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Seasonal Variations of Nitrate and Phosphate Levels in Groundwater: A Case Study of Mpongwe Farming Block in Zambia

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Abstract

In Mpongwe district of Zambia, farming is the major economic activity and is heavily dependent on the use of agrochemicals such as chemical fertilizers. However, excessive application of chemical fertilizers can pollute groundwater with nutrients. It is from this background that a study was undertaken in Mpongwe farming block to determine the seasonal variations of nitrate and phosphate levels in groundwater and their implication on the health of consumers and the ecosystem. Sixteen (16) water samples were collected from the same wells during both dry and rainy seasons and analyzed for nitrate and phosphate using the calorimetric method. A comparison of the concentrations of nitrate and phosphate in collected water samples was then made to determine if there are any seasonal variations of the aforementioned parameters in groundwater. The laboratory analysis revealed that concentrations of nitrate from water samples collected during the dry season ranged from 0 to 1.9mg/L with the mean of 0.4mg/L while those collected during the rainy season ranged from 0.03 to 2.2mg/L with the mean of 0.6mg/L. Concentration of phosphate in water samples collected during the dry season ranged from 0.1 to 7.43mg/L with the mean of 1.8mg/L while those collected during the rainy season ranged from 0.3 to 7.7mg/L with the mean of 2.2mg/L. The result of this study revealed that nitrate and phosphate concentrations in water samples collected during the rainy season where slightly higher than those sampled during the dry season. Variations in concentrations of these nutrients in groundwater samples collected during the rainy season could be attributed to the usage of chemical fertilizers by farmers in the area during the rainy season. However, concentrations of nitrate in all water samples complied with the Zambia Bureau of Standards (ZABS) and World Health Organization (WHO) drinking water maximum permissible limit of 10mg/L and 50mg/L respectively. With phosphate, there are currently no set standards, but the concentrations recorded for both parameters in all water samples is likely to have no negative effect on the health of the consumers and the ecosystem.

Keywords

Nitrate, Phosphate, Groundwater, Mpongwe Farming Block, Zambia

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1. Introduction

Groundwater is the major source of water for domestic and industrial uses in some parts of the globe. For example, an estimated 70% (193 million) of the population in Southern African region rely on groundwater as their only source of water [1]. In Zambia, groundwater accounts for approximately 28% of the domestic water supplies [2], and is increasingly becoming the major source of water especially in peri-urban and rural areas. In the capital city, Lusaka, groundwater accounts for approximately 55% of total supply [3]. However, the groundwater resources in Zambia are under

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threat of pollution from agricultural and other industrial activities [4-6]. It should be noted that once groundwater is polluted, it becomes difficult, expensive and often impossible to remediate hence the need to protect it [7].

Despite the important role that groundwater play in fostering socioeconomic development, there is paucity of information on its chemical composition in Zambia [8, 9]. The available limited chemical data suggest that the Zambian groundwater has generally very low concentrations of dissolved constituents [4]. It is however suggested that any pollution problems with groundwater in Zambia is likely to be associated with anthropogenic activities [10, 11]. As agriculture in Zambia remains one of the leading sectors in terms of food security, economic growth and poverty reduction [6], its impact on the quality of groundwater resources cannot be overlooked. The increase in agricultural productivity in Zambia has led to the growth of traditional livestock farming and also an increased demand of agrochemicals such as fertilisers and pesticides [12]. However, intensified livestock farming, excessive and inappropriate applications of fertilisers and pesticides have the potential to contaminate groundwater.

Pollution of groundwater by agricultural chemicals and wastes is a major issue in almost all developed countries. In developing countries on the other hand, the contributions of agriculture to water pollution are not well known. Quantifying these contributions is essential if national governments are to understand the full extent of the problem and to develop meaningful and cost-effective responses, [13]. According to [4], concentrations of nitrate in groundwater in Zambia are largely unknown although likely to be the highest in urban and agricultural areas. It should be noted that the consumption of groundwater containing high levels of nitrate may cause serious health effects and even death. High intake of nitrate by infants reduces the oxygen-carrying capacity in the blood leading to a serious health condition known as blue baby syndrome [14, 15]. Against, this background, this study intends to analyze the seasonal variations of groundwater in Mpongwe farming block in Zambia.

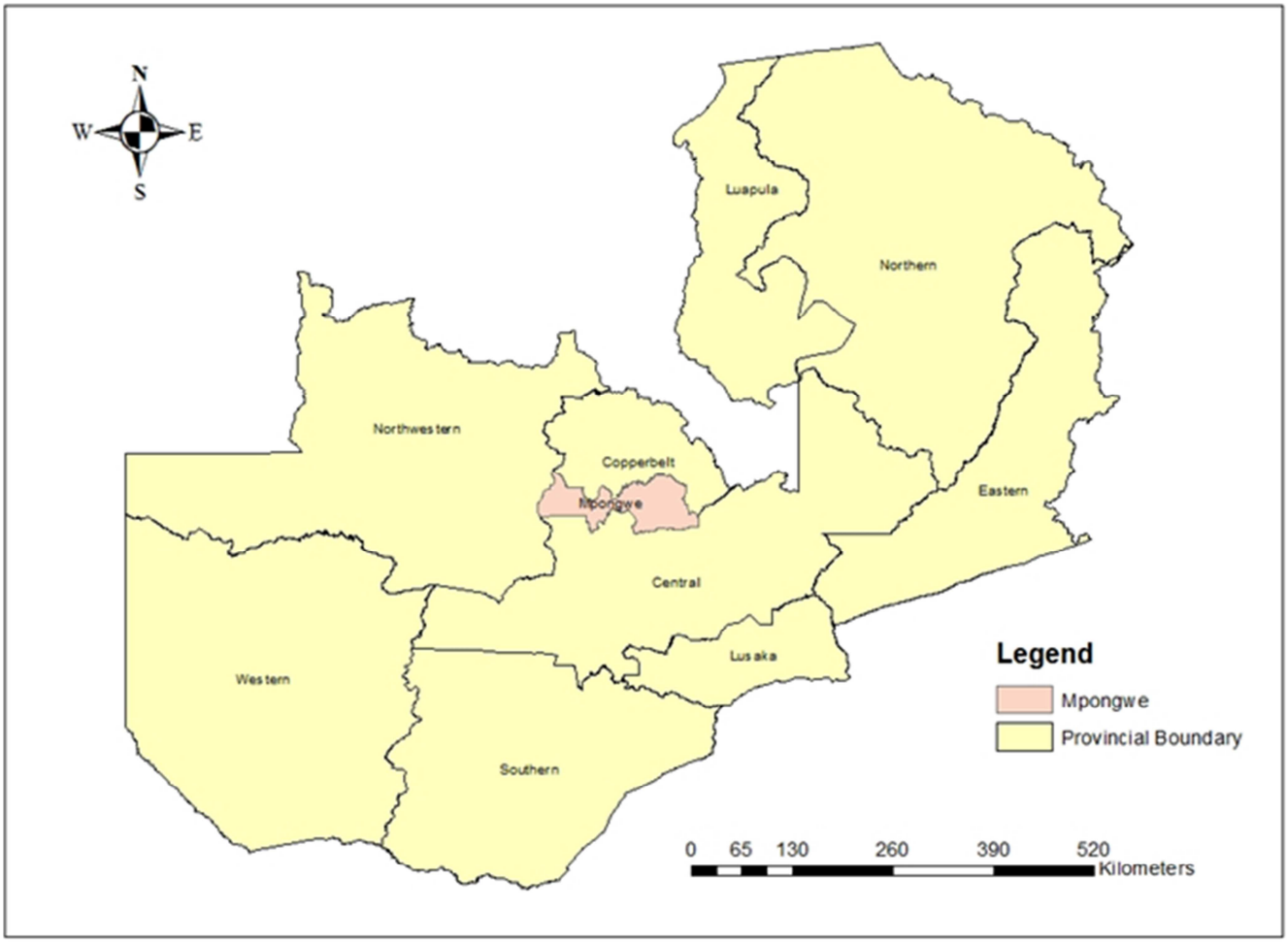

Figure 1. Map of Zambia showing Mpongwe District.

Site Location and Description

Mpongwe farming block is located in Copperbelt Province of Zambia which covers the mineral-rich region and is approximately 210km from the capital city, Lusaka. It also lies to the southern part of the Provincial headquarters, Ndola. Mpongwe district covers an area of approximately 8351km^2 and its geographical coordinates; latitude of -13.533° South and longitude of 28.150° East. According to the [16], Mpongwe district had a population of 89,950 in 2010 people. The district has the highest growth rate of 5.2% way above the national average. This is partly due to recent migrations caused by employment opportunities offered by the large-scale farming activities established in the district as well as the availability of land for resettlement. The major economic activity in the district is agriculture.

2. Methodology

Sample Collection and Analysis

The total of sixteen (16) groundwater samples was collected from the same wells and irrigation boreholes in Mpongwe farming block during both the dry season (September, 2017) and the rainy season (April, 2018). It should be noted that Zambia where the study area lies has two main seasons, the rainy season (November to April) and the dry season (from May to October). Polythene bottles rinsed with distilled water were used to collect the water samples from the wells and boreholes. Once water samples were collected, immediately preserved in a cool box and transported to the laboratory at the Copperbelt University within 24 hours for analysis. Concentrations of nitrate and phosphates were determined using the colorimetric spectrophotometer.

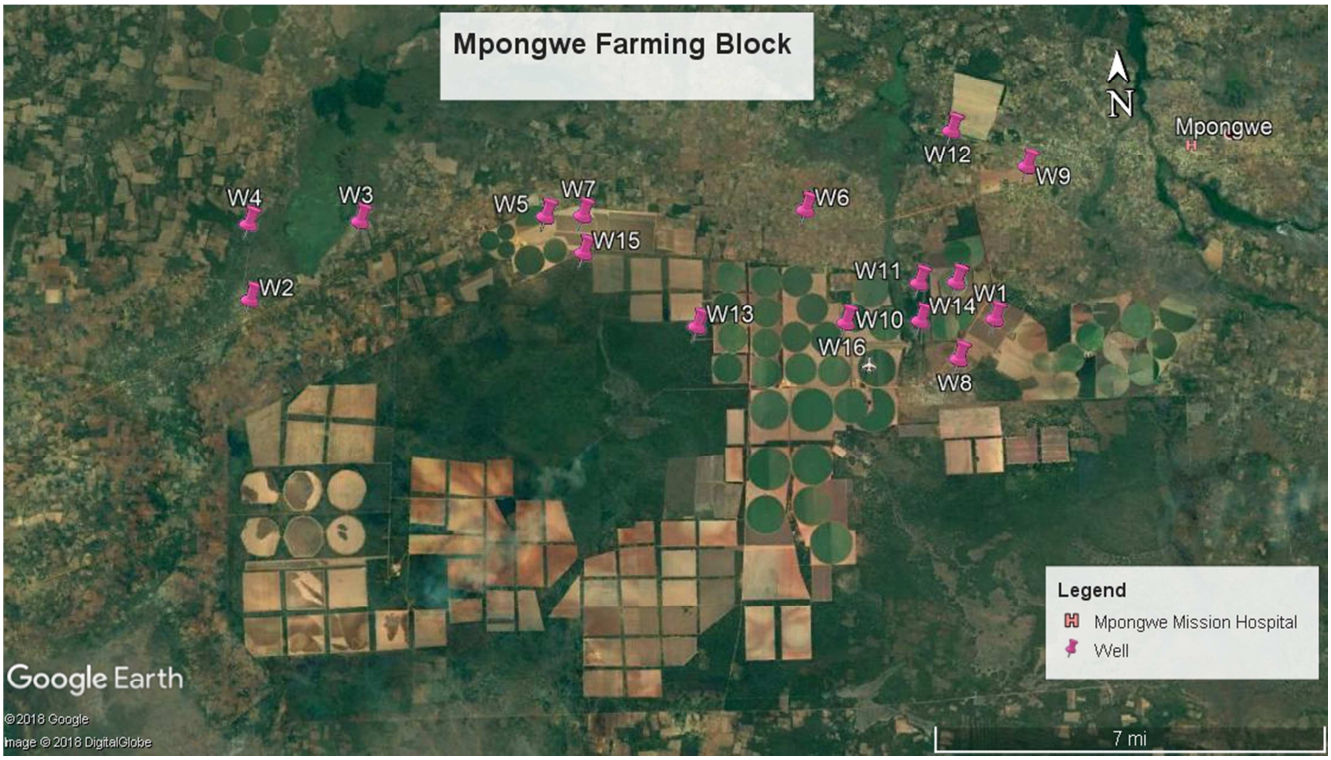

Figure 2. Sampled Wells in Mpongwe Farming Block.

3. Results and Discussion

Table 1. Measured nitrate and phosphate concentrations from the wells.

Well I.D	NITRATES (mg/L)	NITRATES (mg/L)	PHOSPHATES (mg/L)	PHOSPHATES (mg/L)
	Dry Season	Rainy Season	Dry Season	Rainy Season
WP1	0.02	0.07	0.50	0.70
WP2	0.04	0.08	0.10	0.30
WP3	0.00	0.05	1.40	1.70
WP4	0.00	0.06	1.40	2.00
WP5	0.80	1.20	2.50	3.10
WP6	0.03	0.10	1.87	2.30

Well I.D	NITRATES (mg/L)	NITRATES (mg/L)	PHOSPHATES (mg/L)	PHOSPHATES (mg/L)
	Dry Season	Rainy Season	Dry Season	Rainy Season
WP7	0.20	0.50	0.50	0.70
WP8	0.09	0.30	0.60	0.90
WP9	0.45	0.95	0.97	1.05
WP10	0.87	1.10	1.17	1.60
WP11	1.90	2.20	4.35	5.20
WP12	0.00	0.03	7.43	7.70
WP13	1.30	1.80	2.00	2.65
WP14	0.00	0.07	0.15	0.30
WP15	0.30	0.70	2.18	2.78
WP16	0	0.06	1.1	1.90

Results of the laboratory analysis of nitrate and phosphate concentrations for both dry and rainy seasons from the sixteen (16) wells are presented in table 1 above. It should be noted that thorough understanding of groundwater quality is important not only for protecting the health of consumers but also in determining its sustainability for other uses [17].

3.1. Seasonal Variation of Nitrate Concentration

From table 1 above, it can be observed that concentrations of nitrate in water samples collected from the wells during the dry season ranged from 0 to 1.9mg/L with the mean of 0.4mg/L. In the rainy season, the concentrations of nitrate in water sampled from the same wells ranged from 0.03 to 2.2mg/L with the mean of 0.6mg/L. The scatter plot and bar chart (figure 3 and 4 respectively) shown below indicate that the concentrations of nitrate in water samples collected in the dry season were slightly higher than those collected during the rainy season. This is contrary to the generally thought that nitrate concentrations are higher in the dry season and lower in the rainy season. The slightly higher concentrations of nitrate recorded in water samples collected during the dry season could be attributed to the leaching of chemical fertilizers from the soils into the groundwater during recharge. In the study area, farmers apply fertilizers during the rainy season which the main farming season in Zambia. It should be noted that nitrate is mobile in soil and will leach to groundwater unless absorbed by plants or denitrified under reducing conditions before reaching the aquifer [18]. It is further stated that the attenuation mechanism of nitrate in groundwater through dilution is a less important in nonpoint sources of nitrate. However, nitrate concentrations recorded in all the water samples during both rainy and dry seasons were below the maximum limit of 10mg/L and 50mg/L in drinking water set by the Zambia Bureau of Standards (ZABS) and World Health Organization (WHO) respectively.

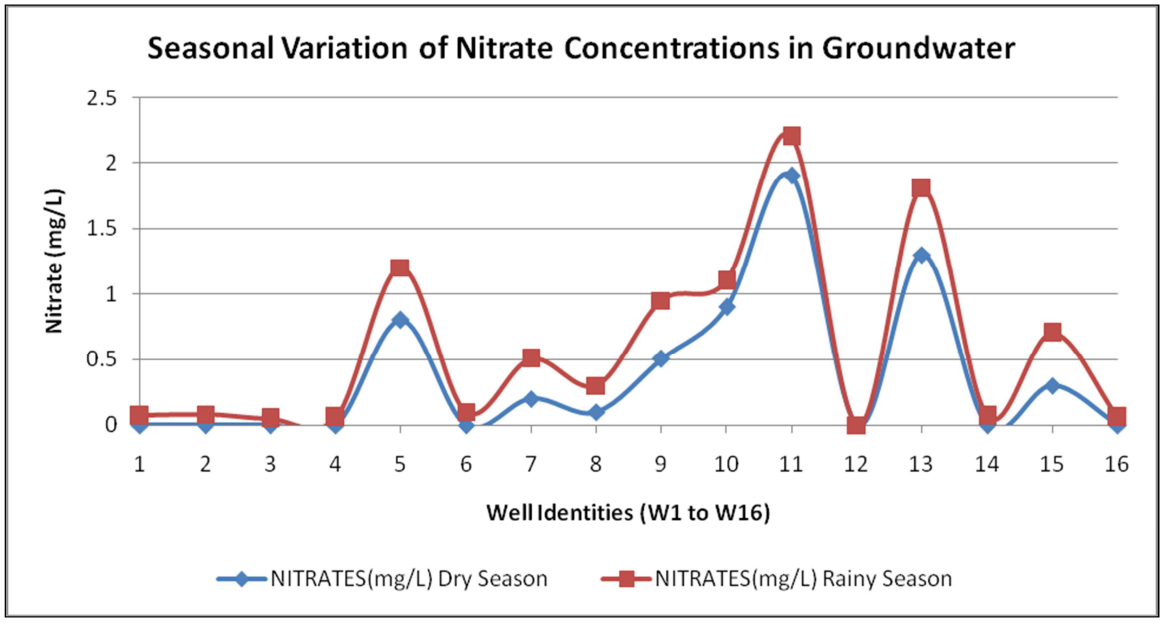

Figure 3. Scatter Plot showing Seasonal Variation of Nitrate in Groundwater.

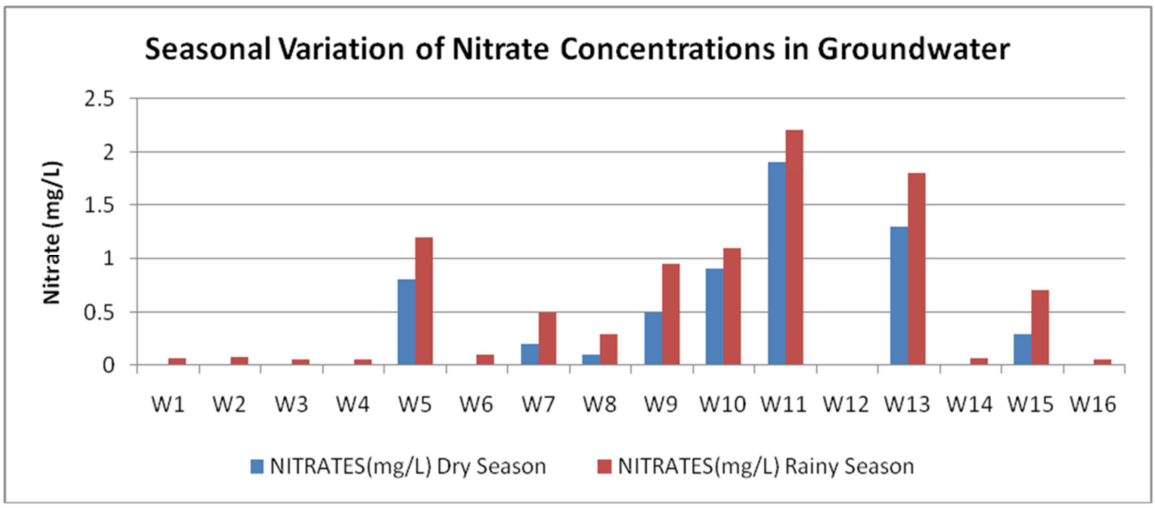

Figure 4. Bar Graph showing the Seasonal Variation of Nitrate in Groundwater.

3.2. Seasonal Variation of Phosphate Concentration

Phosphate is essential component require for the growth of plants and animals. Its main sources are drainage from farmland (fertilisers, manure, etc.) and sewage effluent. Phosphate is generally not toxic to people or animals unless its concentration is very high. Digestive problems could occur from consumption of water with extremely high levels of phosphate [19]. In this study, the concentration of phosphate collected from the wells during the dry season ranged from 0.1 to 7.3mg/L with the mean of 1.8mg/L. In the rainy season, the concentration of phosphate from water samples collected from the same wells ranged from 0.3 to 7.7mg/L with the mean of 2.2mg/L.

From the scatter plot and bar chart (figures 5 and 6 respectively), it can be observed that the concentrations of phosphate from water samples collected during the dry season is slightly higher than those collected during the rainy season. Just like nitrate, the slightly higher concentrations of phosphate recorded in water sampled during the rainy season could be attributed to the leaching of the phosphate fertilizers into groundwater during recharge from precipitation. It should be noted that farming in the study area is heavily depended on the application of chemical fertilizers. Therefore, the application of high quantities of chemical fertilizers may lead to an increase in phosphate concentration in shallow groundwater unless taken up by plants. There are currently no guideline values for phosphate in drinking water from both ZABS and WHO. Although the concentrations of phosphate in all water samples are relatively low, high concentration in groundwater discharged to wetlands or streams can lead to eutrophication, condition whereby aquatic plants and algae are over-produced. The algae bloom in streams consumes a lot of dissolved oxygen and also produces toxins that are harmful and possibly fatal to other aquatic life [20, 21]. It is therefore important to avoid excessive application of chemical fertilizers.

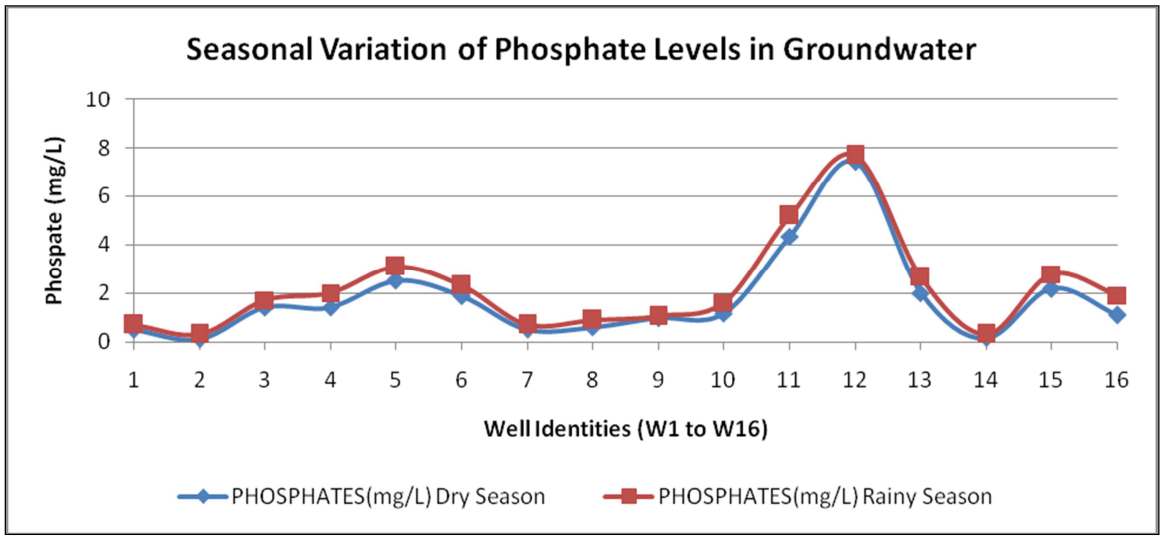

Figure 5. Scatter Plot showing Seasonal Variation of Phosphate in Groundwater.

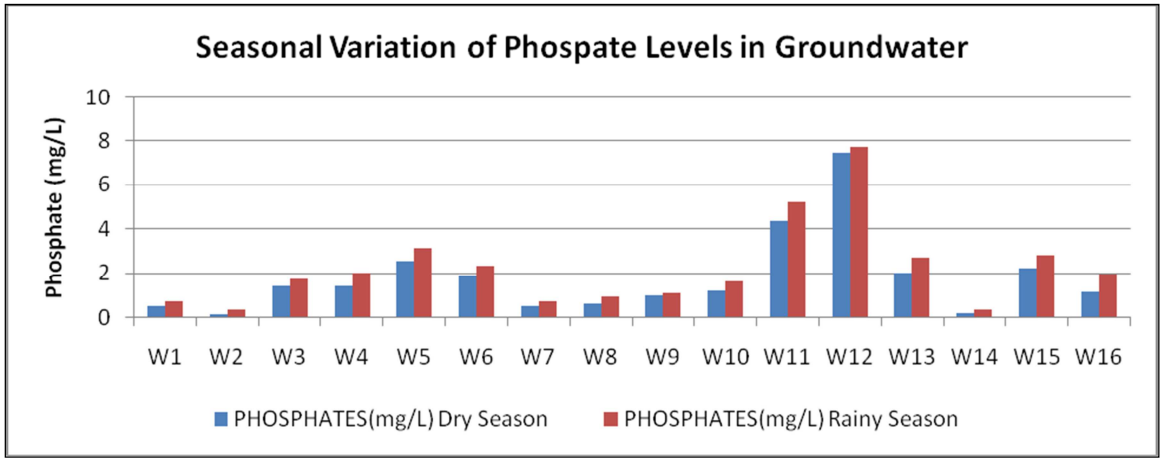

Figure 6. Bar Graph showing Seasonal Variation of Nitrate in Groundwater.

4. Conclusion

The results of this study indicate that nitrate and phosphate concentrations in groundwater samples collected from the same wells in Mpongwe farming block are slighly higher during the rainy season than in the dry season. This is contrary to the general thought that nutrient concentrations in groundwater are likely to be higher during the dry season compared to the rainy season. The higher concentration of nitrate and phosphate during the rainy season could be attributed to the increased usage of chemical fertilizers by farmers in the study area. In nonpoint sources like Mpongwe farming block, dilution during the rainy season is likely to have less effect on the attenuation of nitrate and phosphate leaching into the groundwater. It should however be noted that nitrate concentration in all the water samples collected in Mpongwe were below ZABS and WHO maximum limits of 10mg/L and 50mg/L respectively. In terms of phosphate, there are no set standards from both ZABS and WHO. However, the concentrations of phosphate in all water samples collected in the study area are likely to have no negative effects on human health and the ecosystem.

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