MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY

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SPATIAL VARIABILITY MAPPING OF SOIL PROPERTIES FOR AGRICULTURAL PURPOSES USING GEOSTATISTICAL TOOLS – A CASE OF M'MINA VILLAGE

FLORIDA CHIGULE

Thyolo, Malawi.

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DISSERTATION APPROVED BY:

SUPERVISOR:

Mrs. E.G Chimimba Signature: _____

ASSESSOR:

Title, Initials, Name Signature: _____

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ABSTRACT

The scientific assessment of soil involves the analysis of the physical, chemical as well as the biological properties of soil. These kind of assessments differ from the general tradition assessment (where soil quality is assessed by the quality and stand of the crops grown on the soil) in that they take into consideration important scientific facts such as the variability of soil nutrients in space. The information from such analyses is essential in making the right and proper decisions for improved and sustainable agriculture. It was therefore the aim of this study to conduct such an analysis with the objective of determining the spatial variability of the main three macronutrients, NPK. The study area was M'mina village found in Thyolo which is in the southern region of Malawi. 10 georeferenced soil samples were collected from non-random locations in the area and analyzed at Bvumbwe Research Station to determine their concentrations. The data was then analyzed using geostatistical tools, semivariogram and Ordinary Kriging and maps classifying the concentrations of these elements were produced. The results showed that N was very low and low in 28% and 72% of the whole area respectively; P varied from low, medium, high and very high in 41%, 27%, 9% and 23% of the whole area respectively and K varied from being very low, low and then medium in 48%, 49%, and 3% of the whole area. Conclusions drawn from these results were that legumes are the most suitable crops for this area followed by other plants like lettuce, cassava and sweet potatoes. For other crops like maize, the application of manure and/or synthetic fertilizers would be required. The study therefore proved significant in guiding decisions of crop selection and input application. It would be recommended that further studies be done and they should include the collection of more samples, analysis of various soil properties and take into consideration other factors that affect agriculture.

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TABLE OF CONTENTS

LIST OF FIGURES v
LIST OF TABLES vi
ACRONYMS/ABBREVIATIONS vii
LIST OF EQUATIONS viii
CHAPTER 1: INTRODUCTION 1
1.1 Background 1
1.2 Problem statement 2
1.3 Research questions 3
1.4 Main objective 3
1.4.1 Specific objectives 3
1.5 Significance of study 3
CHAPTER 2: LITERATUTE REVIEW 5
2.1 Concepts of Precision Agriculture 5
2.2 Application of Geosciences in Agriculture 6
2.3 Geostatistical methods of analysis 6
2.3.1 Inverse Distance Weighting (IDW) 7
2.3.2 The ordinary kriging (OK) 7
2.3.3 Semivariograms 8
2.4 Related studies 9
CHAPTER 3: METHODOLOGY 11
3.1 Research design 11
3.2 Materials and Methods 11
3.2.1 Study area 11
3.2.2 Sampling technique and sample sizes 12

3.2.3 Sample analysis 14
3.2.4 Statistical analysis 15
3.2.5 Geostatistical analysis 15
3.2.6 Cross Validation 16
3.3 Study Limitation 17
CHAPTER 4: RESULTS AND DISCUSSION 18
4.1 Descriptive statistics 18
4.2 Semivariogram analysis 19
4.2.1 N Semivariogram 20
4.2.2 P Semivariogram 21
4.2.3 K Semivariogram 21
4.3 Digital mapping using Kriging 22
4.3.1 Nitrogen Map 23
4.3.2 Phosphorus map 24
4.3.3 Potassium map 25
4.4. Application of the Maps 27
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 28
5.1. Conclusion 28
5.2 Recommendations 29
REFERENCES 30
APPENDICES 34

LIST OF FIGURES

Figure 1: The conceptual components of precision farming.....5
Figure 2: Location of study area on map..... 11
Figure 3: Google earth image of study area map..... 12
Figure 4: Soil Sampler - Sampling location.....13
Figure 5: Labeled and shape file format of sample locations..... 14
Figure 6: Semivarigram model of Nitrogen.....20
Figure 7: Semivariogram model of Phosphorus..... 21
Figure 8: Semivariogram model of Potassium.....21
Figure 9: Kriged map of N.....23
Figure 10: Kriged map of P.....25
Figure 11: Kriged map of K..... 26
Figure 12: Soil analysis data sheet.....34
Figure 13: Field assistant, researcher and owner of a field of one sampling point.....34
Figure 14: Field assistants taking a soil sample..... 35
Figure 15: Soil samples in air-tight plastic bags..... 35
Figure 16: Lab technician analyzing soil samples..... 35
Figure 17: AAS for soil elements analysis..... 36
Figure 18: Lab technician conducting Walkley Black Method.....36
Figure 19: Researcher and Lab Technician working on samples..... 36

LIST OF TABLES

Table 1: Rating Chart- Recommended by Bvumbwe Research Station..... 16
Table 2: Descriptive statistics of soil properties..... 18
Table 3:Semivariogran analysis of spatial structure in soil chemical properties..... 19
Table 4: Sizes of areas within the study area under the different recommended ratings of the soil parameters..... 22

ACRONYMS/ABBREVIATIONS

AAS – Atomic Absorption Spectroscopy

CV – Coefficient of Variation

FAO – Food and Agriculture Organization

GIS – Geographic Information Systems

GPS –Global Positioning System

IDW – Inverse Distance Weighting

K – Potassium

N - Nitrogen

OK – Ordinary Kriging

P - Phosphorus

RSME – Root Square Mean Error

SD – Standard Deviation

Sp. D – Spatial Dependency

LIST OF EQUATIONS

Equation 1: IDW 7
Equation 2: ok 7
Equation 3: Semivariogram 8
Equation 4:RMSE 17

CHAPTER 1: INTRODUCTION

1.1 Background

Agriculture is the backbone of the economy of Malawi. It accounts for about 36% of the gross domestic product (GDP), and about 87% of the total employment. Agriculture also provides over 65% of Malawi's manufacturing sector's raw materials and is the poor's most important source of income, accounting for about 63.7% of all income generated by households (IFAD, 2019). As such, the government of Malawi puts much effort to develop this sector such that research services date back in 1938 (Ministry of Agriculture, Irrigation and Water Development, 2016). However, despite these efforts the agricultural sector still faces a lot of challenges resulting into low productivity. These challenges include low access to finance and farm inputs, limited irrigation systems, vulnerability to weather shocks and weak linkages to the market (JiCA Malawi Office, 2016). While most of these challenges can be mitigated by financial support to the farmers, other major challenges need scientific studies to come up with effectual results. Some of these challenges that can be addressed by science studies include low productivity due to lack of sufficient nutrients in the soil and poor management of land, water and soils. One such scientific approach is through practicing precision agriculture (PA).

Precision farming aims to utilize technology to record and manage the variation of crops and soils within a field, thus reducing surplus inputs (e.g. fertilizer), increasing yields and aiding environmental sustainability (Oliver , Bishop , & Marchant , 2013). It represents a new level of high-resolution data collection on farms with regard to soil mapping, soil nutrient analysis and crop growth data. All of these factors can lead to better analytics that use data from real farms to influence management decisions rather than limited, replicated experimental plots that don't compare to real-world scenarios (Webber, et al., 2017). Soil geochemistry in particular, helps to achieve precision agriculture since it involves the study of the main substance needed for agriculture to happen which is soil. Therefore, the integrated study of geosciences and agriculture leads to advanced agricultural production.

If Malawi is to adopt the expertise of precision agriculture and geochemistry to

improve the capacity of the agricultural sector, food security will be achieved and sustainable agricultu

This research project aimed at analyzing the geochemistry and spatial variability of three important soil elements, NPK, in the area to help achieve precision farming. This knowledge will be crucial to help the farmers know how to manage their fields for improved productivity.

1.2 Problem statement

M'mina village just like many other areas in Malawi is inhabited by people with low income levels who practice subsistence farming without enough resources like fertilizer but also with little knowledge about the right site-management practices. The goal for the farmers and for Malawi as a country is attaining food security and this is the most important driver of smallholder agricultural activity (Briggs & Moyo, 2012) but this goal is hardly achieved. The lack of suitability knowledge of the land and insufficient use of chemicals has led to low yields of maize, the main crop grown, as well as other crops. Maize is Malawi's preferred subsistence crop, and it is grown all around the country, regardless of climate or edaphic suitability.

Researches aiming at improving the productivity have been done before. One such research sought to enhance existing soil and terrain (SOTER) models of agricultural suitability, to identify marginal agricultural lands and to uncover the complex interacting edaphic drivers of agricultural land use in Malawi (Li, Messina, Peter, & Snapp, 2017). So far, the SOTER database for Malawi provides an updated GIS-based soil resource inventory with national coverage. The challenge is that it uses a scale of one to one million and therefore considered appropriate for broad scale agro-environmental applications. Another challenge with the SOTER database of Malawi is that it uses very old data form the 1980s. The data was collected by the Land Resources Evaluation Project between 1989 and 1990. It is now called 'legacy data', and is very often in paper format, making it unsuitable for modern (digital) agro-environmental studies (Dijkshoorn, Leenaars, Huting, & Kempen, 2016). Research that has been done also do not concentrate on specific sites and specific crop for precise management.

This study aimed at assessing the soil geochemistry for specific sites and determining suitability of the land for various crop production using methods that provide recent data and also ensure precise agriculture for improved production.

1.3 Research questions

•Can the spatial variation of soil chemical properties essential for agriculture be determined?

•Can geo-statistical methods and GIS help produce a dataset that will help in practicing precise farming?

1.4 Main objective

•To determine the variability of NPK in the area for precise farming.

1.4.1 Specific objectives

• Analyze the soil geochemistry of the area.

•Evaluate the spatial distribution/variability of soil properties using geo-statistical methods.

•Produce a GIS based geochemical map for the area.

1.5 Significance of study

This project identified the soil variations in the area, mapped them and characterized them thus producing a vital output to inform farmers for better management. As an outcome, the soil geochemical maps developed will help in guiding farmers to effectively apply the correct types of soil nutrient supplements to satisfy the demands of crops for optimum growth and development, which will help to boost overall yields. The study will also help to cut production expenses by lowering the cost of agrochemical inputs in crop production by growing crops suited for the area which do not need much fertilizer. In addition, present but also future environmental impact will also be reduced because the right quantity application of agrochemicals avoids excessive residue in soils and water and thus reduces environmental pollution. This study will also offer an opportunity for future technological innovation that would allow estimation of nutrient balance for each field that would aid in nutrient management and environmental sustainability (Khosla,

2010).

CHAPTER 2: LITERATUTE REVIEW

2.1 Concepts of Precision Agriculture

Precision agriculture(PA) also known as 'site-specific farming' or 'precision farming' is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops (Dwivedi, 2017). Satellite farming or site-specific crop

management are other terms for it (SSCM). Precision agriculture research aims to develop a decision

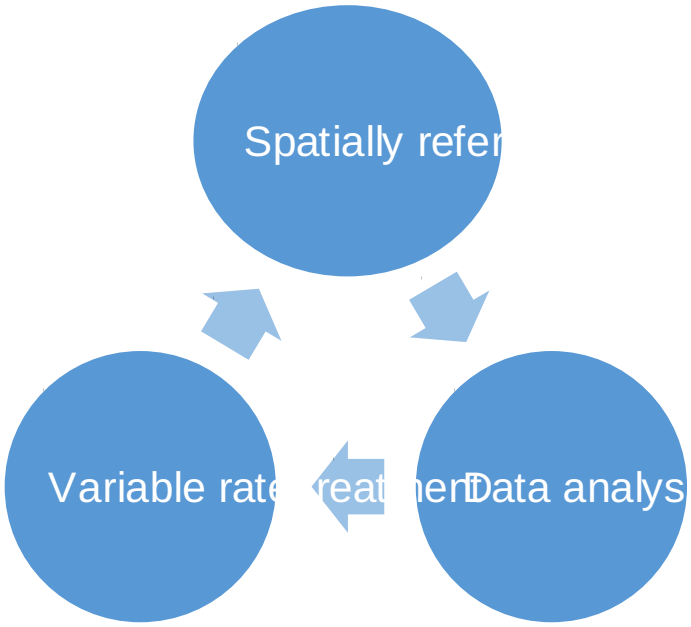


Figure 1: The conceptual components of precision farming

Precision agriculture is a key component of the third wave of modern agricultural revolutions. Precursor nations were the United States, Canada and Australia. In Europe, the United Kingdom was the first to go down this path, followed closely by France, where it first appeared in 1997-1998. In Latin America the leading country is Argentina, where it was introduced in the middle 1990s with the support of the National Agricultural Technology Institute. Brazil established a state-owned enterprise, Embrapa, to research and develop sustainable agriculture. (Dwivedi, 2017)

2.2 Application of Geosciences in Agriculture

The advent of GPS and variable-rate spreading techniques, which primarily use GIS,

helped to anchor the practice of precision farming management practices. GIS are computer hardware

The ability of a farmer or researcher to pinpoint their exact location in a field allows for the creation of maps depicting the spatial variability of as many variables as can be measured (such as crop yield, terrain features/topography, organic matter content, moisture levels, nitrogen levels, pH, EC, Mg, K, and so on). McBratney, Whelan, and Ancev (McBratney, Whelan, & Ancev, 2005). GIS-based models and high-resolution satellite imagery that can give current data for agricultural land use planning are becoming increasingly essential techniques in the area's agricultural development and planning.

2.3 Geostatistical methods of analysis

Geostatistical methods are spatial distribution and variability analysis methods that were developed from classical statistics (Pravat, Bhunia, & Maiti, 2016). The Geostatistical Analyst generates (interpolates) a continuous surface from sample points collected at various locations within a landscape. To predict values for each point in the landscape, the Geostatistical Analyst creates a surface using the values from the measured locations. (Anon, 2001). Some of them include IDW, OK and semivariance. OK and IDW are the commonly used methods for creating interpolated surface thus a comparison of the two **is** necessary to determine a better method for spatial variability analysis.

2.3.1 Inverse Distance Weighting (IDW)

Using the distance and values of nearby known points, IDW estimates the values of unknown points by reducing the contribution of a known point to the interpolated value. Each sample point's weight is proportional to its distance. The further away the point, the less the weight in helping define the un sampled location. The Zi in the equation (Equation 1) is value of known point, the Dij is distance to known point; the Zj is the unknown point and n is a user selected exponent. (Orman, 2012)

Equation 1: IDW

2.3.2 The ordinary kriging (OK)

OK interpolation method, a linear geostatistical interpolation technique, is used to predict and estimates the values of the unmeasured sites (un-sampled locations) by calculating them as weighted sums of the adjacent sampled concentrations (Panday, Maharjan, Chalise, Shrestha, & Twanabasu, 2018). The Kriging process is calculated by the following equation (Wang, 1999):

Equation 2: ok

Where $z^*(x_0)$ is the predicted value at position x_0, $Z(x_i)$ the known value at sampling site x_i, h_i the weighting coefficient of the measured site and n is the number of sites within the neighborhood searched for the interpolation.

An advantage of OK over IDW interpolation is that the prediction estimates in kriging tend to be less biased and are accompanied by prediction standard errors. It also provides information on the distribution of the estimation error and shows strong statistical advantages.

2.3.3 Semivariograms

These are used as the basic tool to examine the spatial distribution structure of the soil properties. Based on the regionalized variable theory and intrinsic hypotheses (Nielsen & Wendroth , 2003), a semivariogram is expressed as:

Equation 3: Semivariogram

where Y(h) is the semivariance, h the lag distance, Z the parameter of the soil property, N the number of pairs of locations separated by a lag distance h, $Z(x_i)$, and $Z(x_i + h)$ are values of Z at positions x_i and $x_i + h$ (Wang, 1999).

In the semivariogram plot, there are three important parameters for describing the spatial dependency of soil variables: nugget (C0), partial sill (C), and range. The amount of spatial structural diversity is represented by partial sill. The nugget is defined as variability on a scale smaller than the sampling interval and/or sampling and analytical error, and range is defined as the distance at which the semivariogram stabilizes around a limiting value. (Khan, Islam, Salam, & Ray, 2021)

2.4 Related studies

Various studies have been done related to application of geosciences to agriculture. One study was done in Nigeria. It aimed at analyzing land suitability for agriculture using GIS and multi-criteria decision analysis in Nasarawa State, Greater Karu Urban area (Kunda , Anyanwu, & Jajere, 2013). GIS overlay was also utilized in the spatial analysis process to merge the different map layers of soil, geology, and slope to select the best areas for agricultural growth. Unlike the Nasarawa State study, this study involved the collection of soil samples to know the actual concentration of various elements thus providing an effective way of evaluating the suitability of an area.

In Malawi, a related study was done by J.A. Dijkshoorn and others in 2016. The study was based on the soil and terrain data collected by the Land Resources Evaluation Project between 1989 and 1990. In this project, emphasis was given to land evaluation and suitability appraisals of Malawi's potential agricultural land. The database contains 231 unique SOTER (Soil and Terrain) units, comprising 298 terrain components and 534 soil components. These units are linked to 327 polygons in the geometric database. Dominant soil units were discovered in various areas. The study covered a lot of areas including assessments of soil organic carbon stocks, hydrological modelling, land

suitability evaluation and crop modelling (Dijkshoorn, Leenaars, Huting, & Kempen, 2016). Since the S

Another area of study related to the concept of precision agriculture and one of the upcoming innovation research sectors is the field of agro-geology. This field closely relates the science of geology to the practices of agriculture. Agro geology, a sub discipline of geology, is the scientific study of the origin, nature, composition and utilization of soils from a geological point of view (Chesworth, 2008). It is one of the applied geology research areas that addresses all geological characteristics of superficial deposits and the related geological processes that occur there, which are critical to agricultural production and provide information on a variety of factors such as the sequences of soil forming sediments and parent rocks, as well as the location and quality of soil. (Kerek, Kuti, & Vatai, 2010). It is indeed one of the education fields that can promote precise and productive agriculture. Applications have been done in Zimbabwe (Kerek, Kuti, & Vatai, 2010) but it is a broad area of study that can be had to adopt and apply.

CHAPTER 3: METHODOLOGY

3.1 Research design

This research was a descriptive study which used quantitative method of collecting data. A soil survey and laboratory tests were done to collect measurable data which was used to construct and calculate statistical models and figures to explain what was observed. Maps showing the distribution of the nutrients under study were then produced.

3.2 Materials and Methods

3.2.1 Study area

The area studied was M'mina village which is situated in Thyolo, a district located in the Southern Region of the country on the Shire highlands. The village is under Traditional Authority Chimaliro. The area is found between 16° 4' 3" S (latitude) and 35° 8' 25" E (longitude) (Mindat.org, n.d.). Thyolo receives an average total rainfall of 1, 125mm (44 in) per year. The climate is dry and with savanna type of vegetation (Government, 2013) . Generally, the area terrain is sloppy surrounded by mountains and rivers/streams. The soil is also generally characterized as roam clay and some parts are rocky.

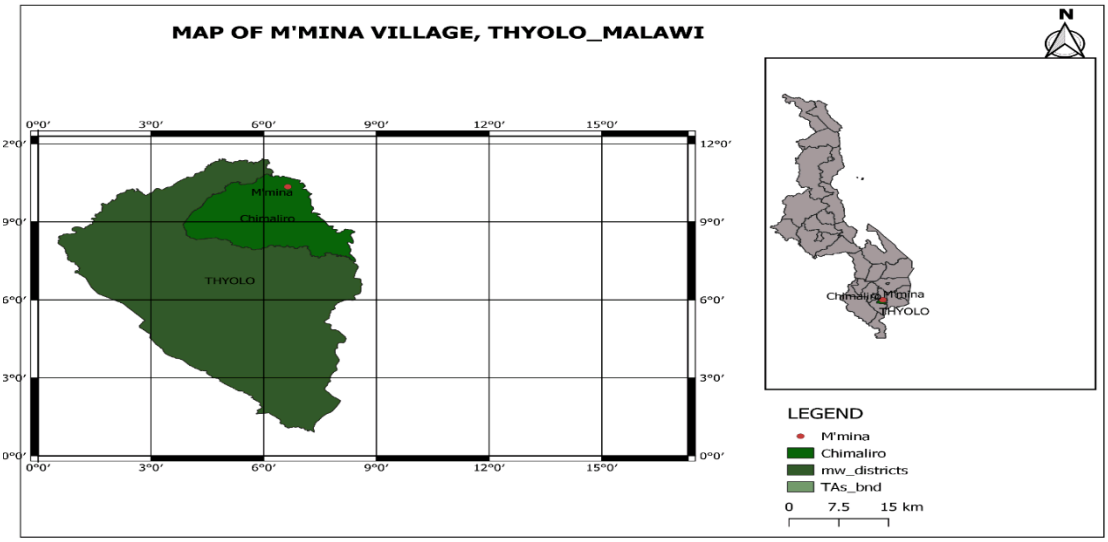


Figure 2*:* Location of study area on map

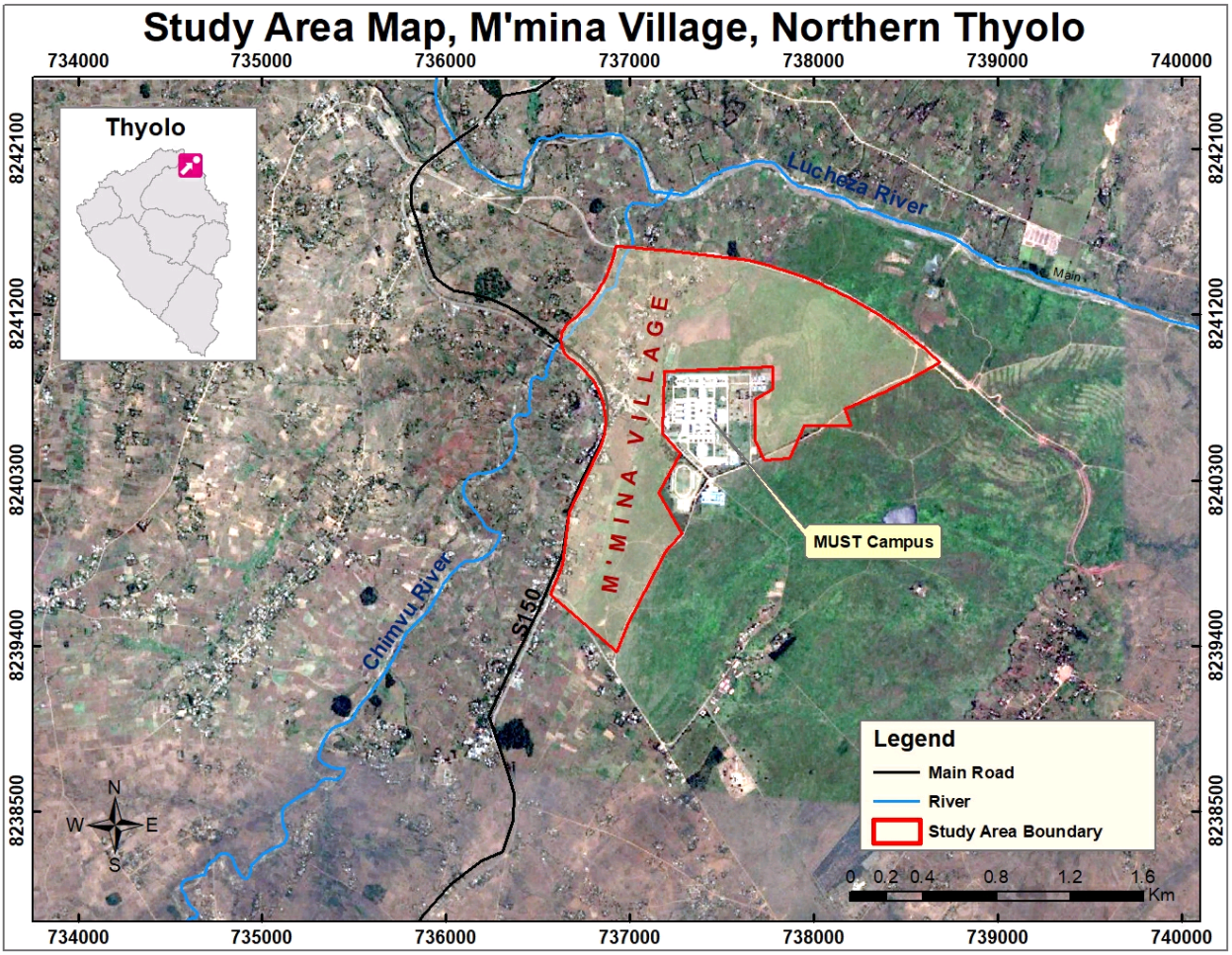


Figure 3: Google earth image of study area map

3.2.2 Sampling technique and sample sizes

Ten soil samples were collected in the field through a non-random sampling method which was determined by a mobile application called soil sampler. Coordinates for each

sample point were also given by the application. The soil samples were taken at depths of 0–20 cm sir

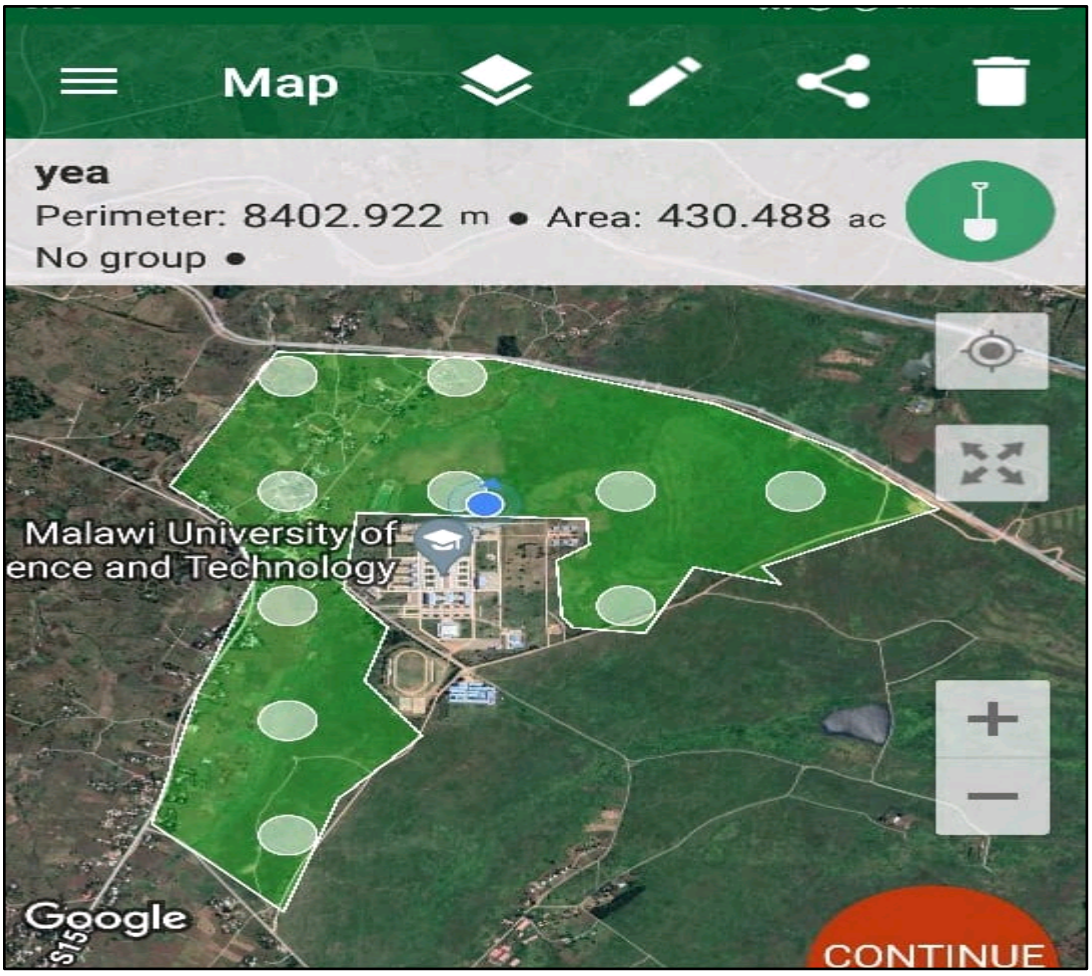


Figure 4: Soil Sampler - Sampling location

(Note: The area measured by the application was not exactly the same with the polygon used for geos

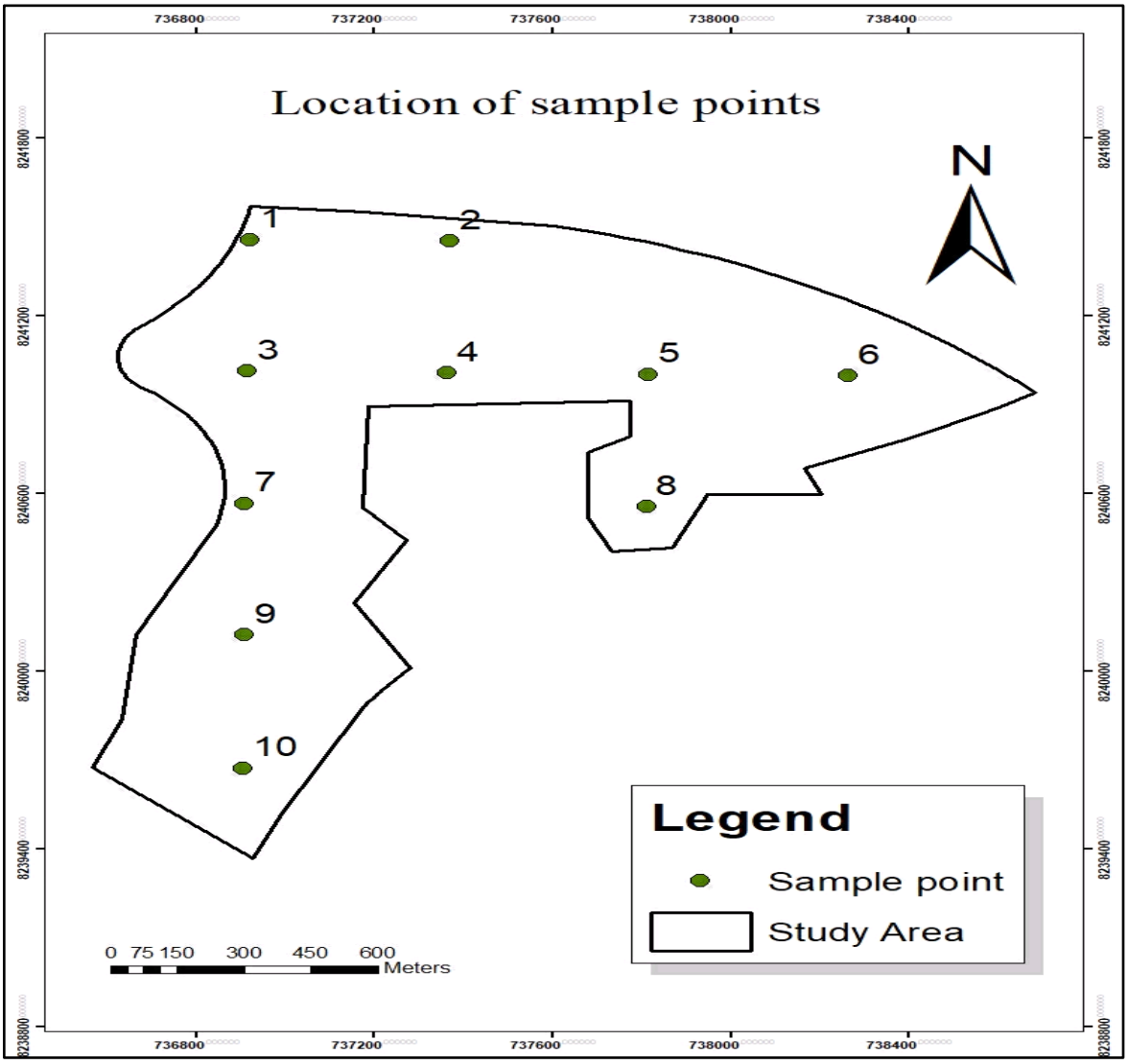


Figure 5*:* Labeled and shape file format of sample locations

3.2.3 Sample analysis

All samples were kept in air tight plastic papers and sent to Bvumbwe Agricultural Center where the laboratory analysis of the elements under study (NPK) in the soil samples were conducted. The Walkley-Black (Walkley & Black, 1943) method was used for determining total organic carbon from which the concentration of N was calculated while Mehlich III (Mehlich, 1984) method was used to determine the concentration of P and K. Figures showing parts of the analyses processes are presented in Appendices (Figure *16* to Figure *19*).

3.2.4 Statistical analysis

Descriptive statistical analysis, including the calculations of mean, standard deviation, coefficient of variation, minimum, maximum, skewness (skew), and kurtosis was carried out first all the measured soil properties. The values of skew and kurtosis were used to test the normality of the soil data and no figures were included for the test. The geostatistical toolset (Explore data) in ArcMap 10.5 and excel software were used to calculate these statistical parameters.

3.2.5 Geostatistical analysis

An xls file was first created in excel which contained the coordinates of the sample locations and corresponding values of concentration of the soil properties (NPK). This file and a shape file of the areas' polygon were uploaded in GIS software, ArcMap version 10.5. These added datasets were used for the geostatistical analyses.

Semivariogram models were plotted for each soil property at different lag distances which determined by the software. The optimal lag distances predicted by the software were used because they still gave the same important results like RMSE even when they were reduced. The experimental semivariogram was then fitted with a suitable theoretical model which were Gaussian models for P and K and Exponential model for N. Semivariogram modeling and estimation are essential for structural analysis and spatial interpolation. Geostatistical parameters, including nugget, structural, sill, and range were produced.

Kriging interpolation method was used as it is considered as the optimal spatial interpolation for making the best linear unbiased estimates of regionalized variables at unknown locations (Khan, Islam, Salam, & Ray, 2021). Details of the kriging formula and calculation are given in the literature review ((Wang, 1999); Equation 2). Data that is closer to a normal distribution can provide the best estimates of probability maps (Panday, Maharjan, Chalise, Shrestha, & Twanabasu, 2018) therefore datasets of K and P which had higher values of skewness and kurtosis were subjected to logarithm transformation to normalize the dataset for kriging analysis (Table 2). The transformation resulted in smaller values of skew and kurtosis. Map layers of the three soil chemical properties were then developed. The ranges of the soil parameters were then classified based on a rating chart provided by the soil analysis department of Bvumbwe Agricultural Research Station (Table 1).

All the geostatistical analysis, including the development of sample variograms and kriging, was performed with the help of a geostatistical software, ArcMap 10.5. The degree of spatial dependency of each variable was decided with geostatistical methods using semivariogram analysis and kriging.

Table 1: Rating Chart- Recommended by Bvumbwe Research Station

Rating	Soil Parameter		
	N (%)	P (ppm)	K (cmol/Kg)
Very Low	≤0.08	< 8	< 0.05
Low	0.08-0.12	9 to 18	0.06-0.10
Medium	0.12-0.20	19 - 20	0.11-0.40
High	0.2-0.3	25 - 33	0.50-0.80
Very High	≥0.3	>34	>1.00

3.2.6 Cross Validation

The performance of the OK interpolation method was evaluated and compared using

the cross-validation methodology. To validate the model, the sample points were arbitrarily separated

Equation 4:RMSE

Where 0i is observed value and Si is the predicted value, N is the Number of samples.

3.3 Study Limitation

The main limitation to the study was lack of funding. As a result of this, other soil properties were not analyzed but also a few samples were collected.

CHAPTER 4: RESULTS AND DISCUSSION

The whole laboratory result sheet is presented in Appendices (Figure 12). The results and discussion s

a. Descriptive statistics of the soil chemical properties
b. Semivariogram analysis
c. Digital soil maps using kriging

4.1 Descriptive statistics

The general statistics of the nutrients under study are presented in Table 2 below.

Table 2: Descriptive statistics of soil properties.

SOIL PROPERTY	STATISTICAL VALUE							AFTER TRANSFORMATION	
	Max	Min	Mean	SD	Skewness	Kurtosis	CV (%)		
N (%)	0.14	0.03	0.09	0.03	0.04	2.2	33	-	-
P (ppm)	91.0	6.9	27.6	30.3	1.38	3.2	109	0.7	3.1
K (cmol/kg)	0.13	0.01	0.06	0.04	0.85	3.1	67	0.6	3.0

The available Nitrogen (N) content in the soils varied from 0.03% to 0.14% with a mean value of 0.09%. Phosphorus (P) content varied from 6.9ppm to 91.0 ppm with a mean value of 27.6ppm and lastly Potassium values varied from 0.01cmol/kg to 0.13cmol/kg with a mean of 0.06cmol/kg.

The variability was interpreted using the coefficient of variation (CV). CV can be classified into most (CV: >35%), moderate (CV: 15 to 35%) and least (CV: <15%) variable ranges (Panday, Maharjan, Chalise, Shrestha, & Twanabasu, 2018). Among the properties, it can be seen that phosphorus has the highest variability seconded by potassium while nitrogen has a moderate variability. The percentage of CV for P was greater than a 100% because the SD was greater than the mean. The different ranges suggest different degrees of heterogeneity among the properties studied.

Normal distribution is represented by a zero (0) value of skewness and a kurtosis of three (3). Phosph

4.2 Semivariogram analysis

The semivariogram model and some of the geostatistical parameters of soil chemical properties are shown in Table 3. The models have been shown from Figure 6 to Figure 8.

*Table 3:*Semivariogran analysis of spatial structure in soil chemical properties.

Parameter	RMSE	Model	Range (a)	Lag size	Nugget (C_0)	Partial	Sill (C_0+C)	Nugget/sill	Sp.D
N	0.04	Exponential	2700	225	0.0007	0.0006	1.29	0.5	M
P	27.30	Gaussian	1305	112	0.6816	0.5259	1.21	0.6	M
K	0.03	Gaussian	2700	225	0.3748	0.43	0.81	0.5	M

The semivariogram parameters include Co which is the nugget, Co+C which is the sill, and a which is the range. These parameters were used to describe and compare the spatial structure of soil properties. The nugget variance (C_0); the structural variance (C), and the sill (C_0+C) represent the degree of spatial variability, which affected by both structural and stochastic factors. The value of the Nugget/Sill ratio can be classifies into <0.25, 0.25–0.75, and >0.75 representing strong, moderate and weak spatial dependency (Sp.D) in soil properties respectively (Orman, 2012). All the properties were found to have moderate spatial dependency (Table 3). A higher ratio indicates that the spatial variability is primarily caused by stochastic factors, such as fertilization, farming measures, cropping systems and other human activities while a lower ratio suggests that structural factors, such as climate, parent material, topography, soil properties and other natural factors, play a significant role in spatial variability (Pravat, Bhunia, & Maiti, 2016).

4.2.1 N Semivariogram

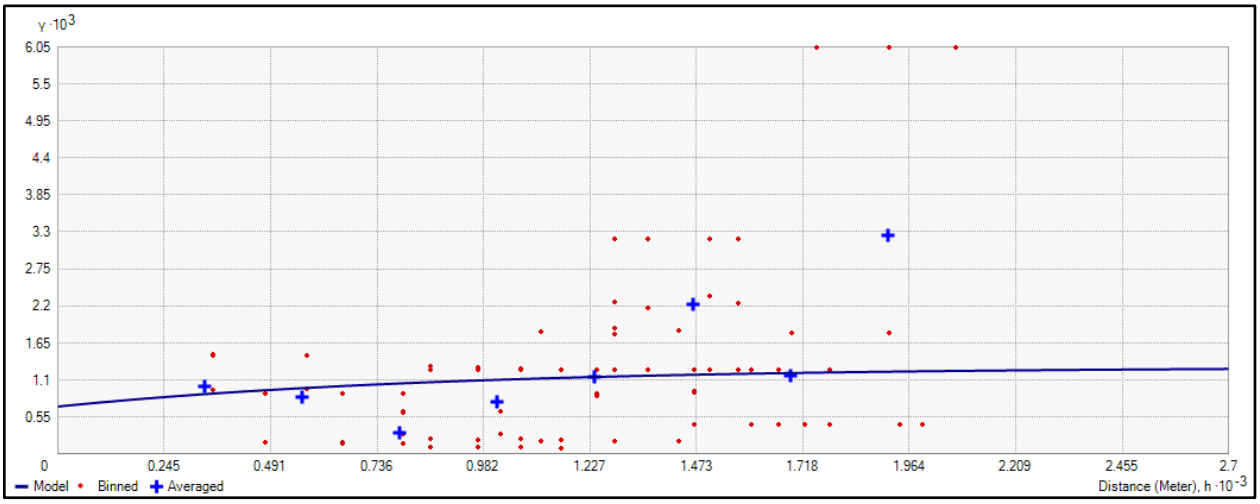


Figure 6: Semivarigram model of Nitrogen

4.2.2 P Semivariogram

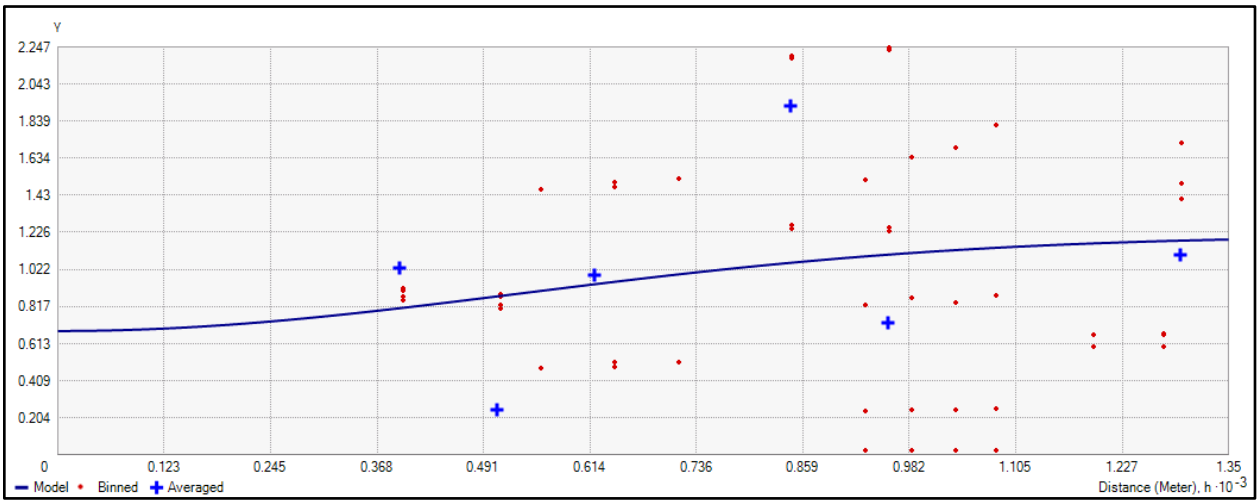


Figure 7: Semivariogram model of Phosphorus

4.2.3 K Semivariogram

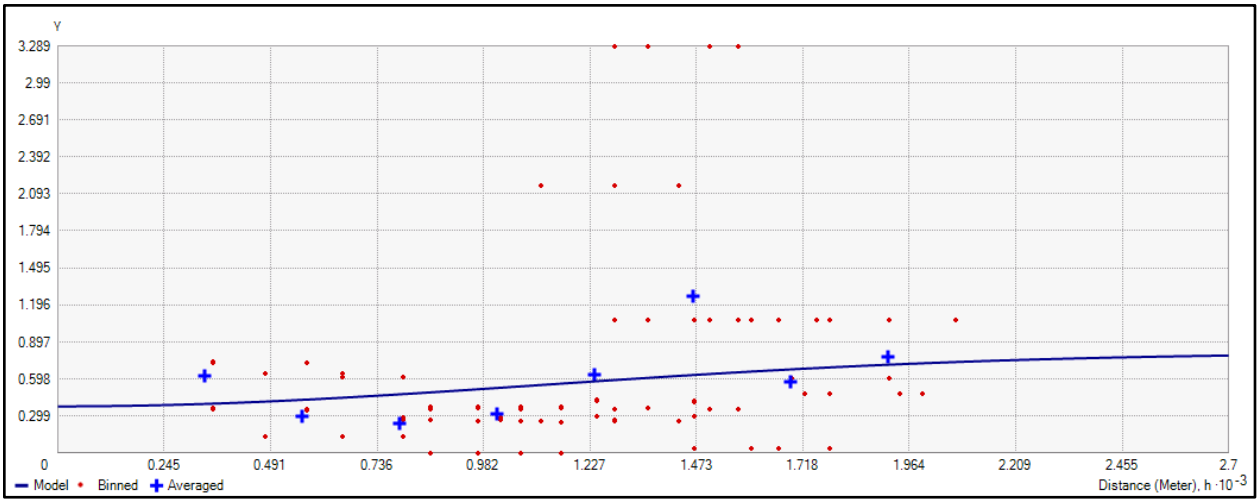


Figure 8: Semivariogram model of Potassium

The different theoretical semivariogram models were selected for the significant fit of soil chemical properties based on the lowest root mean square error (RMSE) (Robertson , 2008). An exponential model provided the best fit to the semivariogram for N while as the gaussian model was the best fit to the semivariogram of P and K. Many findings suggest that the exponential model is the most suitable for assessing spatial variability in soil chemical properties because it explains the maximum variability in the spatial dataset (Lark, 2000).

4.3 Digital mapping using Kriging

Digital maps of soil chemical properties were produced by using kriging on the log transformed dataset (shown from Figure 9 to Figure 11). The results were grouped into

various classes based on the range representing their magnitude in the soil. The estimated area of ea

Table 4: Amount of areas in the study area under different ratings of the soil properties.

Parameter	Unit	Rating	Class	Area (Acres)	% of total area
N	%	≤0.08	Very low	124	27.68
		0.08-0.12	Low	324	72.32
		0.12-0.20	Medium	-	
		0.2-0.3	High	-	
		≥0.3	Very high	-	
P		< 8	Very Low	-	
		9 to 18	Low	185	41.29
		19 - 20	Medium	119	26.56
		25 - 33	High	39	8.71
		>34	Very High	105	23.44
K	Mg/kg	< 8	Very Low	214	47.77
		9 to 18	Low	218	48.66
		19 - 20	Medium	16	3.57
		25 - 33	High	-	
		>34	Very High	-	

4.3.1 Nitrogen Map

Among the measured elements. N has a greater effect on crop growth, crop quality, and yield. However, N was deficient in the whole study area with values very low values recorded in 27.68% of the total area and low values in 72.32% of the total area. (Table 4 and Figure 9). The low nitrogen content could be linked to the fact that N is very mobile in both soil and plant (PennState, 2021). Therefore, it could have been used by the previous plants or leached.

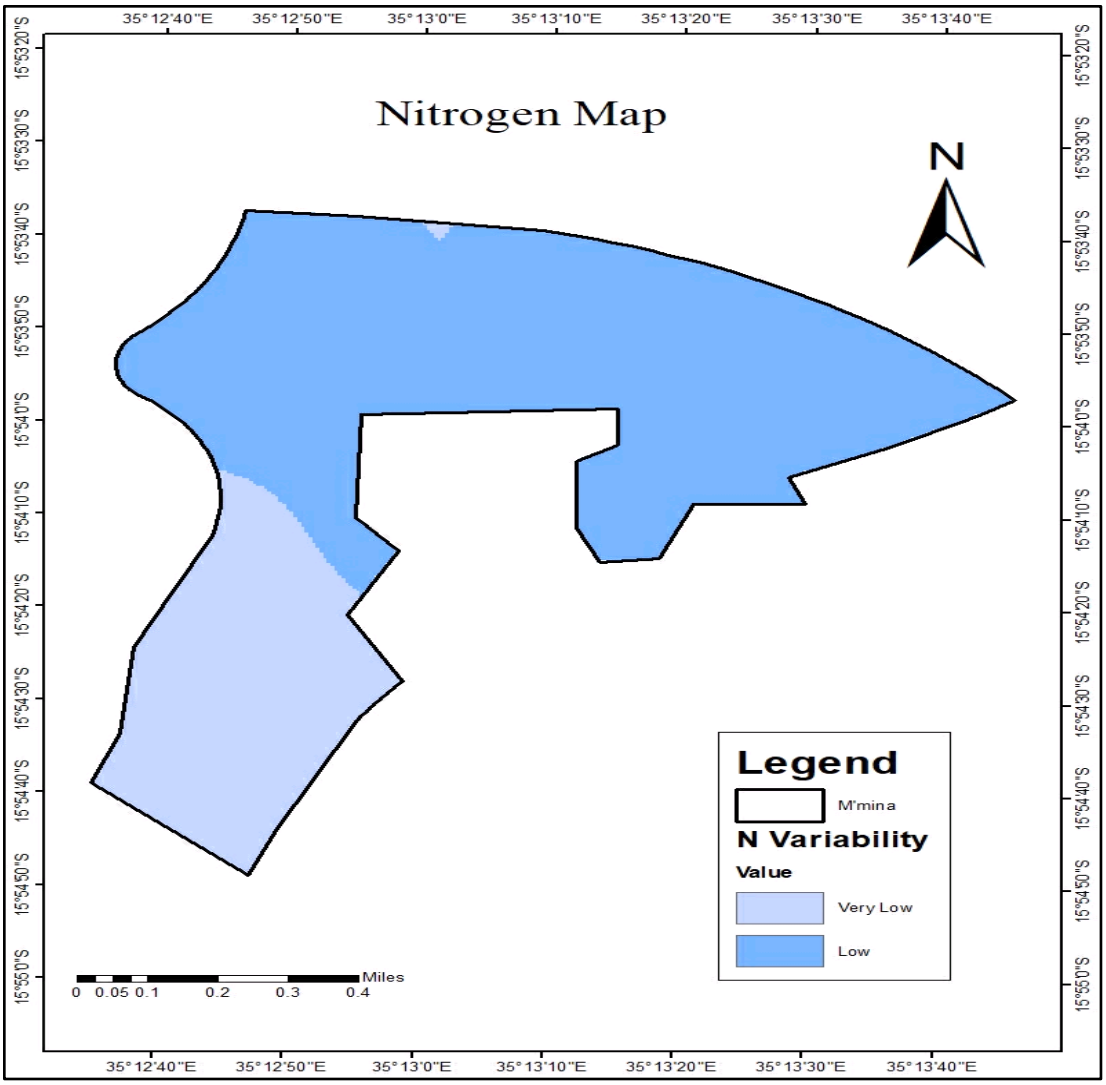


Figure 9: Kriged map of N

4.3.2 Phosphorus map

The content of phosphorus in the area was observed as being better than the other elements (N and K). The availability was classified as being low (41.29%), medium (26.56%), high (8.71%) and very high (23.44%) (Table 4 and Figure 10). High levels of P are usually caused by excessive fertilizer use or use of manure high in P (Provin & Pitt, 2021), indicating that fields located in the west part of the area might have been over fertilized for P to be very high. The low P content area especially to the north and far south of the area might have been caused by low pH soils (pH <5) (Chakraborty & Prasad, 2019).

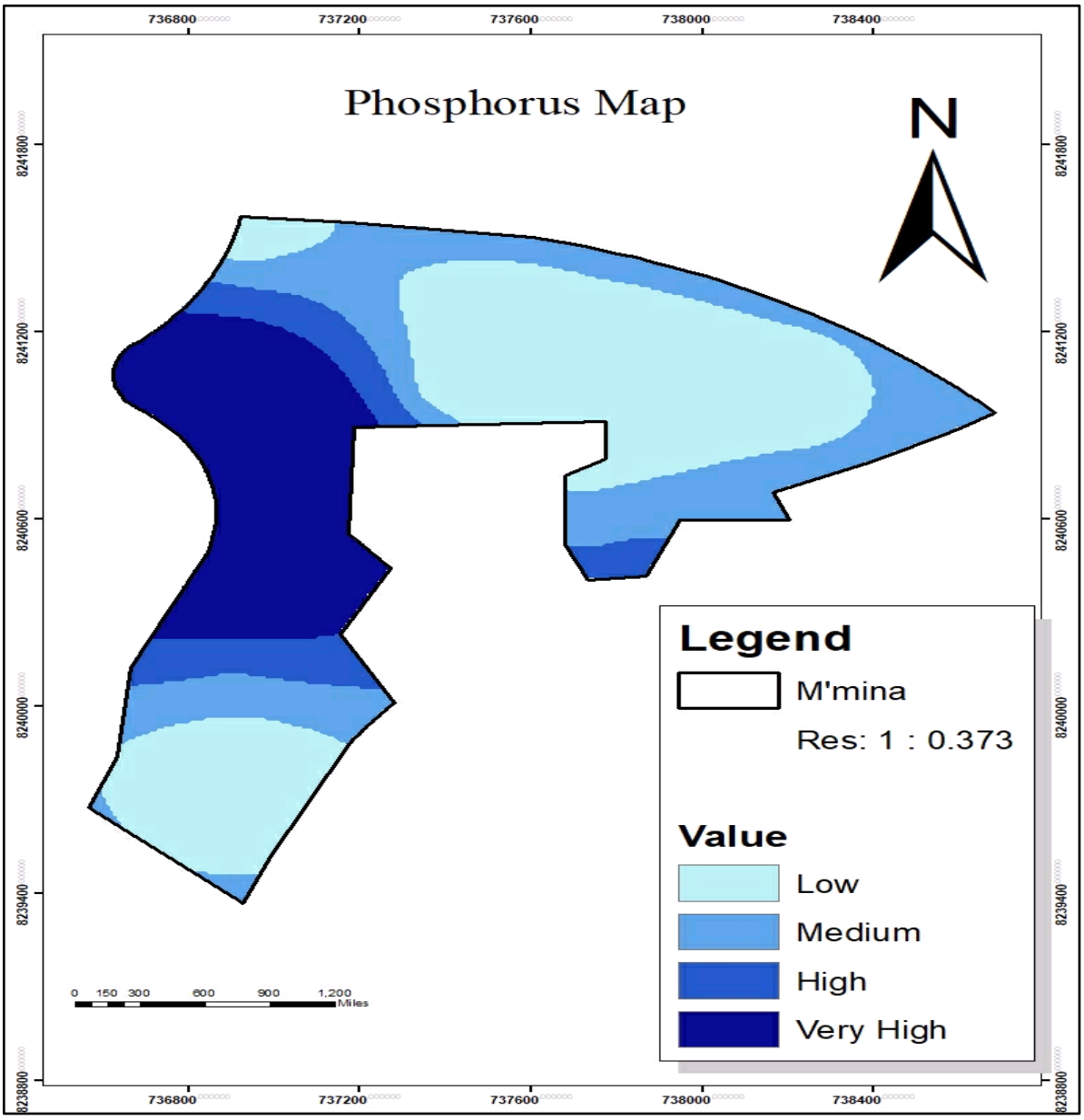

Phosphorus Map
N
736800
737200
737600
738000
738400
8241800
8241200
8240600
8240000
8239400
8238800
Legend
M'mina
Res: 1 : 0.373
Value
Low
Medium
High
Very High
0 150 300 600 900 1,200
Miles

Figure 10: Kriged map of P

4.3.3 Potassium map

The spatial content of K in the soil has been illustrated in Figure 11. The map showed that the content of exchangeable K in the soils of the study area can be classified into three classes, as very low, low and medium (Figure 11) recorded in 47.77%, 48.66% and 3.57% of the total area respectively (Table 4). K concentration is highly affected by soil pH where it tends to be deficient in pH less than 5.8 (Insight FS, 2018). Therefore, the soils in the area might have low pH values.

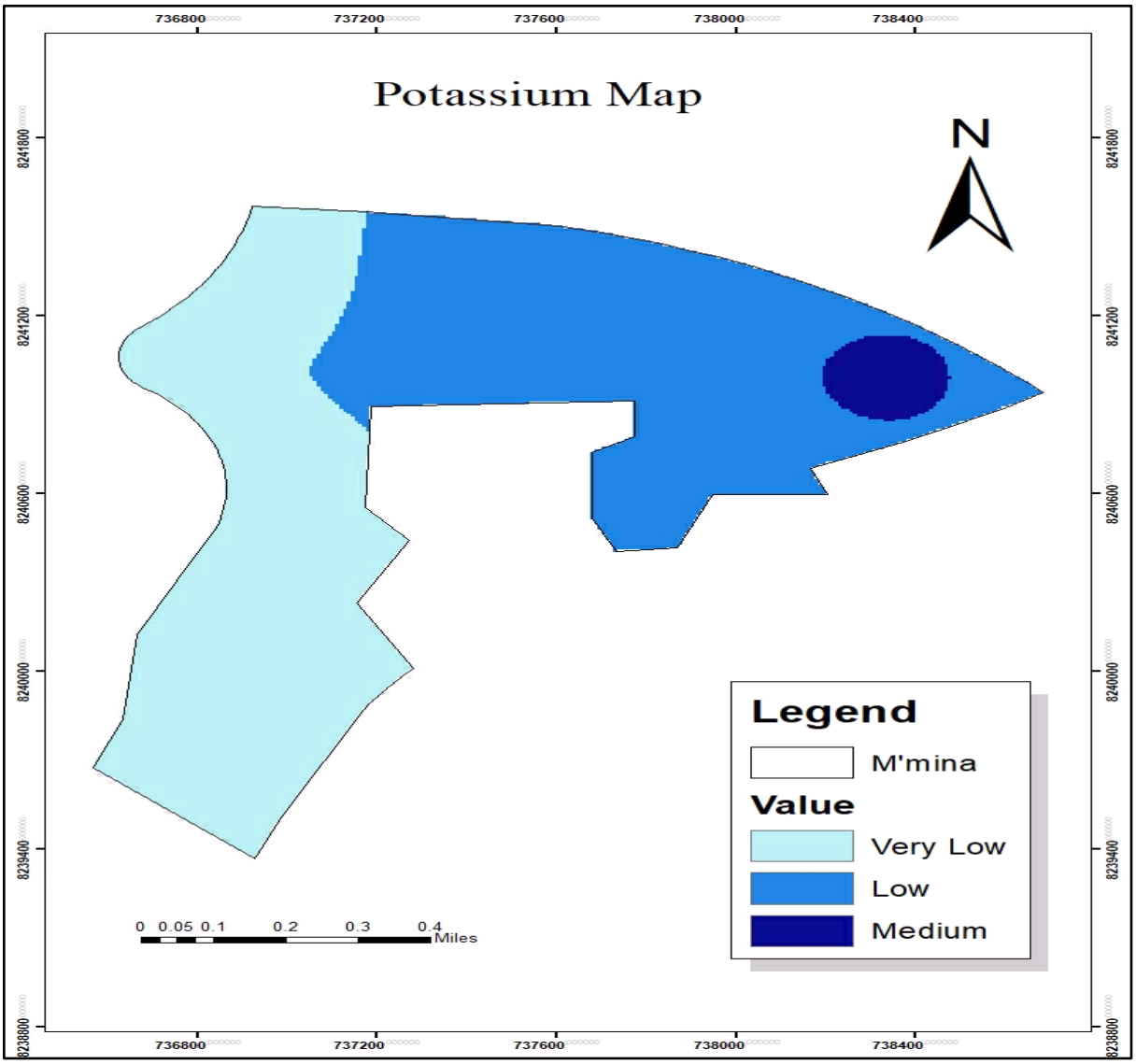


Figure 11: Kriged map of K

4.4. Application of the Maps

The maps are of importance to the farmers directly as well as to agricultural workers who can use them to guide the farmers in practicing appropriate field management practices. By knowing the amount and classification of a particular element in a specific site, farmers will be able to apply the right type of supplements. For instance, on the area with low nitrate content but moderate P and K content, nitrate supplements can be applied instead of applying whole NPK fertilizers which may provide excessive P and K that may remain and pollute the land. In the long run, right applications of fertilizer will reduce the costs of production, increase productivity but also reduce land pollution and degradation. In addition, these maps can also be used to determine the best crops to be grown in a specific field depending on the crop requirements corresponding to the available type and amount of elements.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In conclusion, the main objective of the study was to determine the variability of NPK in the area for precise farming. Geostatistical tools essentially kriging and semivariogram analysis were used to determine the spatial structure of NPK concentration and create maps showing the variability of these macro elements. The results showed that most of the area is deficient in NPK (100% of the area for N and K; 41% of for P). The low values of P and K suggested that the soils might also have low pH values.

Based on the results, it can be concluded that whole NPK fertilizer application is necessary. Crops that can do better in this area without requiring much of synthetic fertilizer include legumes which do not need a lot of N. The legumes produce their own N through a process called nitrogen fixation whereby bacteria living in the root nodules are able to take nitrogen gas from the atmosphere and convert it into a form that plants can use (Magdoff & Van Es, 2021) . Legumes are also suitable for the area since they require substantial amount of phosphorus (California Fertilizer Foundation , 2009) and P is available in good amounts in most part of the area. Therefore, the farmers in the area would consider growing more legume crops like groundnuts, pigeon peas, beans, cow pea and soya beans. However, soya beans have to be considered only on the north west part where there is medium levels of potassium since they do not do well in areas deficient of K. Lettuce plants are high-phosphorus users (California Fertilizer Foundation , 2009) and could also be suitable for this area since phosphorus in abundant in 59% of the area. Farmers would also be encouraged to grow cassava and potatoes since they do not need high synthetic fertilizer application. A lot of N is tied up to organic matter therefore the application of manure is encouraged in the area and manure also builds up levels of P and K (Magdoff & Van Es, 2021) which would make the area support the productivity of crops like Maize.

5.2 Recommendations

The study used a small sample size which might not give the real/actual extent of the variability as they may not be enough representation of the population. Therefore, it is recommended that more sample sizes be used if similar or further study is to be done. Analysis of other soil properties including micro-elements could be added in order to increase the accuracy when making management decisions. It would also be recommended that other factors that affect agriculture such as climate and slope be included in future studies.

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APPENDICES

BVUMBWE AGRICULTURAL RESEARCH STATION
P.O. BOX 5748
LIMBE
Tel: 01471207

ATT: MISS FLORIDA CHIGULE
MUST

07.07.2021

Lab. No	Sample Description	Depth(cm)	% OC	% OM	% N	P ppm	K cmol/kg
4325	FIELD 1	0-20	1.01	1.74	0.09	8.7	0.01
4326	FIELD 2	0-20	0.71	1.22	0.06	20.6	0.08
4327	FIELD 3	0-20	1.01	1.74	0.09	75.6	0.06
4328	FIELD 4	0-20	1.36	2.35	0.12	6.9	0.06
4329	FIELD 5	0-20	0.74	1.27	0.06	7.0	0.04
4330	FIELD 6	0-20	1.61	2.77	0.14	11.8	0.13
4331	FIELD 7	0-20	0.68	1.18	0.06	91.0	0.03
4332	FIELD 8	0-20	1.23	2.12	0.11	25.9	0.08
4333	FIELD 9	0-20	1.06	1.83	0.09	20.8	0.03
4334	FIELD 10	0-20	0.35	0.61	0.03	7.7	0.03

Sheet1

Figure 12: Soil analysis data sheet



Figure 13: From left; Field assistant, researcher and owner of a field of one sampling point



Figure 14: Field assistants taking a soil sample



Figure 15: Soil samples in air-tight plastic bags



Figure 16: Lab technician analyzing soil samples for K and P



Figure 17: AAS for sample elements analysis



Figure 18: Lab technician conducting Walkley Black Method



Figure 19: Researcher and Lab Technician working on samples