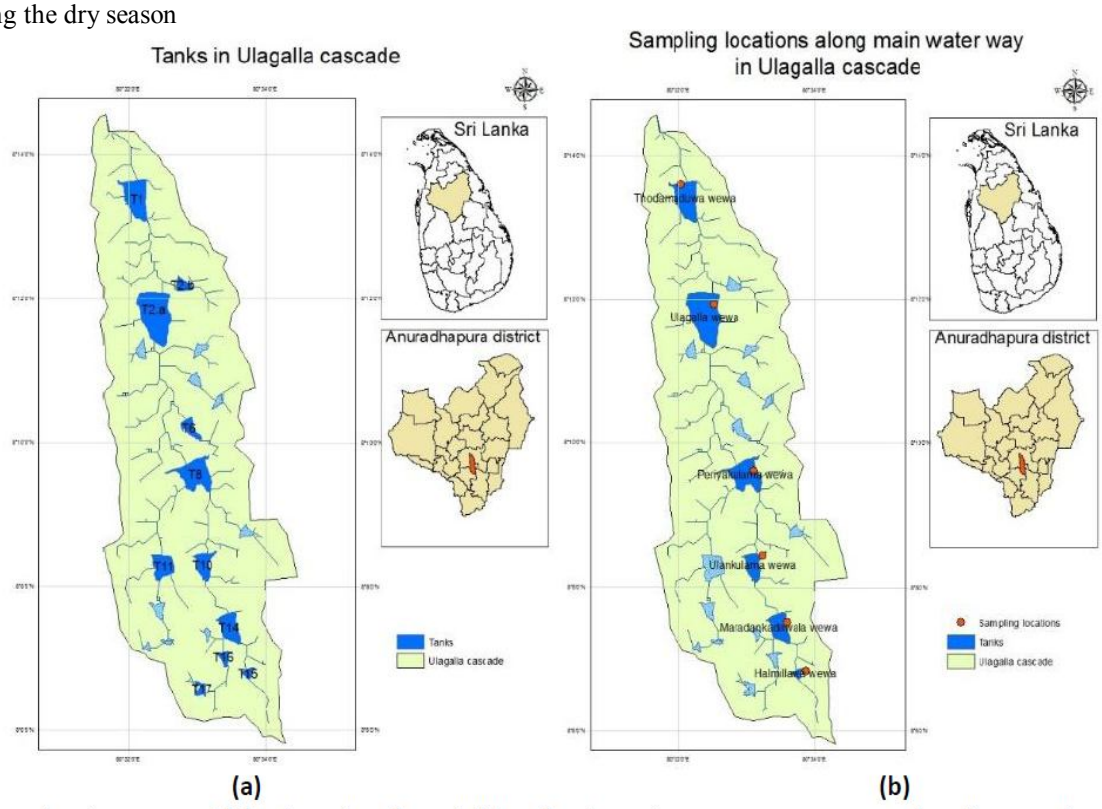


Figure 1: Sampling locations of (a) selected tanks and (b) tanks along the main water way in Ulagalla cascade

contributes to the high levels of nutrients in the tank. (Mahatantila et al., 2008). Thirappane, Ulagalla and Mahakanamulla are the typical cascades close to Anuradhapura, dry zone of Sri Lanka. Though it is one of the typical cascades in north central province, no any research has been conducted to evaluate the surface water quality in Ulagalla cascade. Hence, this study intend to assess the surface water quality in Ulagalla cascade and to identify the potential factors that explain the variation in water quality.

II. MATERIALS AND METHODS

A. Study Area

Ulagalla cascade is located in low country Dry Zone (DL_{1b}) agro-ecological region in Sri Lanka. Total land area is approximately 51 Km^2. It consists of nineteen connected tanks and this tank cascade system type can be categorized as "linier". Thodamaduwa wewa (T1), Ulagalla wewa (T2a), Waranamaduwa wewa (T2b), Pudukkulama wewa (T6), Periyakulama wewa (T8), Ulankulama wewa (T10), Itikattiya wewa (T11), Maradankadawala wewa (T14), Halmillewa wewa (T15), Settikulama wewa (T16) and Heenukwegama wewa (T17) were selected for the study (Fig.1).

B. Water quality parameters and analytical methods

Water samples from each tank in study area were collected during June 2016 to May 2017. Water samples were collected monthly intervals from three locations of each tank and the samples were collected in to 200 ml of clean plastic bottles after rinsing two or three times with the water to be sampled. The data set of 11 tanks comprising 16 physio-chemical parameters monitored monthly for one year were obtained for the analysis. The pH, electrical conductivity (EC) and total dissolved solids (TDS) were measure in-situ using Hach HQ 40d Multi parameter analyzer. Sodium (Na), potassium (K) and magnesium (Mg), calcium (Ca), arsenic (As), lead (Pb) and cadmium (Cd) were measured using inductively coupled plasma optical emission spectrometry (ICP-OES). Alkalinity as CaCO3 was analyzed using acid base titration. Ammonium-nitrogen (NH_4-N), available phosphorus (PO_4^{3-}) and nitrate-nitrogen (NO_3−N) were analyzed by Spectrophotometer (UV-Visible double beam). Powder pillows method was used to measure Sulphate (SO_4^{2-}) concentration. Chloride (Cl^-) was determined titrimetrically by standard AgNO3 titration.

C. Multivariate statistical techniques

Tank water quality data set were subjected to two multivariate techniques: cluster analysis and principal component analysis (Wunderlin et al., 2001). CA and PCA were applied to experimental data, standardized through z-scale transformation to avoid misclassifications arising from the different orders of magnitude of numerical values. The Shapiro-Wilk test was used to test the goodness of fit of the data. According to the Shapiro-Wilk test all the parameters were normally distributed with 95% or higher

confidence.

III. RESULTS AND DISCUSSION

A. Temporal variation of selected water quality parameters

The average pH of the selected tanks were varied from 7 to 7.86 (Fig. 2). The optimum pH range for irrigation water is 6.5 to 8.4. Therefore based on pH, all the tanks had good quality water for irrigation. EC can be successfully used to measure the salinity in irrigation water. Average EC values in the study area were varied between 300.8 to 793.36 µS/cm. As shown in Figure 3 EC values of the tanks were higher during dry periods and it has been reduced with the onset of rainfall. This is due to the dilution of the saltwater which was concentrated due to excessive evaporation and irrigation during the dry period (Sugarnan et al., 2013).

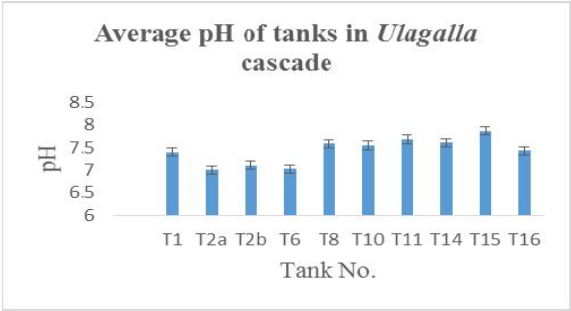


Figure 2: Variation of average pH in Ulagalla cascade

B.Spatial variation of water quality along the main axis

As can be seen in Figure 4 average EC has increased along the main axis. It is mainly due to the accumulation effect of pollutants and the dissolved ions as the water is passing from higher to lower elevation tanks while it is utilized. Not only EC almost all the parameters showed the same pattern of increasing trend towards the lower elevation of the cascade.

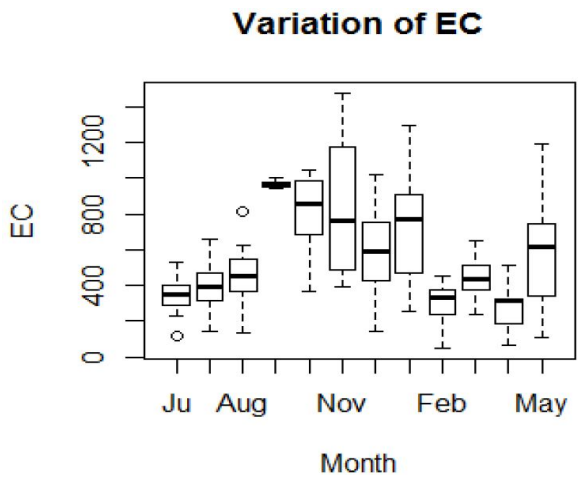


Figure 3: Whisker box plot of the EC in Ulagalla cascade

C. Multivariate statistical techniques

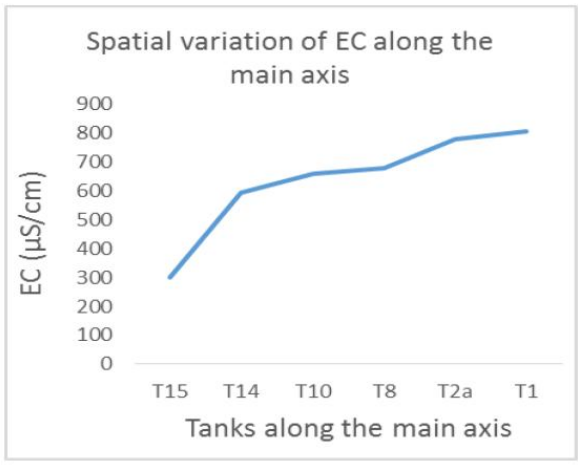


Figure 4: Spatial variation of average EC and along the main axis

PCA was performed on the normalized data set. Eigenvalues of 1.0 or greater are considered significant (Kim and Muller, 1987). Since there is no any hard and fast rule for the determination of number of components, first two PCs explaining 50.45 and 67.56 of the cumulative variance in the respective water quality data set were selected for the interpretation (Fig. 5).

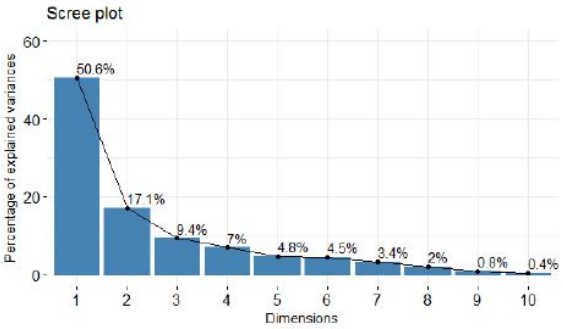


Figure 5: The scree plot

According to p values ($p<0.05$) Na, Cl, EC, Ca, Mg, N, K, NO3- N, NH4-N and As showed significant effect on surface water quality variation in Ulagalla cascade (Fig.6). The first component had higher loading of the seven variables related to mineral dissolution (natural). This includes Na, Cl, Ca, Mg and K concentration, TDS, and EC.

The second components has higher contribution of nitrogen concentration (NO_3-N, NH_4-N) and As contributed from agricultural activities and animal husbandry. Nitrate nitrogen and ammonium nitrogen comes to the surface water basically from excess application of fertilizer, wastewater /runoff from livestock and leaking of sewage systems. Excessive application of agro chemicals act as the main source of

arsenic.

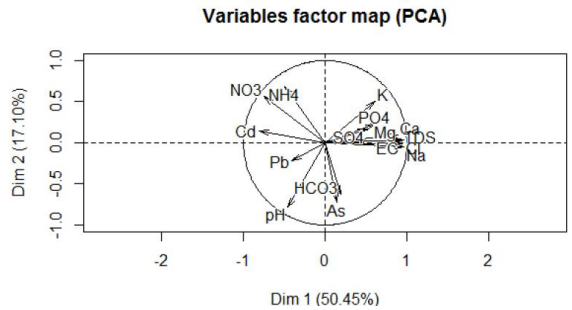


Figure 6: Variable factor map of PCA for first two principal components in Ulagalla cascade

Cluster analysis assemble the objects based on their characteristic and the resulting clusters exhibit high internal (within-cluster) homogeneity and high external (between-cluster) heterogeneity. Hierarchical agglomerative clustering is the most common approach to classify variables by starting with combining the most similar objects and forms higher clusters gradually (McKenna, 2003). In this study hierarchical agglomerative clustering was performed on normalized data set.

Temporal similarity and period grouping

Temporal CA generated a dendrogram (Fig.7), grouping of twelve months in to three clusters. Cluster 1 included October, November, December and January, which corresponds to high flow period. In this period, all the tanks receives heavy flow of runoff in wet season due to the second inter monsoon and north east monsoon rainfall. Cluster 2 included June, July, August and September which corresponds very low flow due to the dry season prevailing in the study area (no / very low rainfall with high evaporation). Cluster 3 comprised February, March, April and May approximately corresponds to the moderate flow.

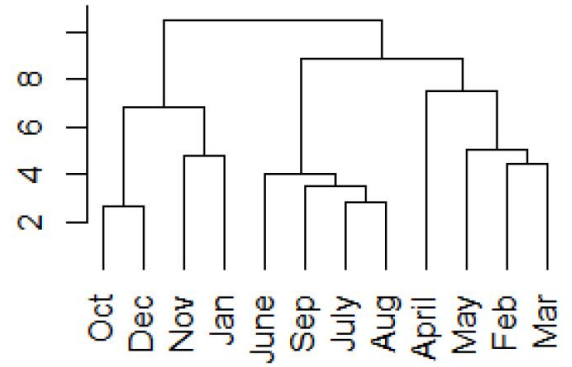


Figure 7: Dendrogram showing clustering of monitoring period in Ulagalla cascade

As shown in Figure 8 dendrogram yielded three clusters. The cluster 1 corresponds to relatively less polluted (LP) sits as T17,T11 and T6 are located at the side valleys, relatively small in size and the nutrient loading flowing to these tanks are comparatively low. Cluster 2 (T8, T10, T14, T15 and T16) correspond to moderately polluted (MP) though they are situated in low and middle elevation of the cascade sites, these tanks receives pollutants from non-point sources i.e, mostly from agricultural lands and livestock production systems. Cluster 3 (T1, T2a and T2b) correspond to polluted sites (P). These tanks receives pollutants from agricultural lands, livestock and from the lower level tanks due to the accumulation effect of tank cascade system. This results indicate that the CA technique is useful in classifying surface water.

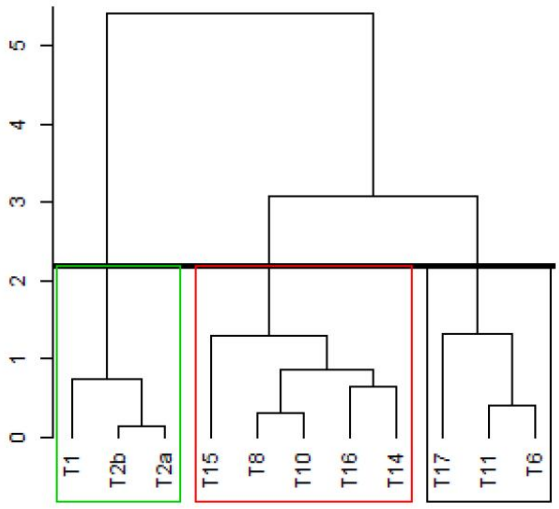


Figure 8: Dendrogram showing clustering of tanks according to the surface water quality characteristics

CONCLUSION

It was observed that almost all the chemical parameters monitored tends to concentrate towards the lower part of the cascade. Based on the temporal variation, most of the ions recorded highest concentration during dry period and gradually decrease the concentration with the onset of rainfall. Hierarchical cluster analysis grouped 11 sampling locations into three clusters of similar water quality characteristics as less polluted (LP), moderately polluted (MP) and polluted (P). PCA helped to extract and identify the factors/sources responsible for the variation of surface water quality in Ulagalla cascade. It indicates that the parameters responsible for water quality variation are mainly related to mineral dissolution (natural process) and nutrients (non-point sources: agricultural practices and livestock production).

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