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Assessment of Factors Controlling Nitrate Levels In Groundwater of Bolinao Using Geographic Information System (GIS)

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Abstract: *This study aims to combine GIS and statistical methods such as Multiple Factor Analysis (MFA) and Multiple Linear Regression to characterize the spatio-temporal variation of groundwater quality and the factors affecting nitrate levels in groundwater of Bolinao. A hundred and twelve (112) wells in total were sampled for water quality including parameters such as pH, DO, ORP, salinity, conductivity, chlorophyll a and nitrate. About half of the nitrate levels in the study area exceeded the Maximum Concentrate Level (MCL) recommended by USEPA of 44.66 mg/L ranging from undetectable to 196 mg/L. Results showed that water quality was poor mostly at the vicinity of the foreshore area and high density built-up area, indicating human activity released significant amounts of pollutants to the groundwater. MFA revealed that septic tank density, TDS, Three-Dimensional Inverse Distance Weight (3D IDW), well depth, and distance to the shoreline had intercorrelation with nitrate in dry and early of rainy season. However, during the mid-rainy season, nitrate had no relationship with any variable that may be due to the effect of run off and rain water dilution on groundwater. Results from multiple regression analysis showed that the variables providing significant information to the variability of nitrate keep changing spatially and temporally, suggesting assumption of using the same explanatory variables to describe nitrate in the entire study area and every season is ineffective.*

Keywords: Groundwater; Nitrate; GIS; MFA; Multiple linear regression

1. INTRODUCTION

The major concerns of nitrate contamination are in the area of high density development or subdivided lots in close proximity to one another using septic tanks and water supply wells (Schneider et al, 1989; Taylor, 2003; McQuillan, 2004).Conventional septic tank system is designed specifically to remove partial BOD5, grease and bacteria threat. Yet, this design criteria does not address the water qualityproblems related tonitrate loading, total dissolved solid (TDS), nor cumulative impacts of the multiple systems(Schneider et al, 1989).

According to the United State Environmental Protection Agency (USEPA) the limit amount of nitrate in drinking water is 44.27 mg/l. Excessive nitrate can lead to methaemoglobinaemia or blue baby syndrome for young infants, gastric cancer, eutrophication, fishkill and aquatic ecosystem degradation (Taylor, 2003;Rios et al, 2011).

Accuracy in nitrate quantification is rarely to be met since nitrate concentration in groundwater is affected by many complex controlling factors(Alley, 1993). Regional groundwater quality assessment is complicated by the fact that nitrogen sources are highly spatially variable.

Understanding of interaction of nitrate and these factors is important in spatio-temporal variation analysis and transport fate modeling. GIS offers the tools to manage, manipulateprocess, analyze, map, visualize of nitrate movement in groundwater spatially and temporally (Almasri, 2007). However, GIS has no built-in function to interpret and distinguish the regional effect and other

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relating factors in nitrate variation. Thus, it is necessary to havean applied technique forfinding the spatial correlations or other spatial patterns using probability, statistics and modeling (Lee et al, 2011).

Many studies have attempted to combine GIS with statistical methods to find the factors affecting nitrate movement in groundwater. Barbiker et al. (2004) combined GIS and statistical analysis to study the extent and variation of nitrate contamination and to establish spatial relationships with responsible land use types. Hudak(2000) and Berktay (2006) used GIS and correlation methods to evaluate the relation between well depth and regional trend of nitrate. Masetti et al.(2008) use the weights of evidence (WofE) modeling implemented as an ESRI ArcView extension, basically based on map-correlation and map-integration processes to definerelationships between nitrate and combine predictor factors such as geoenvironment and population density.

In this study GIS and multiple statistical methodswill be used to characterize the spatio-temporal variation of ground water quality, with emphasis on nitrate concentration, in Bolinao, Pangasinan, Philippines. In addition, relative importance of anthropogenic and natural factors in influencing nitrate levels in groundwater will be identified and assessed.

2. MATERIALS AND METHODS

2.1 Study Area

Located in the western part of Lingayen Gulf, Bolinao, one of Pangasinan's municipal, is bounded by the China Sea on the north and west side; on the east, by the Kakiputan Channel and on the south by the rolling hills and plateaus of Bani. Study areas covers the town proper (Barangay Germinal and Concordia) and small part of Barangay Luciente 1 (Figure 1).The livelihood of people in the town proper is basically relied on commerce, tourism and trade as the economic activities among the small-scale businessmen. Meanwhile, agriculture, crop production, fishing, and mariculture are the chief economic activities outside the town.

Bolinao has two pronounced seasons, namely, wet and dry. Dry season starts from mid-November to early June while the rainy or wet season starts from mid-June to early part of November.The temperature of the region can be reached up to 34.7 degrees centigrade with the annual mean temperature is estimated from 27.74 degrees centigrade. The main relative humidity varies from 78 to 91 percent which is unlikely to occur during the dry season starting from February to May.July and especially August are the wettest months with rainfall reaching 852.40 mm.

With the small portion of land about 1 square kilo meter,Bolinaois suffering from water quality pollution from about 1970 septic tanks and ditches. Those systems can release nutrients such as nitrate and phosphorus, bacteria and other chemical substances into the groundwater if they fail to perform properly or leak. Moreover, based on field observations, the spacing of each septic tank to the wells is not compliant with the standard distance recommended by the USEPA (15 m). This requires the assessment on the water quality of those drinking wells to ensure that this common practice do not provide any hazard to users. However, no research has been made to examine groundwater quality as well as the sources of nitrate in groundwater of that area before.

Fig.1. Location map of the study area

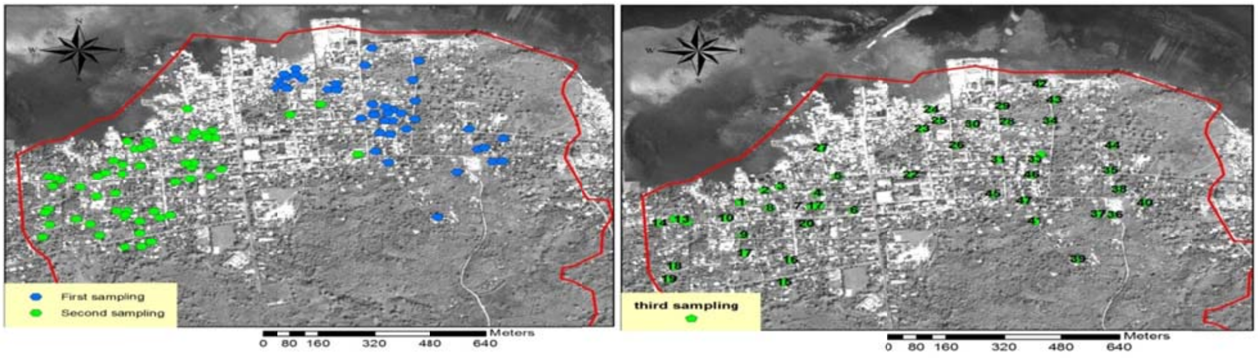
2.2 Water quality sampling

46 wells were sampled during the dry season (February 26 - March 3, 2012) between East of Bolinao town proper and Barangay Luciente 1 and another fifty-six (56) wells were collected in the start of rainy season (May 31 - June 2, 2012) at the West part of Bolinao town proper (Figure 2 a).The sampling wells were the shallow type with the depth ranges from 1 to 25 m.

A CTD-type instrument (AAQ-1183, Alec Instrument Co., Japan) was used to measure pH, salinity, conductivity, dissolve oxygen (DO), Oxidation Reduction Potential (ORP), and Chlorophyll a. Nitrate in mg/l was tested by a Nitrate Electrode NO 800 (WTW GmBH, Germany). The last sampling was held in the mid-rainy season from July 28 – 29, 2012 (Figure2 b) for the same in situ parameters as before except more samples of nitrate were collected and analyzed offsite using photometer (V-2000, Chemetrics, Inc., USA) to compare with the results of Nitrate Electrode that were interfered by many ions in groundwater.

2.3 Data management and analysis using GIS

Figure 3 is the overall data processing in GIS. First, watershed boundary was delineated from the ASTERG DEM with a 30 m by 30 m resolution. Second, building, and coastline location were mapped from high resolutionsatellite image via manual digitizing. Then, the septic tank density of a 100 m search radius was obtained from the building map by using Kernal Density function in ArcGIS Spatial Analyst tools. Position of wells consisting of water quality data, information of households were converted from excels sheets to shapefiles using Create XY Event Layer in ArcGIS10 tool box. After this, 3-Dimensional Inverse Distance Weight (3D IDW), which accounted for the distance from the depth of the each sampling wellto the 50 m surrounding septic tanks, were computed by theNear function in GIS spatial analysis.Finally, all the data were overlaid for spatio-temporal and statisticalanalysis of nitrate distribution.



(a) (b)

Fig.2. Sampling wells in (a) the dry season and the beginning of rainy season (b) the mid-rainy season

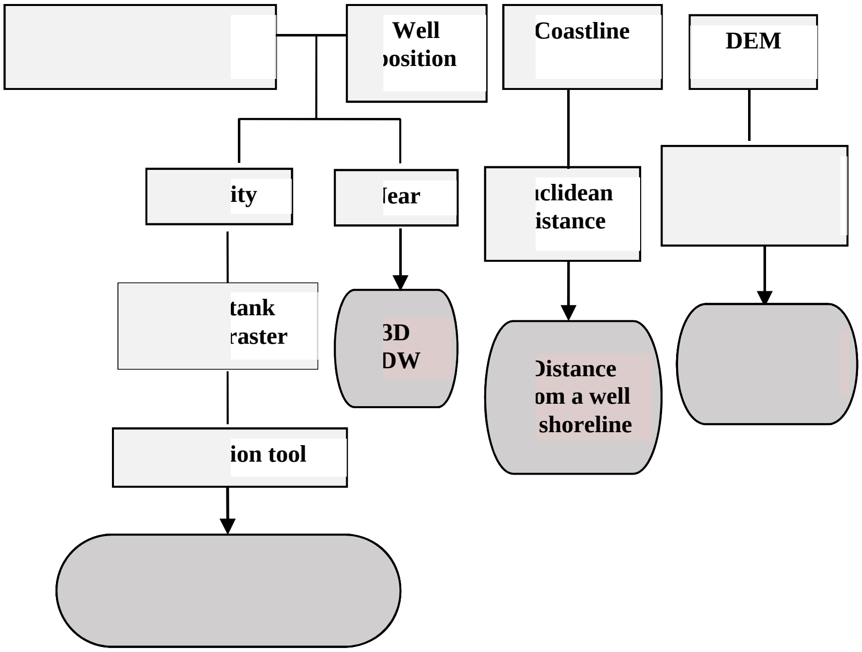


Fig.3. Overall data processing in GIS

2.4 Three-Dimensional Inverse Distance Weight (3D IDW)

3D IDW was used instead of the two-dimensional version due to the fact that when two-dimensional IDW and septic tank density were added together in the multiple regression analysis, these two factors may produce multicolinearity. Multicolinearity occurs when two variables are highly correlated. To avoid this, IDW wasalso taken into account for the depth of each sampling well with the equation and figure below:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (1) \quad \text{or}$$

$$D = \sqrt{(\text{distance between well and septic tank})^2 + (\text{water table})^2} \quad (2)$$

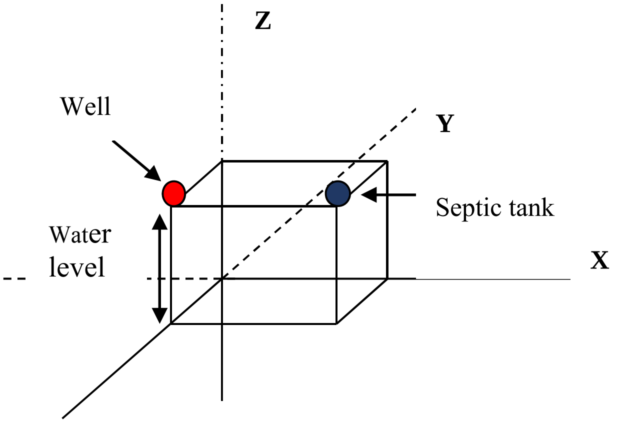


Fig.4. Distance between two points in 3D space

2.5 Statistical Analysis

The obtained matrix of dataset was subjected for multivariate analytical techniques such as correlation analysis, multiple factor analysis (MFA) and multiple regression analysis.

These techniques help to find the relationship between two or multiple factors and simplify large data sets in order to make useful generalizations and insight. These analyses were performed using an add-ins software for Microsoft Excel, namely XLSTAT.

2.5.1Multiple Factor Analysis

Since many variables are highly correlated with each other and redundant, factor analysis aims to explain observed relation between nitrate and numerous variables in term of simpler relations. By applying this method, an originally large number of variables are reduced to a few factors through factor analysis method. These factors can be interpreted in terms of new variables. It is also a way to classifying manifestation of variables (Singh et al., 2008). The factor model used is expressed as:

$$X_j = \sum_{r=1}^{p} a_{jr} f_r \in_j$$

Where fr is the rth common factors, p is the specified number of factors, "j" is the random variation unique to the original variable Xj, aji is the loading of the Jthvariate on the rth factor. It corresponds to the loading or weights on principal components. The principal component approach was started by extracting eigenvalues and eigenvectors of the correlation matrix and then discarding the less important of these(Singh et al., 2008).

2.5.2 Multiple Linear Regression

Regression analysis attempts to study the relationship between a dependent variable and a set of independent variables (one or more). In this study, multiple linear regressions will be used to examine, and explore spatial relationships between any parameters that have significant relationships with nitrate.

Regression is the process of fitting an equation to the data. Sometimes, regression is called curve fitting or parameter estimation. Empirical models are widely used in engineering. Sometimes the model is a straight line; sometimes a mathematical French curve — a smooth interpolating function — is needed. Regression provides the means for selecting the complexity of the French curve that can be supported by the available data (Berthou and Brown, 2002).

A multiple regression model that might describe this relationship is

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \epsilon$$

where:

Y is the dependent variable, $X_i$are explanatory variables,

Coefficients (β): values, computed by the regression tool, reflecting the relationship and strength of each explanatory variable to the dependent variable,

Residuals (ε): the portion of the dependent variable that isn't explained by the model; the model under and over predictions.

All the variables were input into the regression to select the best model to predict nitrate variation. As this regression work best for the linear relationship, nitrate will be transformed to logarithm scale for some cases in order to obtain straight-line relationship between multiple variables.

3. RESULTS AND DISCUSSION

3.1 Ion selective Method vs. Colorimetric Method in Analyzing Nitrate in Groundwater

As groundwater usually contains many kinds of ions, nitrate was analyzed using combination methods such as Nitrate Electrode and colorimeter to overcome the interferences of ions on the measurement. As a result, linear equation was obtained from the comparison of both equipments in the third sampling. This equation was then used totransform all the data in the first and second sampling.

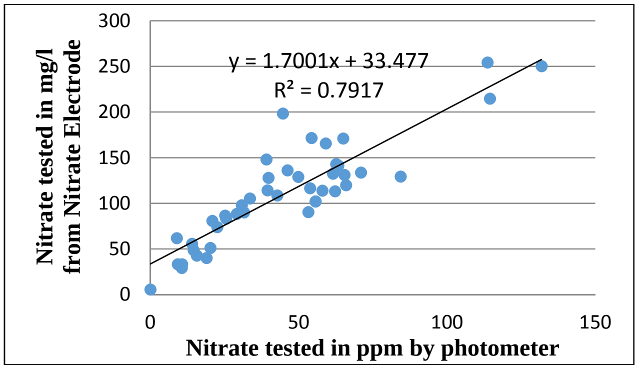


Fig.5. Relationship between nitrate concentrations measured using from Nitrate Ion Selective Electrode and Photometer

3.2 Spatial Variation of Water Quality in the Study Area

pH in the first sampling ranged from 6.64 to 7.76 with the temperature of 27 to 31^{0}C. pH ranged from 6.7 to 7.1 with the temperature of 28 to 35.5^{0}C in the second sampling. No significant variation of pH and temperature were detected. The pH values of both sampling periods indicate the bicarbonate environment, which is dominated by Ca and Mgb(Hounslow, 1995). These ions were the major sources of interference during the sampling. Average DO was 3.6 mg/l ranging from 6.2 to 1.4 mg/l in the first sampling. The highest DO was found in the barangay Luciente 1, where the distribution of houses was sparse. DO droppedbelow 4 mg/l once the groundwater reached the town proper boundary and kept decreasing below 2.5 mg/l towards the shoreline, where high density of informal settlers could be found. Depletion of DOin the crowded area indicatedthe presence of oxygen demanding materials from anthropogenic sources.

DO in the second sampling varied from 1.3 to 6.72 mg/l. However there was no trend of DO variation to be observed in the second sampling.

In the first sampling, TDS ranged from 425 to 3667 mg/l with the average of 880 mg/l. All of the up-gradient wells in the Barangay Luciente 1 had acceptable TDS value (about 500 mg/l). 8 of the 11 wells located about 100 m were affected by sea water intrusion (TDS above 1000 mg/l).25 out of 56 or 45 % of the wells measured in the second sampling were found brackish. Those brackish wells were observed from about 3m to 400 m offshore. As TDS can be increased due to human activities, all the salt encroachment wells were excluded from the statically analysis in order to avoid misinterpretation(Figure 6 A,B).

In the first sampling, ORP ranged from 259 to 114 mV with the averageof 224 mV. ORP did not vary significantly, except few wells close to the sea that ORP dropped below 200 mV. ORP ranged from 67 to 257 mV in the second sampling. ORP drop once salt increase due to the oxidation of organic compound and ion species (Kresic, 2009). ORP is the indicator of nitrogen form. Under reducing or anaerobic condition, nitrate will be converted to nitrogen gas. The current oxidation system implies that the chance of water to recover from nitrate contamination by denitrification is very low(Figure 6 A,B).

During the first sampling, few wells located in the upper part of the watershed about 2 km from the town proper were measured for nitrate as the controlling wells. None of those wells had nitrate concentration more than 10 mg/l. Those wells are located in fallow land with small crop activities. On the other hand, nitrate concentrations ranged from 2 to 96.2 mg/l with the mean of 35.89 mg/l in the first sampling site. Nitrate levels increased as the location of the wells became closer to the town proper. As a result, 10 out of 42 wells (24 %)had nitrate concentrations exceed USEPA MCL of 44.27 mg/l. Acceptable nitrate level wells were found in the Barangay Luciete 1, but high nitrate levels were found in the town proper wells. In addition, peak value of nitrate were observed in the informal settler area close to the sea (where septic tank density varies from 50 – 90 per ha) as shown in Figure 7 A,B).

In the second sampling, 31 of 56 wells (55.35%) had nitrate level over the standard limit. Nitrate ranged from undectected to 196 mg/l with the mean of 60.8 mg/l. Most of the wells with elevated nitrate concentrations are located close to the shore and near the center of the town proper (Figure 8 A,B).

3.3 Temporal Variation of groundwater quality in the study area

According to Figure 9, pH was more alkaline during the dry season (Feb 26 – Mar 3, 2012) due to the geology of the study area and effect from the tides since the study area is located in a coastal land.Usually, when groundwater is diluted with rainwater, pH become less alkaline. As a result, in the beginning of rainy season, pH dropped a bit. In the heavy rain season, pH dropped more.

Wells with low DO were compensated by the recharge raindrop providing such amount of oxygen to the soil and groundwater. However, wells that had the lowest DO for all the seasons are located at the vicinity of the foreshore area or discharge points where oxygen is already depleted due to the organic material along the pathway.

TDS in themid-rainy season were lower than in the dry and beginning of rainy season.Therewere no more wells severely contaminated by saltwater encroachment (TDS

>1000 mg/l). The lower level of TDS concentration during the mid-rainy season may be due to a combination of the following: septic tank seepage dilution effect; increased throughflow from increased precipitation; and declining soil salinity due to a flushing effect. In addition, redox potential in most wells was increased due to the supply of DO and dilution of ion species.

During the mid-rainy season, 48 % of sampling wells have nitrate concentration exceeding the MCL of nitrate. Nitrate in most wells increased more compared to the dry season. This could be caused by the rains, which enhanced the leakage of existing septic tank, poor drainage system, and spread of pollutants from the houses using ditch system and other surrounding sources. The levels of nitrate between early and mid-rainy seasons varied more or less according to the location of the wells.

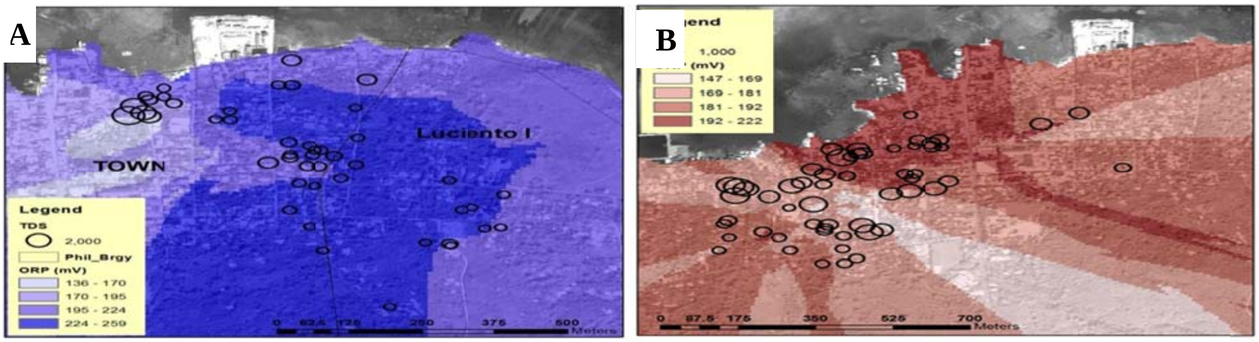


Fig.6. Spatial variation of ORP and TDS (A) in the first sampling, (B) in the second sampling

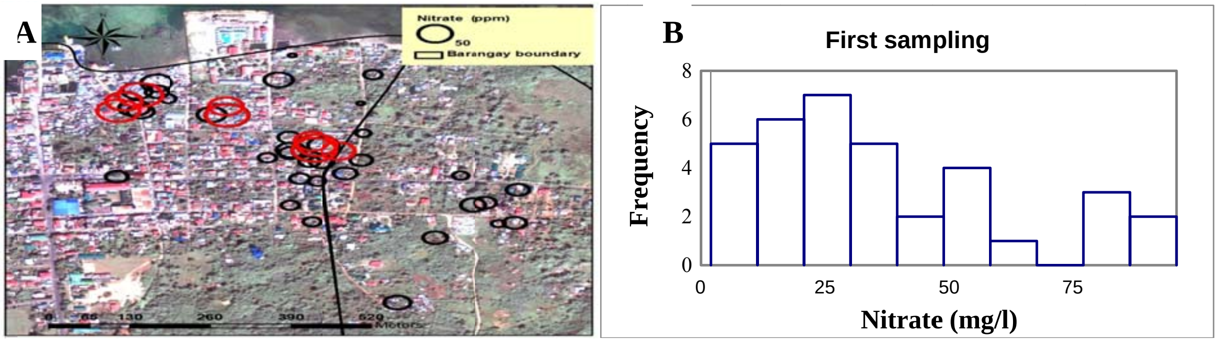


Fig.7 (A) Nitrate concentration of the first sampling with the excessive amount shown in red circle; (B) Frequency histogram of nitrate level during the first sampling

Fig. 8 (A) Nitrate concentration of the second sampling with the excessive amount shown in red circle; (B) Frequency histogram of nitrate levelduring the second sampling

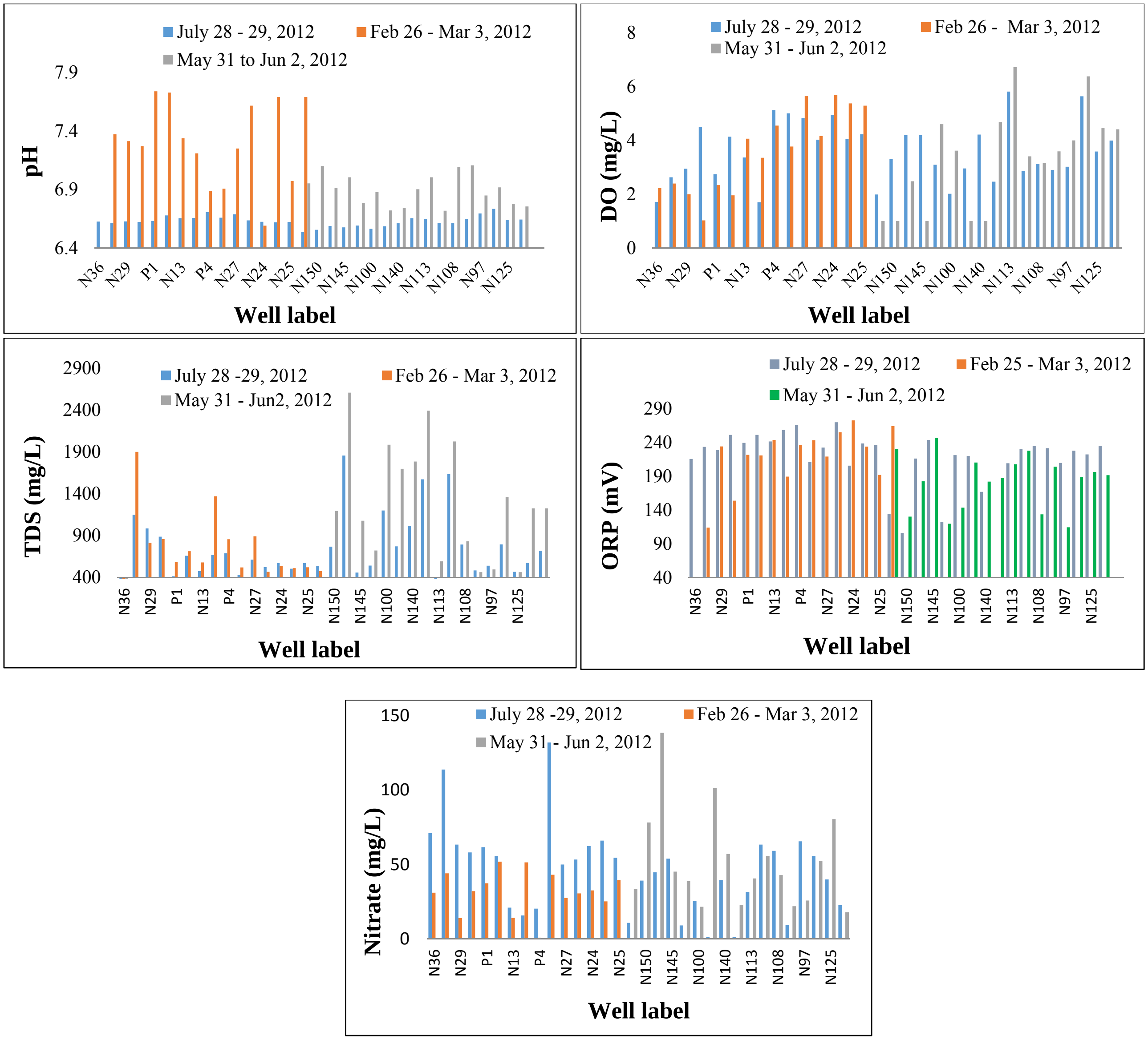


Fig.9. Temporal variation of groundwater quality in the study area

3.4 Multiple Factor Analysis for factors affecting nitrate level

During the first sampling, all parameters affecting water quality were broken down into four main factors, which explain about 67 % of total sample variance as indicated in Table 1.

The variances as explained by the factors were 32.73 % for factor 1, 15.42 % for factor 2, 11.54 for factor 3, and 7.83 % for factor 4.The first factor was positive related to pH, septic tank density, TDS, and nitrate; meanwhile it was negatively related to the DO, well depth and distance to the shore. The positive correlation suggested that nitrate increased accordingly to the level of TDS, pH and number of septic tank. The negative relationship between nitrateand other parameters indicated that shallow wells were more susceptible to nitrate than the deep ones, and the more closer the well were to the shore, the more nitrate concentration increased. In addition, low DO would be found where water contains high nitrate.

The second factor was positively loaded on chlorophyll-a and negatively loaded on temperature. The third factor was heavily loaded on 3D IDW, while the last factor was positively related to ORP.

Table 1. Multivariate factor analysis of chemical constituents of groundwater samples in the 1st sampling

Variables	F1	F2	F3	F4
Temp	-0.02	**-0.49**	0.28	-0.31
Chl_a	0.24	**0.77**	-0.28	-0.31
pH	**0.49**	-0.35	0.35	0.26
ORP	-0.35	0.09	-0.03	**0.45**
DO	**-0.39**	-0.28	0.13	0.13
septic tank density	**0.89**	0.03	0.15	0.25
well depth	**-0.73**	0.50	0.17	0.42
TDS	**0.76**	0.05	0.23	0.00
distance to the shore	**-0.59**	-0.16	0.35	-0.09
nitrate	**0.801**	-0.026	-0.294	0.298
3D IDW	0.247	0.563	**0.780**	-0.120
Percentage of variance	32.730	15.425	11.541	7.837

According to Table 2, the variables of factor 1 in the second sampling such as septic tank, nitrate, 3D IDW and TDS were found to have intercorrelation with each other suggesting water quality was affected by human pollution. Nitrate increased according to the number of the septic tanks and the distance from them to the well. The same case with the first sampling, nitrate correlated negatively with well depth and distance to the shore, revealing that nitrate accumulation occurred in the downgradient wells where the depth was most likely shallow. Variables of the factor 2 and 3 seemed to be affected by the natural process such as temperature and seasonal conditions. As a result, pH increased according to the temperature, and ORP decreased while chlorophyll increased simultaneously with DO during the beginning of rainy season.

Table 2: Multivariate factor analysis of chemical constituents of groundwater samples in the 2nd sampling

Variables	F1	F2	F3
Temp	0.010	**-0.439**	-0.306
Chl_a	-0.321	-0.193	**0.527**
pH	0.322	**-0.700**	-0.272
ORP	-0.336	0.363	**-0.605**
DO	0.198	0.237	**0.515**
septic tank density	**-0.839**	-0.072	0.049
well depth	**0.481**	-0.220	0.000
TDS	**-0.836**	-0.155	0.141
distance to the shore	**0.840**	0.398	0.068
nitrate	**-0.716**	-0.246	0.153
3D IDW	**-0.749**	0.403	-0.191
Percentage of variance	35.136	12.664	10.630

However, regarding to Table 3, nitrate in the third sampling (mid-rainy season) did not correlate with any parameters, which may result from the effect of heavy rainfall.

Table 3: Multivariate factor analysis of chemical constituents of groundwater samples of the third sampling

Variables	F1	F2	F3	F4
Temp	0.112	-0.094	0.119	**-0.453**
Chl_a	**0.645**	-0.134	-0.246	0.293
pH	-0.284	**0.338**	0.208	-0.004
ORP	-0.157	**0.489**	-0.064	-0.186
DO	-0.219	**0.421**	0.144	-0.115
septic tank density	**0.724**	0.061	-0.087	-0.082
well depth	-0.481	**-0.699**	-0.303	-0.005
TDS	0.364	**-0.678**	0.633	0.064
distance to the shore	**-0.798**	0.276	0.201	0.379
Nitrate	0.165	0.118	**0.245**	0.001
3D IDW	**0.858**	0.465	0.030	0.158
Percentage of variance	26.684	16.821	8.683	6.840

3.5Multiple Linear Regression analysis between nitrate and independent factors

As shown in Table 4, after all the variables including water quality parameters, septic tank, well depth, distance to the shoreline and the 3D IDW were input together, five variables were selected as the best explanatory variables for the model with the coefficient of determination R^2= 0.63 (after nitrate values were transformed to logarithm scale) meaning that 63% of the variability of nitrate in the study area was predicted. Those independent parameters are temperature, pH, ORP, DO, septic tank density. The root mean square value (RMSE) is 0.057. With the Fisher's F test lower than 0.001, it means that we would be taking a lower than 0.01% risk in assuming that the null hypothesis (no effect of the all explanatory variable) is wrong.

The probability P to the t value (Pr> t) can be used to indicate whether a variable brought significant information or not after all the other variables were included in the model. The probability P to the t value (Pr> t) of each variable showed that only septic tank density and DO (Pr>t belowthe threshold value of 0.05) contributed significant information the model once other variables were added at the same time (Table 4).

Table 4: Model parameters of the first sampling

Parameter	Value	Standard error	t	Pr> |t|	Pr> F
Intercept	3.29	1.66	1.98	0.06	**<0.0001**
Temp	-0.05	0.05	-1.03	0.31	
Chl_a	-0.29	0.14	-1.96	0.06	
DO	-0.09	0.04	-2.20	**0.03**	
septic tank density	0.01	0.00	4.94	**< 0.00**	

R^2 =0.6 with the equation: lognitrate = 3.29 - 5.91E-02 * Temp - 0.291*Chl_a - 9.74E-02 * DO + 1.01E-02 * Septic tank density

As shown in Table 5, four parameters of the second sampling were selected for the best model including septic tank density, TDS, shoreline and DO. The model accounted for 66 % of nitrate variability. RMSE is 28.98. Based on the Fisher's F test of 0.0004, the risk of rejecting the null hypothesis (variables has no effect) is less than 0.01 %. Based on the probability to the t (Pr> t) equal to 0.05, DO and shoreline distance contributed significant information to the model among the four variables. This may be because septic tank density in the beginning of rainy season was not the only dominant source of nitrate. As mention above, the run off can promote the existing leakage of septic tank, overflow of toilet ditch and carry pollutants from point sources such as markets, hospital and other infrastructures, leading to the accumulation of nitrate at the shoreline (discharge point) and dissolved oxygen increase.

Table 5: Model parameters of the second sampling

Parameter	Value	Standard error	t	Pr> |t|	Pr> F
Intercept	48.97	60.44	0.81	0.428	**0.0004**
DO	12.36	5.18	2.38	**0.028**	
septic tank density	-0.95	1.03	-0.92	0.369	
shoreline distance	-0.28	0.08	-3.24	**0.005**	
TDS	0.10	0.07	1.34	0.196	

R^2=0.66 with the equation: Nitrate = 48.97 + 12.36 * DO - 0.95 * septic tank density - 0.28 * shoreline distance + 0.10 * TDS

During the third sampling, the best performance of the model accounted only for 13 % of variation (R^2 = 0.13). Moreover, none of thePr> t value contributed significant information to the model (Pr>t higher than 0.05). According to Table 6, this performance is very poor, meaning during the heavy rainy season, there are other important factors that have not included in this analysis.

Table 6: Best model selected for the second sampling

Parameter	Value	Standard error	t	Pr> |t|	Pr> F
Intercept	-82.7	99.4	-0.83	0.41	0.25
Temp	2.59	3.38	0.77	0.45	
Chl_a	9.64	5.60	1.72	0.09	
DO	3.07	2.02	1.52	0.14	
septic tank density	0.25	0.14	1.76	0.09	
shoreline distance	0.02	0.02	1.18	0.25	

R^2=0.13 with the equation: Nitrate = -82.70 + 2.59 *Temp + 9.63 * Chl_a + 3.07 * DO + 0.24 * septic tank density +1.95E-02 * shoreline distance

4. CONCLUSIONS

The aim to characterize the spatio-temporal variation of groundwater quality in the study has been accomplished with the help of GIS in enhancing data collection, processing, and rapid visualization. Results showed that water quality was poor mostly at the vicinity of the foreshore area and high density built-up area, especially the informal settlement with a septic tank density of about 50 to 90 per ha. This degradation of water quality proportional with population density indicated human activities released pollutants to the groundwater. However, beside human activity, salinity of the wells in the area was also affected by seawater intrusion.

About 4 %, 55.35 % and 48 % of sampling wells had nitrate concentration exceeding the MCL of 44.66 mg/l in the first, second and third sampling, respectively. Overall nitrate from the sampling wells ranged from undetectable to 196 mg/l. Nitrate about 2 km inland from the shore was below the background value and increased dramatically as the distance nears the town proper. Moreover, aerobic and oxidation condition of groundwater in the study area imply that the chance of biological removal of nitrate by denitrification is low.

According to temporal analysis of water constituents, during the wet season, the quality of DO, ORP and TDS were better due to the effect of dilution and more oxygen supplying by rainwater. Meanwhile, pH became lower (more acidic) and nitrate increased severely due to the effect of stormwater runoff, which carry pollutants from the upper part of the watershed (agricultural land), and surrounding places. Also, the rainwater can enhance leakage from septic tanks, poor sewage system, and ditch overflow.

Results from MFA revealed that septic tank density, TDS, 3D IDW, well depth, and distance to the shoreline had correlation with nitrate in the first and second sampling, which was conducted in the dry and beginningof rainy season. The results suggested that nitrate level increased according to the number of the surrounding septic tanks and the level of TDS. However, nitrate varied inversely with the depth of the well and distance from the well to the septic tank. During the third sampling held in the mid-rainy season, nitrate had no relationship with any variable and this may be due to the effect of run off and dilution with the rain water on the groundwater.

Results from multiple regression analysis revealed alternative group of variables affecting nitrate. The variables providing significant information to the variability of nitrate keep changing spatially and temporally, suggesting assumption of using the same explanatory variables to describe nitrate in the entire study area and every season is ineffective. Since the optimum performance of the model is about 66 % only (R^2 0.66), it means that there are other underlying parameters need to be studied due to the complex mechanism of nitrate contamination resulting from seasonal changing, landuse pattern, plant uptake, geology of the study area, and so forth.

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