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N and P variation in Groundwater in Wet Zone and Dry Zone in Sri Lanka due to Fertilization of Paddy Crop

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Abstract- Nitrate and phosphates are the main contaminants in groundwater due to application of fertilizer in agricultural sector. Therefore, present study was conducted to identify the general trend of fertilizer usage in the paddy sector and how much N and P affect to underground water. A total of 142 groundwater samples were collected from drinking water wells, covering two different climatic zones. The physico-chemical parameters were determined using standard procedures (APHA1992). pH and EC, fluoride, nitrate, phosphates and sulfates were measured. The average NO_3–N concentrations in groundwater before fertilization in wet and dry zones are 1.47 and 0.98 mg/L. During the cultivation period farmers applied three times fertilizer their land and average value of NO_3-N was increased up to 7.8 mg/L in wet zone and 3.7 mg/L in dry zone groundwater. 17% of the groundwater samples were over the maximum contaminated level of 10 mg/L as NO_3-N before fertilization and it was increased up to 26% after fertilization in wet zone. In dry zone nitrate concentration in all samples was less than the maximum limit before applying fertilizer. But during the cultivation period 12% of the samples exceeded the WHO maximum contaminating level. The phosphate concentrations in all groundwater samples were exceeded the WHO maximum contamination limits (0.01 mg/L) before and after fertilization. High EC, high TH and high pH in the dry zone are notable compared to that of in the wet zone. However it was observed that timing and amounts for fertilizer applied directly influence the potential groundwater contamination in different climatic zones in Sri Lanka. Therefore proper management practices are needed where intensive agricultural activities are practiced.

Index Terms- Contamination, Fertilization, Groundwater, Nitrate and Phosphate

I. Introduction

Water quality has deteriorated in almost all agricultural regions worldwide, with increased concentrations of dissolved salts, suspended solids, pesticides, fertilizers and other agrochemical. With respect to paddy, major nutrients namely N, P and K are essential primary nutrients. Among these nutrients N is a major nutrient demanded by paddy plants to increase yield. Plants use 50% of nitrogenous fertilizers applied to soil, 2-20% lost evaporation, 15-25% react organic compounds in the clay soil and the remaining 2-10% interfere surface and groundwater[1]. According to research carried out in farms wells in Ontario, Canada, 14% of the wells were over the limit values of NO_3-N concentration (10 mg/L) [2]. In Antalya region of Kumluca, nitrate concentrations of well water samples were ranged from 2.46-164.91 mg/L and 50% of the wells were exceeded the maximum contaminated level of 10 mg/L as NO_3-N [2]. High nitrates can lead to eutrophication of both surface and groundwater and cause methemoglobinemia and gastrointestinal cancer [3, 4].

Phosphorus is the other primary nutrient that needs plant growth and higher productivity. Phosphate rock is the only suitable source of phosphorus in the manufacture of phosphate fertilizer and phosphate based chemicals. These fertilizers commonly supply the crop phosphorus requirement or replenish P removed from a harvested crop biomass. When the phosphorus exceeds the absorption limits of the top soil, excess will dissolve and move freely to surface water bodies or downward to an aquifer. Long-term over-application of chemical fertilizer contributes to phosphorus to streams and lakes as well as potential contamination of the groundwater resources. Excess P contributes to excess growth of algae in downstream water bodies, reducing dissolved oxygen level in water body leading to kill sensitive species living in the water.

Scope of the study

Rice is the preferred food for the people of the Sri Lanka. With the increase of population in Sri Lanka, traditional patterns and practices of agriculture have gradually been changed into certain levels of commercialized form with the increase of demand for agricultural products over time, especially during last three decades. As a result, farmers have been applying different types of fertilizers and other agrochemicals with a view to fertile the soils and protect the crops from infectious diseases. They are generally not concerned about the environmental consequences, but interested in increasing their crop yield and profit **[5]**. In Sri Lanka a total of around 500 tons of fertilizer is distributed annually through various agencies, for use in all crops. From this amount, approximately 40 percent has been for applied in paddy cultivation annually. During the period from 2005 to 2007, the fertilizer used has increased by 32% while the yield and the cultivation extent have increased only by 17% and 10% respectively**[6]**.

Rice production is dependent on rainfall and irrigation practices. Sri Lanka receives about 12 million-hectare meters of water annually from rainfall, of which more than 50% through evapotranspiration, 20% seeps down to replenish groundwater while only 30% or about 3.5 million-hectare meters, is available as stream flow for irrigation or other purposes [7]. The principal cultivation season in the country known as "Maha", is from October to March and the subsidiary cultivation season, known as "Yala", is from April to

September in Sri Lanka. There is enough water for the cultivation for all rice fields in Maha season nevertheless in Yala season is only enough water for cultivation of half of the land extent. According to the water usage, paddy land can be categorized as major and medium irrigated system, minor irrigated systems and rainfed systems. Rainfed systems are mainly found in the Wet Zone of the country which gets up to 2,000–2,500 mm of annual rainfall. It constitutes about one third of the country's total area and accommodates about 63% of the population. Paddy lands which cultivated under major and medium irrigated systems are found in dry zone in Sri Lanka which gets annual rainfall less than 1500mm. Due to the seasonal drought the major paddy producing season in the dry zone comes during the Yala season.

The sources of portable water are surface water, shallow dug wells and deep ground water in the country. Before last three decades, people had been used to consume surface water and the ground water extracted from dug wells. Many researchers pointed out that groundwater contamination has been occurred due to fertilization on paddy crops in Sri Lanka for several decades [8, 9]. According to a recent study on the distribution of nitrates in the groundwater of Sri Lanka, direct relationship has been existed between the nitrate concentrations in groundwater, paddy cultivation and with the population distribution [10]. Dense paddy cultivations in the wetlands of Sri Lanka showed the maximum average nitrate levels, polluting drinking water sources. Pollution of groundwater by nitrate is receiving attention in the Jaffna peninsula [11, 12]. Rapid and over extraction of groundwater by mechanical and electrical motors have been increased sea water increment into fresh water leading to an increase in salinity[13]. About 65% of wells were very high in salinity in the Jaffna Peninsula but not clustered into vulnerability areas [12]. According to [14] the vulnerability areas were identified in Vavuniya district and it could be used for better management and conservation of the groundwater in the study area. Therefore, present study was conducted to identify the general trend of fertilizer usage in the paddy sector and how much N and P affect to underground water.

II. MATERIALS AND METHODS

A total of 142 groundwater samples were collected from drinking water wells, covering two different climatic zones, from which 61 samples were from the wet zone while 81 samples were from the dry zone areas (Figure 1). These wells are constructed either in the weathered and residual overburden or in the fractured bed rock of the metamorphic rocks. The wet zone samplings were carried out in February to April 2013, while dry zone samplings were carried out in October 2013 and February 2014, avoiding the extreme dry or rainy weather conditions. Water samples were collected into high-density polyethylene bottles which were acid soaked overnight and then washed thoroughly with distilled water. Before the collection of samples, bottles were further rinsed with water to be sampled.

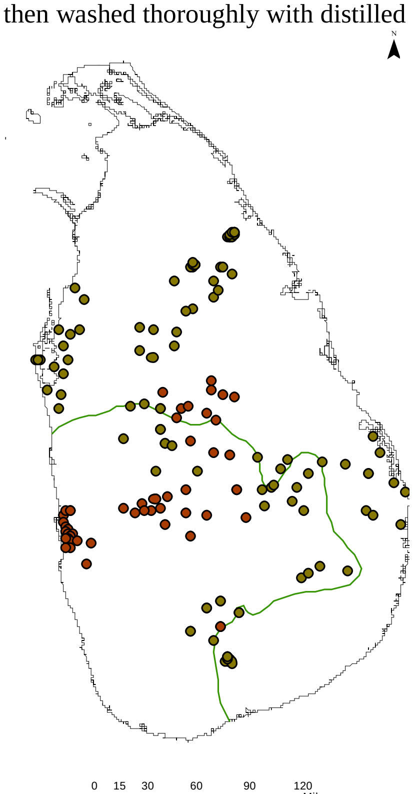

Figure1. Climatic Zones and Sample Locations in Sri Lanka

The physico-chemical parameters were determined using standard procedures (APHA1992). pH and EC of water samples were measured in situ using pre-calibrated Hach Sension pH/EC meter. All collected samples were kept cool until the analyses were performed, while the alkalinity of samples was determined as early as possible using H_2SO_4 titrimetric method. The HCO_3^- and CO_3^{2-} were calculated using alkalinity and pH values. Total hardness (TH) and chloride were measured using titrimetric methods, while fluoride, nitrate, phosphates and sulfates were measured using HACH DR 2700 spectrophotometer.

III. RESULTS AND DISCUSSION

The chemical compositions of physico-chemical parameters in groundwater samples collected from two different zones were measured. 73% of the groundwater samples show that the water is alkaline (pH >7) in dry zone in the country reaching the highest desirable level in Sri Lankan potable water standards (pH 7.0 – 8.5). The increase in groundwater pH from an average value of 5.29 in wet zone to 8.22 in dry zone may be due to contamination with ammonia based agrochemicals which are used heavily and higher evaporation in warmer months. Average values of EC in wet zone, and dry zone were 239.35 and 857.43 µS/cm. Since the EC has a direct relationship with the total dissolve solids in the sample, the high EC values from the dry zone indicate the mineralization of groundwater. Almost all wells in the wet zone and 75 % of the groundwater samples from the dry zone were within the permissible limit of 1500lS/cm [15]. Particularly in the dry zone where characterized with low rainfall and high ambient temperature, groundwater tends to move upward and more salts can accumulate during the evaporation [16]. A higher EC may be attributed to anthropogenic activities prevailing in dry zone. When considering these two zones, there is a clear indication that the aquifer in question has been subjected to salinization processes either naturally or anthropogenically.

Classification of water based on Total Hardness (TH) as suggested by [17] was showed as 15% of the samples were hard in dry zone with TH ranging between 150 and 300 mg/L. 26% samples were very hard with TH (or ppm of $CaCO_3$) above 300 mg/L in dry zone. The mean hardness of wet zone water is 79 mg/L, while it is 236 mg/L in dry zone where hardness up to 1104 mg/L was also recorded. Total hardness in the wet zone lie below the limits of 'moderately hard' (<150 mg/L of TH) and can be considered as soft water. Groundwater in these zones varies from 'hard' to 'very hard' in terms of Ca–Mg hardness [16]. Higher sulfates in the dry zone regions (mean 29 mg/L) indicate the occurrence of permanent hardness in certain parts of this region. The long-term consumption of extremely hard water may result in increased incidence of some types of cancer, and chronic kidney diseases which widely spread in the dry and intermediate zone in Sri Lanka.

The mean chloride content in wet zone (27.4 mg/L) is lower than that of in the dry zone (185 mg/L). The chloride content is found to vary between 4.4 and 1001 mg/L in the dry zone areas. Particularly, aquifers bounded to the coastal belt showed high chloride contents, possibly due to salt water intrusion. Highly soluble chloride can be leached from agricultural activities such as fertilizer applications, saline water intrusion or due to mixing or groundwater with irrigated water.

A. Effect of fertilizer application

In Sri Lanka the distribution of fertilizers is under government control. Government concerns with the supply of fertilizers to remote areas and low-income farmers, and with balanced use of fertilizers. But still imbalance of applied nutrients is a major problem in the country. Nitrogen applications tend to be too high comparing with the amount of potassium and phosphate used. The recommended amount for paddy is 270 kg of fertilizers as urea, triple super phosphates (TSP) and potash (MOP) per hectare per season. However, application of fertilizers has increased more than double during past decades exceeding the recommended levels [5]. During the period of water logging in rice cultivation, pollutants can be leached easily to the subsurface and eventually contaminate the groundwater which rural people use for drinking water source.

Nitrate and phosphates were the main contaminants in groundwater that results from fertilizer applications. The average NO_3–N concentrations in groundwater before fertilization in wetzone and dry zone were 1.47 and 0.98 mg/L. NO_3–N levels was varied between 0.5-5.5 mg/L in wet zone and 0.5-2.6 mg/L in dry zone before applied fertilizer to paddy field. But during the cultivation period farmers applied three times fertilizer their land and average value of NO_3- N was increased up to 7.8 mg/L in wet zone and 3.7 mg/L in dry zone groundwater. 17% of the groundwater samples were over the maximum contaminated level of 10 mg/L as NO_3-N before fertilization and it was increased up to 26% after fertilization in wet zone. In dry zone nitrate concentration in all samples was less than the maximum limit before applying fertilizer. But during the cultivation period 12% of the samples exceeded the WHO maximum contaminating level.

Most importantly, the phosphate concentrations in all groundwater samples were exceeded the WHO maximum contamination limits (0.01 mg/L) before and after fertilization. Before fertilization phosphate concentration of groundwater samples in wet zone varied from 0.05-0.4 indicating the average value is 0.77 mg/L. After fertilization it was varied between 1.0-34 mg/L and average value was 9.8 mg/L. In dry zone before cultivation the phosphate concentration in the samples were varied between 0.08 to1.46 and average value was 0.4 mg/L. But after cultivation it was varied between 0.5-31 mg/L being average value is 9.4 mg/L (Figure 2). Although phosphorus (P) is essential for plant growth, it is considered as a main limiting factor for algae growth in surface water. Heavy application of P-containing fertilizer such as single and triple super phosphates in paddy cultivation leads to the saturation of sorption sites of soils and therefore increases the risk of P loss to surface or groundwater via runoff or leaching.

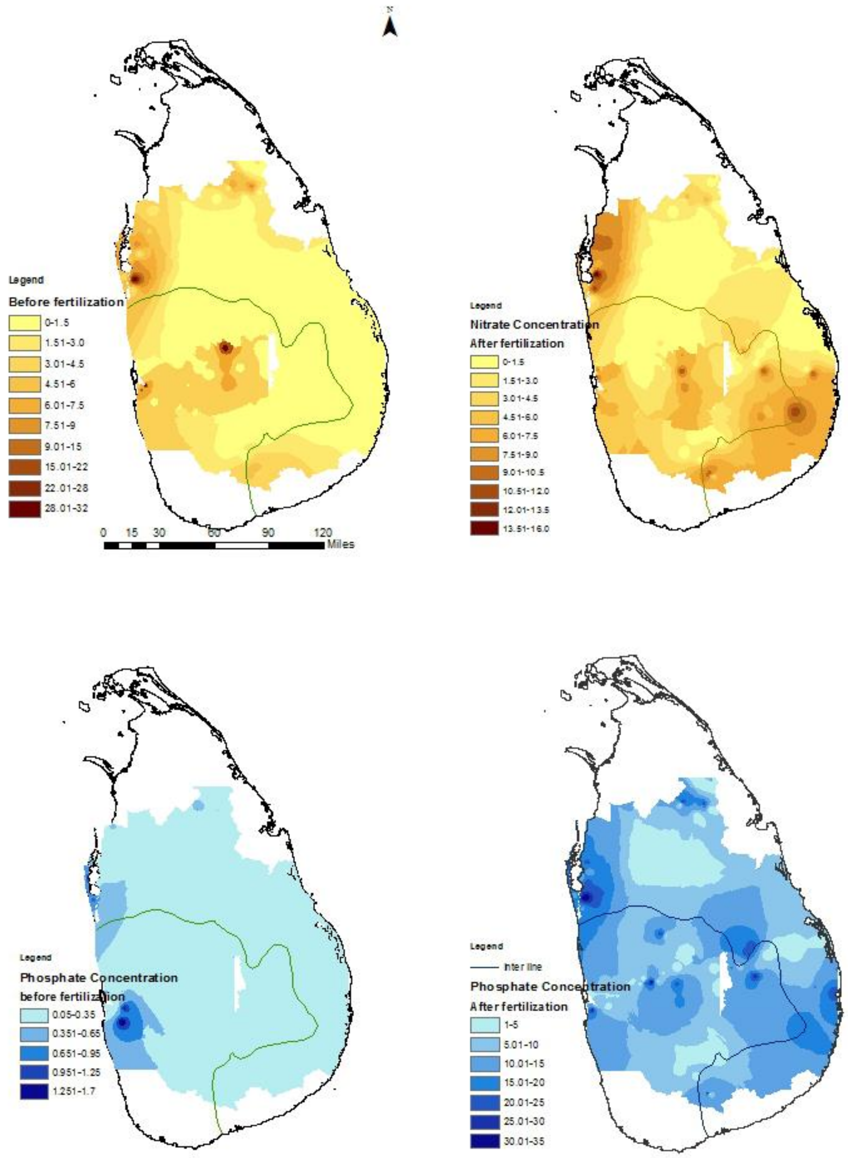

Figure 2 N and P variation in Wet Zone and Dry Zone Before and After Fertilization

The phosphate fertilizers are known to contain many trace metals such as uranium, radium [18] and cadmium [19] which can be accumulated in the environment. Nearly 75% from the entire population of Sri Lanka live in close association with the physical environment, obtaining their food and water from the immediate vicinity. Therefore any imbalance in the local environment with respect to minerals and human health could lead to health problems. The linkage of the incidence of some geographically distributed diseases (e.g.: dental fluorosis, iodine deficiency disorders) and environmental factors is clearly seen in Sri Lanka [20]. Among these environment related health problems, endemic occurrence of a chronic kidney disease (CKD) with an uncertain aetiology was first recognized in mid-1990s in certain geographically discrete areas in the Dry Zone districts of Sri Lanka particularly in the North Central Province (NCP) where the paddy cultivation is widespread. Recent studies revealed that some phosphate fertilizers used in chronic Kidney Disease (CKD) affected areas contain very high amount of potentially toxic trace metals. However it is speculated that fertilizers applied to the rice fields, mainly phosphates fertilizers should be investigated fully in terms of application, accumulation in soils and transferring into drinking water hence into the humans.

Compared to wet zones, the dry zone showed a higher level of phosphate and nitrate level is high in wet zone. It was observed that the amount of a nitrate lead fertilizer that reaches groundwater depends on a number of factors such as the amount used to the paddy fields. the geology of the region, climate of the region, groundwater flow direction and the characteristics of the fertilizer itself, such as how mobile and soluble it is in water. Aquifers are fractured in many places. In wet zone groundwater table is very close to surface and nitrate ion can be leached into shallow groundwater just after fertilization giving economic loss to farmers and lands can be vulnerable for cultivation regularly.

IV. CONCLUSION

According to the results of this study, it can be summarized that the groundwater collected from wet zone and dry zone in Sri Lanka indicated a clear difference in their water quality. High EC, high TH and high pH in the dry zone are notable compared to that of in the wet zone. This research found that NO3-N concentration in samples collected in shallow wells in wet zone shows the highest figures with compared with dry zone. The high rainfall (over 2500 mm/a) in wet zone leaches most of the major elements in wet zone, while opposite can be observed in dry zone areas. Deep ground water table in dry zone remains unpolluted and not vulnerable for nitrate pollution. However it was observed that timing and amounts for fertilizer applied directly influence the potential groundwater contamination in different climatic zones in Sri Lanka. When we consider the economic aspects of current practices, the removal of nutrients to groundwater body is considered to be great economical loss to farmers. Therefore proper management practices are needed where intensive agricultural activities are practiced.

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