SOIL POLLUTION ASSESSMENT USING MASS SPECIFIC MAGNETIC SUSCEPTIBILITY MEASUREMENTS: A CASE STUDY OF KANO RIVER IRRIGATION PROJECT (KRIP) FARMLAND

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DOCTOR OF PHILOSOPY DEREE IN APPLIED GEOPYSICS

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SEPTEMBER, 2021

DECLARATION

I declare that this thesis titled "SOIL POLLUTION ASSESSMENT USING MASS SPECIFIC MAGNETIC SUSCEPTIBILITY MEASUREMENTS: A CASE STUDY OF KANO RIVER IRRIGATION PROJECT (KRIP) FARMLAND" is my own research work. It is being submitted for the degree of Doctor of Philosophy to the Department Physics, Faculty of Physical Science Ahmadu Bello University Zaria, Nigeria. The information derived from the literature has been acknowledged in the text and list of references provided. No part of this thesis has been submitted for any degree or examination to any other Institution.

Zira, Abraham Musa

_____	_____	_____
Name of Student	Signature	Date

CERTIFICATION

This thesis titled "SOIL POLLUTION ASSESSMENT USING MASS SPECIFIC MAGNETIC SUSCEPTIBILITY MEASUREMENTS: A CASE STUDY OF KANO RIVER IRRIGATION PROJECT (KRIP) FARMLAND" by Abraham Musa Zira meets the requirement governing the award of the degree of Doctor of Philosophy (Physics) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary.

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DEDICATION

This thesis is dedicated to my lovely wife, Racheal Zira, my caring children Esther Zira, Emmanuel Zira and Elishua Zira.

ACKNOWLEDGEMENT

First of all, I would like to say thank you to the Almighty God who has given me life and has supplied all my needs to carry out this research work.

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ABSTRACT

An assessment of soil pollution of Kano River Irrigation Project was carried out by measuring the mass specific magnetic susceptibility (MSMS) and geochemical method of the soil to characterize the magnetic and geochemical properties of the study area. The study investigated the potential pollution on the irrigation farmland due to anthropogenic activities. Two hundred and fifty (250) samples of soils were collected from the study area for measurements of MSMS. The results of the measurements of the MSMS of the soils showed that at low frequency (0.47 kHz), the values ranged from 1.8 – 104.5 x $10^{-8}m^3kg^{-1}$while at high frequency (4.7 kHz), the values ranged from 1.8 – 103.4 x$10^{-8}m^3kg^{-1}$. The soil samples from irrigation sectors revealed that 20% were coarser grains which are multi-domain grains (MD), 62% were mixture of coarse grains (MD) and super paramagnetic grains (SP) 10% were SP grains coarse grains and 8% were due to contamination. The soil samples from upland sectors revealed that no coarse grains (MD) were present, 41% were mixture of coarse grains (MD) and super paramagnetic grains (SP) 44% are SP grains coarse grains and 15% were due to contamination. Likewise, the soil samples from uncultivated sectors revealed that 11% were coarse grains (MD), 69% were mixture of coarse grains (MD) and super paramagnetic grains (SP) 11% were SP grains coarse grains and 9% are due to contamination. The values of the frequency dependent mass specific magnetic susceptibility ($\chi_{fd\%}$) were found to range from 0 – 71.15%. The mean concentrations of the heavy metals of Fe, Pb, Cd, Cu, Zn, Cr and Ni for irrigation sectors 40.774, BDL, 0.005, 0.021, 0.165, 0.010, BDL and for upland sectors 45.233, 0.375, 0.37, 0.223, 0.336, 0.250, BDL $mgkg^{-1}$ respectively. The concentrations of the heavy metals in irrigation and upland soils were low. This indicates that the concentrations of heavy metals in the irrigation sectors soil exist in the following order: Fe > Zn > Cu> Cr > Cd, while Pb and Ni were not detected. The concentrations of the heavy metals in upland sectors exist in this order as well: Fe > Ni > Pb> Cd > Zn > Cr >Cu. The results of the study showed that the study area is not polluted but has a tendency to be polluted with time if measures are not taken since the anthropogenic materials in the study area are 20%.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Soil pollution as part of land degradation is caused by the presence of xenobiotics (human-made) chemicals or other alteration in the natural soil environment. The issue concerning environmental pollution on farms, urban areas and industrial areas are of great importance since most of the population in the world resides and earn their livelihood in these areas unlike some decades ago. Soil pollution originates from a wide variety of natural and anthropogenic sources. The natural sources include forest fires, volcanic eruptions, pollen dispersal, evaporation of organic compounds and natural radioactivity (Pope et al., 2002). The anthropogenic activities are emissions from vehicles, trains, ships, aircraft, power plants, manufacturing industries, pesticides, herbicides and insecticides. Others are waste deposits, fertilizers and burning facilities and household heating systems are all anthropogenic sources of pollution (Pope *et al*., 2002). These sources release various contaminants like heavy metals, particulate matter (PM), polyaromatic hydrocarbons (PAH), which are deposited in urban, industrial, farmland soil and maritime environments, thus posing serious health risks to human, animals and plants both on land and sea. Several studies have shown that long-term exposure to airborne pollutants, including those originating from road traffic, can lead to respiratory and cardiovascular diseases (Pope *et al*., 2002; Pope and Dockery, 2006; Kanu *et al*., 2013). These toxic heavy metals that are generated mostly by human activities cause threatening illness to human.

The heavy metals are soluble in water, so they easily find their way into drinking water. But many of them also tend to bind tightly to proteins found within certain organs. For instance, cadmium is known to bind tightly with metallothionein, which is abundant human liver and kidney. So, once these chemicals enter the human body, they stay there for a long-time

despite being highly water soluble. Then when they reach heightened levels, their harmful effects start to set in some heavy metals.

According to the National Public Health Institute of Finland, as many as 2 million Finns suffer from occasional respiratory symptoms caused by airborne particles (Finnish Ministry of Transport and Communications, 2005). Moreover, it was estimated that around 200-400 Finns die prematurely every year because of air pollution. As the quality of the urban environment significantly influences human health, current environmental research is focused on spatial and temporal monitoring of anthropogenic pollutants. Several studies have demonstrated that the impact of road traffic on the environment is accompanied by significant emissions of Fe-rich particles (Hoffmann *et al*., 1999, Matzka and Maher, 1999, Sagnotti *et al*., 2006), which are transported through atmospheric pathways and deposited in nearby surroundings.

These pollutants can be easily detected due to their specific magnetic signature. The development of geophysical technology has enabled the application of magnetic susceptibility methods in advanced studies of urban pollutants compared to conventional geochemical analyses. Magnetic susceptibility analyses are fast, non-intrusive and cost-efficient. Since in many cases, anthropogenic magnetic particles share an origin and existence with heavy metal (Goddu *et al*., 2004; Gautam *et al*., 2005a), magnetic techniques can be applied in order to trace urban pollution sources, together with geochemical analyses.

There has been a great rate of development in the use of magnetic measurements in examining environmental pollution caused by anthropogenic activities such as industrial activities, domestic heating, traffic and power plant. Dusts and fly ashes produced by anthropogenic activities contain significant portion of magnetic materials (Flanders, 1994). The incorporation of anthropogenic magnetic materials into environmental media produces a magnetic enhancement. Dust and fly ashes from various anthropogenic sources also contain

very high level of heavy metals. Magnetic materials may incorporate heavy metals into their atomic lattice or they form separate particles (Klučiarová *et al.,* 2008) or the heavy metals are adsorbed on the surface of magnetic particles (Kapicka *et al.,* 2008). Coexistence of magnetic materials and heavy metals by ligan association makes it possible to determine the relationship between magnetic parameters and concentration of heavy metals and this is the basic principle to use magnetic parameters as proxy parameters in environmental pollution analysis.

Air pollution has deprived many industrialized cities of the world sources of good air. The sources of the pollution consist of both inorganic and organic pollutants. Some of the pollutants are heavy metals such as: Hg, As, Ni, Cd, Pb usual from Some sources like wearing of tyres on roads, application of fertilizer on farms, application of pesticides, organic waste, air borne contaminants (gaseous emissions from industrial areas, burning fuels, smelting and mining. This has caused a lot of health and ecosystem problems. The most tragic and serious problem is lack of research to determine the levels of these pollutions in our soils, water and air.

1.2 Statement of the Research Problem

The activities of irrigation in Kano River Irrigation Project have been on for over forty years where agrochemicals such as pesticides, fertilizer and herbicides are being used for farming. These agrochemicals contain heavy metals which when taken in excess are toxic to humans, animals and plants (Friday, *et al*., 2015. This causes pollution to the farm soil. The issue of pollution is a potential atomic bomb to any nation that does not manage it well. There are highly toxic heavy metals that are involved in pollution issues which when neglected cause a lot of life threatening, illness. This matter therefore calls for research work to understand the state of our farmland soil where food is grown. Proper attention should be given to pollution issues so that we do not dig our graves and that of our young unborn with our hands.

The health risk and the effect on the quality of livelihood caused by human activities that enhances pollution calls for comprehensive approach to assess the impact on the environment. No attention has been given to this aspect of research in this KRIP using MSMS hence the purpose for this work.

The research work was set to determine how pollution has affected irrigation farmland soil of Kano River Irrigation Project Phase I located in Kura Local Government Area in Kano State using magnetic susceptibility method and geochemical analysis.

1.3 Justification/Significance of the Study.

The problem of pollution exists as a global problem which affects soil, sea and air spaces. There is therefore need to assess the scale of pollution on our farm soil for proper mitigation. Thus KRIP farmland soil in Kura local government are of Kano State that has been under cultivation for over 40 years to determine the level of pollution of our farms where crops are grown.

The result of this study will provide:

(i) an insight into the state of the pollution of KRIP soil using environmental impact assessment of human activities by MSMS.

(ii) Information that would be useful to put in place for the government to create prevention plans.

(iii) Information that may be useful to addressing the health related issues caused by pollution.

(iv) Document for further research in the field of geoscience in relation to pollution.

1.4 Aim and Objectives

The aim of this research work is to assess the environmental impact o f human activities on irrigation farmland soil of Kano River Irrigation Project Phase I Extension located in Kura

Local Government Area in Kano State using mass specific mahnetic susceptibility (MSMS)method and geochemical analysis.

The aim of the study is to be achieved through the following objectives:

(i) To measure the MSMS of the farmland topsoil.

(ii) To investigate the variation of MSMS with depth of the farmland soil

(iii) To analyse the magnetic domain grain size of the MSMS of the farmland soil.

(iv) To determine the magnetic susceptibility enhancement of the farmland soils in ` the study area

(v) To determine concentration of some heavy metals from selected samples of the irrigation farmland soil

(vi) To determine the pollution status of the farmland soils

(vii) Recommend areas of further research that are not covered by this research.

1.5 Location of the Study Area

The Kano River Irrigation Scheme (KRIP), lies between latitude 11^0 35′0″and 11^0 55′0″ North of the equator and longitude 8^0 15′0″ and 8^0 40′0″ East of the Greenwich mean (Figure 1.1). It is located at a vast area over 25km south of Kano city and it is essentially most of irrigable land both sides of the Kano Zaria highway and on both sides of the Karfi – Rano highway. It is a scheme designed to provide irrigation facilities via gravity for about 22,000 hectares of land utilizing water release from the Tiga dam (via the Ruwan Kanya reservoir). The KRIP system according to the feasibility study by Royal Haskoning DHV comprises the Tiga Dam, Ruwan Kanyan reservoir, the Main Canal system (MC1 and MC2), the East Branch Canal system (with 14 sectors), the Ganyere Branch Canal (3 sectors) and the West Branch Canal system (with 29 sectors) and the field channels systems which irrigate the farmlands. These irrigated areas are located in seven Local Government Areas in Kano state namely, Tudun Wadan, Rano, Bebeji, Dawakin Kudu, Garum Mallam, Bunkure and Kura.

The scheme (Farmlands) where the rehabilitation civil works of irrigation infrastructure are proposed is however located in the three local Government Areas (LGA) of Garum Mallam, Bunkure and Kura southwest of Kano city. The Tiga Dam that supplies water to the irrigation farm is an earth dam, designed and built within 1970 to 1974. The dam reservoir surface area according to the Tiga dam manager is about 18,900 ha with a structural height of 48 m, hydraulic height of 42.68 m and an active storage capacity of 1,845 million m3 at full supply level. It lies across the Kano River, the main tributary of the Hadejia River. Water from the dam supplies the Kano River Irrigation Project. However, reduction in the reservoir capacity due to sedimentation since its construction has not been assessed.

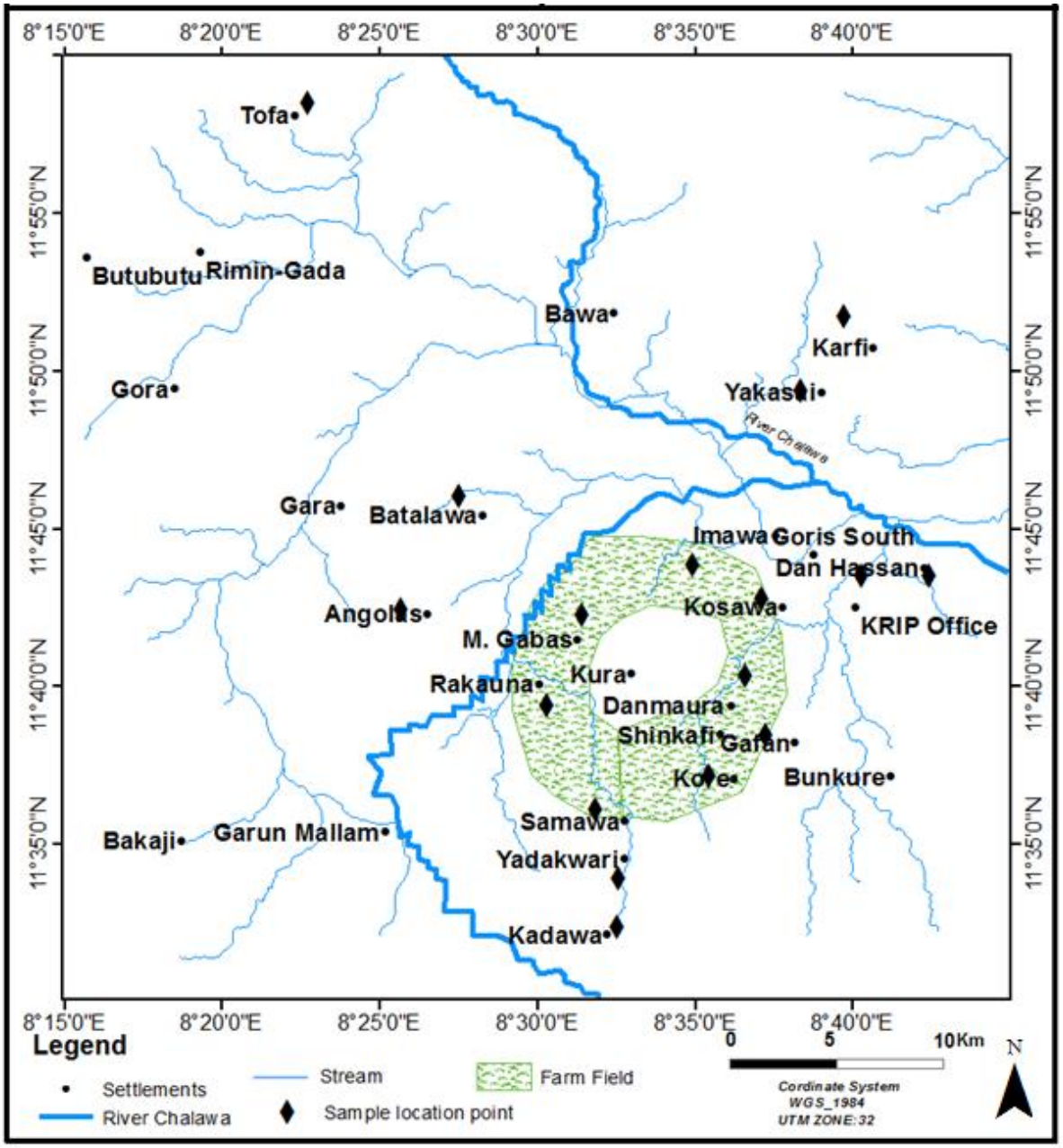


Figure 1.1 Location of the Study Area

1.6 Climate and Vegetation of the Study area

The main crops cultivated include groundnut, garlic, cotton, guinea corn, millet, maize, rice, cow-pea, wheat and vegetables such as tomato, pepper, onions, cabbage, etc. The mean daily maximum and minimum temperatures are 31°C and 21°C, respectively. The year is divided into well marked rainy and dry seasons. The dry season lasts from October to June. During the month of November and January, the Harmattan (dry north-easterly winds) is at its height

blowing thin dust over the state from the Sahara Desert, at this time temperature can fall to as low as 15°C. From March to May, however, the dry, cold air humidifies, beaming hot air with temperatures rising to more than 40°C. Rainfall is concentrated between July and September with maximum and minimum of 214.0 mm and 132.7 mm, respectively. The rains are preceded by violent sand storms followed by tornadoes mainly during the months of May and June. The average annual rain fall is 884.4 mm with 60% of which falls in July and August (Maina *et al*., 2012)

1.7 Geological Setting of the Study Area

Geologically, more than half of Kano is underlain by quartzite, undifferentiated meta-sediments and basement complex rocks of the pre-Cambrian upper cambrian origin. Prolonged weathering of the rocks produced deep clay rich regoliths, which have been subjected to laterization. The lateritic outcrops dot the interfluve areas of the upland plain serving as caps for regolith hills e.g. Gwauron Dutse and Dala hills. Well jointed younger granites of Jurassic origin occur in ring complexes in the extreme south. A narrow strip of the Chad Formation occurs to the east.

The study area is located mostly in Kura local government in Kano State whose rock types are medium to fine grain biotite granite and porphyrite biotite and biotite hornblende granite as in Figure 1.2.

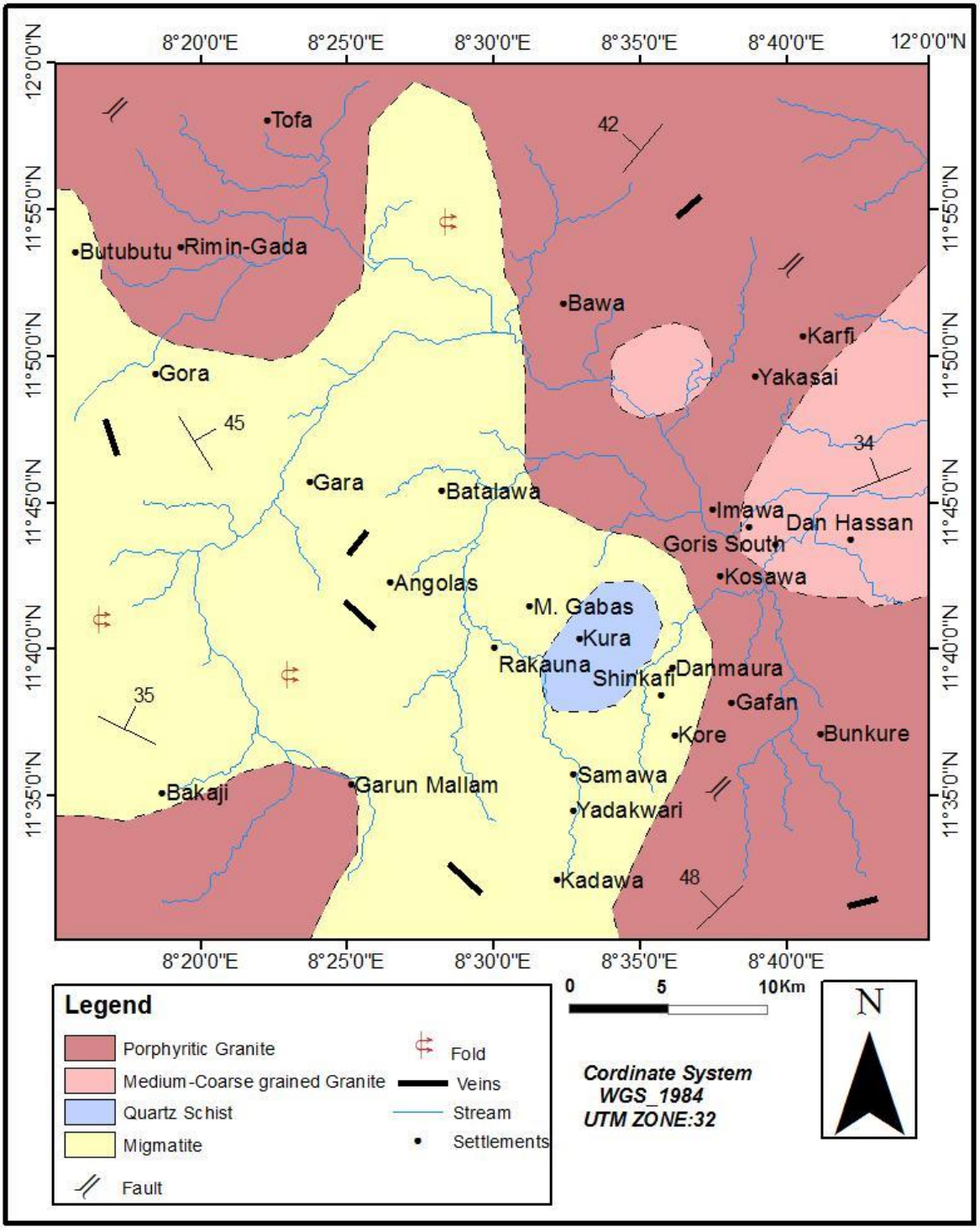


Figure 1.2 Geological Map of the Study Area

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The chapter provides an overview of previous research on knowledge sharing and intranets. This introduces the frame work for the case study that comprises the main focus of the research described in this thesis.

2.1.1 Previous Work on Pollution Study using Magnetic Susceptibility Measurement

There has not been any MSMS research work done on the Kano river irrigation project as at the time this work was done but previous work was done by some authors elsewhere as reported.

2.1.2 Previous Work of MSMS Done in Other Places

According Hanesch *et al.,* (2003 magnetic susceptibility is a reliable proxy for anthropogenic pollution. It cannot totally replace chemical measurements as it does not yield information about the chemical composition of the pollutants. Pollution has become a threat to human, animals and plants existence on the earth due to the risk it offers to both terrestrial and aquatic dwellers. Hanesch *et al.,* (2003) used magnetic susceptibility method to determine pollution as a proxy for chemical methods because pollutants and magnetic particles are genetically related. The magnetic susceptibility method is fast and can detect magnetic minerals present in the soil sensitively.

The Study magnetic susceptibility measurements of topsoil and soil at depth of 40 cm on roadside soils of Central district, Garki district, Wuse district, Maitama district and Asokoro district of Abuja the Capital of Nigeria reveals that multi;domain and single state domain mostly accumulate at the surface and hardly accumulate at depth(Jatto *et al.*,2017)

*Karimi et al., (*2011) used magnetic susceptibility as a proxy for industrial contamination in urban topsoils in the arid region of Isfahan. They measured the magnetic susceptibility of 113

collected soil samples from public parks and green strips along the rim of roads with high-density traffic within the city of Isfahan using the Bartington MS2 dual frequency sensor. The authors performed geochemical analysis on all the collected soil samples and discovered that Pb, Cu, Zn, and Ba have positive significant correlations with magnetic susceptibility, but As, Sr, Cd, Mn, Cr and V have no significant correlation with the magnetic susceptibility. There was also a significant correlation between pollution load index (PLI) and magnetic susceptibility. Finally, they indicated the potential of the magnetometric methods to evaluate the heavy metal pollution of soils.

Many authors reported that (Petrovsky and Ellywood 1999; Gautam *et al*., 2005b; Mohammed *et al*., 2015) roadsides in Urban area are commonly polluted by particulate matter derived mostly from motor vehicles exhaust, abrasive of tyres, plant and combustion emissions. This particulate matter consists of several heavy metals which are responsible for pollution of high w ays. The heavy metals can be determined by measuring the magnetic susceptibility of the topsoil of study area and coupled with geochemical analysis of the topsoil.

Charparro *et al*., (2010) said these magnetic minerals could be due to lithology, farm activities; military activities or from atmosphere while heavy metals may be due to particles of worn out tyres or due to burning of gas from vehicles exhaust. On the other hand Lu *et al*., (2006) said magnetic susceptibility in recent times has been used as a tool for estimation of anthropogenic pollution of industrial areas, soil studies, road side dust studies and sea sediments.

Some Studies made by Jordanova *et al*, (2004) and Kanu *et al*., (2013) revealed that there is a highly correlated relationship between magnetic susceptibility and heavy metal contents in soil. According Magiera *et al*., (2011) who studied soil contamination in the municipal forests of Upper Silesia, the correlation coefficient of magnetic susceptibility with heavy metals

varies to a significant degree. Thus, the correlation varies from 0.98 to 0.15 with zinc in different areas, from 0.98 to –0.57 with lead, from 0.98 to 0.0 with cadmium, from 0.98 to 0.22 with copper, from 0.91 to –0.30 with chromium, and from 0.88 to –0.06 with nickel. For this reason, it is not always possible to detect a positive correlation between the magnetic susceptibility and the content of heavy metals in contaminated soils or this correlation is not established for some heavy metals.

Lu *et al*., (2010) studied the soils of Gandzhou (China) and got a reliable correlation between the magnetic susceptibility of soils and zinc. This correlation was weak with copper and cadmium. In the industrial district of Shanghai (China), the authors obtained the magnetic susceptibility of soils which varied from 18×10^{-8} to 1127×10^{-8} kg-^{1}m^{3} and also measured the magnetic susceptibility of the nearby agricultural land soil and discovered that it was much lower: from 18×10^{-8} to 167×10^{-8} kg-^{1}m$^{3.}$ This could be due to loss of magnetic minerals by plant uptake or by cultivation process which lead to erosion.

Jiang *et al*., (2010) obtained a correlation between the magnetic susceptibility of soils in Luoyang and heavy metals to be moderately high: R^2= 0.61 for Cr, R^2 = 0.71 for Pb. The authors Performed field measurements of magnetic susceptibility to identify areas of high chromium and lead contamination in the city. The correlation coefficient of heavy metals increases when the magnetic susceptibility of soil is especially high, i.e., when the content of magnetite/maghemite is maximum.

Kanu *et al*, (2013) measured the magnetic susceptibility of soil in Jalingo, Taraba State (Nigeria) and reported that the magnetic susceptibility and heavy metals have a positive Pearson correlation of 0.994.

Similarly, a study was done by Paradelo *et al*, (2014) on magnetic susceptibility and trace elements distribution in compost size fractions and reported the following correlations for a concentration of 20 mg: MS= 3.9 + 0.044Cu with R^2 =0. 88; MS=2.1 + 0.038Zn, R^2 = 0.84;

Ms=3.9 + 0.071Pb, R^2=0.85. The correlations are high and are good index to use magnetic properties for pollution study.

The study of El Baghdadi *et al*., (2011) on magnetic susceptibility and geochemical analysis showed the correlation between magnetic susceptibility and concentration of heavy metals have a good correlation as shown in the table 2.1 below. The table shows that correlation between the magnetic parameters and heavy metals are high.

Table 2.1: Correlation matrix between Magnetic Susceptibility and Heavy Metals (El Bagdadi *et al*., 2011**)**

	Cd	Cu	Fe%	Pb	Zn	Cr	κ MS (10^{-5} SI)
Cd	1	0.73	0.57	0.89	0.86	0.72	0.83
Cu		1	0.38	0.78	0.92	0.74	0.63
Fe%			1	0.58	0.51	0.40	0.60
Pb				1	0.92	0.83	0.87
Zn					1	0.76	0.83
Cr						1	0.72
κ MS (10^{-5} SI)							1

The report of Perry and Taylor, (2007) revealed some source of heavy metals which are contaminants in the soil which affects humans, animals and plants health. Some of the contaminants with their sources are presented in Table. 2.2.

Table 2.2: Contaminant Sources of Road-Deposited Sediments (Perry and Taylor, 2007)

Contaminant	Source
Pb	Petrol combustion, paint, smelters, coal combustion
Zn, Cd	Tyre wear, galvanized roofs, abrasion of vehicles, lubricating oils, alloys
Cu	Brake linings, alloys, metal industry
Fe	Car exhaust particulates, corrosion of vehicle body work, background geology
Mn	Tyre wear, brake linings, background geology
Cr	Engine wear, vehicle plating and alloys, road surface wear
Ni	Engine wear, metal industry, background, geology Asbestos, Brake clutch linings
Cl, Na	Road salt
PGEs (Pt, Pd, Os)	Catalytic convertors Pesticides/herbicides, Garden application
PAHs	Biomass burning, petroleum combustion
PCBs	Petroleum combustion, industry
Bacteria	Sewage treatment works, animal faeces
Pharmaceutical compounds	Sewage treatment works, animal faeces

Dunlop and Ozdemir (1997) and Dekker, (2007) discovered magnetic materials types and mineral compositions based on their magnetization which are presented below in Table 2.3 below

Table 2:3: Magnetic Properties of Selected Minerals (Ozdemir, 1997 and Dekker, 2007)

Mineral	Composition	$T_{v,}$ M $T_{C,N}$ (C^0)	Hc (mT)	Ms	Magnetic Structure
		$_{INV}$ (C^0)		KAm^{-1}	
Magnetite	Fe_3O_4	- 158 580	5-80	480	Ferromagnetic
Titanomagnetite	$Fe_{3-x}Ti_xO_4$	150-540	125		Ferromagnetic
Maghemite	YFe_2O_3	<250 590-675	5-80		Ferromagnetic
Hematite	αFe_2O_3	-15 675	100-500	-2.5	antiferromagnetic
Pyrrhotite	Fe_7S_2	(-240) 320	8-100	-80	Ferromagnetic
Goethite	$\alpha FeOOH$	120	>1000	-2	antiferromagnetic
Iron	αFe	765	<1-10	1715	Ferromagnetic
Greigite	Fe_3S_4	-330	15-40	-125	Ferromagnetic

The review of many authors that used various techniques to study magnetic parameters of different media like **Soil** (urban roadside and street soils, playground soils, industrial areas soils, recreational sites soils), **Biomonitors** (Roadside tree, leaves of birch, different tree species, pine leaves), **Filters** (air quality, air monitoring stations) and **Combinations of Techniques** are reported in Table 2.4 below.

Table 2.4: Review of literature (selected papers) reporting the use of various techniques for sampling of Soils, Biomonitors, Filters and Combinations of Techniques are presented in the table below (Michal, S.B.(2012)

References	Studies material and area	Rock-magnetic parameters	Other analyses/parameters
SOIL			
Olson and Skogerboe, 1975	Urban roadside soils and street dust samples collected from three distinct geographic areas in Colorado, Missouri		Magnetic separation, gradient density, XRD, chemical analysis: Pb, microscopic observations, emission spectrography
Hoffmann *et al*.**, 1999**	Roadside soil along a major road in SW Germany	K_{is} X. IRM, low-field susceptibility vs temperature, M_s vs temperature	
Haneesch and scholger*et al.*, 2007	Soils collected from urban X (various sampling sites: parts, residential areas, road sections, playgrounds for children) and industrial areas in Austria		Chemical analysis As, Cd, Co, Cr, Cu Hg, Mo, Ni, Pb, Pt, Se, V, Zn.
Amereih *et al*.**, 2005**	Soil samples along two X Austrian motorways		Chemical analysis Sb:
Gautam *et al*.**, 2005a**	Soils collected from the following areas in Kathmandu, Nepal: suburban background site, recreational areas and parks situated in core urban areas, recreational park close to an industrial area.	X, IRM SIRM, SIRM/X ratio, X vs temperature	Chemical analysis: Cd, Cu, Co, Cr, Mn Ni, Pb, Zn, Fe, PLI.
Lu and Bai, 2006	Soil collected from industrial, roadside, residential, campus areas and public parks located around Hangzhou City, China	X_{if} X_{hf} $X_{fd\%}$ IRM, SIRM, HIRM, magnetization parameter ($F_{300\ mT}$%) = [100 x (IRM_{300mT}/SIRM)] S_{100}, $IRM_{20mT,\ ARM}$	Chemical analysis: Fe, Mn, Cd, Cr, Mn, Cu, Zn,XRD, PLI.
Yang et al., 2007	Urban soil samples collected from: industrial areas, villages, a main road and heavy traffic and roads around the East Lake in Wuhan	X_{if} X_{hf} $X_{fd\%}$ ARM, IRM, SIRM, $_{S\text{-}300}$ X vs temperature	Chemical analysis: C0, Cr, Cu, Mn Ni, Pb, Zn, Fe, PLI.
El-Hassan,	Urban roadside top soils of	X_{in},,Ms	

2008	sahab city, Jordan		
El-Hassan *et al*., 2009	Urban topsoil samples collected across the whole of Sahab city, Jourdan		Chemical analysis: Fe, Mn, Cu, Co, Ni, Nn, Zn, Cb, and Pb XRD, IP
BIOMONITORS			
Matzka and Maher, 1999	Roadside tree leaves of birch (*Betula pendula*) collected in the rural coast of Norwich, England	$IRM_{300mT,}$ AF demagnetization	
Gautam *et al*., 2005b	Three types of tree leaves obtained from cypress (mainly *Cupressus corneyana*), silky oak (*Gervillea robusta*), and bottlebrush (*Callistemon laceolatus*), sampled along road corridor and recreational parts in both urban and suburban areas of Kathmandu, Nepal	X, IRM	Chemical analysis: Cd, Cu, Co, Cr, Fe, Mn, Ni, Pb Zn, SEM with EDS
Davila *et al*., 2006	Tree leaves obtained from London plane (*Platanus hispanica*) in urban and sub-uban areas of the coastal city of Vigo, Spain	$SIRM_{IT,}$ S_{-300}	SEM with EDXPA chemical analysis: Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn
Mcintosh *et al*., 2007	Tree leaves of Hybrid Plane (*Platanu x hispanica*) 100_{mT} collected in a central, urban area of Madrid, Spain: roadside, plaze and park locations.	IRM_{IT} S_{-300}, S_{100mT} $IRM_{IT/K}$	
Szonyi et al., 2008	Tree leaves of evergreen oak (Quercus liex) collected in Rome, Italy at sites with Different traffic conditions (e.g urban parks, intersection with very high traffic)	K, X, IRM H_{CR} hysteresis parameters, ARM, X_{ARM} temperature-dependence of magnetic susceptibility	SEM with EDS
FILTERS			
Muxworthy *et al*., 2001	PM_{10} and PM_{70} filters collected at two permanent stations located in areas of Munich,	ms, Ms, H_c magnetization vs. temperature	Ozone, benzene, toluene, o-dimethyibenezene, CO, NO, $NO_{2,}$ SO_2 SEM with

	Germany. One station is in the city centre and one in the city suburbs		EDX
Muxworthy *et al*., 2002	Two self-constructed PM fallout collectors were placed at different distances from the street, Munich, Germany	Hysteresis parameters, rotational hysteresis, magnetic sussceptiility/magnetization vs. temperature	Mossbauer spectroscopy, SEM with EDX
Muxworthy *et al*., 2003	PM_{10} filter samples collected at two permanent air monitoring stations located in the city centre and suburbs of Munich, Germany	SIRM, SIRM AF_{25}/SIRM AF_{10} ratio	CO, NO, NO_x ($NO+NO_2$), SO_2
Segnotti *et al*., 2006	PM_{10} filters collected at six air-monitoring stations distributed with Rome Italy, at sites with different traffic conditions, varying from urban park to high-traffic industrial area	K, X, ARM, hysteresis parameters, FORCs, IRM $H_{CR,}$ S_{-300}, S_{-100} thermal demagnetization of M_{RS}, $X_{fd\%}$	
URBAN DUST			
Hopke *et al*., 1980	Road dust from Urbana, Illinois, USA		Magnetic separation, gradient density, chemical analysis: Sb, As, Ba, Br, Ca, Cd Ce, Cs, Cr, Co, Dy, Eu, Ga, Hf, Fe, La, Pb, Lu, Mn, Hg, Ni, K, Rb, Sm, Sc, Se, Ag, Na, Sr, Tb, Th, U, Yb, Zn, Zr
Xie *et al*., 1999	Street dust from street gutters and pavements in the city of Liveerpool, UK. The sampling sites were distributed over diverse locations: pedestrian streets, gardens and roads with different traffic densities	X_{if} X_{hf} $X_{fd\%}$ ARM, X_{ARM} $SIRM_{IT}$ $IRM_{20mT,}$ $IRM_{20Mt,}$ $IRM_{-300mT,}$ SOFT, HIRM, $X_{HIGH,}$ X_{ARM}/SIRM, SOFT%, HARD% ($SIRM-IRM_{20mT}$), X_{HIGH}/X_{if}	
Xie *et al*., 2010	Street dust samples obtained from street gutters and pavements in the city of Liverpool, UK. The sampling	X_{if} X_{hf} $X_{fd\%}$, X_{ARM} $SIRM_{IT}$ IRM, ARM, ARM, $IRM\text{-}20_{mT}$, IRM_{-300mT} SOFT,	Organic matter content measured by LOI, X-ray florescence (XRF): Si, Ti, Ca, K, Fe, S, Pb, Rb, Sr,

	sites were distributed over diverse locations: pedestrian streets, gardens and roads with different traffic densities covering the whole city centre.	HIRM, SOFT%, HARD%, X_{ARM}/SIRM	Zn, Zr.
Robertson *et al*., 2003	Urban sediment from inner and outer city road surfaces in Manchester, UK		Chemical analysis: Fe, Cu, Zn, Pb, Mn, organic matter content based on LOI, SEM
Goddu *et al*., 2004	Road dust from an industrial area in Visakhapatnam city india	K, $K_{fd\%,}$ SIRM, IRM hysteresis parameters, FORCs, temperature-dependence of k	SEM with EDX
Lu *et al*., 2006	Vehicle emission particulates collected from the inner wall of exhaust pipes in Hangzhou city, china	X_{if} X_{hf} $X_{fd\%}$, IRM, SIRM, ARM, $HIRM_{20mT}$	Chemical analysis: Cu, Cd, Pb, Fe
Shilton *et al*., 2005	Street dust collected from three roads (two urban and one residential road) in the West Midlands, UK.	X_{if} X_{hf} $X_{fd\%}$, ARM, X_{ARM} IRM, X_{ARM}/SIRM, $SIRM/_X$, $ARM/_X$, S-ratio, HIRM, SIRM	Chemical matter content based on LOI, SEM
Kim *et al*., 2007	Roadside dust collected in the city of Seoul, Korea, from industrial and high traffic sites (e.g. in a tunnel, on a bridge nearby the railway station)	X, ARM, SIRM, IRM, S_{-300}, temperature-dependence of magnetic susceptibility	SEM with EDS, chemical analysis: Cr, Cu, Fe, Mn, Pb, Zn
Kim *et al*., 2009	Roadside dust collected at industrial, park, residential and traffic areas in Seoul, Korea	X, ARM, SIRM, M_s, IRM, S_{-300}, X vs. Temperature	SEM with EDS
Yang *et al*., 2010	Road dust samples collected from an industrial area, villages a main road with heavy traffic and roads around the East Lake in Wuhan, China	X_{if} X_{hf} $X_{fd\%}$, ARM, IRM, SIRM, hysteresis parameters, H_{CR}, X_{ARM}/X_{if}, ARM/X_{if},X vs. temperature	Chemical analysis: Fe, Cu, Pb, Zn, Mn, Co, V, Ni, Cr, PLI
COMBINATION OF TECHNIQUES			
Flanders, 1994	Airborne particulates collected from various surfaces and	Magnetization	SEM

	directly from the atmosphere (e.g. spider webs, tree trunk and leaves, fly ash from oil and coal combustion, road dust)		
Xie *et al*., 2000	Street dust from street gutters and pavements. The dust sampling sites were distributed over diverse locations: pedestrian streets, gardens and roads with different traffic densities. Topsoil samples were collected from roadsides, gardens or waste land in Liverpool, UK.	X_{if} X_{hf} $X_{fd\%}$, X_{ARM}, $SIRM_{IT}$, IRM, ARM, IRM-20_{mT}, IRM-300_{mT} SOFT, HIRM, SOFT% HARD%, X_{HIGH}, X_{if}, X_{ARM}/SIRM	Organic matter content measured by LOI
Charlesworth and Lees, 2001	Urban dusts and sediments from lakes, streams, streets and wetlands simpled in Coventry UK.	X_{if} SIRM	
Gautam *et al*., 2003	Sediment and road dust sample collected from urban and suburban areas in Kathmandu, Nepal.	K_{is}. X, IRM, X vs. temperature	SEM with EDS
Maher *et al*., 2008	Urban roadside tree leaves of birch (*Betula pendula*), air filter samples (high-volume air sampler) in Norwich, UK	SIRM	Chemical analysis: Fe, Pb, Zn, Mn, Ba, Cd, Cr, SEM with EDXA
Maher, 2009	Leaves of lime trees (*Tilia platyllos*) collected within the perimeter of the city ring road, background and suburban areas in Lancaster, UK. In addition, air PM_{10} filters (high-volume air sampler) collected from each sampled tree location	X_{ARM}, IRM, ARM, SIRM, HARD%, X_{ARM}/SIRM ration temperature dependence of IRM	SEM with EDX
Sagnotti *et al*., 2009	Tree leaves of evergreen oak (*Quercus ilex*) collected along a high-traffic square and a large green park in Rome, Italy. In addition, material collected from exhaust pipes of gasoline and diesel engines,	Hysteresis parameters, IRM, $H_{CR,}$ FORCs, $K_{fd\%}$, temperature dependence	SEM with EDS

	wheel rims around disk brakes, engine hoods and filters at an automatic air monitoring station on a high-traffic road.		
Chaparro *et al*., 2010	Samples collected from exhaust pipes of gasoline and diesel vehicles, brake systems, roadside sediments and soils, Buenos Aires, Argentina	K_{is}, K, ARM, IRM, X, K_{ARM}, K_{ARM}/K ratio, SIRM, S_{-300}, H_{CR}, SIRM/K ratio	SEM with EDS chemical analysis: Li, K, Na, Mg, Ca, Sr, Ba, Cr, Mn, Fe, Co, Ni, Cu, Al, Zn, Cd, Pb, PLI
Marie *et al*., 2010	Samples collected from exhaust pipes of gasoline and soil and soils, asphalt material, Buenous Aires, Argentina	K_{is}, K, ARM, IRM, K_{ARM}, K_{ARM}, K_{ARM}/K ratio, SIRM, S_{-300}, H_{CR}, SIRM/k ratio, thermal demagnetization of magnetic susceptibility and remanent magnetization	Chemical analysis: Li, K, Na, Mg, Ca, Sr, Ba, Cr, Mn, Fe, Co, Ni, Cu, Al, Zn, Cd, Pb, SEM with EDS

Das (2014) compared the concentration of MSMS of Mumbai, India with some values of MSMS of some materials worldwide in Table 2.5 below.

Table 2.5 Worldwide magnetic susceptibility data compared with the observed susceptibility data of Mumbai dusts (Das, 2014)

Material Type	Study Area	Background Rock	$\chi(10^{-7}m^3kg^{-1})$	Instru-ment	Reference
Road dust	Mumbai MMR, India	Deccan basalt	59.3–1046.0	MFK1	This study
Topsoil (This study)	Nashik, India	Deccan basalt	15.9–68.7	MFK1	This study
Drainage sediment	London	NA	34.5–72.8	MS2	Beckwith et al. (1986)
Topsoil	England		<3–8	MFK1	Hay et al. (1997)
Soil profile	France	Alps conglomerate deposit	2.9–14.6	MFK1	Lecoanet et al. (2003)
Road dust	Visakhapatnam, India	Khondalite	1.4–10.1	MS2B	Goddu et al. (2004)
Road dust	West midland, UK	NA	157.1	MS2B	Shilton et al. (2005)
Dust loaded leaves	Nepal	NA	0.1–5.4	MFK1	Gautam et al. (2005)
Road dust	Seoul, S. Korea	NA	3.2–14.4	MS2B	Kim et al. (2007)
Soil	Luoyang, China	Loess parent material	6.5–10.9	MFK1	Lu et al. (2007)
Dust loaded leaves	China	NA	1.6–85.6	MS2B	Lu et al. (2008)
Soil	Slovakia	Alternating clay stone and sandstone	3.4–5.8	MFK1	Kluciarova et al. (2008)
Road side soil	Finland	NA	1.6–17.9	KLY-4	Bucko et al. (2010)
Road dust	Wuhan, China	NA	4.4–29.4	MS2B	Yang et al. (2010)
River sediment	Loudi, China	Lime stone	10–105	MS2B	Zhang et al. (2011)
Soil	China	Loess and fluvial deposits	1.4–39.4	MS2B	Yan et al. (2011)
Road side soil	China	Quaternary alluvial deposits	1.9–50.3	MS2B	Lu et al. (2011)
Road dust	Sofia, Bulgaria	NA	10.0–120.0	MFK1	Jordanova et al. (2012)
Indoor dust	China	NA	10.1–63.6	MFK1	Zhu et al. (2012)
Road dust	Lanzhou, china	Gobi Desert	11.1–98.7	MS2B	Wang G. (2012)
Soil	Pune, India	Deccan basalt	1.8–30.4	MS2B	Sangode et al. (2012)
Soil	Mumbai, India	Deccan basalt	0.2–33.4	MS2B	Gudadhe et al. (2012)

2.1.3 Philosophy of Environmental Magnetism for Pollution Assessment

Environmental magnetism involves the application of rock and mineral magnetic techniques to situations in which the transport, deposition or transformation of magnetic grains is influenced by environmental processes in the atmosphere, hydrosphere and lithosphere (Verosub & Roberts, 1995). An important aspect of environmental magnetism is that its techniques are relatively rapid, simple, non-destructive, inexpensive, and can be applied to a wide range of materials, including rocks, sediments, soils, atmospheric particulates and biological materials. The studies encompassed by this discipline can be divided in three major categories:

a) Regional and global climate, concerning short- and long-term estimation, through the study of lake sediments and ice cores, for the former case, and loess and deep sea sediments for the latter.

b) Anthropogenic pollution, by studying sediments (aeolian, marine, lake, rivers) and soils.

c) Bio magnetism, which concerns magnetic bacteria and human/animal tissue.

A thorough review of environmental magnetism principles and applications can be found in Evans and Heller (2003).

2.1.4 Heavy-Metal Pollution

Motivations for controlling heavy metal concentrations are diverse as some of them are dangerous to health or to the environment (e.g. Hg, Cd, As, Pb, Cr), some may cause corrosion (e.g. Zn, Pb) and some are harmful in other ways (e.g. Arsenic may pollute catalysts). There are 13 elements of highest concern which are As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sn, and Tl, the emissions of which are regulated in waste incinerators. Some of these elements are actually necessary for humans in minute amounts (Co, Cu, Cr, Ni) while others are carcinogenic or toxic, affecting, among others, the central nervous system (Hg, Pb, As), the kidneys or liver (Hg, Pb, Cd, Cu) or skin, bones and teeth (Ni, Cd, Cu, Cr). Heavy metal pollution can arise from many sources but most commonly is due to the purification of metals, e.g., the smelting of copper and the preparation of fuels. Electroplating is the primary source of chromium and cadmium. Through precipitation of their compounds or by ion exchange into soils and muds, heavy metal pollutants can localize and lay dormant. Unlike organic pollutants, heavy metals do not decay and thus pose a different kind of challenge for remediation. Currently, plants or microrganisms are tentatively used to remove some heavy metals such as mercury. Plants which exhibit hyper accumulation can be used to remove heavy metals from soils by concentrating them in their bio matter. Some treatment of mining tailings has occurred where the vegetation is then incinerated to recover the heavy metals.

2.1.5 Basic Principles

Iron is one of the most common elements in the Earth's crust. In combination with oxygen and sulphur it forms magnetic minerals, which occur to a greater or lesser extent universally. Nanometre sized particles are of particular interest because they occur in great quantities, implying a large surface area. Due to these properties, nanoparticles can provoke biological reactions itself or act as a vehicle for other toxic components. Iron oxides and sulfides have excellent adsorbent properties and attract not only heavy metals (Watson et al. 1995) but also organic contaminants and even radioactive pollutants (Watson et al., 2001). For obvious reasons magnetic methods can be used for the characterisation of pollution and have become commonplace by many international laboratories (e.g. Dearing et al., 1996; Petrovsky et al., 1998; Evans & Heller, 2003; Hanesch et al., 2003).

2.2 Magnetic Susceptibility

Magnetic susceptibility specifies the ability of material to acquire magnetization when subjected to external magnetic field. Volume magnetic susceptibility is defined as the magnetization (M) acquired per unit field (H),

$$\kappa = \frac{M}{H} \qquad (1)$$

In SI unit's M and H are measured in A/m, thus κ is dimensionless. The measured magnetic susceptibility is generally expressed as mass-specific susceptibility, which is calculated from the following equation,

$$\chi = \frac{\kappa}{\rho} \qquad (2)$$

where ρ is the density of material and the values of χ are given in m^3kg^{-1}. The mass specific magnetic susceptibility of a diamagnetic material is negative. Water is considered to be a very strong diamagnetic (χ = -0.90 × $10^{-8}m^3kg^{-1}$) (Evans and Heller, 2003). Paramagnetic materials exhibit slightly positive mass specific magnetic susceptibility. Magnetic

susceptibility reflects the concentration, grain-size, and type of magnetic minerals present in a sample. A high value of magnetic susceptibility indicates a high concentration of magnetic minerals (Maher, 1986; Thompson and Oldfield, 1986). Specimens such as soil or road dust usually are a composite of diamagnetic, paramagnetic, and ferro/ferrimagnetic contributions. Ferro/ferrimagnetic materials have very high mass specific magnetic susceptibilities so that for concentrations larger than ~1% the measured susceptibility may be equated to the ferromagnetic susceptibility. In the case of lower concentrations, the paramagnetic and diamagnetic contributions can be substantial (Dekkers, 2007). In environmental studies, magnetic susceptibility is a very convenient parameter since virtually all materials can be measured and the measurements are simple and fast. The measurements are also non-destructive and can be made in the laboratory as well as in the field (Evans and Heller, 2003). This means that magnetic susceptibility measurements can be used as a primary tool for the mapping of spatial and temporal distribution of pollutants and the identification of their sources, before other time

2.2.1 Magnetic Susceptibility of Soil

The study of the magnetic properties of soils is a difficult field of study but Thompson & Oldfield (1986) point out that some characterisation of the magnetic properties of soils is vital since the weathering of rocks releases iron which is transformed into chemically stable magnetic oxides which may then persist in the soil, in the suspended load of rivers, in atmospheric dusts and in the historical record preserved in sediment, peat and ice cores. They have suggested that if the magnetic properties of soil can be characterised, they can then be applied in almost any other environmental magnetism problem. Soils contain a wide variety of minerals and their magnetic properties reflect the combination of minerals present. The diamagnetic component of soils includes quartz, orthoclase, calcium carbonate, organic matter and water (Thompson & Oldfield, 1986). These components do not contribute to the

magnetic properties except in an extreme case such as pure silica sand. Many soil minerals, both primary (inherited from the parent rock) and secondary (formed by weathering processes), are paramagnetic. Ferrimagnetic minerals such as maghemite and magnetite usually dominate but when they are absent paramagnetic minerals such as olivine and pyroxene contribute significantly to the magnetic susceptibility (Thompson & Oldfield 1986). Some clay minerals are iron-rich and have high susceptibilities. Several antiferromagnetic minerals are found in soils with goethite and haematite being the most important (Dearing 1999). Goethite is more common in temperate climates while haematite is found in drier and more highly oxidising conditions. Lepidocrocite is also a canted antiferromagnetic mineral, largely confirmed to gleyed (waterlogged, reducing conditions) soils where it occurs as orange mottles (Thompson & Oldfield 1986). Magnetite and maghaemite are the most important ferrimagnetic oxides. Magnetite occurs as a primary mineral, inherited from basic igneous rocks, and as a secondary mineral, maghaemite is also a secondary mineral

2.2.2 The Magnetic Enhancement of Surface Soils

Many researchers have noted that the magnetic susceptibility of soil is higher than that of the parent material, and that the susceptibility of the topsoil is usually higher than that of the subsoil (De long *et al*., 1997; Thompson & Oldfield 1986) has suggested that this enhanced susceptibility of the soil is due to the in situ conversion of the iron oxides from an antiferromagnetic form such as haematite (0:Fe_2O_3) or goethite (0: FeOOH) in a moist soils which has low magnetic susceptibility to the ferromagnetic in form of maghaemite (yFe_2O_3) and magnetite (Fe_3O_4) which has higher MS. Le Borgne(1995) also proposed two possible mechanisms involving reduction, followed by re-oxidation to maghaemite. In the first process, he proposed that during wet conditions, anaerobic breakdown of soil organic matter leads to the reduction of iron and then during the subsequent dry period the iron is re-oxidised to form maghaemite. The second process is a heating mechanism whereby the burning of

organic material produces the temperature increase and reducing conditions necessary for the reduction to magnetite (Fe_30_4) in a thin layer of soil underlying the fire and re-oxidation occurs during the cooling down of the fires when air enters the system. These findings have been substantiated by researchers like Mullins and Tite (1977) which form the basis of most work performed since then and stating that burning of surface vegetation cover and topsoil can promote a massive increase in MS. Mullins and Tite (1977) identifies four ways in which maghaemite is formed in soil and refers to them either as 'burning mechanisms' or 'paedogenic mechanisms. Thompson and Oldfield (1986) have noted that soils near cities may have a higher susceptibility in the topsoil due to fallout from the atmosphere of magnetic particles derived from fossil-fuel combustion. This will not always be the case but should be considered when selecting sites for magnetic susceptibility studies.

Magnetic susceptibility measurements of soils are mostly used for two purposes: to read the climatic signal recorded by palaeosols (Maher *et al.* 2003), to identify pollution in soils and also attempts have been made to delineate areas of hydrilic soils by magnetic susceptibility measurements in the field (Petrovský & Ellwood 1999; Lecoanet *et al.* 2003). Complexity of the relationship between soil and susceptibility can be imagined if we regard the factors acting during soil formation. Some factors are that influence magnetic susceptibility in soil. All these factors may also affect the susceptibility signal within a soil.

(i) Climatic influences on susceptibility are mainly temperature and rainfall (Eyre, 1997). Modern analogues of the association between soil susceptibility and climate can be used to approximate the intensities of palaeoprecipitation (Dearing *et al.* 1996; Maher *et al.* 2003).

(ii) Parent material is especially important for the content of magnetic minerals. In some cases, it is the dominating influence on soil susceptibility (Hanesch *et al.* 2003).

(iii) The effects of topography on susceptibility were studied for example by De Jong *et al.* (2000). They found that soil susceptibility changes with the position of the soil profile on a slope. Texture and drainage class are assumed to be the main reason.

(iv) The water regime is one of the most important influences on the magnetic properties of a soil. If the soil is arid, pedogenic magnetite does not form. If waterlogging occurs (e.g. gleysol), magnetic minerals are dissoluted.

Therefore, the same susceptibility value can be a relatively low value for a well-drained brown earth but an average value for a waterlogged soil. These relationships are qualitatively known (Maher 1998) but we still lack information on which values can be regarded as normal for a certain soil type. Water also acts as the transporting agent if clay (in luvisol) or organic matter (in podzol) is relocated within the soil profile. These transport processes depend, inter alia, on the pH value throughout the soil profile. Iron and aluminium are often transported together with the clay or the organic matter to deeper soil horizons. Hence, these processes affect the vertical distribution of magnetic susceptibility.

(v) Fauna and flora may also affect the susceptibility throughout a soil profile. Animals (e.g. worms) relocate material in the horizontal and vertical direction. Roots of plants create channels, which make transport of solutions easier. Different vegetation causes different processes in the soils, which in turn affects the susceptibility profile (Dearing *et al.* 1996).

(vi) Erosion (e.g. by gravity at slope sites, but also by wind) can lead to loss of the magnetically enhanced soil horizon.

(vii) Anthropogenic influences are mainly industrial pollution but also agricultural use, removal or disposal of material.

(viii) Another important factor of soil formation is time. It also influences the magnetic properties. While a well-drained soil matures, the enhancement of susceptibility increases. This enrichment of magnetically susceptible minerals does not always occur at a constant rate (White & Walden 1997).

The high number of interacting processes makes it difficult to specify typical values for the susceptibility in soils. In this study, we want to find standard values for the irrigation soil, which help us to interpret susceptibility values measured for individual soils used for irrigation farming system. The statistical parameters calculated for these groups can be used as a reference for the classification of individual measurement.

2.3 Difficulties Associated with Magnetic Pollution Study

For areas of low magnetic background such as sedimentary limestone or sandstone, many authors have shown that the magnetic technique proved quite successful (Lecoanet *et al*., 2003; Blaha *et al*., 2007 and Meena *et al*., 2011). The magnetic minerals of basalts are mostly of ferrimagnetic nature and the stage of basalt weathering differs from place to place leading to non-uniform composition of soil and dusts developed from such bed rocks. Besides high magnetic content, soils and dusts developed from basaltic rocks have also a high content of heavy metals of (Pb, Zn, Cu, As, Cr and V), compared to those developed from sedimentary background. Since high magnetic background values suppress lower levels of anthropogenic inputs and as the background magnetic concentration is variable and heterogeneous from site-to-site, accurate assessment of the stage of contamination becomes difficult for pollution screening in basaltic rock environment (Pettigrove and Hoffmann, 2003).

2.4 Long Term Magnetic Mineralogical Effects of Redox Processes in Flooded Soils

The reduction of Fe (III) oxides to dissolved, adsorbed and solid Fe(II) phases is discussed by van Breemen (1988) with particular regard to the periodic or long-terin flooding of soils. Two

processes of particular importance under such conditions are: ferrolysis, the cyclic displacement of adsorbed cations by Fe(II) and the segregation of iron oxides due to redox processes. Ferrolysis begins with the reduction of iron oxides providing Fe^{2+} ions that exchange with Ca^{2+} and Mg^{2+} cations within the clay fraction. These displaced cations together with the anions separated during the production of Fe^{2+} are removed from the soil by percolation and diffusion and in the short term' will not be replaced through the weathering of primary minerals. Subsequent aeration of the soil results in the oxidation of the exchangeable Fe^{2+} to less soluble Fe^{3+} oxy-hydroxides and its replacement by less stable H^{+} in base anions. The H^{+} will subsequently be replaced by Al^{3+} that again may be displaced by Fe^{2+} arising from reduction during further flooding incidents leading to the partial dissolution of clay minerals. Over an extended period of time ferrolysis will lead to a siltier, highly acidic soil and an increased concentration of ferric hydroxides. Seasonally waterlogged soils, or gleys, are generally identified through the separation between brown/red horizons containing concentrations of Fe^{2+} oxides and adjacent grey/green/blue/black where solid Fe^{2+} predominates. The formation of these layers arises from the higher solubility of many Fe^{2+} compounds those results in a higher mobility and translocation within the soil section. As with ferrolysis, the process begins with the reduction of Fe^{3+} to Fe^{2+} through microbial action (Kostka et al., 1999) accelerated by the absence of 0_2 and the presence of organic matter as an energy source for the bacteria. Translocation of the liberated Fe^{2+} will then occur through either diffusion or mass flow until the Fe^{2+} is immobilised. Immobilisation may occur through either the precipitation of solid Fe^{2+} compounds (high pH, concentration of sulphide), the adsorption of Fe^{2+} by clay or Fe^{2+} oxides or the direct oxidation to Fe^{2+} following the re-introduction of 0^2 during subsequent dry periods together with possible bacterial catalysis under acidic conditions (Fischer *et al.*,2003). The effect of repeated waterlogging on a soil is to lead to a concentration of fine grained, iron oxides of poor crystallinity that hampers preci

identification. However, both goethite and lepidocrocite occur widely in such hydromorphic soils with lepidocrocite forming distinctive bright orange mottles around root tubers following the rapid oxidation of mixed Fe^{2+} / Fe^{3+} hydroxides "green rusts". Femhydrite may also be present as an intermediary phase in soils undergoing frequent redox cycling but is difficult to identify in low concentrations. Magnetite and maghaemite despite being typical products of the slow oxidation of Fe^{2+}/ Fe^{3+} hydroxides are rarely found in hydromorphic soils due to the more rapid kinetics of the oxidation reaction. The effect of prolonged gley conditions would appear to reduce the magnetic susceptibility of a waterlogged soil through the preferential dissolution of fine superparamagnetic iron oxides such as magnetite or maghaemite (Thompson and Oldfield, 1986). In addition, the degree of magnetic iron oxide depletion depends upon the local soil environment that may well be moderated by surface vegetation over comparatively short periods of time. For example, Dearing (1999) reported a result from similar soils collected under stands of deciduous oak and pine that showed that the latter species produced a marked reduction in the subsoil magnetic properties. This depletion correlated with an increase in both the acidity and concentration of organic matter beneath the pine that may well account for enhanced microbial oxidation of Fe^{3+} to Fe^{2+}. It seems likely that increased levels of microbial activity within waterlogged soils would account for the poor survival of fine ferromagnetic material as opposed to their apparent persistence in lacustrine and marine sediments (Oldfield, 1991).

Occurrence of iron sulphides in terrestrial soils the occurrence of magnetic iron-sulphide minerals is not uncommon within marine anoxic sulphate reducing sediments, particularly in the presence of organic matter (Roberts and Turner 1993) and it is possible that such conditions may be supported on waterlogged terrestrial sites. The most stable iron sulphide found under these conditions is the paramagnetic mineral pyrite, which is the ultimate product of a well-defined chemical pathway beginning with the formation of intermediate

ferrimagnetic sulphides such as mackinawite, pyrrhotite and greigite. This process begins with the production of H_2S through the reduction of sulphate by anaerobic bacteria utilising organic matter within the sediment as an energy source. Ferrous ions produced either by bacterial or inorganic decomposition of detrital iron minerals will then react to form a series of metastable iron sulphides resulting in the formation of pyrite. The amount of iron sulphide formed is critically controlled by the availability of reactive iron compounds, the concentration of dissolved sulphate and the presence of organic matter for the bacterial reduction of H_2S. The survival of greigite within soil is comparatively rare (Stanjek *et al*., 1994) and will result from a phase of arrested diagenesis where the detestable ferromagnetic iron sulphides survive, and the ultimate formation of pyrite has not yet occurred. This may be due to the reduced availability of H_2S that is unable to freely permeate through the fine-grained sediment (Roberts and Turner 1993) or the absence of sufficient organic matter for bacterial respiration. The presence of greigite dominating the magnetic properties of a sample may be supported by high values of coercivity and distinctive high-temperature thermomagnetic curves and the unique acquisition of gyro or rotational remanent magentisation (Roberts and Turner 1993).

2.5 Frequency Dependent Magnetic Susceptibility

Since magnetic susceptibility is dependent on concentration as well as grain size, low concentration of superparamagnetic (SP) grains as well as high concentration of single domains (SD) grains can result in similar magnetic susceptibility signals. To determine whether the high magnetic susceptibility signal result from either concentration of magnetic susceptibility or domains grain size, we use the ratio of magnetic susceptibility called frequency dependent magnetic susceptibility. Magnetic susceptibility decreases with increasing operating frequency of the analytical equipment, but the small magnetic grains near the SP/SD boundary are much more sensitive to this increase in frequency than larger

grains (Thomson and Oldfield, 1986). The frequency dependent magnetic susceptibility is obtained from magnetic susceptibility measurements performed at two different frequencies: low (χ_{lf}) and high (χ_{hf}). Measurements made at these two frequenciesare generally used to detect the presence of ultrafine (<0.03μm) SP minerals in samples. Samples where SP minerals are present will show slightly lower values when measured at high frequency while samples without superparamagnetic minerals will show identical χ values at both frequencies (Dearing, 1999). Frequency dependent susceptibility is mostly expressed as a percentage of the mass-specific frequency dependent susceptibility: $\chi_{fd\%} = \frac{\chi_{lf-\chi_{hf}}}{\chi_{lf}} X100$

Worm in 1998 said that the frequency dependent magnetic susceptibility has an empirical value of 30%. According to Dearing et al (1996), the maximum value for frequency dependent magnetic susceptibility is 15% any value above that was due to error/contamination χ

2.5.1 Frequency-Dependent Magnetic Susceptibility (χfd%) for Discriminating the Content of Pedogenic from Lithogenic Soils.

The frequency-dependent magnetic susceptibility is widely used by many authors for the detection of fine nanometer-sized ferromagnetic coarsed particles in environmental and rock magnetism (Mullins and Tite, 1973; Thompson and Oldfield, 1986; Maher, 1986; Dearing *et al*., 1996; Evans and Heller, 2003; Liu *et al*., 2012). This magnetic parameter is extensively used, especially in environmental studies (e.g., Maher, 1998; Liu *et al*., 2012; Roberts, 2015), since pedogenesis in soils and diagenesis in sediments produce fine-grained submicrometer and nanometer-sized particles, usually magnetite and/or maghemite. In contrast, lithogenic, rock inherited particles are commonly coarse grained and thus predominantly display multidomain (MD) properties. Therefore, magnetic grain-size and sensitive proxy parameters successfully discriminate pedogenic/diagenetic from lithogenic

magnetic fractions. Theoretical studies on SP-SD transition in magnetite and the frequency-dependence of magnetic susceptibility (Mullins and Tite, 1973; Eyre, 1997; Worm, 1998) provide the physical basis of the experimentally obtained data on different natural materials. The empirically derived relations between the content of the fine-grained magnetite/maghemite and the χ_{fd} % value (Dearing et al., 1996, 1997) in different soil types are used as a standard fast and non-destructive test for the evaluation of the relative contribution of the SP strongly magnetic fraction into the measured bulk (low field) magnetic susceptibility. The "threshold" χ_{fd} % values proposed by Dearing (1999) suggest that, if χ_{fd} % > 10% (between 10% and 14%), the SP assemblage dominates the magnetic susceptibility (SP content >75%); medium range: 2% < χ_{fd} % < 10% shows an admixture of SP and coarse grains, while χ_{fd} % < 2% is obtained when SP grains are practically missing.

These empirical considerations, theories, and experimental data on the reliability of χ_{fd} % as a proxy for the content of the SP magnetite/maghemite fraction in soil are developed and based on the studies of soils from the temperate climatic belt. In these conditions, magnetite/maghemite is the pedogenic magnetic mineral that dominates magnetic susceptibility, while the antiferromagnetic fractions (hematite, goethite), although in a much larger amount, provide a minor contribution to the measured signal (Dearing, 1999).

2.6 Association of Heavy Metals with Magnetic Materials

Magnetic susceptibility of soil can be used as a proxy for anthropogenic dust pollution because ferromagnetic minerals are produced during combustion processes together with different heavy metals. There has been a great rate of development in the use of magnetic measurements in examining environmental pollution caused by anthropogenic activities such as industrial activities, domestic heating, traffic and power plant. Dusts and fly ashes, fertilizer, pesticides and insecticides produced by anthropogenic activities contain significant portion of magnetic materials (Flanders, 1994). These magnetic materials are deposited from

the sources on the surface of different environmental media such as soils, vegetation, rivers, lakes, street and building. The incorporation of anthropogenic magnetic materials into environmental media produces a magnetic enhancement. Dust and fly ashes from various anthropogenic sources also contain very high level of heavy metals. Magnetic materials may incorporate heavy metals into their atomic lattice or they form separate particles (Klučiarová*et al.*, 2008). In a similar vein Kapicka*et al* (2008) said that heavy metals are absorbed on the surface of magnetic particles. Coexistence of magnetic materials and heavy metals makes it possible to determine relationship between magnetic parameters and concentration of heavy metals and which is the basic principle used magnetic parameters as proxy parameters in environmental pollution analysis.

2.7 Magnetic Susceptibility as Indicator in Pollution study

Many researchers have reported that magnetic materials and heavy metals co-exist since they are produced together during combustion process (Hanesch *et al*., 2003). Kluviarova and Kapicka*et al* (2008) reported that heavy metals either incorporate themselves in the atomic structure of magnetic materials or attaches themselves to the surfaces of the magnetic materials. Generally, magnetic measurements as a tool for evaluating pollutions are based on two reasons. First, the magnetic parameters (e.g. magnetic susceptibility) of soils are greater than its corresponding background. Secondly, magnetic parameters have significant correlations with the concentrations of pollutants. According to Tao *et al* (2007), the magnetic susceptibility of top soils is much higher than that of the subsoils and the difference between them range from 23.12 to 226.86 $\times 10^{-8}$ $m^3 kg^{-1}$ with an average of 102.63 $\times 10^{-8}$ m^3 kg^{-1}. In addition, the magnetic susceptibility of topsoils significantly correlates with Cu, Pb, Zn and Hg with Pearson's correlation coefficients of 0.736, 0.675, 0.678 and 0.631, respectively. These results propose that magnetic susceptibility can actually serve as an

effective indicator for mapping the heavy metal pollutions in the East Lake region, Wuhan, China (Tao *et al*., 2007).

2.8 Laboratory Techniques used in Soil Pollution Studies

Various techniques have been used to determine characteristics and provenance of soil pollution (Perry and Taylor, 2007). Measurements of soil, street dust and sediments have been used to map areas polluted by industrial emissions, such as coal-burning power plants, lead ore smelters, and roadside pollution due to automotive traffic and other atmospheric pollution.

The most widely used techniques are: Inductively Coupled Plasma-Mass Spectroscopy (ICPMS) (Anagnostopoulo and Day, 2006). Scanning Electron Microscope (SEM) techniques (Robertson *et al*., 2003), sequential extraction methods (Charlesworth *et al*., 2003; Robertson *et al*., 2003), and X-Ray Fluorescence (XRF) spectrometry (Xie et al., 2000). These studies successfully revealed heavy metal concentrations in soil with a range of intensities indicating local and regional pollution. However, traditional geochemical methods (AAS, ICP-MS) are relatively complex, time-consuming and expensive due to the expensive instrumentation and additional expertise to operate. These instruments are bound to static locations and require specific laboratory environments and are therefore unsuitable for mapping or monitoring of large-scale pollution. Magnetic methods are hoped to be used in this study because of its advantages over the other methods mentioned above. However, the traditional methods cannot be completely abandoned in pollution studies because magnetic method cannot determine the concentrations of pollutants (heavy metals). Therefore, Agilent 4200 Microwave Plasma Atomic Emission Spectroscopy (MP-AES) was used to determine the concentrations of heavy metals of samples of the study area.

2.9 Sources of Pollution in Soil

Sources of heavy metals in the soil originate from many sources, which include atmospheric deposition sewage irrigation, improper stacking of the industrial solid waste, mining activities, the use of pesticides, herbicides and fertilizers (Zhang et al., 2012).

2.9.1 Atmosphere to soils pathway

Heavy metals in the atmosphere are mainly from gas and dust produced by energy, transport, metallurgy and production of construction materials. Excepting mercury, heavy metals basically go into the atmosphere in the form of aerosol and deposit to the soil through natural sedimentation and precipitation. Lead pollution in a downtown, Central Sweden, was reported mainly from the urban industrial copper plant, sulphuric acid plant, paint factory, and the large amount of waste from mining and chemical industries. Due to transporting by wind, these fine lead particles spread from industrial waste heap to surrounding areas. The superimposed chromium contamination by a heavy industrial factory producing chromium (Zhang *et al.,* 2012) in Nanjing, was reported more than 4.4 times of the local background value. A sulphuric acid production plant in Russia (Chao *et al*., 2014) was reported to contaminate the environment because of the discharge of S, V, and As from the factory chimneys.

Transport, especially the automotive transport, causes serious heavy metal contamination (Pb, Zn, Cd, Cr, Cu, etc.) of the atmosphere and soils (Chao *et al*., 2014). Heavy metals come from burning leaded gasoline and the dust produced by automobile tire wear. According to the report, the exhaust from the car contained Pb up to 20 ~ 50 μg / L, which formed a zonal distribution and there was a clear difference as the change of the distance of from railway, traffic highway, city centre, and the car traffic volume. In the Nanjing section of Nanjing-Hangzhou highway, the soil on both sides of the road had formed contamination zone of Pb, Cr, and Co. And the contamination zone was distributed along the direction of the highway.

The contamination was weakened along the direction of the both sides of the highway (Chao *et al*., 2014). The amount of heavy metals which went into the soil through natural deposition and raining sedimentation are related to the level of development of heavy industry, the city's population density, land utilization and traffic level. Soil contamination became to be heavier as closing to the city.

2.9.2 Vehicle Emissions

Pollutants originating from road traffic can be grouped into two major types: exhaust and nonexhaust emissions. Exhaust emissions are produced during incomplete combustion of vehicle fuel which is a mixture of hydrocarbons and compounds improving combustion properties. During this process several types of pollutants are generated such as carbon monoxide (CO), nitrogen dioxide (NO2) volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and particulate matter (PM). Incomplete combustion of fossil fuels as well as traffic-related suspension of road, soil and mineral dust leads to direct emission of various liquids and solids into the air (primary particles). Moreover, the gaseous substances released from exhaust systems, undergo gas-to-particle conversion (secondary particles) in the atmosphere (new particle formation by nucleation and condensation of gaseous precursors) (Pope *et al.,* 2006). Secondary particles are mainly composed of inorganic compounds, including sulphates, ammonium and nitrates. Non-exhaust emissions are generated through mechanical (e.g. braking, clutch usage, tyre wear, road abrasion) and chemical processes (e.g. corrosion of vehicle elements). Elements that have often been associated with vehicular emissions include Ba, Br, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Pb and Zn (Zhang*et al.,* 2012) concluded that materials rich in Cu, Ba and Fe serve as an indication of abrasive vehicular wear, in particular brake linings. SEM and EDS analyses of brake linings and brake dust material generated during the application of brakes performed by Ingo et al. (2004) identified the presence of BaSO4 -containing particles in both brake lining

material and break wear dust samples. The presence of Zn-containing particles may be attributed to the abrasion of tyres. In northern European countries, road sanding and the use of studded tyres are considered as major sources of the non-exhaust fraction which can account for up to 90% of airborne particulate matter (Omstedt *et al*., 2000).

2.9.3 Soil Contamination by Sewage

Wastewater can be divided into several categories, sanitary sewage, chemical wastewater, industrial mining wastewater and urban mining mixed sewage. Heavy metals are brought to the soil by irrigative sewage and are fixed in the soil in different ways. It causes heavy metals to continually accumulate in the soil year by year (Chao *et al*., 2014).

2.9.4 Soils contamination by disposal of Solid Wastes

There are a variety of solid wastes which have complex composition of which mining and industrial solid waste contamination is the most serious. When these wastes are in the process of being piled up, heavy metals move easily due to the facilitation of sunlight, raining and washing (Chao *et al*., 2014). The continues accumulation of solid wastes material in soil can cause the level of Cr, Pb, Cu, Zn and as to exceed the control standards easily. Solid wastes can expand contamination scope easily with the help of wind and water.

2.9.5 Contamination to Soils by Agricultural Supplies

Fertilizers, pesticides and mulch are important agricultural inputs for agricultural production (Zhang *et al*., 2012). Nevertheless, the long-term excessive application has resulted in the heavy metal contamination of soils. The vast majority of pesticides are organic compounds, and a few are organic - inorganic compound or pure mineral, and some pesticides contain Hg, As, Cu, Zn and other heavy metals. Heavy metals are the most reported pollutants in fertilizers. Heavy metal content is relatively low in nitrogen and potash fertilizers, while phosphoric fertilizers usually contain considerable toxic heavy metals. Cd is an important heavy metal contaminant in the soil which is brought to soils by the application of phosphoric

fertilizers. Many studies showed that, with the application of a large amount of phosphate fertilizers and compound fertilizers, the available content of Cd in soils increases constantly, and Cd taken by plants increases accordingly (Chao *et al*., 2014). In recent years, the mulch has been promoted and used in large areas, which results in increasing heavy metals contamination to soils (Sharma *et al*., 2008).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used for collections of soil samples and analyses are as follows:

(i) augar was used to collect samples at depth

(ii) small plastics bags were used to package the soil samples to minimize contamination

(iii) magnetic susceptibility metre with two sensors with frequencies of 0.47 KHz and 4.7 KHz respectively was used for measurements of MSMS of the soil in the laboratory

(iv) Microwave Plasma-Atomic Emission Spectrometer (MP-AES) AGILENT 4200 was used for geochemical analysis of soil samples in the laboratory.

3.2 Sample Collection Method for this Work.

Reconnaissance survey was done which prepared the site for sampling of the soil samples by Studying the topography; topographic maps of the study area.

The site of the study area consists of irrigation sectors, upland sectors and uncultivated soils in Kura local government of Kano state in North-western Nigeria. The irrigation activities have been on for over forty years in the study area. The soil samples were taken randomly by using global positioning system (GPS) to indicate sample locations on the farmland sectors. Random sampling is easy to use and has accuracy of representation of the entire population. The collected soil Samples were collected in plastic materials to avoid contamination. The soil samples were taken from the topsoil and others were taken at depths of 15, 30, 40 and 50 cm as in (Figures3.1, 3.2, 3.3, 3.4, 3.5,).



Figure 3.1: Researcher collecting sample soil from tomatoes irrigation farm



Figure 3.2: One of the wheat irrigation farm where soil was collected



Figure 3.3: This is a mixed cropping irrigation farm where soil sampled was taken

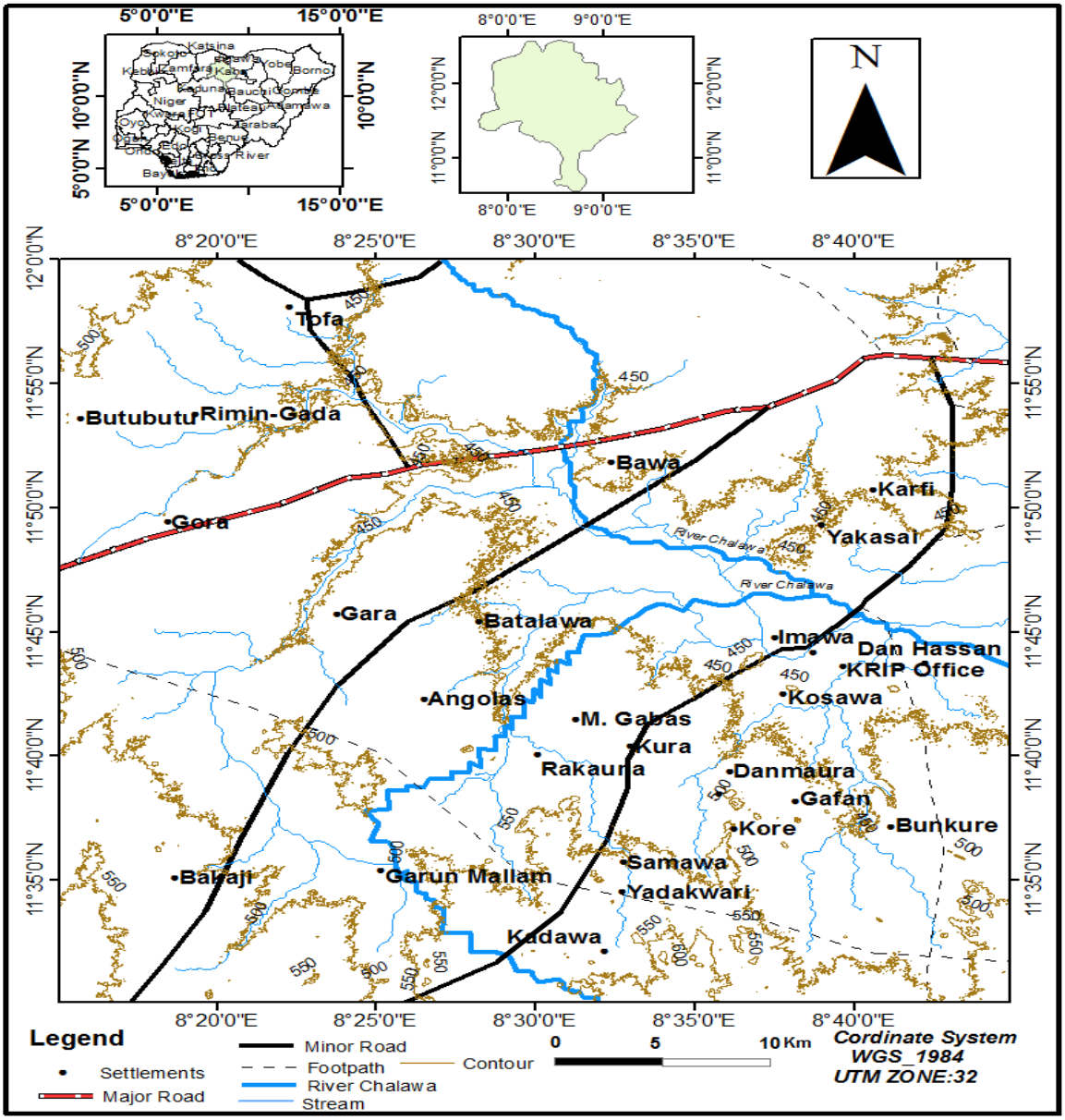


Figure 3.4: This is a maize irrigation farm where sample of soil was taken

3.3 Map of the Communities Where Samples Were Collected

The soil samples were labelled and enveloped in plastic container ($10cm^3$) for magnetic susceptibility.

The data for this work was generated by magnetic susceptibility method using MS2 magnetic susceptibility meter combined with MP-AES AGILENT 4200 for analysis of heavy metals concentration in samples.



Fiure 3.5: Sample collection map

3.4 Laboratory Methods

The study has employed a sampling strategy of Random Sampling Techniques for collection of soil samples from three types of different land use. The number of the soil samples collected from the sectors was based on their sizes. The first two land uses are irrigation farmland and upland farmland. The third land use is the uncultivated land where no farm activities take place. There were 177 samples of soil collected from irrigation farmland sectors. While 27 soil samples were collected from upland sectors and 46 soil samples were

collected from uncultivated land which served as control site for the study. The study has covered eighteen farm sectors and two different uncultivated lands as control sites for the study area.

3.4.1 Sample Preparation

In the laboratory, samples were screened to remove macroscopic traces of stones, and animal and plant matter to ensure that the materials to be analysed were not contaminated with foreign materials. Thereafter, the samples were air-dried at room temperature for some days to reduce the mass contribution of water. The samples were sieved through a 2mm sieve mesh (Zhang *et al*, 2011), and stored in labelled plastic containers for further laboratory measurements.

3.4.2 Magnetic Susceptibility Measurements in the Laboratory

The mass specific magnetic susceptibility was measured using Bartington MS2B dual frequency sensor (low (0.47 kHz and high 4.7 kHz) connected to MS2 meter linked to computer using Multisus 2.4 software. A measurement taken for each sample represents a mean value of three readings to avoid measurement error. The readings were taken as follows: 1. Background measurement was taken before inserting the sample into the MS2B meter. 2. Sample reading was taken by inserting the sample into the MS2B meter. 3. Then finally second air reading was taken. Then the result was obtained as mean of the readings after drift correction was taken by multisus 2.4 software. This was further used to calculate the frequency dependent susceptibility.

The MS2B is a portable laboratory sensor which accepts 10 cm^3 samples in plastic holders.

3.4.3 Frequency Dependent Magnetic Susceptibility Measurements

This parameter was obtained from magnetic susceptibility measurements performed at two different frequencies: Low (χlf) and high (χhf). Measurements made at these two frequencies are generally used to detect the presence of fine grained < 0.03 um) super paramagnetic (SP)

ferrimagnetic minerals in samples. Samples where ultrafine minerals are present will show slightly lower values at high frequency; samples without the superparamagnetic minerals will show identical χ values at the two frequencies (Dearing, 1999). Frequency dependent magnetic susceptibility can be presented as either mass specific frequency dependent susceptibility (1) (χfd in m^3kg^{-1}) or percentage mass specific frequency dependent susceptibility (2) (χfd%). In this study, both parameters were determined. χfd was calculated using the relation:

$$\chi fd = \frac{\chi lf - \chi hf}{\chi lf} \quad (m^3kg^{-1}) \qquad (1)$$

$$\chi fd\% = \frac{\chi lf - \chi hf}{\chi lf} x100 \qquad (2)$$

The sensor is used for mass or volume specific susceptibility measurements of soil samples in studies of soil and mineral magnetism. The unique dual frequency facility permits identification of ferromagnetic grains close to the superparamagnetic stable single domain transition.

When setting up the magnetic susceptibility meter it should not be near any metallic objects like the transformer and mains cable, all electronic devices and sources of vibration. The temperature of the room should be kept constant and the meter should be switched on at least 10 minutes before the first measurement is made (Dearing, 1999).

3.4.4 Low Frequency Measurement (0.47 kHz)

1. The plastic pack (standard, 10cm3) was weighed first and then together with prepared soil to find the mass (weight) of soil used (W).
2. Before starting the measurement, the meter was switched to low frequency (LF) and zero the meter by pressing the Z button.
3. The M button was pressed when the metre was empty to take air measurement (M1).
4. The sample was then lowered into the meter and button M pressed again to take a sample measurement (sample κ)

5. The sample was removed from the metre and a second air measurement (M2) was taken later which gives the volume-specific magnetic susceptibility in 10^{-8} m^3 kg^{-1}

3.4.5 High Frequency Measurement (4.7 kHz)

By measuring the magnetic susceptibility of the sample at both low and high frequencies (0.47 and 4.7 kHz) the purpose was to detect certain type of grains (superparamagnetic ferrimagnetic crystals) that are created by certain soil processes (pedogenesis). The metre was switched to high frequency (hf) and the measurements of the sample were repeated exactly the same way as for the low frequency measurement. Frequency dependent is the difference of the low frequency (lf) and high frequency (hf) measurements expressed as a percentage of the low frequency measurement. The percentage frequency dependant susceptibility ($X_{fd\%}$) of a sample was calculated using.

3.5 Digestion and Analysis of Soil Samples

Twenty-seven (27) soil samples selected for chemical analysis. The selection was based on high, medium and low values of mass specific magnetic specific of the study area.

The short description of the digestion procedure for geochemical analysis is iven below.

10 mL of 1:1 HNO_3 was added to 1.00 g of soil samples from KRIP in a 25 x 150 mm glass digestion tube and the samples were heated to 95 $\pm$ 10 ^{0}C for about 15 minutes. When cool 5 mL of HNO_3 was added and heat was applied for another 30 minutes. The digest was allowed to cool, and2 mL of Milli-Q water and 3 mL of 30% H_20_2 was added and heated to 95 $\pm$ 5 ^{0}C. After the digest were cooled, another 1 mL of 30% H_20_2 was added. Heating continued until the sample volumes reduced to about 5 mL. The digest was allowed to cool and then diluted to 5o mL with Milli-Q water. Prior to analysis, the soil digest was diluted x10 to reduce the effect of background emission due to the high sample matrix. The digested samples were introduced into plasma of the MP-AES machine using a concentric nebulizer and single-pass cyclonic spray chamber for analysis of Cr, Cu, Fe, Ni, Pb, Zn and Cd. The

4200 MP-AES is fully automated for routine sample analysis using Agilent MP Expert software, which runs on the Microsoft 7 operating system.

3.6 Assessments of Degree of Contamination of the Study Area

The degree of contamination of the study area was determined using indices such as pollution load index (PLI), enrichment factor (EF) and geo-accumulation index (Igeo) Wang *et al*.,2021; Gajghate *et al*.,2012).

3.6.1 Pollution Load Indices (PLI):

The Tomlinson pollution load index (PLI) (Blaha *et al*., 2010; Chaparro *et al*., 2002) indicate how much a sample exceeds the heavy metal concentrations for natural environments and give an assessment of the overall toxicity status of the sample contributed from a number of heavy metals. PLI is defined as the nth root of the multiplication of the concentration factors (CF), where CF for a particular heavy metal is defined as the ratio of the concentration of that heavy metal in the sample to the respective mean values or background concentration of the metal for natural environment. Mathematically, this factor and index are given by:

$$CF_{metal} = \frac{C_{metal}}{C_{background}} \ , \quad PLI = \sqrt[n]{CF_1 X\ CF_2 X \ldots CF_n} \qquad (3)$$

PLI value of <1 is considered unpolluted while that >1 is considered as polluted (Das, 2014).

3.6.2 Enrichment Factor (EF)

A common approach of estimating the anthropogenic impact on the environmental media is to calculate a normalized enrichment factor (EF) for metal concentrations above uncontaminated background levels. The EF method normalises the measured heavy metal, trace elements, and rare earth elements with respect to a sample reference metal such as Fe, Sc or Al (Sagnotti *et al.*, 2009). The EF is calculated according this equation:

$$EF_x = \frac{\left(\frac{C_x}{C_{ref.}}\right)sample}{\left(\frac{C_x}{C_{ref.}}\right)background} \qquad (4)$$

where Sample Cx and Cref are the concentrations of heavy metal x reference element (i.e. normalising element) respectively in the sample. (Sagnotti *et al.,* 2009). If the EF for each element is ≤1 it shows that the main source is natural and metal contribution came from crustal or marine sources. Otherwise, if the EF is much greater than one, it indicates that the main source is of anthropogenic origin (Nolting *et al*., 1999).

3.6.3 Geoaccumulation Index (I-geo):

$$I_{geo} = log_2\left(\frac{Cn}{1.5XBn}\right) \quad (6)$$

A common approach to estimate the enrichment of metal concentrations above background or baseline concentrations is to calculate the geoaccumulation index (I-geo) (Müller, 1969). This index is calculated as iven in equation (3): where Cn is the concentration of the element in the enriched samples, and Bn is the background concentration of the element. The factor 1.5 is introduced to minimise the effect of possible variations in the background values which may be attributed to lithogenic variations in the sediments (Das, 2014).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Mass Specific Magnetic Susceptibility of Irrigation Farm Soil, Upland (Raining Season Farm Soil) and Uncultivated Land Soil

In this study the measurement of magnetic susceptibility has been used as proxy to study the pollution status of Kano River Irrigation Farm Sectors is as a result of human activities on the irrigation farm. The samples were taken from several sectors of the irrigation farm and their magnetic susceptibilities were measured and recorded.

4.1.1 Results of Low Field Mass Specific Magnetic Susceptibility (χlf) and High Field Mass Specific Magnetic Susceptibility (χhf) for the Irrigation Soil.

The magnetic susceptibility of the samples collected was determined using a Bartington MS2 meter equipped with the MS2B Dual Frequency Sensor, which measured low (χ_{lf} at 0.47kHz) and high (χ_{lf} at 4.70kHz) frequencies. The spatial distribution of magnetic susceptibility values from the topsoil and at depth from 15 – 50 cm of the Kano River Irrigation Project where irrigation takes place is shown in Tables 4.1a-c . The rest of the tables (d-p) are in Appendix 1. The χ values at low frequency exhibit a wide variation ranging from the least value of 1.8 to highest value of 91.4 $\times 10^{-8} m^3 kg^{-1}$ with a mean value of 13.29 $\times 10^{-8} \mathrm{m^3 kg^{-1}}$. The most enhanced magnetic susceptibility values measured were observed in farm sectors of Yakasi ($91.4 \times 10^{-8} \mathrm{m^3 kg^{-1}}$), Gori South ($69.1 \times 10^{-8} \mathrm{m^3 kg^{-1}}$), Batalawa ($90.3 \times 10^{-8} \mathrm{m^3 kg^{-1}}$), $87.1 \times 10^{-8} \mathrm{m^3 kg^{-1}}$, Agolos ($58.0 \times 10^{-8} \mathrm{m^3 kg^{-1}}$). Yang *et al* (2015) reported a similar work on irrigation farmland which was irrigated with waste water and groundwater and reported that the magnetic susceptibility values ranges between $44.1\times 10^{-8} \mathrm{m^3 kg^{-1}}$ to $108\times 10^{-8} \mathrm{m^3 kg^{-1}}$ and from $40.0\times 10^{-8} \mathrm{m^3 kg^{-1}}$ to $87.4\times 10^{-8} \mathrm{m^3 kg^{-1}}$ respectively. Mohammed et al (2011) reported also that magnetic susceptibility values of farmland soil are generally low mostly due to reduction of

iron oxide in the presence of organic matter degradation especially in a waterlogging irrigation farmland. These values are low compared to magnetic susceptibility values of well-drained soil samples obtained from mechanic village in Jalingo as reported by Kanu *et al* (2013). According to John et al (2010) the lower values of the magnetic susceptibility of the study area were found in farm sectors that were waterlogged where most of the values of magnetic susceptibility ranged between 1 to $10\times 10^{-8}\mathrm{m}^3\mathrm{kg}^{-1}$. This could be due to the redox effects and iron-reducing bacteria enhanced export of iron from the soil in runoff and also percolation of the magnetic minerals (John *et al*; 2010). Dearing *et al(*1996) analysed UK topsoil data set and found MS mean values of 149×10^{-8} m^3 kg^{-1} for typical brown earth (cambisol), 36×10^{-8} m^3 kg^{-1} for typical stagnosol and 45×10^{-8} m^3 kg^{-1} for typical water logging (gley) soil. Another reason for reduction in iron enhancement in the study area could be due a downward vertical migration of iron minerals in waterlogging environment as reported by Sapkota and Cioppa (2012) who observed that iron particles migrated to a maximum depth of 9 cm in 4 months in waterlogged soil. On the hand it was also found out that some samples from a farmland sector that are waterlogging have high values at low field MS. This is possible because in waterlogging farmland, anaerobic (without air) conditions are met where iron sulphide compounds are formed such as greigite (Fe_3S_4) which enhances MS values (Dearing, 1999). The MS values obtained from the farmland sectors where irrigation and raining seasons takes place yearly reflects the concentration of the magnetic minerals and types of magnetic grains such as Ferrimagnetic (magnetite, magnetite), Antiferrimagnetic (goethite, hematite) of the area in study (Yang *et al*., 1980).

Table 4.1a: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Yakasai Sector

S/No	Sample	Lat.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Yk1(15 cm)	$11^0$77′1″	$8^0$44′2″	14.61	19.7	18.0	8.63
2	Yk1(30 cm)	$11^0$77′1″	$8^0$44′2″	15.05	8.7	8.3	4.60
3	Yk1(40 cm)	$11^0$77′1″	$8^0$44′2″	14.51	14.7	13.4	8.84
4	Yk1(50 cm)	$11^0$77′1″	$8^0$44′2″	13.60	7.6	7.2	5.26
5	Yk2	$11^0$77′5″	$8^0$44′5″	13.11	8.9	8.4	5.62
6	Yk3	$11^0$77′9″	$8^0$44′9″	14.92	10.0	9.4	6.00
7	Yk4	$11^0$81′2″	$8^0$42′2″	14.56	12.6	12.7	- 0.79
8	Yk5	$11^0$81′3″	$8^0$45′3″	14.09	8.2	7.7	6.09
9	Yk6	$11^0$81′5″	$8^0$45′5″	13.79	8.4	7.1	15.48
10	Yk7	$11^0$81′6″	$8^0$45′7″	14.63	26.1	24.0	8.05
11	Yk8	$11^0$81′8″	$8^0$45′9″	13.40	91.4	89.9	1.67
12	Yk9	$11^0$81′9″	$8^0$49′2″	14.75	9.3	8.4	9.68
13	Yk10	$11^0$80′7″	$8^0$47′5″	14.10	10.7	9.7	9.35

Table 4.1b: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Raji sector

S/N	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Rj1(15 cm)	$11^0$67′8″	$8^0$42′0″	15.14	6.6	6.2	6.06
2	Rj1(30 cm)	$11^0$67′8″	$8^0$42′0″	14.51	13.6	12.6	7.35
3	Rj1(40 cm)	$11^0$67′8″	$8^0$42′0″	14.30	9.5	9.3	2.11
4	Rj1(50 cm)	$11^0$67′8″	$8^0$42′0″	14.09	8.7	8.2	5.75
5	Rj2	$11^0$68′5″	$8^0$42′7″	13.55	6.4	5.9	7.81
6	Rj3	11.687	$8^0$43′1″	12.64	8.4	8.0	4.76

Table 4.1c: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Agalawa Sector

S/No	Sample	N(^{0})	E(^{0})	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ag1(15 cm)	$11^0$67′2″	$8^0$41′6″	13.36	6.6	7.2	9.09
2	Ag1(30 cm)	$11^0$67′2″	$8^0$41′6″	14.59	7.7	7.5	2.60
3	Ag1(40 cm)	$11^0$67′2″	$8^0$41′6″	14.01	7.2	6.7	6.94
4	Ag1(50 cm)	$11^0$67′2″	$8^0$41′6″	11.71	10.7	10.0	6.54
5	Ag2	$11^0$67′5″	$8^0$41′7″	11.95	12.0	11.4	5.00
6	Ag3	$11^0$67′7″	$8^0$41′9″	12.41	12.5	11.9	4.80

4.1.2 Worldwide Magnetic Susceptibility Data Compare with KRIP Data

The table 4.4 below showed the MSMS of the present study and the MSMS of the worldwide magnetic susceptibility data (Das, 2014)

Table 4.2: Worldwide Magnetic Susceptibility Data compare with the Observed Susceptibility of the Study Area.

Material Type	Study Area	Background Rock	X($10^{-8}m^3kg^{-1}$)	Instrument	Reference
Uncultivated soil	KRIP,Nigeria	Prophyrite biotite	8.4-104.5	MS2B	This study
Upland soil	KRIP, Nigeria	biotite granite	12.5-32.8	MS2B	This study
Irrigation soil	KRIP, Nigeria	biotite hornblende	1.8-91.4	MS2B	This study
Road side soil	Jalingo,Nigeria	Laterite	21.17-614.89	MS2B	Kanu et al 2013
Residential soil	Jalingo,Nigeria	Laterite	16.07-1669.04	MS2B	Kanu et al 2013
Dumpsite	Jalingo,Nigeria	Laterite	43.33-373.58	MS2B	Kanu et al 2013
Road dust	Mumbai India	Deccan basalt	593-10460	MFK1	Das, 2014
Topsoil (This Study)	Nashik,India	Deccan basalt	159-687	MFK1	Das, 2014
Drainage sediment	London	NA	345-728	MS2	Beckwith et al (1986)
Topsoil	England		30-80	MFK1	Hay et al (1997)
Soil profile	France	Alps conglomerate deposit	29-146	MFK1	Lecoanet et al (2003)
Road dust	Visakhapatnam, India	Khondalite	14-101	MS2B	Goddu et al. (2004)
Road dust	West midland,	NA	1571	MS2B	Shilton et al

	UK				(2005)
Dust loaded leaves	Nepal	NA	01-54	MFK1	Gautam et al. (2005)
Road dust	Seol S. Korea	NA	32-144	MS2B	Kim et al. (2007)
Soil	Luoyang, China	Loess parent material	65-109	MFK1	Lu et al. (2007)
Dust loaded leaves	China	NA	16-856	MS2B	Lu et al. (2008)
Soil	Slovakia	Alternating clay stone and sandstone	34-58	MFK1	Kluciarova et al. (2008)
Road side soil	Finland	NA	16-179	KLY-4	Bucko et al (2010)
Road dust	Wuhan, China	NA	44-294	MS2B	Yang et at (2010)
River sediment	Loudi, China	Limestone	100-105	MS2B	Zhang et al. (2011)
Soil	China	Loes and fluvial deposits	14-394	MS2B	Yan et al. (2011)
Road side soil	China	Quaternary alluvial deposits	19-503	MS2B	Lu et al. (2011)
Road dust	Sofia, Bulgaria	NA	100-1200	MFK1	Jordanova et al (2012)
Indoor dust	China	NA	101-636	MFK1	Zhu et al. (2012)
Road dust	Lanzhou, China	Gobi Desert	111-987	MS2B	Wang G. (2012)
Soil	Pune, India	Deccan basalt	18-304	MS2B	Sangode et al. (2012)
Soil	Mumbai, India	Deccan basalt	02-334	MS2B	Gudadhe et al (2012)

KRIP =Kano River Irrigation Project

4.1.3 Statistical Summaries of Magnetic Parameters of the Study Area

The statistical summaries of the MSMS parameters of the KRIP study area is tabulated in Table 4.5

Table 4.3: Statistical Summaries of Magnetic Parameters of the Study Area

S/N	Sampling sector	$\chi_{lf} X10^{-8} m^3 kg^{-1}$	$X_{hf} X10^{-8} m^3 kg^{-1}$	$x_{fd\%}$
1	Yakasi(n=13) Range	7.6 - 89.9	7.1 – 91.4	1.67 – 15.48
	Mean ±S.D	18.06±22.24	17.34±22.80	6.67±4.25
	CV (%)	123.18	131.47	63.69
2	Raji (n=6) Range	6.6 – 13.6	5.9 – 12.6	2.11 – 7.81
	Mean ± S.D	8.87±2.62	8.37±2.44	5.82±2.24
	CV (%)	29.53	29.15	38.57
3	Agalawa(n=6) Range	7.2 -12.5	6.6 – 11.9	2.60 – 9.09
	Mean±S.D	9.45±2.60	9.12±2.28	2.80±6.02
	CV (%)	27.43	24.95	215.26
4	Danmaura(n=8) Range	4.9 – 17.2	4.5 – 15.5	1.82 – 19.13
	Mean±S.D	8.35±4.23	7.27±3.98	7.40±6.50
	CV (%)	50.73	54.75	87.57
5	Kore(n=23) Range	1.8 – 29.6	1.8 – 28.8	0 – 26.47
	Mean±S.D	8.14±5.73	7.65±5.72	6.63±6.17
	CV (%)	70.33	74.69	93.07
6	Gafan(n=23) Range	4.9 – 26.7	4.1 – 24.6	0 – 16.33
	Mean±S.D	10.29±5.39	9.39±4.96	6.28±4.39
	CV (%)	52.33	52.90	69.82
7	Samawa(n= 8) Range	3.2 – 4.5	3.0 – 4.2	0.- 6.33
	Mean±S.D	3.95±0.43	3.25±0.42	6.84±5.82
	CV (%)	10.91	11.23	85.16
8	Yadakwari (n=6) Range	7.3 – 22.7	6.2 – 14.0	8.05 – 56.22
	Mean±S.D	14.36±7.18	10.08±3.09	23.39±18.31
	CV (%)	49.99	30.14	78.29
9	M.Gabas(n=9) Range	5.7 – 11.8	5.4 -11.2	1.02 – 26.67
	Mean±S.D	3.20±2.32	7.53±2.15	7.67±8.04

	CV (%)	28.27	31.14	104.78
10	Gori- South (n=4) Range	8.6 – 69.1	8.1 – 66.0	3.50 – 6.15
	Mean±S.D	40.0±26.11	38.18±25.12	4.99±1.22
	CV (%)	65.28	65.81	24.52
11	Bathalawa(n=10) Range	4.30 – 90.3	3.8 – 85.5	1.18 – 11.63
	Mean±S.D	27.05±33.22	25.77±31.82	5.48±3.55
	CV (%)	122.70	123.48	64.83
12	Kadawa(n=17) Range	4.3 – 22.5	4.2 – 22.2	0.9 – 9.38
	Mean±S.D	8.99±5.92	8.58±5.49	4.34±3.63
	CV (%)	65.77	65.19	88.75
13	Rakauna(n=9) Range	4.1 - 32.2	3.9 – 31.2	3.11 – 12.96
	Mean±S.D	14.46±10.16	13.50±9.61	7.35±3.22
	CV (%)	70.28	71.20	43.84
14	Karfi(n=15) Range	2.9 – 10.0	2.9 – 9.3	0 – 30.91
	Mean±S.D	5.37±1.97	4.93±1.84	7.92±6.79
	CV (%)	36.63	37.38	85.73
15	Kosawa(n=14) Range	4.0 -18.7	3.60 – 17.0	0 – 12.2
	Mean±S.D	7.70±3.76	7.21±3.34	5.01±3.91
	CV (%)	48.79	47.54	77.93
16	Angolas(n=8) Range	6.9 – 58.0	6.4 – 53.0	3.64 – 10.87
	Mean±S.D	19.35±15.74	18.35±14.59	5.67±5.08
	CV (%)	81.30	79.53	89.65
17	Danhassan(n=9) Range	12.5 – 25.1	11.5 – 22.6	5.82 – 29.45
	Mean±S.D	18.0±3.87	16.11±3.53	11.12±6.66
	CV (%)	21.49	222.05	59.83
18	Tofa(n=18) Range	19.2 – 36.2	17.0 – 32.8	8.75 – 15.98
	Mean±S.D	29.08±5.28	25.56±4.81	12.55±3.51

	CV (%)	18.16	18.81	27.94
19	Kadawa Background(n=25)			
	Range	8.4 – 104.5	7.3 – 104.4	0.10 – 71.15
	Mean±S.D	24.21±19.09	22.05±19.65	10.73±13.11
	CV (%)	80-85	89.12	122.18
20	KRIP Background (n=21)			
	Range	24.4 – 74.9	22.5 – 69.0	1.03 – 20.80
	Mean±S.D	39.89±11.32	36.91±10.06	7.98±4.10
	CV (%)	28.38	27.24	5.48

4.1.4 Magnetic Susceptibility Anomaly in the Study Area

The magnetic susceptibility anomaly is obtained by calculating the difference between the mean of topsoil and the mean of subsoil magnetic susceptibility as in Table 4.6. The difference that gives positive value indicates higher value of MSMS in the topsoil. This suggests the top soil has higher magnetic minerals than that of subsoil. The negative values as seen in sectors of Danhassan, Raji, Kano River Irrigation Project Office, Yadakwari and Kadawa (Table 4.6) which show that the subsoil magnetic susceptibility is higher than the values of topsoil of MSMS. This may be due to lithogenic materials in the subsoil since the magnetic minerals increases with depth. The difference in the median values of the MSMS consists of negative and positive values. This shows that those positive are due to anthropogenic activities while negative values are due to lithogenic activities. The case where the subsoil magnetic susceptibility is higher shows that the enhancement could be due to lithology (Kanu *et al.,* 2013).

Table 4.4: MSMS Mean Difference of Topsoil and Subsoil of KRIP

S/N	Sector	Mean Topsoil ($\overline{\chi_T}$) MSMS ($10^{-8}m^{-3}Kg$)	Mean Subsoil ($\overline{\chi_S}$) MS($10^{-8}m^{-3}Kg$)	No Samples	Mean diff. ($\overline{\chi_T} - \overline{\chi_S}$) ($10^{-8}m^{-3}Kg$)	$\chi_{MIT-}\chi_{MIS}$ (($10^{-8}m^{-3}Kg$)	$\chi_{MxT-}\chi_{MxS}$ ($10^{-8}m^{-3}Kg$)
1	Dh	15.35	16.0	9	-0.65	-2.1	7.7
2	Yk	19.54	11.15	13	8.30	0.6	76.7
3	Rj	8.75	9.10	6	-0.35	-2.8	4.9
4	Ag	9.85	8.95	6	0.90	0	1.8
5	KRIP	34.35	42.30	21	-7.95	-6.8	22.9
6	Dm	9.28	5.55	8	3.73	-0.2	22.6
7	Ko	9.9	9.0	23	0.90	-3.6	12.3
8	Ga	10.54	7.65	23	2.89	-2.6	18.9
9	Sw	3.93	4.0	8	0.07	-0.6	0.3
10	Yad	12.43	17.25	6	-4.82	-3.5	-1.4
11	Mg	8.54	7.0	9	1.54	-0.9	4.4
12	Bt	32.64	4.7	10	27.94	3.8	85.2
13	Ka	7.61	19.35	17	-11.74	-12.0	0.1
14	Tf	29.11	28.83	18	0.28	-4.8	2.6
15	Ra	17.40	4.15	9	13.25	0.4	28.0
16	Kf	5.70	3.25	15	2.45	0.8	6.4
17	Ks	8.29	4.15	14	4.14	-0.1	14.5
18	Al	21.62	12.55	8	9.07	-1.9	41.7
19	Ka1	26.39	10.85	25	15.54	-1.2	89.8

4.1.5 The Variation of Mass Specific Magnetic Susceptibility of Irrigation Farm Soil, Upland (raining Season Farm) Soil and Uncultivated Land Soil.

The low frequency magnetic susceptibility of the soils of the study area shows that the values ranged from 1.8 – 104.5 x 10^{-8} m^3kg^{-1} which are low compare to values of low frequency magnetic susceptibility of soil of Jalingo city in Taraba State in Nigeria which ranged from 19.8 – 1612x 10^{-8} m^3kg^{-1}.(Kanu et al.,2013). The magnetic minerals in the irrigation farm soil

was observed to be low perhaps due to flooding, water logging and ploughing active ties in the top soil. The figure in Figure 4.1 shows that Ka2 which is a background of the study area shows that it has the highest mass specific magnetic susceptibility at low frequency.

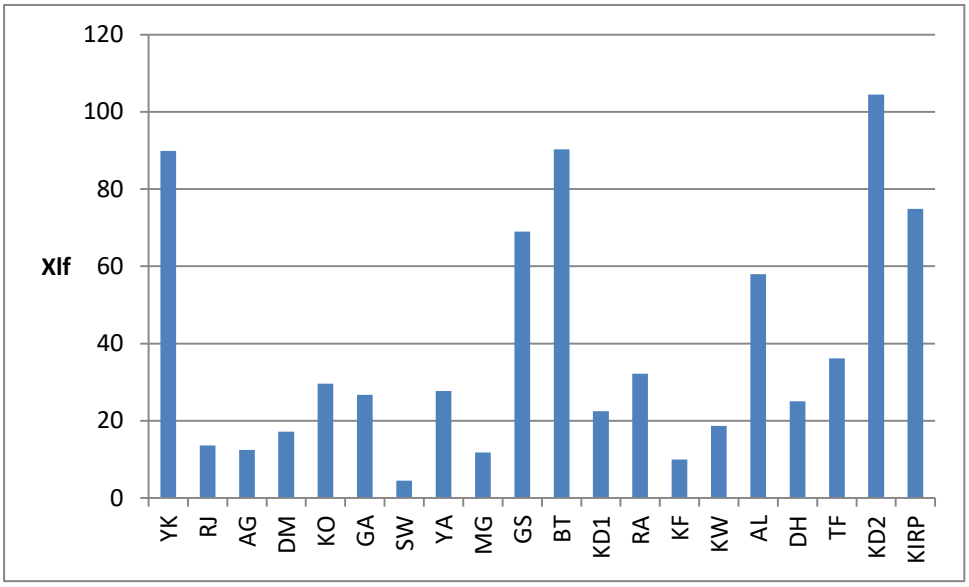


Fig 4.1 Comparism of the low frequency mass specific magnetic susceptibility of KRIP

4.1.6 The Correlation between Percentage Frequency Dependent Mass Specific Magnetic Susceptibility ($\chi_{fd\%}$) and Low Frequency Mass Specific Magnetic Susceptibility (χ_{lf}) of KRIP

The scatergram plots in Figure 4.2a-4.2c show the plots of percentage frequency dependent mass specific magnetic susceptibility($\chi_{fd\%}$) which ranged from 0.00 –71.15% and low frequency mass magnetic susceptibility (χ_{lf}) which and also ranged 1.8 – 91.4x$10^{-8}$$m^3$$Kg^{-1}$. While the rest of the plots are in Appendix 2(Fiure 4.2d 4.2r). The plots for irrigation farm land soil have shown three different patterns. The first pattern (Figure 4.2a, 4.2b, 4.2c, 4.2p and 4.2r) has shown that the plot of $\chi_{fd\%\ against}\chi_{lf}$ gave a negative correlation. The pattern indicates that the magnetic mineral enhancement was contributed by coarse multi domain (MD) magnetic grains from anthropogenic sources which is similar to a result obtained by Wang *et al*., (2000) on Chinese loess. The anthropogenic activities in the soil of study may be

due to influence of ploughing tillage, flood irrigation and waterlogged conditions similar to paddy soil enable the MSMS of the irrigation soil to be lowest on the farm (Gest *et al*., 2015). It is observed from the study that most of the samples whose mass specific magnetic susceptibility frequency dependence is less than seven (7%) is found to have a negative correlation with mass specific magnetic susceptibility at low frequency. The magnetic grains within the range of 1 – 6% contain a lot of coarser non SP grains which is due to anthropogenic activities (Laura *et al*, 2011). The second pattern (Figure 4.2d, 4.2e, 4.2g, 4.2h, 4.2i, 4.2j, 4.2k, 4.2m, and 4.2q) has a positive correlation between $\chi_{fd\%\ against}\chi_{lf}$ which is typical of sedimentary rocks as observed by Lu *et al* (2007). The second one is a positive correlation that exists between the two parameters which according to Laura *et al* (2011) indicates the presence of ultra-fine grains SP which is due to pedogenic process and it is frequency dependent. The SP grains are due to soil process over time due abiotic factors. The third pattern is the case when the correlation between the plot of $\chi_{fd\%\ and}\chi_{lf}$ tend to zero as in figure 4.2f, 4.2l, 4.2n and 4.2o. All the sectors are from irrigation farm. This may be due to the fact that the minerals present in such samples are in a transition from SD to MD. The correlation between the percentage frequency dependent mass specific magnetic susceptibility and low frequency mass specific magnetic susceptibility in the uncultivated land soil of KRIP office background was negative. The negative correlation is due to coarse magnetic grains of multi-domain sources. This may be due emissions of vehicles because the background is an office area where petrochemical activities is much.

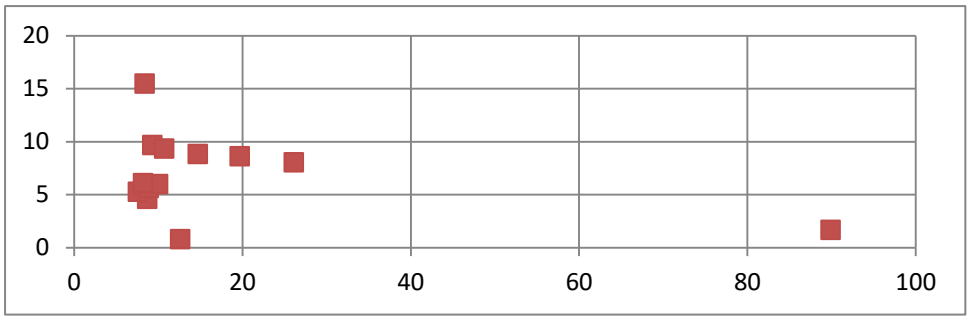


Figure4.2a Scatergram of $\chi_{fd\%\ against}\chi_{lf}$ of Yakasi

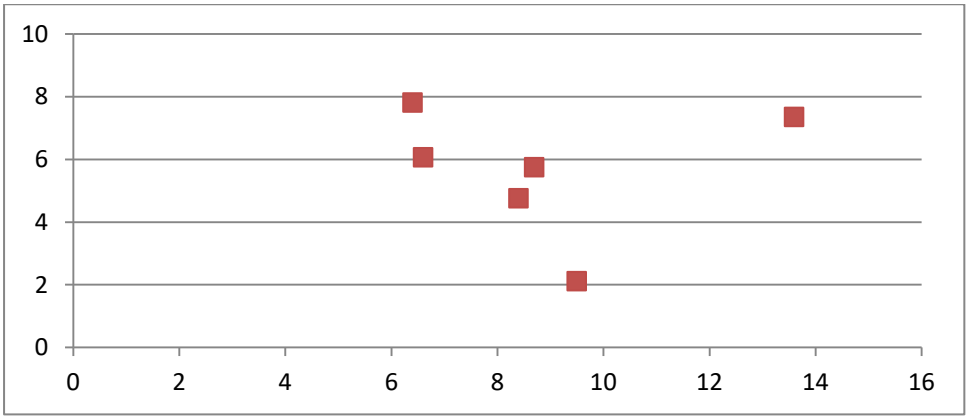


Figure 4.2b Scatergram of $\chi_{fd\%\ against}\chi_{lf}$ of Raji sector

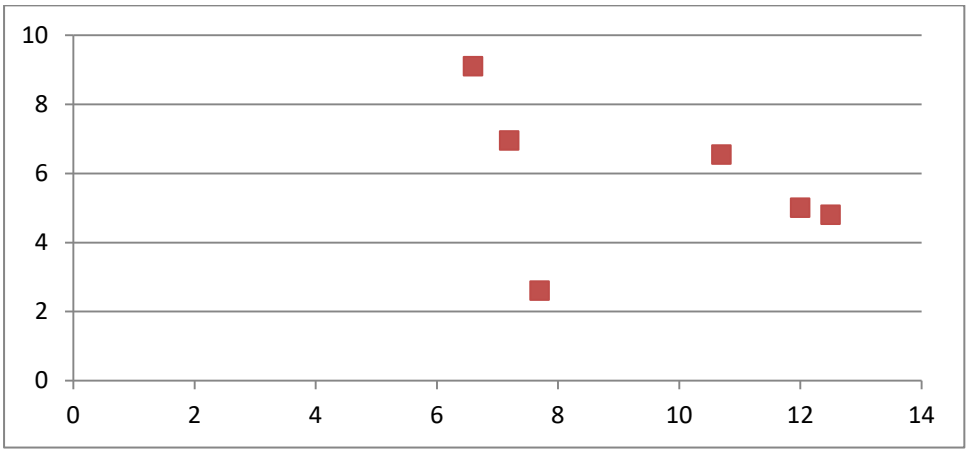


Figure 4.2c Scatergram of $\chi_{fd\%\ against}\chi_{lf}$ of Agalawa

4.1.7 Variation of Magnetic Susceptibility with Depth

The variation of low frequency mass specific magnetic susceptibility (MSMS) with depth of the study area is due either the inhomogenity of the soil, pedogenic activities or due to anthropogenic activities. The figures presented here are 4.2a-4.2c. The rests are in Appendix 3.The results showed that some sectors (Figure 4.2a, 4.2b, 4.2h, 4.2j, 4.2k, 4.2l, 4.2m, 4.2o,

4.2p, 4.2q, and 4.2r) revealed that their low frequency MSMS values decrease with increase in depth of 0 – 50 cm while others (4.2c, 4.2d, 4.2e, 4.2f, 4.2g, 4.2i, and 4.2n) revealed that the MSMS increased with Depth. The decrease in depth of the low frequency MSMS values shows that the magnetic materials are concentrated more on the top of the soil than at depth which could be due to anthropogenic activities on the soil while the case of MSMS increasing with depth may be due to lithogenic and farming activities of ploughing the soil (Kanu et al.,2013).

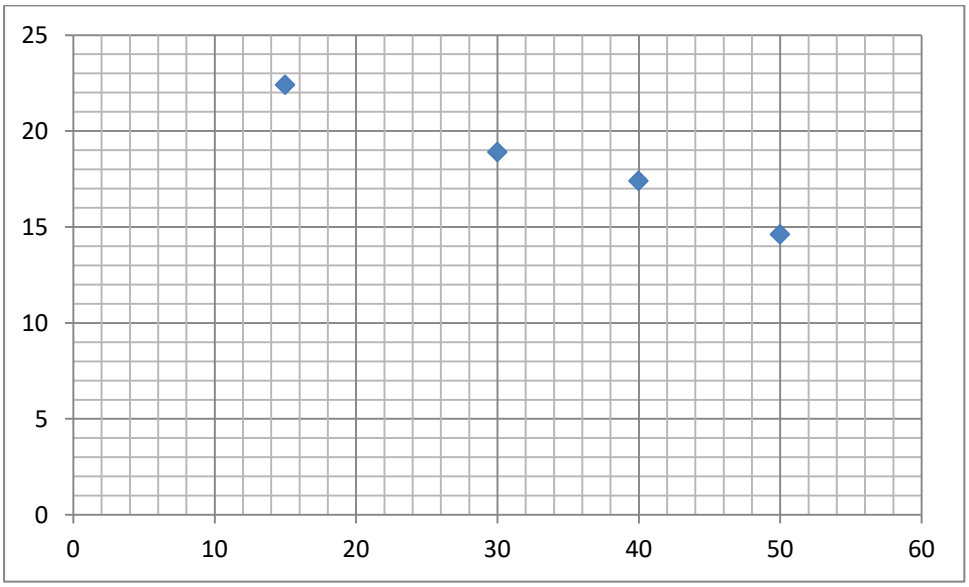


Figure 4.3a Variation of xlf ($10^{-8}m^3kg^{-1}$) depth(cm) of Dahassan sector

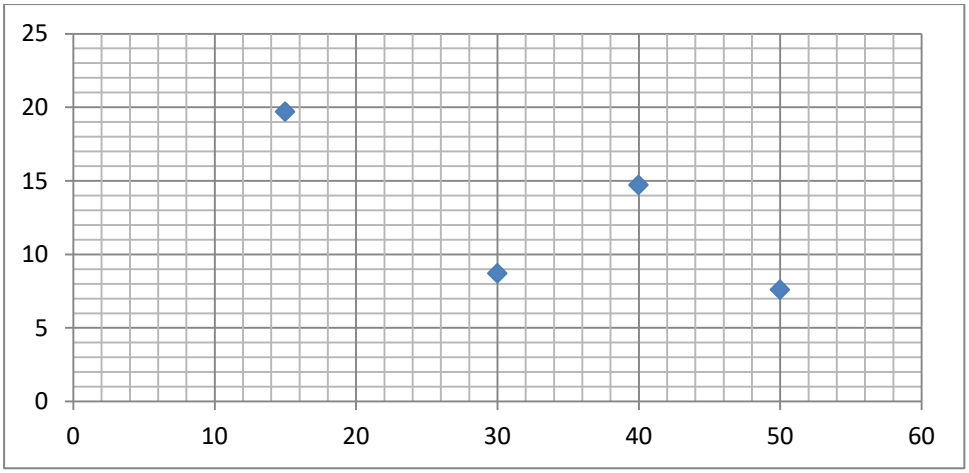


Figure 4.3b Variation of xlf ($10^{-8}m^3kg^{-1}$) depth(cm) of Yakasi sector

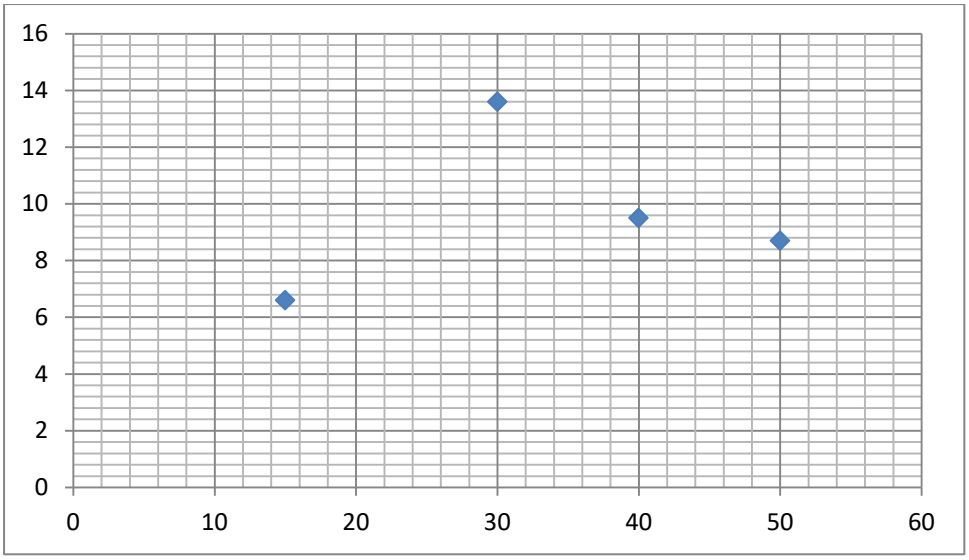


Figure 4.3c; Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Raji sector

4.2 The Distributions of Grains Domains of the Studied Area of Irrigation, Upland (raining Season Farming) and Uncultivated Soil

The grain size analysis according to the semi-quantitative model proposed by Dearing (1999) which classified environmental magnetic samples into four classes as:

(i) Samples that have virtually no SP grains in it. The same contains purely multi-domain grains (MD) which are anthropogenic coarser grains ($\chi_{fd\%} < 2\%$)

(ii) Samples that have $\chi_{fd\%}$ ranging between 2 – 10% are composition of MD amd SP grains.

(iii) Samples that have $\chi_{fd\%}$ ranging between 10 – 14% are samples which are virtually all ($> 75\%$) SP domain grains.

(iv) Samples that have $\chi_{fd\%} > 14\%$ are samples which are recorded as contaminated samples or due to error.

As seen in Fig.4.8a, 20% of the samples from the irrigation farm soil are virtually no SP grains but are coarser, (MD) grains, 60% of the samples are admixture of coarser (MD) and SP grains, 14% are pure SP grains and 6% area due to contamination or weak samples according to Dearing (1999) model.

The magnetic domain grains in raining season farmland soil (fig.4.8b) samples have no virtually no Sp grains, 33% are mixture of coarser (MD) grains and SP grains, 48% of the total samples are purely SP grains (pedogonic) and 19% of the samples are due to contamination or error in the samples (Dearing, 1999)

The magnetic domain grains in uncultivated land soil (background soil) fig. 4.8c samples have 9% virtually no Sp grains, 81% are mixture of coarser (MD) grains and SP grains, 5% of the total samples are purely SP grains and 5% of the samples are due to contamination or error in the samples (Dearing, 1999). The background soil is dominated by thin superparamagnetic (SP) and stable single domain (SSD) domain grains which is 5%.

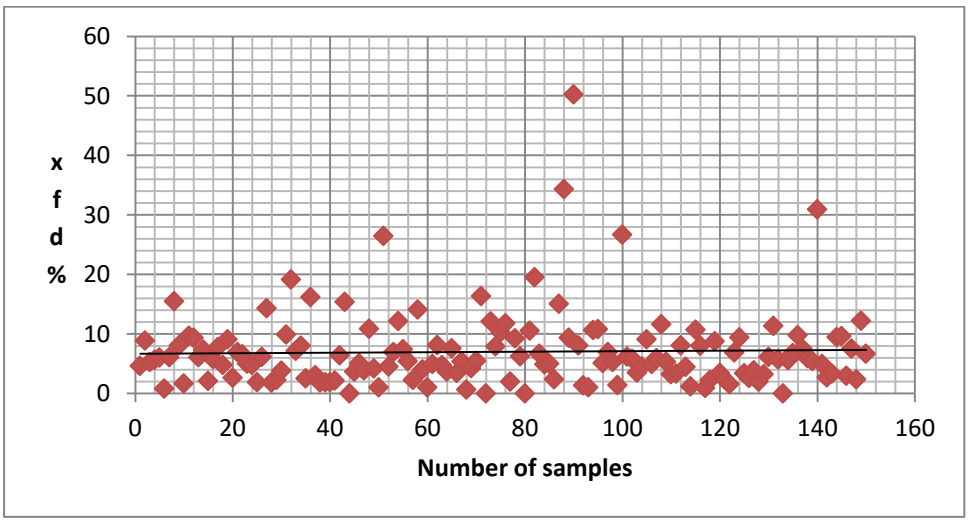


Figure 4.4a: Magnetic domain grains distribution of irrigation soil

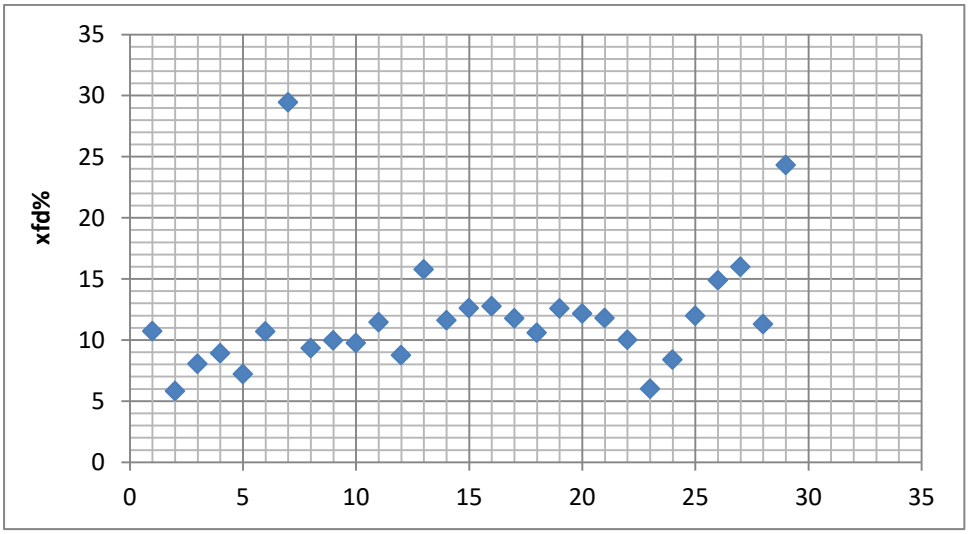


Figure 4.4b: Magnetic domain grains distribution of upland soil

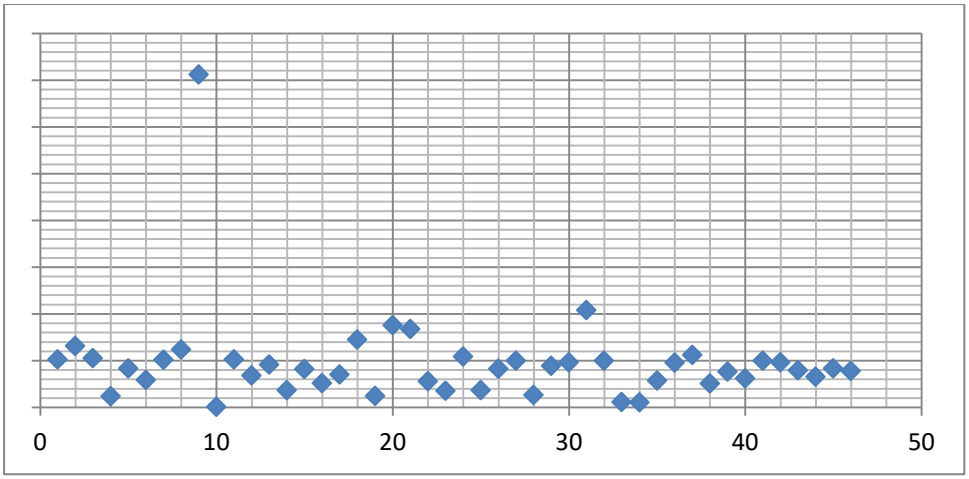


Figure 4.4c: Magnetic domain grains distribution of the uncultivated land soil

4.2.1 Variation of Magnetic Domain Grains Distribution with Depth of irrigation, upland sectors soils and uncultivated land

The study area is a complex area since it consists of areas where irrigation sectors, upland sectors and also uncultivated land which serve as the background for the study so it contains mixture of domain rains. The distribution of $\chi_{fd\%}$ results revealed that mixture of Coarse (MD, SSD) and SP domain grains dominate the core samples obtained at various depths (0 – 50 cm) as in Table 4.7a-4.7c.The magnetic domain grains with depth for irrigation, upland and uncultivated soils have a mixture of coarse and SP grains (86.5%. 74.0% 80.0%, 60.0% at depth 15, 30, 40, and 50 cm respectively) which decrease with depth possibly because of the persistent cultivation of the soil and effect of water logging which minimizes the MSMS of magnetic minerals. The domain grains distribution in upland sectors are little from that of irrigation sectors because they have both mixtures of coarser (MD) and superparamagnetic SP grains and pure SP grains and soils samples that are contaminated possibly due to metallic depositions in the soil samples collected. The case of the uncultivated soil samples is quite different because 100% of the soil samples collected showed that the domain grains at various depths is mixture of coarser and SP grains.

Table 4.5a: Magnetic Domain Grains with Depth for Irrigation Sectors

Depth (cm)	Xfd%	%
0	0-2	20
15	2-10	62
	10-14	10
	>14	8
	0 – 2	6.5
	2 – 10	87
	10 – 14	0
	>14	6.5
30	0 -2	13
	2 – 10	74
	10 – 14	13
	>14	0
40	0 -2	13
	2 – 10	80
	10 – 14	7
	>14	0
50	0 -2	7
	2 – 10	60
	10 – 14	26
	>14	26
		7

Table 4.5b: Magnetic Domain Grains with Depth for Upland Sectors

Depth (cm)	Xfd%	%
0	0 – 2	0
	2 – 10	41
	10 – 14	44
	>14	15
15	0 – 2	0
	2 – 10	100
	10 – 14	0
	>14	0
30	0 -2	0
	2 – 10	50
	10 – 14	50
	>14	0
40	0 -2	0
	2 – 10	100
	10 – 14	0
	>14	0
50	0 -2	0
	2 – 10	50
	10 – 14	0
	>14	50

Table 4.5c: Magnetic Domain Grains with Depth for Uncultivated Soil

Depth (cm)	Xfd%	%
0	0 – 2	11
	2 – 10	69
	10 – 14	11
	>14	9
15	0 – 2	0
	2 – 10	100
	10 – 14	0
	>14	0
30	0 -2	0
	2 – 10	100
	10 – 14	0
	>14	0
40	0 -2	0
	2 – 10	100
	10 – 14	0
	>14	0
50	0 -2	0
	2 – 10	100
	10 – 14	0
	>14	0

4.2.2 Detection of Anthropogenic Grains by Frequency-Dependent Magnetic susceptibility

The samples soils from Kano River Irrigation Project where irrigation, upland was raining season farming takes place and uncultivated soil where no cultivation takes place were analysed and have the following frequency dependent magnetic susceptibility values grouped according to Dearing *et al* model (1999) Table 4.8(a, b, c)

The percentage frequency dependent mass specific magnetic susceptibility (χfd%) in table 4.8a of Some Kano irrigation farm sectors shows that 20% are non-SP domain grains in the samples of the soil collected from the site. It also shows that 62% of the domains grains are admixture of SP and coarser non-SP and while 10% of the samples were pure SP grain domains with 8% due to contaminated samples.

The frequency dependent mass specific magnetic susceptibility ($\chi_{fd\%}$) 0 – 2% are coarse-grained, and are therefore dominated by multidomain (MD) and stable single domain (SSD) grain sizes (Petrovský, 1999). While the fine superparamegnetic SP (2 – 10%)) domain grain particles are of pedogenic origin. The results of the mass specific magnetic susceptibility measurements of the irrigation sectors showed that the samples are dominated by admixture domain grains which are coarser particles and fine superparamagnetic particles anthropogenic magnetic particles from different sources suggest coarser particles. The average value of χfd% of the irrigation soil is 7.17% which falls within the mixtures of the coarser magnetic domain (MD, SSD) and SP grains. According to Dearing *et al*. (1996) χfd% below 2–3% indicates a negligible proportion of ultra-fine pedogenic ferrimagnetic minerals in soil samples. The study shows that most of the samples were found to have magnetic domain grains of mixtures of coarse grains (MD, SSD) and SP grains.

Table 4.6a: Magnetic Domain Grains of Irrigation Soil based on Dearing Model (1999)

Irrigation Farmland Soil of KRIP $\chi_{fd\%}$

	Value	Interpretation
low$\chi_{fd\%}$	<2%s	35 samples have virtually no SP grains in this farmland sectors selected. These anthropogenic coarser grains (MD and PSD).
$medium\chi_{fd\%}$	2 – 10%	110 samples are admixture of SP and coarser non-SP grains or SP grains less than 0.005μm. These are mixture of pethogenic and anthropogenic grains.
$High\chi_{fd\%}$	10 – 14%	17 samples are virtually all ($> 75\%$) SP domain grains in the sectors.
$Very\ high\chi_{fd\%}$	$> 14\ \%$	15 samples are recorded as contaminated samples since $\chi_{fd\%}$ of the samples are greater than 14%.

The frequency dependent mass magnetic susceptibility (χfd%) of upland sectors of the study area shows that there were no pure coarse domain grains in the samples of the soil collected from the site as in Table 4.8b. The result has shown that 41% of the domain grains were admixture of SP and coarser non-SP and with 44% of the samples pure SP grain domains while 15% were due to contaminated samples (Dearing, 1999).

The average value of χfd% of the upland sectors farmland soil was 11.84% which are virtually all SP grains. According to Dearing (1999) χfd% between 10 – 14% indicates a greater proportion of ultra-fine pedogenic ferrimagnetic minerals in soil samples. The study shows that most of the samples have magnetic domain grains to be SP grains.

Table 4.6b: Magnetic Domain Grains of Upland Soil based on Dearing Model (1999)

Upland Farmland Soil ($\chi_{fd\%}$) of KRIP		
	Value	**Interpretation**
low$\chi_{fd\%}$	<2%	0 samples have virtually no SP grains in this farmland sectors selected. These are anthropogenic coarser grains (MD andPSD)
$medium\chi_{fd\%}$	2 – 10%	11 samples are admixture of SP and coarser non-SP grains or SP grains less than0.005μ. These are mixture of pethogenic and anthropogenic grains.
$High\chi_{fd\%}$	10 – 14%	12samples are virtually all (> 75%) SP(ultrafine) domain grains in the sectors
$Very\ high\chi_{fd\%}$	> 14 %	4 samples are recorded as contaminated samples since $\chi_{fd\%}$ is greater than 14%.

The frequency dependent mass magnetic susceptibility (χfd%) of 46 samples of uncultivated land soil of Kano irrigation farm sectors and shows that 11% were non-SP domain grains in the samples of the soil collected from the site as in table 4.8c. It also shows that 69% of the domain grains were admixture of SP and coarser non-SP and 11% of the samples were pure SP grain domains while 9% are due to contaminated samples (Dearing, 1999).

The average value of χfd% of the uncultivated soil is 10.73% which are mostly ultrafine SP grains. According to Yu and Shoba (2014) background soils are dominated by thin superparamagnetic and single domain particles while larger multidomain particles prevail in urban soils. The soil of this land has not been cultivated for about thirty years for agricultural activities; therefore, the presence of SP and SSD grains in the soil may be due to paedogenic process due to redox action (Yu and Shoba, 2014).

The results of measurements of frequency dependence of mass specific magnetic susceptibility in percentage (χfd%) on samples from farmland of irrigation where χfd% ranges from 0.0 to 50.22% (with an average of 7.17%) while the samples from upland farmlands where only raining season farming is practiced yearly ranges from 5.82 to 29.45% (average 11.84%) and the samples from uncultivated land where no farming activities is practiced ranges from 1.03 to 20.80% with average of 10.74%. The samples from the Kano river irrigation project where farming activities takes place during wet and dry season has the least average frequency dependent magnetic susceptibility (χfd%) of 7.17%. The χfd% average value for the upland sectors farmlands were raining season is practiced has a second least value of 11.84% while for the case of uncultivated land where no farming is practiced has the value of 10.74%. It is clearly seen that where irrigation takes place yearly, most of the samples contain superparamagnetic domain grain which is a small magnetic mineral that blocks out at high frequency measurements but fully participate at low frequency measurements.

Table 4.6c: Magnetic Domain Grains of Uncultivated based on Dearing Model (1999)

Uncultivated land soil $\chi_{fd\%}$	Value	Interpretation
low$\chi_{fd\%}$	<2%	5 samples have virtually no SP grains in this farmland soil sector selected. These are anthropogenic coarser MD and PSD grains
$medium\chi_{fd\%}$	2 – 10%	32 samples are admixture of SP and coarser non-SP (MD grains or SP) grains less than 0.005μm.
$High\chi_{fd\%}$	10 – 14%	5 samples are virtually all (> 75%) SP domain grains in the sectors. These are purely paedogenic grains (ultrafine grains)
$Very\ high\chi_{fd\%}$	> 14 %	4 samples are recorded as contaminated samples since $\chi_{fd\%}$ are greater than 14%.

According to model of Dearing (1999) who studied soils in England, that when $\chi_{fd\%} > 15\%$ the sample is either contaminated or is due to error. According to Worms and Jackson (1998) who studied soils of Yucca mountain in USA said that for samples with narrow size distribution of SP and SSD particles, $\chi_{fd\%}$ can exceed 30% for reasonable distribution. The two authors had their study from low climatic belt region. This present study is from Nigeria a tropical region with higher temperature and pressure than that of USA and England, so the present study discovered that for reasonable distribution of SP and SSD the maximum value of $\chi_{fd\%}$ can exceed 50%.

4.3 Heavy Metal Concentration in Irrigation Sectors Soils

The result of the descriptive statistics of selected heavy metal concentrations in the topsoil of the study area of irrigation and upland sectors area presented in Tables 4.9a and 4.9b. The mean concentrations of Iron(Fe), Lead(Pb), Cadminium(Cd), Copper(Cu), Zinc(Zn), Cr and

Nickel(Ni) for irrigation 40.774, BDL, 0.0011, 0.021, 0.165, 0.010, BDL and for upland 45.233, 0.375, 0.375, 0.223, 0.336, 0.250, BDL $mgkg^{-1}$ respectively.

This indicates that the concentrations of heavy metals in the irrigation sectors soil exist in the following order: Fe > Zn > Cu> Cr > Cd, while Pb and Ni were not detected by MP-AES Agilet 4200. The concentrations of the heavy metals in upland sectors exist in this order as well: Fe > Ni > Pb> Cd > Zn > Cr >Cu.

Iron (Fe) is the most concentrated in the soils of irrigation and upland sectors. The heavy metals (Ni, Pb, Cd, Zn, Cr, and Cu) are more pronounced in upland sectors soils than in irrigation soils. This is possibly because the soil in the upland sectors are well drained as at the time the samples of the soils were taken unlike irrigation sectors that have waterlogging and experiences flood. Their concentration can either be from parent rock materials or anthropogenic sources. High concentration of Fe have been found in car exhaust particulates and other car derivatives such as corrosion of body parts (Hopke *et al*, 1980; Lu *et al*, 2005) as well as soils (Robertson *et al*, 2003). The concentration of Fe in both irrigation and upland soil sectors were (20.51-109.11 $mgkg^{-1}$) found to be lower than Fe in irrigated farmlands in Makera area of Kaduna State (1425.0- 1981.6 $mgkg^{-1}$) (Mohammed and Folorunsho, 2015). The heavy metals (Fe, Pb, Cd, Cu, Zn, Cr and Ni) in the study area were found to be lower than the values of the heavy metals in samples of soil from Karak in Pakistan(Afzeel *et al*.,2013) and in Halton the mean value of Fe was found to be 22.630 mgg^{-1} in UK (Crosby, 2012) and has lower value when compared to study area. Zn has been suggested to be derived from vehicle tyres (Hopke *et al*, 1980).

Table 4.7a Descriptive Statistics showing mean, median, S.D., Min., Max., and CV of concentrations of heavy metals in soils samples of irrigation sectors

	Fe (mg/kg)	**Pb (mg/kg)**	**Cd (mg/kg)**	**Cu (mg/kg)**	**Zn (mg/kg)**	**Cr (mg/kg)**	**Ni (mg/kg)**
Mean	40.774	BDL	0.004	0.021	0.166	0.999	BDL
Median	32.140	BDL	0.005	0.018	0.152	0.068	BDL
S.D	24.672	BDL	0.045	0.169	0.043	0.075	BDL
Min.	20.51	BDL	0	0.003	0.123	0.004	BDL
Max.	109.110	BDL	0.010	0.062	0.314	0.284	BDL
CV %	60.51	BDL	221.280	79.290	25.51	75.31	BDL
WMSC[1]	47200	20	0.3	45	95	850	
WHO[2] SQG	-	-	6	25	123	-	
USEPA[3] SQG	20	40	0.6	16	110	30	

Values are in mg/kg, BDL = Below Detection Limit, S.D = Standard Deviation, CV = Coefficient of Variation, WMSC = World Mean shale concentration SQG = Sediment quality guidelines, [1]Turakin and Wedepohl (1961),[2] WHO (2004),[3] USEPA (1999).

Table 4.7b Descriptive Statistics showing mean, median, S.D., Min., Max., and CV of concentrations of heavy metals in soils samples of upland sectors

	Fe (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Cr (mg/kg)	Ni (mg/kg
Mean	45.233	0.375	0.370	0.223	0.336	0.25	BDL
Median	40.490	0.3925	0.740	0.0675	0.121	0.0944	BDL
S.D	23.679	0.340	0.369	0.324	0.381	0.246	BDL
Min.	20.74	0.035	0.002	0.007	0.105	0.044	BDL
Max.	79.210	0.715	0.739	0.783	0.995	0.669	BDL
CV %	52.350	90.670	99.460	145.120	113.380	98.400	BDL
WMSC[1]	47200	20	0.3	45	95	850	
WHO[2] SQG	-	-	6	25	123	-	
USEPA[3] SQG	20	40	0.6	16	110	30	

Values are in mg/kg, BDL = Below Detection Limit, S.D = Standard Deviation, CV = Coefficient of Variation, WMSC = World Mean shale concentration SQG = Sediment quality guidelines, [1]Turakin and Wedepohl (1961), [2] WHO (2004), [3] USEPA (1999).

4.3.1 Assessment According to Contamination Factor (CF) and Degree of Contamination (CD)

Tables 4.10a and 4.10b show the assessments of contamination factor of heavy metal for irrigation and upland sectors. The contamination factor mean values of heavy metals for irrigation sectors are as follows: Fe, 0.750; Pb, BDL; Cd, 0.779; Cu, 0.981; Zn, 0.880; Cr, 1.325 and Ni, BDL. The contamination factor of irrigation sectors soil is low because CF ≥ 1 with exception of Cr which has value of 1.325 and is moderately comtaminated (Hakanson, 1980 as in table 4.10c). The contamination factor mean values for heavy metals for upland sectors are as follows: Fe, 0.831; Pb, BDL; Cd, 55.547; Cu, 10.304; Zn, 1.783; Cr, 3.312 and Ni, BDL. In upland sectors, the contamination factor is very high for Cd and Cu because CF

≥ 6, that of Cr and Zn is moderately contaminated because 1 ≤CF < 3. The CF value of Fe is low while Pb and Ni are found to be BDL 4.10c.

Table 4.8a Descriptive Statistics showing Min., Max., Mean and S.D. of Contamination Factor (CF) in soils samples of irrigation sectors.

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Min.	0.3770	BDL	0.1499	0.3231	0.6532	0.6106	BDL
Max.	2.0055	BDL	1.4999	2.8615	1.6676	3.7966	BDL
Mean	0.7499	BDL	0.7790	0.9807	0.8779	1.3254	BDL
S.D.	0.4649	BDL	0.4021	0.7978	0.2298	1.0224	BDL

BDL = Below Detection Limit, SD = Standard Deviation

Table 4.8b Descriptive Statistics showing Min., Max., Mean and S.D. of Contamination Factor (CF) in soils samples of upland sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Min.	0.3812	BDL	0.3000	0.3231	0.5576	0.5841	BDL
Max.	1.4559	BDL	110.7946	36.1379	5.2840	8.8544	BDL
Mean	0.8314	BDL	55.5473	10.3037	1.7830	3.3121	BDL
S.D.	0.5026	BDL	78.1315	17.2656	2.3344	3.7588	BDL

BDL = Below Detection Limit, SD = Standard Deviation

Table 4.8c: Index Classification of Sediment Quality

CF Values (Hakanson, 1980)	Class	Sediment Quality
CF <1	1	Low contamination
1≤ CF < 3	2	Moderate contamination
3 ≤ CF < 6	3	Considerable contamination
CF ≥ 6	4	Very high contamination

4.3.2 Index of Geoaccummulation (I_{geo}) for Contamintion Level in the Study Area Based on Muller equation, $I_{geo} = log2(\frac{C_n}{1.5xB_n})$ (Boszke et al., 2004).

In Tables 4.11a the mean values of I_{geo} for heavy metals (Fe, Cd, Cu, Zn, and Cr) of irrigation sectors show that the soil is uncontaminated while Pb and Ni were BDL table 4.11c

In Tables 4.11b the mean values of I_{geo} for heavy metals (Fe, Pb, Cd, Cu, Zn, Cr and Ni) of upland sectors show that the soil is moderately contaminated with Cu, uncontaminated to moderately contaminate with Cd and Cr, uncontaminated with Fe and Zn and Pb and Ni were discovered to be BDL table 4.11c. The reason for low value of I_{geo} in irrigation sectors may be due to the fact that it experiences flood and this enhances washing away of heavy metals from the surface.

Table 4.9a: Descriptive Statistics showing Min., Max., Mean and S.D. of Index of Geoaccummulation (I_{geo}) for Contamintion Level in soils samples of irrigation sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Min.	-1.9928	BDL	-3.3289	-2.6163	-1.1996	-1.4985	BDL
Max.	0.4191	BDL	0.0010	0.7849	0.1528	1.3400	BDL
Mean	-1.0743	BDL	-1.0552	-1.1844	-0.7801	-0.4433	BDL
S.D.	0.8943	BDL	1.751	1.0901	0.3158	0.8731	BDL

BDL = Below Detection, SD = Standard Deviation

Table 4.9b: Descriptive Statistics showing Min., Max., Mean and S.D. of Index of Geoaccummulation (I_{geo}) for Contamintion Level in soils samples of upland sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Min.	-1.6731	BD	-2.3224	-0.0224	-1.2232	-1.3610	BD
Max.	–0.0431	BD	2.8854	4.5915	1.8170	2.5620	BD
Mean	-1.0631	BD	0.2815	1.6418	-0.5114	0.4596	BD
S.D.	0.9130	BD	3.6825	2.0273	1.5554	1.6261	BD

Table 4.9c: The degree of metal pollution in terms in of seven enrichment classes (Muller, 1969)

I_{geo} Value	I_{geo} Class	designation of sediment quality
> 5	6	extremely contaminated
4 - 5	5	strongly to extremely contaminated
3 - 4	4	strongly contaminated
2 - 3	3	moderately to strongly contaminated
1 - 2	2	moderately contaminated
0 - 1	1	uncontaminted to moderately contaminated
0 <	0	uncontaminated

BD = Below Detection, SD = Standard Deviation

4.3.3 Assessment according to Pollution Load Index (PLI)

The Tomlison Pollution Load Index (Tomlinson *et al*, 1980) indicates how much a sample exceeds the heavy metal concentrations for the natural environments and gives an assessment of overall toxicity status for a sample (Angulo, 1996). The PLI was calculated to establish the association with magnetic parameters. In this study, PLI is determined using equation 3.2 (Tomlinson *et al,* 1980). According to Singh *et al* (2003) and Zhang *et al* (2011), PLI values vary from 0 (unpolluted) to 10 (highly polluted) as follows: PLI = 0 (background

concentration); 0 < PLI ≤ 1 (unpolluted); 1 < PLI ≤ 2 (moderately to unpolluted); 2 < PLI ≤ 3 (moderately polluted); 3 < PLI ≤ 4 (moderately to highly polluted); 4 < PLI ≤ 5 (highly polluted) and PLI > 5 (very highly polluted).

The results of PLI in this study are shown in Tables 4.12a. and 4.12b. The mean values of PLI for heavy metals (Fe, 0.6541; Pb, - ; Cd, 0.6406; Cu, 0.7410; Zn, 0.8565; Cr, 1.0790 and Ni, -) in irrigation sectors showed unpolluted. The mean values of PLI for heavy metals (Fe, 0.7180; Pb, -; Cd, 1.0211; Cu, 2.7418; Zn, 0.8565; Cr, 2.0620 and Ni, -) in upland sectors were unpolluted except for Cu and Cr which are moderately polluted (Singh *et al.*, 2003). The upland sectors were moderately polluted with Cu and Cr because the soil is not flooded with water like the irrigation sectors which are flooded throughout dry and wet season which helps to wash away magnetic materials and heavy metals.

Table 4.10a: Showing Pollution Load Index PLI in soils samples of Irrigation Sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
PLI	0.6561	-	0.6406	0.7410	0.8565	1.0790	-

Table 4.10b: Showing Pollution Load Index PLI in soils samples of upland Sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
PLI	0.7180	-	1.0211	2.7418	0.8565	2.0620	-

4.3.4 Assessment According to Enrichment Factor (EF).

Table 4.13a shows that only Cr has an EF value of 17.6823 that is higher than 1.5 which is the maximum value for lithology. Any value of EF that is above 1.5 is considered to be due to human activity or anthropogenic influence. Therefore, the EF due to Fe, Cd, Cu and Zn are less than 1.5 and hence due lithology.

Table 4.11a: Showing *Enrichment factors EF* in soils samples of Irrigation Sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
EF	1.000	-	0.9412	1.3089	1.1710	17.6823	-

Table 4.13a and 4.13bShows that Cd, Cu and Cr has an EF value of 66.8653, 12.3958 and 3.9906 respectively that are higher than 1.5. Therefore, their contribution is due to anthropogenic influence. The values of EF for Fe and Zn are below 1.5 so their contribution is due to lithogenic influence. The contribution of Pb and Ni was not detectable.

Table 4:11b Showing Enrichment factors EF in Soils samples of upland Sectors

	Fe	Pb	Cd	Cu	Zn	Cr	Ni
EF	1.000	-	66.8653	12.3958	1.1710	3.9906	-

4.4 Correlation between Magnetic Susceptibility and Heavy Metal Concentration

The values of the mean, SD, minimum, maximum, and CV concentrations of magnetic and nonmagnetic parameters for both irrigation and upland sectors are shown in table 4.14. The concentrations of the two parameters are higher in upland soil because the soil is well drained and does not experience flood and water logging like the case of irrigation sectors.

To investigate the potential of using magnetic measurements as proxies for heavy metal pollution, correlation analysis was performed between magnetic susceptibility and geochemical parameters. The Table 4.14 shows how MSMS parameters and heavy metals concentration varies based on human influence on the soil of the area of study. The mean values of MSMS and heavy metals are higher in concentrations in upland sectors that in irrigation sectors because irrigation sectors are waterlogged and flooded almost every time and minerals are washed away by such flood. The upland sectors are well drained since the samples were collected in the dry season. The coefficient variations (CV) for MSMS parameters in irrigation sectors are high due to dynamics of the flood activities on the soil.

The CV is observed to be low in upland sector since the soil is well drained and stable at that time.

Table 4.12: Showing the Mean, SD, Min., Max, CV of Magnetic and Nonmagnetic Parameters

Sector	**MSMS (10^{-8} m^3Kg)**		**Heavy Metals (mg/Kg)**						
Irrigation sector	X	xfd%	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Mean	13.29	7.07	40.774	BDL	0.004	0.021	0.166	0.999	BDL
SD	9.347	`5.570	24.672	BDL	0.045	0.169	0.043	0.075	BDL
Min	1.8	0	20.510	BDL	0	0.003	0.123	0.004	BDL
Max	91.4	50.22	209.11	BDL	0.01	0.062	0.314	0.284	BDL
CV	70.331	78.78	60.51	BDL	221.28	79.29	25.5	75.31	BDL
Upland sector									
Mean	23.54	11.84	45.233	0.375	0.370	0.223	0.336	0.25	BDL
SD	7.049	5.081	23.679	0.340	0.369	0.324	0.381	0.246	BDL
Min	12.50	5.82	20.74	0.035	0.002	0.007	0.105	0.440	BDL
Max	32.80	9.45	79.21	0.715	0.739	0.783	0.995	0.669	BDL
CV	29.94	43.885	52.359	0.679	9.46	145.12	113.38	96.4	BDL

The correlation analysis was performed using Microsoft Excel 2007 and the results are displayed on a correlation tables (Tables 4.15 and 4.16). The result shows good and positive correlation n between magnetic susceptibility and the concentration of heavy metals. This shows the potential of using χlf as a proxy to the heavy metals contamination (Petrovsky *et al*, 2001). The good and positive correlation obtained is an indication that magnetic susceptibility could be a good indicator of heavy metal contamination.

Table 4.13: Pearson's Correlation Matrix for Mass Specific Magnetic Susceptibility and Geochemical Parameters for Soil of Irrigation Sectors

	Xlf	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Xlf	1							
Fe	0.8859	1						
Pb	-	-	1					
Cd	0.8249	0.6519	-	1				
Cu	0.5401	0.3355	-	0.7792	1			
Zn	0.5934	0.1994	-	0.3792	0.4571	1		
Cr	0.4379	0.2455	-	0.6224	0.9118	0.2735	1	
Ni	-	-	-	-	-	-	-	-

The correlation between the concentration of MSMS and PLI for irrigation sectors is**,** MSMS = 30.46PLI – 14.248 with R^2 = 0.7612. The correlation between magnetic parameter and heavy metal is high so this makes MSMS study a good method for pollution study on this site.

Table 4.14: Pearson's Correlation Matrix for Mass Specific Magnetic Susceptibility and Geochemical Parameters for Soil of Upland Sectors

	Xlf	Fe	Pb	Cd	Cu	Zn	Cr	Ni
Xlf	1							
Fe	0.8859	1						
Pb	-	-	-					
Cd	0.8024	0.8733	-	1				
Cu	0.8769	0.6397	-	0.7806	1			
Zn	0.8924	0.6890	-	0.8348	0.9941	1		
Cr	0.8605	0.8485	-	0.9880	0.8415	0.8917	1	
Ni	-	-	-	-	-	-	-	-

Correlation between mass specific magnetic susceptibility and heavy metals could give information on the possible sources and associations of the heavy metals. The good

correlations between magnetic susceptibility parameters and heavy metals shows that MSMS method is suitable for pollution studies as shown by authors (Lu *et al*, 2005; Robertson *et al*, 2003; Crosby, 2012). The correlations between heavy metals in soil samples of irrigation and upland sectors showed strong associations between Fe, Cd, Cu, Zn, and Cr except for the presence of Pb and Ni were found to be below detectable limit in the soil samples. These inter-correlations suggest evidence of anthropogenic input. The correlation between the concentration of MSMS and PLI for upland sectors is**,** MSMS = 30.46PLI – 14.248 with R^2 = 0.7612. The correlation between magnetic parameter and heavy metal is high so this makes MSMS study a good method for pollution study on this site.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Results

The soil samples were collected from topsoil and at depths of 15, 30, 40, and 50 cm randomly with GPS for each sample taken and packaged in plastic container across the farm sectors. The KRIP farmland sectors soil showed the following magnetic susceptibility parameters: Irrigation soil has MSMS range of 1.8 – 91.4 x 10^{-8} m^3kg^{-1} with an average 13.29 x 10^{-8} m^3kg^{-1} and χfd% 0.00 – 50.22 % with an average value of 7.07 %, upland farmland soil sectors 12.5 – 32.8 x 10^{-8} m^3kg^{-1} with a mean of 23.54 x 10^{-8} m^3kg^{-1} with χfd% 5.82 – 29.45 % with average 11.84 % and uncultivated soil 8.4 – 104.5 x 10^{-8} m^3kge with 31.05 x 10^{-8} m^3kg^{-1} and χfd% between 0.10 – 71.15% with average 9.372%.

The mean vertical variation of MSMS for irrigation topsoil was 10.89 x 10^{-8} $m^3kg^{-1}$with a range of 3.2 – 30.9 10^{-8} m^3kg^{-1}while its subsoil MSMS mean was calculated to be 8.75x 10^{-8} m^3kg^{-1} with its range found to be 3.6 – 22.5 x 10^{-8} m^3kg^{-1}. The mean vertical variation of MSMS for upland topsoil was 21.45 10^{-8} $m^3kg^{-1}$with a range of 20.5 – 22.4 x 10^{-8} m^3kg^{-1}while its subsoil MSMS mean was calculated to be 31.4x 10^{-8} m^3kg^{-1} with its range found to be 14.6 -33.6 x 10^{-8} m^3kg^{-1}.The mean vertical variation of MSMS for uncultivated topsoil was 30.85x10^{-8} $m^3kg^{-1}$with a range of 30.4- 31.3 x 10^{-8} m^3kg^{-1}while its subsoil MSMS mean was calculated to be 24.55x 10^{-8} m^3kg^{-1} with its range found to be 8.5 – 40.6 x 10^{-8} m^3kg^{-1}. This study revealed variable values of MSMS with depth within the study area, but most of the profiles showed moderate enhancement of MSMS on the surface soil since few of the profiles showed decrease in MSMS with depth. Majority showed increase in MSMS with depth which is an indication of lithology. The correlation between percentage frequency dependent magnetic susceptibility and low frequency magnetic susceptibility showed three patterns. The first one is positive correlation which is an indication of the presence of

superparamagnetic fine particles which are due to abiotic factors (pedogenic). The second pattern gives negative correlation and indicates the presence of anthropogenic magnetic particles which are due to biotic factors. The third pattern gives a correlation that is zero to almost zero, which may be due to transition of single domain (SD) grains to multidomain (MD) grains.

The percentage frequency dependent MSMS showed that irrigation sectors has a mean value of 7.07%, upland sectors has a mean value of 11.84% and uncultivated land soil has a mean value of 9.37%. These domain grains sizes analysis shows that most of the soil in the study area are mixtures of anthropogenic (multidomain, MD) and pethogenic (superparamagnetic, SP) activities. The assessment of the impact of human activities on KRIP was done using the Percentage frequency dependent mass specific magnetic susceptibility ($\chi_{fd\%}$) with geochemical analysis. Most of the soil samples from irrigation sectors revealed that 20% are coarser grains (anthropogenic, MD), 62% are mixture of coarse grains (MD) and super paramagnetic grains (SP), 10% are pure super paramagnetic grains (SP) while 8% are due to error. In a similar manner there was no coarser gains in the samples of upland soil but the soil samples revealed that 41% are mixture of Coarse grains (MD) and super paramagnetic grains (SP) while 44 % are super paramagnetic grains (SP) and 15% are due to error. Likewise, the soil samples from uncultivated soil revealed that 11% are due coarser grains domain, 69% are mixture of coarser grains (MD) and super paramagnetic grains (SP), 11% are due to pure super paramagnetic grains (SP) while 9% are erratic.

The mean concentrations of Fe, Pb, Cd, Cu, Zn, Cr and Ni for irrigation 40.774, BDL, 0.005, 0.021, 0.165, 0.010, BDL and for upland 45.233, 0.375, 0.375, 0.223, 0.336, 0.250, BDL $mgkg^{-1}$ respectively. The mean values of the Contamination Factor (CF) for irrigation sectors for various heavy metals (Fe, 0.7499; Pb, BDL; Cd, 0.7790; Cu, 0.9807; Zn, 0.8779; Cr, 1.3254 and Ni, BDL) and for upland sectors for various heavy metals (Fe, 0.8314; Pb, BDL;

Cd, 55.5473; Cu, 10.3037; Zn,1.7830; Cr, 3.3121 and Ni, BDL) Index of Geoaccumulation (I_{geo}) for irrigation sectors for various heavy metals (Fe, -1.0743; Pb, BDL; Cd, -1.0552; Cu, -1.1844; Zn, -0.7801;Cr, -0.4433 and Ni, BDL) and for upland sectors for various heavy metals (Fe, -1.0631; Pb, BDL; Cd, 0.2815; Cu, 1.6418; Zn, -0.5114; Cr, 0.4596; and Ni BDL), Pollution Load Index (PLI), for irrigation sectors for various heavy metals (Fe, 0.6551; Pb, BDL; Cd, 0.6406; Cu, 0.7410; Zn, 0.8565; Cr, 1.0790 and Ni, BDL) and for upland for various heavy metals (Fe, 0.7180; Pb, BDL; Cd, 1.0211; Cu, 2.7418; Zn, 0.8565; Cr, 2.0620 and Ni, BDL), (EF) for irrigation for various heavy metals (Fe, 1.000; Pb, BDL; Cd, 0.9912; Cu, 1.3089; Zn, 1.1710; Cr, 17.6823; and Ni, BDL) and for upland sectors for various heavy metals (Fe, 1.000; Pb, BDL; Cd, 66.8653; Cu, 12.3958; Zn, 1.1710; Cr, 3.9906 and Ni, BDL).

The four parameters of pollution (geochemical analysis) study showed that the study area is not polluted even though the EF of Cr of irrigation sector is revealed to be polluted and Cd, Cu and Cr in Upland sectors also revealed that they are toxic to the soil. The general result shows that the soil is not polluted. The Pearson's Correlation matrix for mass specific magnetic susceptibility and geochemical parameters for soil of irrigation upland sectors showed that there is a high correlation between them which shows that MSMS method is good for pollution study of KRIP.

5.2 Conclusion

*The study has examined the environmental impact of human activities in agricultural soils of KRIP using MSMS with geochemical analysis. In many developing nations like Nigeria, Environmental Impact Assessment (EIA) has not been properly established to determine the background state of the heavy metals in our soils and to ascertain the level of the pollution index of our farm lands soils. The study has addressed the issue of pollution due to human activities at KRIP. The study has generated data on concentration of MSMS of KRIP soils

which has shown the level of human activities on the soils is moderate. The data provides information to stake holders and citizen to serve as a basis for decision making.

* The study employed random sampling for collection two hundred and fifty (250) soils samples which include topsoil and core samples. The MSMS measurements were done on two hundred and fifty (250) samples of soil in the Laboratory using mass specific magnetic susceptibility meter (MS2) with two sensors (MS2B). The MSMS measurements revealed variable values with concentration that range from 1.8 – 104.5 x 10^{-8} m^3kg^{-1} depending on the human activities. The irrigation sector soils have MSMS mean value of 13.29 x 10^{-8} m^3kg^{-1}, the upland sectors soils have MSMS mean value of 23.54 x 10^{-8} m^3kg^{-1} and the uncultivated land soils has MSMS mean value of 31.05 x 10^{-8} m^3kg^{-1}. The value of MSMS are higher in uncultivated land soils perhaps due to the fact that the land is not ploughed and also the washing away of the surface of the uncultivated land is minimum.

* Geochemical analysis was done on some selected soil samples with low, medium and high MSMS to determine the concentration of some selected heavy metals (Fe, Pb, Cd, Cu, Zn, Cr and Ni).

* The MSMS concentrations of the irrigation sectors were found to be lower than the MSMS concentrations found in upland sectors. This could be due to the presence of water logging in irrigation sectors that causes reduction in iron minerals, flooding that washes away the minerals over time and vertical migration of the minerals.

*The study showed that the MSMS of samples at lower frequency has higher values than the samples of soils at higher frequency because of the presence of superparamagnetic minerals which takes a longer time to show up than other magnetic minerals.

*The study showed that frequency dependence of mass specific magnetic susceptibility measurements showed that the samples were dominated by mixture of multi-domain coarse

(MD) and superparamagnetic (SP) grained sizes from both pedogenic and anthropogenic activities.

* Discrimination between lithogenic and anthropogenic source of pollution using magnetic susceptibility was done by measuring the vertical variation of magnetic susceptibility across a vertical soil profile. In this study, only very few enhanced magnetic susceptibility values were obtained in the topsoil down the profile which is an indication of anthropogenic input. It shows that the KRIP farm soils are not polluted but has trace of pollution.

* The heavy metals Fe, Pb, Cd, Cu, Zn, Cr and Ni correlate reasonably well with MSMS which shows efficient indicators of anthropogenic contamination in the farmland soils of KRIP

* The quantitative measurement of the degree of contamination by heavy metals (Fe, Pb, Cd, Cu, Zn, Cr and Ni) was calculated.

*The level of contamination of KRIP soil can be considered to be (almost) unpolluted though there is a possibility of pollution of the farmland soil with time.

* The assessment of the pollution status of the KRIP soils indicates that the soils are not polluted. However, enrichment factor analysis showed that some of the heavy metals have been enriched. It is evident that these heavy metals may increase over time if proactive steps are not taken to check pollution sources in future.

* The study showed that the percentage frequency mass specific magnetic susceptibility (χfd%) of KRIP has a value that range from 0.00 – 50.22% unlike the χfd% threshold of Dearing model (1999) which was obtained to be 15%. The χfd% of KRIP is higher than that of Dearing (1999) may be because Dearing obtained his results on soils of temperate climate belt while our study was done on soil of tropical climate of the world.

* The percentage frequency dependent mass specific magnetic susceptibility ($X_{fd\%}$) $\leq$2% for irrigation sectors, upland sectors and uncultivated land are 20%, 33% and 9% of the area

studied respectively. This shows that the study area is slightly polluted with coarse grains (MD) which are anthropogenic in nature.

* In this study, the few enhanced magnetic susceptibility values were obtained on the surface of the soil as MSMS decreases with depth.

* The four parameters of pollution study of geochemical analysis showed that the study area is not polluted even though the EF of Cr of irrigation sectors revealed that it was above the natural value. It revealed also that Cd, Cu and Cr in upland sectors are toxic to the soil. The toxicity in upland of heavy metal is more in upland soil because it does not experience flood to wash away the soil surface as in irrigation soil. The general results drawn from MSMS and geochemical analysis showed that the study area is not polluted.

5.3 Recommendation (Future Prospect)

1. Further research work to study magnetic properties of areas affected by erosion in flooded KRIP farm sectors by using MSMS techniques.

2.The study has observed that there is need to establish specific reference values for MSMS and heavy metals of Nigerian farm soil which are important for prevention, protection and recuperation tools for agricultural soils especially as the activities of agriculture is on the increase because of population growth.

3. Since this work is the first measurement of MSMS conducted on KRIP, It will give a wholesome work to have a seasonal measurement of the MSMS on the samples of the KRIP soils so that a spatial variation of the magnetic susceptibility with time and season is observed.

4. The study showed that there was low concentration of MSMS in water logged irrigation sectors. It will be good to conduct a further research using magnetic method to check the vertical migration of magnetic particles and plants uptake of the magnetic particles and also to check magnetic particles and heavy metals in the streams within the farm.

5.4 Contribution to Knowledge

The Major Achievements in This Work are:

1. The study is the first to measure mass specific magnetic susceptibility (MSMS) of topsoil and subsoil of Kano river irrigation Project in Kura local government of Kano State.
2. The study has successfully applied mass specific magnetic susceptibility to study man activities on irrigation farmland soils and discovered that the magnetic domain grains present in the soils are mostly mixture of superparamagnetic (SP) grains and multidomain grains which are pethogenic in nature.
3. The concentration of magnetic minerals in the irrigation sectors soils and magnetic domain grains were determined
4. This work may be the first attempt in assessing pollution study on irrigation of KRIP using MSMS and showed that the soil is not polluted but has the tendency to be polluted with time if no remedy is taken.
5. The study has also shown that MSMS of the soil of KRIP can be used as proxy to study pollution because of its good correlation with heavy metals of the soil.

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APPENDIX 1

Table 4.1d: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Danmaura sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Dm1(15 cm)	$11^0$67′1″	$8^0$42′3″	14.76	5.3	5.2	1.89
2	Dm1(30 cm)	$11^0$67′1″	$8^0$42′3″	14.91	4.9	4.6	6.12
3	Dm1(40 cm)	$11^0$67′1″	$8^0$42′3″	15.71	5.6	4.8	14.29
4	Dm1(50 cm)	$11^0$67′1″	$8^0$42′3″	16.66	5.5	4.5	1.82
5	DM2	$11^0$67′2″	$8^0$42′5″	12.66	8.9	8.7	2.25
6	Dm3	$11^0$67′3″	$8^0$42′7″	13.22	7.9	7.6	3.80
7	Dm4	$11^0$67′4″	$8^0$42′9″	12.69	17.2	15.5	9.89
8	Dm5	$11^0$67′5″	$8^0$42′6″	13.11	11.5	9.3	19.13

Table 4.1e: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Kore sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ko1a(15 cm)	$11^0$74′5″	$8^0$42′5″	17.80	7.0	6.5	7.14
2	Ko1a(30 cm)	$11^0$74′5″	$8^0$42′5″	13.89	7.5	6.9	8.00
3	Ko1a(40 cm)	$11^0$74′5″	$8^0$42′5″	19.07	7.9	7.7	2.53
4	Ko1a(50 cm)	$11^0$74′5″	$8^0$42′5″	16.74	17.3	14.5	16.18
5	Ko1b(15 cm)	$11^0$73′0″	$8^0$42′3″	18.05	3.3	3.2	3.03
6	Ko1b(30 cm)	$11^0$73′0″	$8^0$42′3″	19.09	5.6	5.5	1.79
7	Ko1b(40 cm)	$11^0$73′0″	$8^0$42′3″	19.03	5.4	5.3	1.89
8	Ko1b(50 cm)	$11^0$73′0″	$8^0$42′3″	19.34	5.4	5.3	1.89
9	Ko2	$11^0$72′9″	$8^0$42′2″	15.29	4.8	4.7	2.13

10	Ko3	$11^0$72′8″	$8^0$42′1″	17.82	5.0	4.7	6.38
11	Ko4	$11^0$72′7″	$8^0$41′9″	19.20	3.9	3.3	15.38
12	Ko5	$11^0$72′5″	$8^0$41′8″	19.17	1.8	1.8	0
13	Ko6	$11^0$73′8″	$8^0$41′7″	14.40	5.5	5.3	3.64
14	Ko7	$11^0$73′5″	$8^0$41′6″	13.20	15.8	14.9	5.00
15	Ko8	$11^0$73′1″	$8^0$41′5″	16.98	5.2	5.0	3.85
16	Ko9	$11^0$73′6″	$8^0$41′4″	14.26	8.3	7.4	10.8
17	Ko10	$11^0$72′0″	$8^0$41′3″	15.42	29.6	28.8	4.17
18	Ko11	$11^0$71′9″	$8^0$41′2″	18.97	9.7	9.6	1.03
19	Ko12	$11^0$71′8″	$8^0$41′2″	15.85	6.8	5.0	26.47
20	Ko13	$11^0$72′6″	$8^0$41′0″	16.90	6.7	6.4	4.48
21	Ko14	$11^0$73′1″	$8^0$42′0″	16.17	10.1	9.4	6.93
22	Ko15	$11^0$73′2″	$8^0$40′7″	18.42	7.4	6.5	12.16
23	Ko16	$11^0$73′2″	$8^0$40′6″	17.19	8.1	7.5	7.4

Table 4.1f: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Gafan sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ga1(15 cm)	$11^0$67′6″	$8^0$42′0″	16.07	14.8	13.9	5.44
2	Ga1(30 cm)	$11^0$67′6″	$8^0$42′0″	18.54	9.0	8.8	22.22
3	Ga1(40 cm)	$11^0$67′6″	$8^0$42′0″	17.83	7.8	6.7	14.10
4	Ga1(50 cm)	$11^0$67′6″	$8^0$42′0″	20.33	7.5	7.2	4.00
5	Ga2	$11^0$67′7″	$8^0$42′1″	16.90	9.9	8.9	1.00

6	Ga3	$11^0678''$	$8^042'2''$	18.95	6.1	5.8	4.92
7	Ga4	$11^067'9''$	$8^042'3''$	16.52	12.3	11.3	8.13
8	Ga5	$11^068'0''$	$8^042'4''$	14.94	8.5	8.1	4.70
9	Ga6	$11^068'1''$	$8^042'5''$	20.35	8.2	7.9	3.66
10	Ga7	$11^068'2''$	$8^042'6''$	18.43	6.6	6.1	7.58
11	Ga8	$11^068'3''$	$8^042'7''$	21.01	5.8	5.6	3.45
12	Ga9	$11^068'4''$	$8^042'7''$	20.15	9.3	8.8	5.38
13	Ga10	$11^068'5''$	$8^042'8''$	15.28	15.1	9.0	0/66
14	Ga11	$11^068'6''$	$8^043'0''$	16.21	7.1	6.8	4.22
15	Ga12	$11^067'7''$	$8^043'1''$	15.29	7.3	6.9	5.48
16	Ga13	$11^068'8''$	$8^043'2''$	17.59	4.9	4.1	16.33
17	Ga14	$11^068'9''$	$8^043'3''$	16.50	20.0	20.0	0
18	Ga15	$11^069'0''$	$8^043'4''$	16.22	9.1	8.0	12.09
19	Ga16	$11^069'1''$	$8^043'5''$	17.15	26.7	24.6	7.87
20	Ga17	$11^069'2''$	$8^043'6''$	18.06	16.6	14.9	10.24
21	Ga181	$11^069'3''$	$8^043'7''$	17.85	13.6	12.0	11.76
22	Ga19	$11^069'6''$	$8^043'8''$	19.03	5.1	5.2	1.96
23	G20	$11^069'7''$	$8^043'9''$	14.29	5.4	4.9	9.26

Table 4.1g: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Samawa sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Sw1(15 cm)	$11^0$73′4″	$8^0$42′3″	18.14	3.2	3.0	6.25
2	Sw1(30 cm)	$11^0$73′4″	$8^0$42′3″	18.81	3.5	3.5	0
3	Sw1(40 cm)	$11^0$73′4″	$8^0$42′3″	19.23	3.8	3.4	10.53
4	Sw1(50 cm)	$11^0$73′4″	$8^0$42′3″	19.62	4.2	4.0	19.05
5	Sw2	$11^0$73′5″	$8^0$42′4″	18.91	4.5	4.2	6.67
6	Sw3	$11^0$73′6″	$8^0$42′5″	14.48	4.1	3.9	4.88
7	Sw4	$11^0$73′7″	$8^0$42′6″	16.80	4.0	3.8	5.00
8	Sw5	$11^0$73′8″	$8^0$42′7″	16.80	4.3	4.2	2.33

Table 4.1h: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Yadakwari sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ya1(15 cm)	$11^0$66′4″	$8^0$41′5″	16.72	7.3	6.2	15.70
2	Ya1(30 cm)	$11^0$66′4″	$8^0$41′5″	18.33	21.3	14.0	34.27
3	Ya1(40 cm)	$11^0$66′4″	$8^0$41′5″	17.35	11.8	10.9	9.32
4	Ya1(50 cm)	$11^0$66′4″	$8^0$41′5″	19.27	22.7	11.3	50.22
5	Ya2	$11^0$66′5″	$8^0$41′6″	16.53	8.7	8.0	8.05

Table 4.1i: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of M. Gabas sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Mg1(15 cm)	$11^0$97′9″	$8^0$56′6″	13.81	7.5	7.4	1.33
2	Mg1(30 cm0	$11^0$97′9″	$8^0$56′6″	13.71	9.9	8.9	1.01
3	Mg1(40 cm)	$11^0$97′9″	$8^0$56′6″	-	6.6	5.9	10.61
4	Mg1(50 cm)	$11^0$97′9″	$8^0$56′6″	10.26	7.4	6.6	10.81
5	Mg2	$11^0$97′3″	$8^0$56′7″	13.94	11.8	11.2	5.08
6	Mg3	$11^0$97′2″	$8^0$56′8″	14.93	11.6	10.8	6.90
7	Mg4	$11^0$97′5″	$8^0$56′9″	13.10	5.11	5.4	5.26
8	Mg5	$11^0$97′6″	$8^0$57′0″	13.15	7.3	7.2	1.37
9	Mg6	$11^0$97′7″	$8^0$57′1″	15.52	6.0	4.4	26.67

Table 4.1j: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Gori South sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi s_{fd}\%$
1	Gs1	$11^0$97′9″	$8^0$41′4″	16.09	30.9	29.0	6.15
2	Gs2	$11^0$97′4″	$8^0$41′7″	16.80	8.6	8.1	5.81
3	Gs3	$11^0$97′3″	$8^0$41′6″	15.00	51.4	49.6	3.50
4	Gs4	$11^0$97′1″	$8^0$41′8″	15.83	69.1	66.0	4.49

Table 4.1k: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Batalawa sector

k)s/n	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Bt1(15 cm)	$11^0$78′1″	$8^0$42′9″	12.36	8.8	8.0	9.10
2	Bt1(30 cm)	$11^0$78′1″	$8^0$42′9″	15.51	8.1	7.7	4.94
3	Bt1(40 cm)	$11^0$78′1″	$8^0$42′9″	14.90	5.1	4.8	5.88
4	Bt1(50 cm)	$11^0$78′1″	$8^0$42′9″	13.63	4.3	3.8	11.63
5	Bt2	$11^0$78′3″	$8^0$41′9″	14.21	90.3	85.5	5.32
6	Bt3	$11^0$78′5″	$8^0$43′9″	15.85	87.1	84.3	3.21
7	Bt4	$11^0$78′7″	$8^0$43′7″	15.32	21.1	20.4	3.32
8	Bt5	$11^0$78′4″	$8^0$43′0″	14.21	26.0	23.9	8.08
9	Bt6	$11^0$78′8″	$8^0$42′0″	15.09	11.2	10.7	4.46
10	Bt7	$11^0$78′9″	$8^0$42′1″	13.46	8.5	8.6	1.18

Table 4.1L: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Kadawa sector

S/No	Sample	N(^{0})	E(^{0})	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ka1(15 cm)	$11^0$63′4″	$8^0$42′3″	16.57	22.5	20.1	10.67
2	Ka1(40 cm)	$11^0$63′4″	$8^0$42′3″	15.13	16.3	15.0	7.98
3	Ka1(50 cm0	$11^0$63′4″	$8^0$42′3″	20.01	22.2	22.4	0..90
4	Ka2	$11^0$63′7″	$8^0$42′4″	16.05	8.9	8.7	2.25
5	Ka3	$11^0$63′9″	$8^0$42′5″	11.86	5.7	5.2	8.77
6	Ka4	$11^0$62′4″	$8^0$42′6″	12.67	8.8	8.5	3.41
7	Ka5	$11^0$61′4″	$8^0$42′8″	16.43	4.3	4.2	2.33
8	Ka6	$11^0$63′4″	$8^0$42′7″	16.03	6.5	6.4	1.54
9	Ka7	$11^0$63′5″	$8^0$42′9″	17.25	7.3	6.8	6.85
10	Ka8	$11^0$63′7″	$8^0$43′3″	17.44	6.4	5.8	9.38
11	Ka9	$11^0$63′8″	$8^0$43′1″	18.33	5.9	5.7	3.39
12	Ka10	$11^0$63′3″	$8^0$43′2″	14.39	7.8	7.9	2.56
13	Ka11	$11^0$63′6″	$8^0$43′1″	18.37	5.2	5.0	3.85
14	Ka12	$11^0$63′9″	$8^0$43′4″	15.07	5.0	4.9	-2.0
15	Ka13	$11^0$63′0″	$8^0$43′5″	15.24	6.2	6.0	3.23
16	Ka14	$11^0$63′1″	$8^0$43′8″	16.92	4.9	4.6	6.12

Table 4.1m: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Rakauna Sector

S/No	Sample	N(^{0})	E(^{0})	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ra1(15 cm)	$11^0$77′0″	$8^0$42′3″	17.78	4.7	4.1	12.77
2	Ra1(30 cm)	$11^0$77′0″	$8^0$42′3″	13.59	4.5	4.3	6.67
3	Ra1(40 cm)	$11^0$77′0″	$8^0$42′3″	18.29	4.2	3.9	4.76
4	Ra1(50 cm)	$11^0$77′0″	$8^0$42′3″	18.31	4.1	3.9	4.88
5	Ra2	$11^0$77′1″	$8^0$42′4″	16.29	15.5	14.5	6.45
6	Ra3	$11^0$77′3″	$8^0$42′5″	16.84	21.0	19.3	8.10
7	Ra4	$11^0$77′5″	$8^0$42′6″	15.72	16.9	15.8	6.51
8	Ra5	$11^0$77′6″	$8^0$42′7″	16.18	32.2	31.2	3.11
9	Ra6	$11^0$77′8″	$8^0$42′8″	14.65	27.0	24.5	12.96

Table 4.1n: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Karfi sector

S/N	Sample	Lan.	Lon.	Mass (g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Kf1(15 cm)	$11^0$81′1	$8^0$48′4″	12.82	4.4	3.9	11.36
2	Kf1(30 cm0	$11^0$81′1	$8^0$48′4″	20.20	3.5	3.3	5.71
3	Kf1(40 cm)	$11^0$81′1	$8^0$48′4″	20.44	2.9	2.9	0
4	Kf1(50 cm)	$11^0$81′1	$8^0$48′5″	18.95	3.6	3.4	5.56
5	Kf2	$11^0$81′1	$8^0$48′6″	16.87	7.4	6.9	6.76
6	Kf3	$11^0$81′1	$8^0$48′7″	19.90	4.1	3.7	9.76
7	Kf4	$11^0$81′1	$8^0$48′8″	16.60	10.0	9.3	7.53
8	Kf5	$11^0$81′1	$8^0$48′9″	16.10	5.1	4.8	5.88

9	Kf6	$11^0$81′1	$8^0$48′1″	19.12	3.7	3.5	5.41
10	Kf7	$11^0$81′1	$8^0$48′2″	15.28	5.5	3.8	30.91
11	Kf8	$11^0$81′1	$8^0$48′3″	15.57	8.1	7.7	4.94
12	Kf9	$11^0$81′1	$8^0$48′0″	16.42	3.7	3.6	2.70
13	Kf10	$11^0$81′1	$8^0$49′0″	17.25	6.0	5.8	3.33
14	Kf11	$11^0$81′1	$8^0$49′4″	17.91	5,3	4.8	9.43
15	Kf12	$11^0$81′1	$8^0$49′1″	17.93	7.3	6.6	9.59

Table 4.1o: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Kosawa sector

	Sample	Lan.	Lon.	Mass (g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Ks1(15 cm)	$11^0$77′6″	$8^0$43′0″	19.94	6.8	6.6	2.94
2	Ks1(30 cm)	$11^0$77′6″	$8^0$43′0″	16.42	4.0	3.7	7.50
3	Ks1(40 cm)	$11^0$77′6″	$8^0$43′0″	15.53	4.2	4.1	2.38
4	Ks1(50 cm)	$11^0$77′6″	$8^0$43′0″	15.43	4.1	3.6	12.20
5	Ks2	$11^0$77′2″	$8^0$42′0″	17.00	7.5	7.0	6.67
6	Ks3	$11^0$77′4″	$8^0$42′8″	17.77	9.4	8.6	8.51
7	Ks4	$11^0$77′5″	$8^0$43′1″	16.39	18.7	17.0	9.09
8	Ks5	$11^0$77′6″	$8^0$43′1″	15.81	6.0	6.0	0
9	Ks6	$11^0$77′7″	$8^0$43′3″	16.81	6.6	6.3	4.55
10	Ks7	$11^0$77′8″	$8^0$43′2″	15.96	6.4	6.3	1.56
11	Ks8	$11^0$77′9″	$8^0$43′5″	16.29	9.7	9.5	2.06
12	KS9	$11^0$77′1″	$8^0$43′6″	15.91	10.5	10.9	3.81
13	KS10	$11^0$77′0″	$8^0$43′7″	18.92	6.2	5.7	8.06

Table 4.1p: Low and High Frequency Mass Specific Magnetic Susceptibility (χlf and χhf) of Irrigation Farm Soil of Agolas sector

S/No	Sample	Lan.	Lon.	Mass(g)	$\chi_{lf(}10^{-8}m^3kg^{-1})$	$\chi_{hf(10^{-8}m^3kg^{-1})}$	$\chi_{fd}\%$
1	Al1(15 cm)	$11^0$75′8′	$8^0$42′3″	19.94	19.0	18.1	5.79
2	Al1(30 cm)	$11^0$75′8′	$8^0$42′3″	14.82	58.0	53.0	8.62
3	Al1(40 cm)	$11^0$75′8′	$8^0$42′3″	15.00	16.3	15.2	6.75
4	Al1(50 cm)	$11^0$75′8′	$8^0$42′3″	14.95	8.8	8.0	9.09
5	Al2	$11^0$75′3′	$8^0$42′7″	15.01	9.2	8.2	10.87
6	Al3	$11^0$75′5′	$8^0$42′5″	15.21	27.3	25.6	6.64
7	Al4	$11^0$75′6′	$8^0$42′6″	13.04	11.0	10.6	3.64
8	Al5	$11^0$75′7′	$8^0$42′8″	15.29	6.9	6.4	7.25

APPENDIX 2

Scattergram of $\chi_{fd\%}$ of χ_{lf}

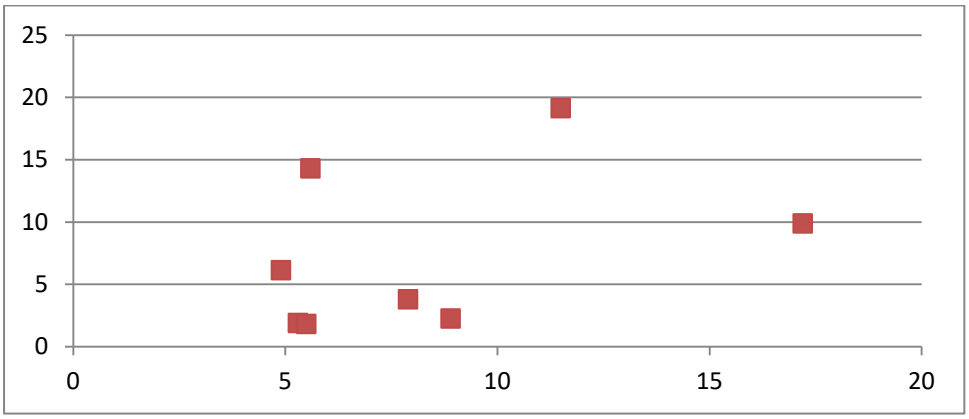


Figure 4.2d Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Danmaura

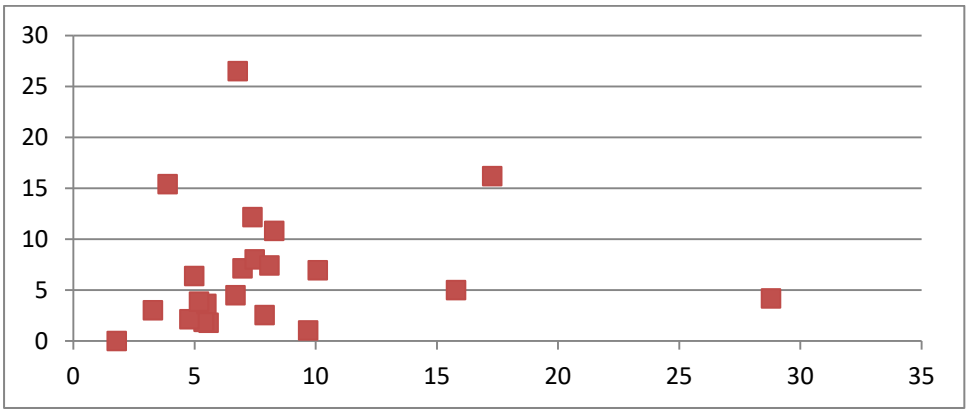


Figure 4.2e Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Kore sector

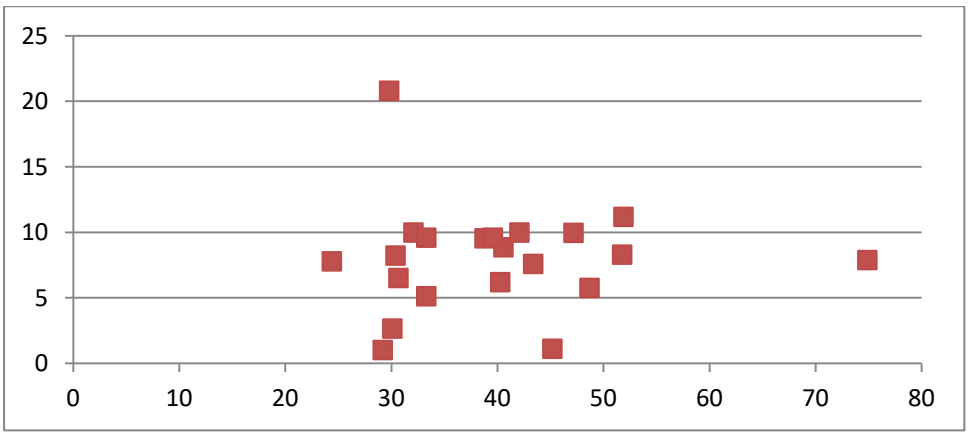


Figure 4.2f Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Gafan sector

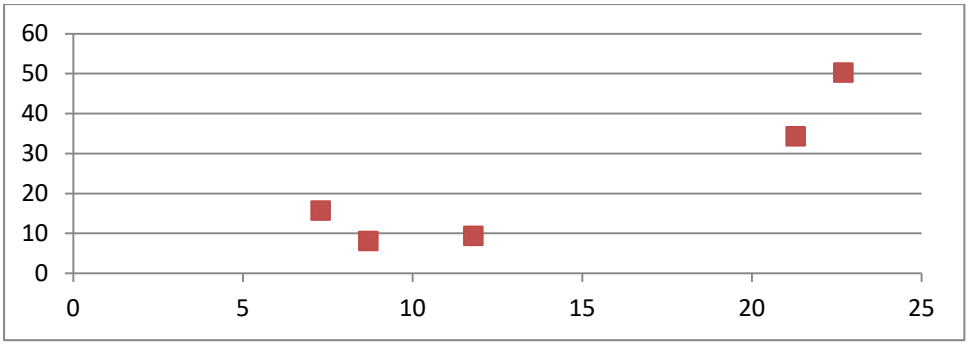


Figure 4.2g Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Yadakwari

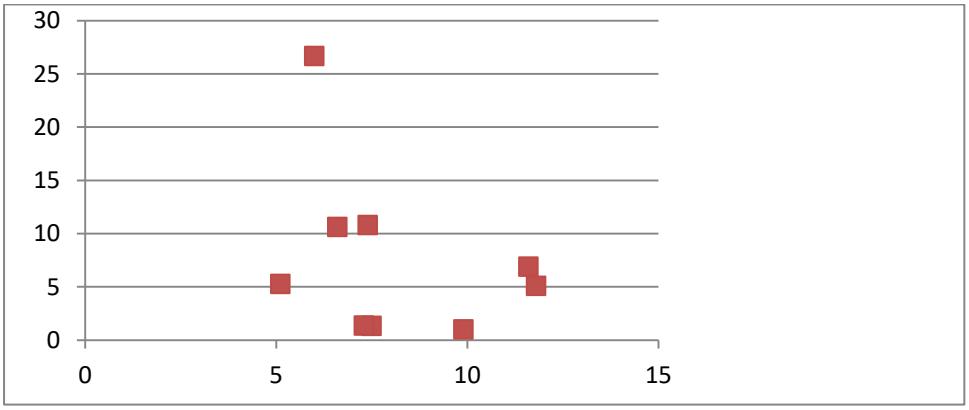


Figure 4.2h Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of M. gabas

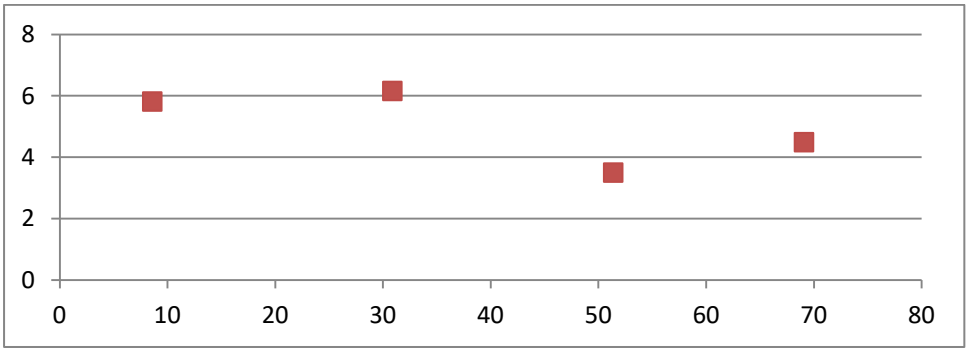


Figure 4.2i Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Gori south

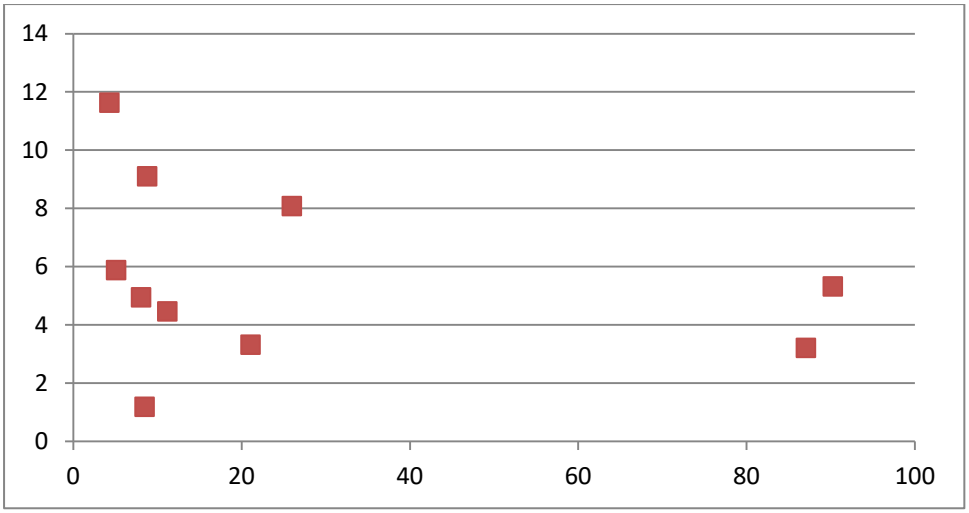


Figure 4.2j Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Batalawa

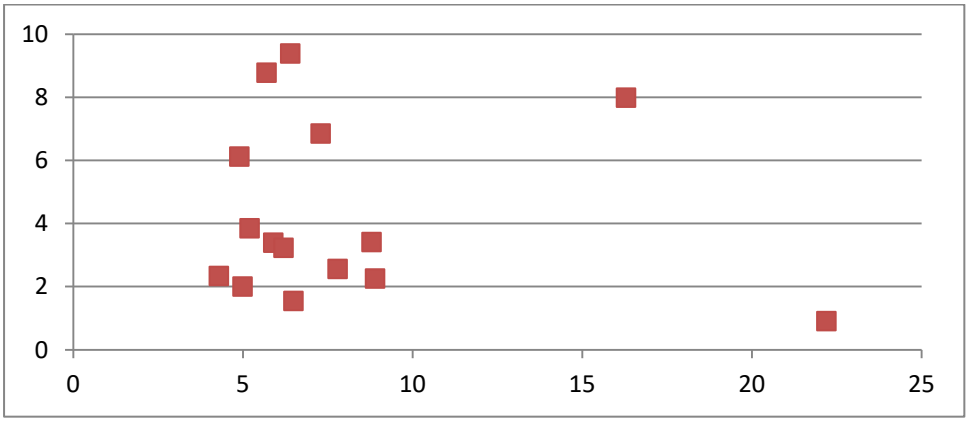


Figure 4.2k Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Kadawa

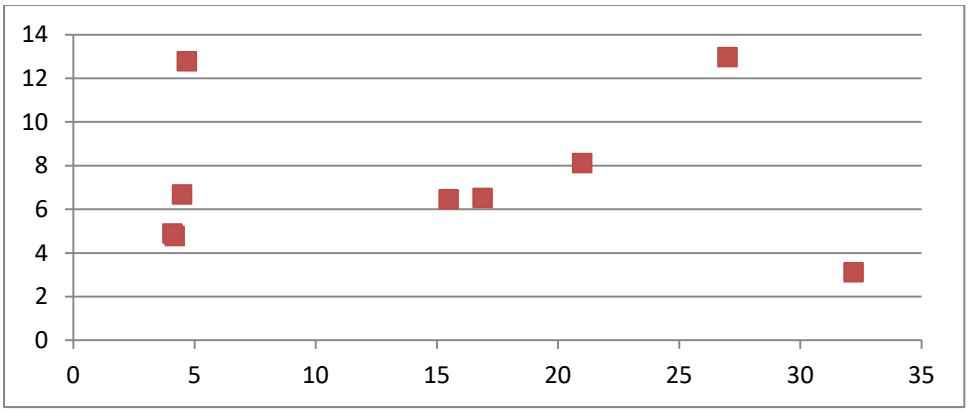


Figure 4.2l Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Rakauna

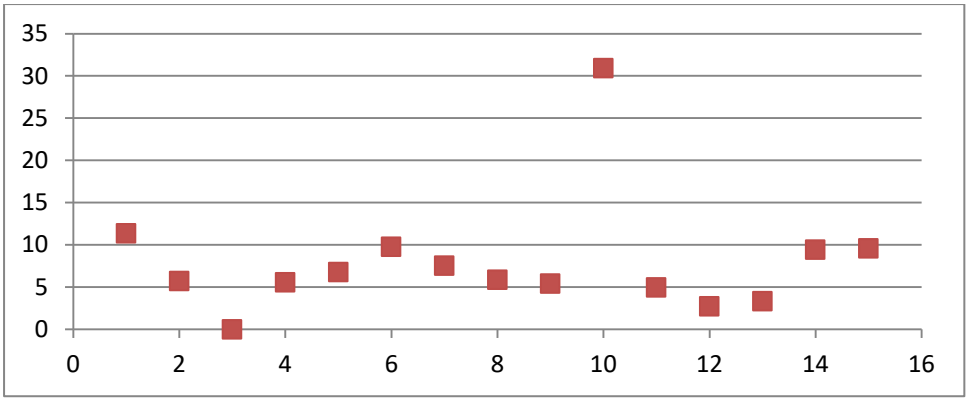


Figure 4.2m Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Karfi

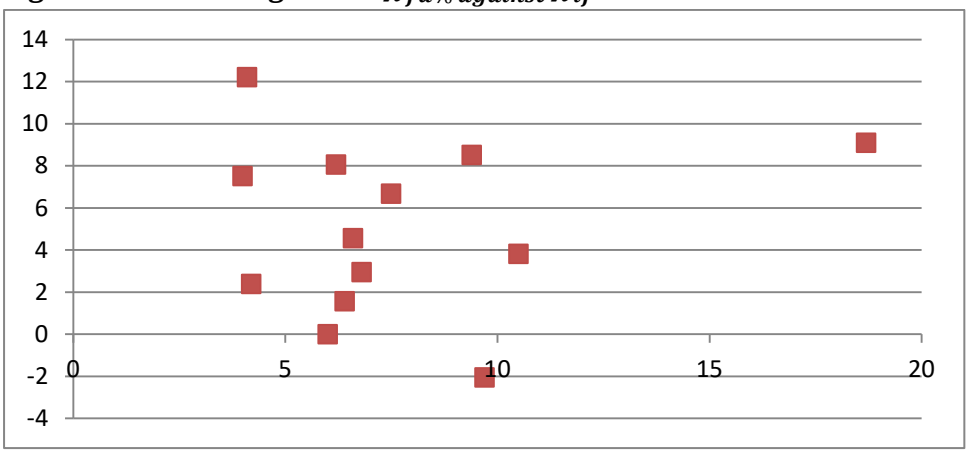


Figure 4.2n Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Kosawa

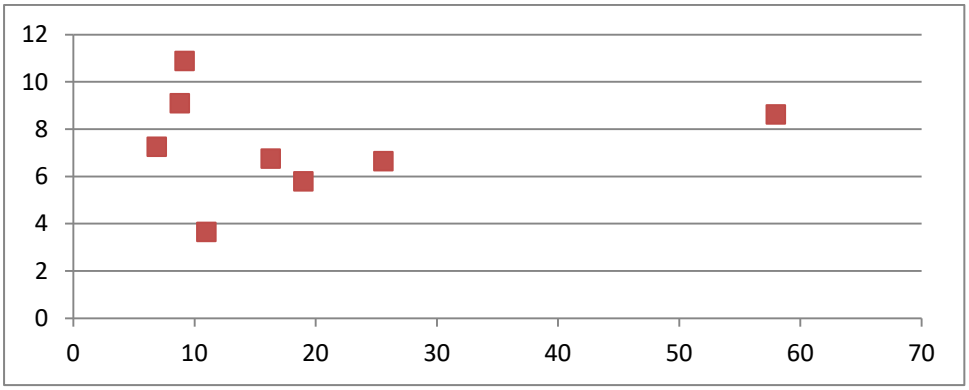


Figure 4.2o Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Angolas

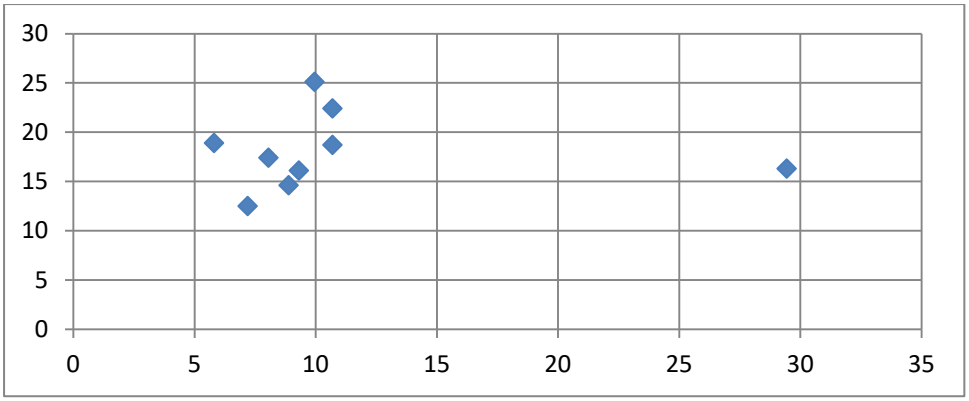


Figure 4.2p Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Danhassan

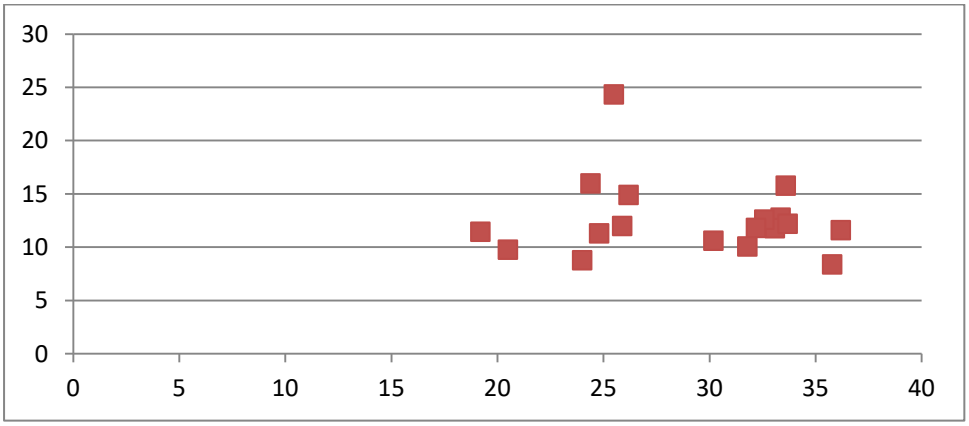


Figure 4.2q Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of Tofa

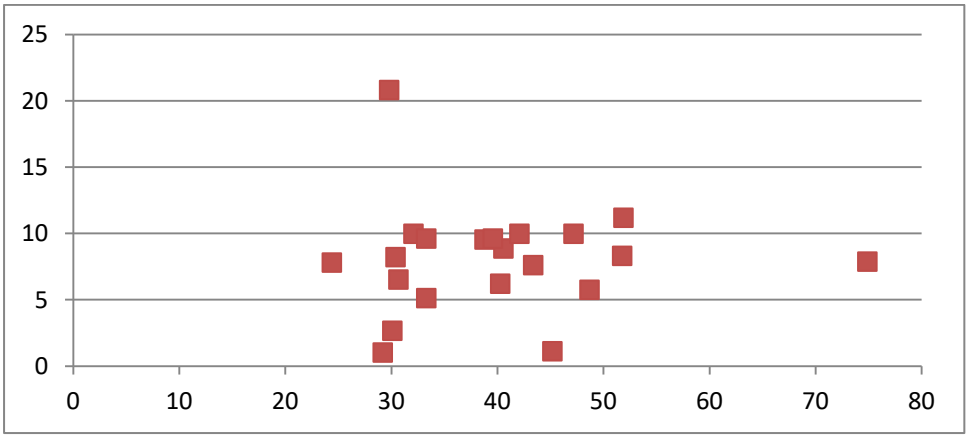


Figure 4.2r Scatergram of $\chi_{fd\%\ against}\ \chi_{lf}$ of KRIP Office

APPENDIX 3

Variation of MSMS wit Depth of te Study Area

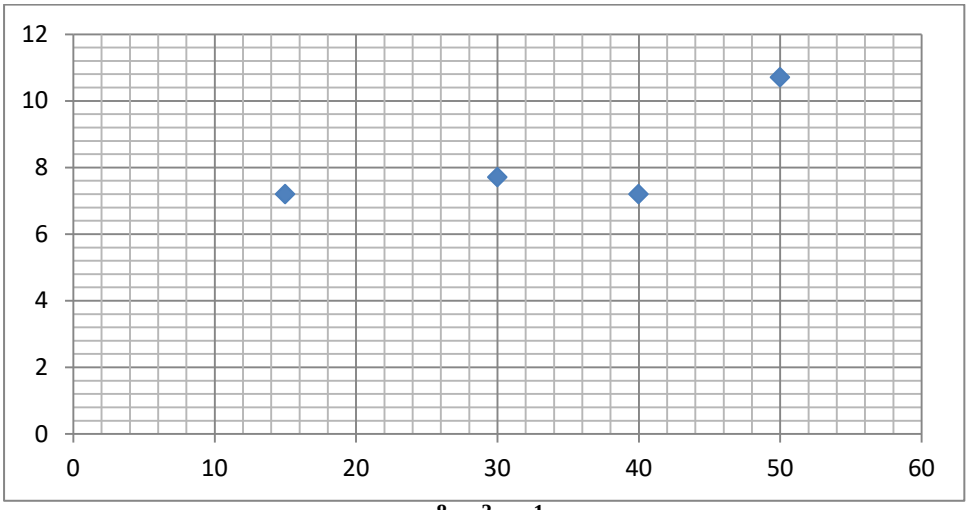


Figure 4.3d; Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Agalawa sector

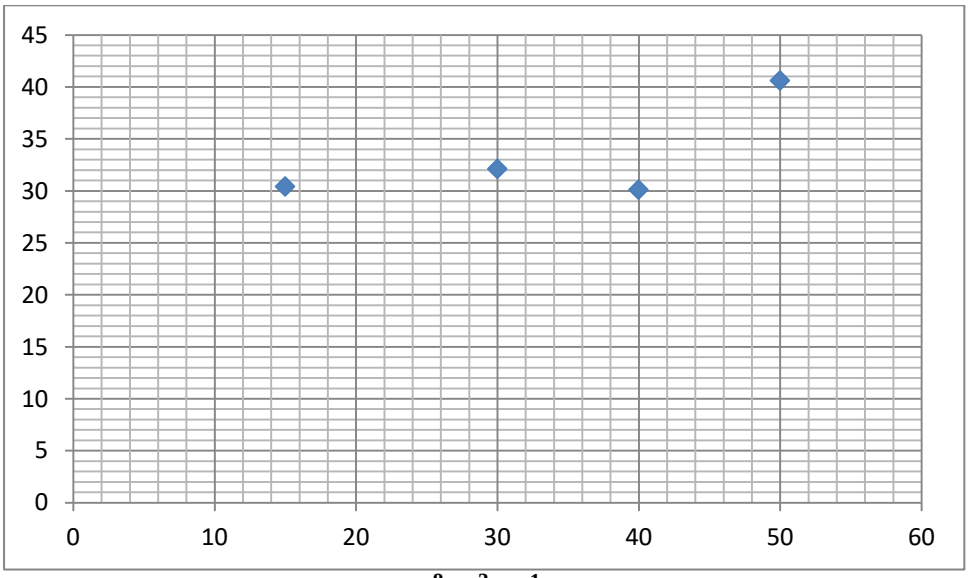


Figure 4.3e: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of KRIP Office

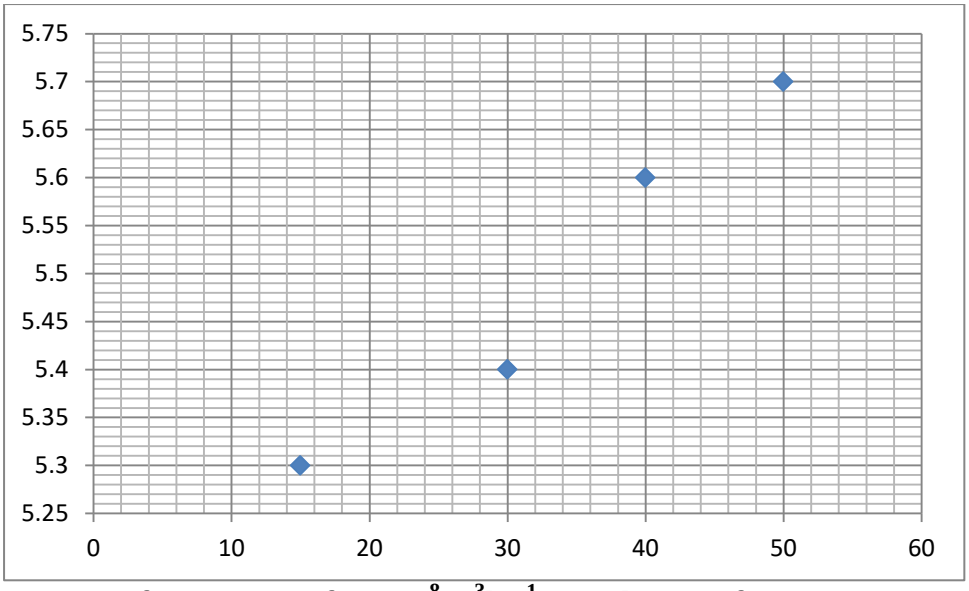


Figure 4.3f: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Danmaura Sector

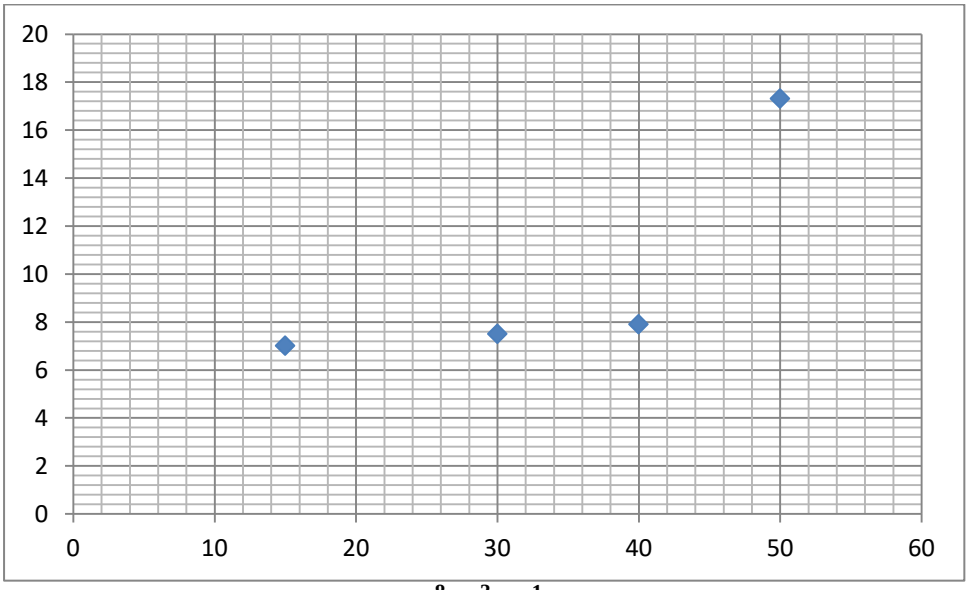


Figure 4.3g: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Kore Sector

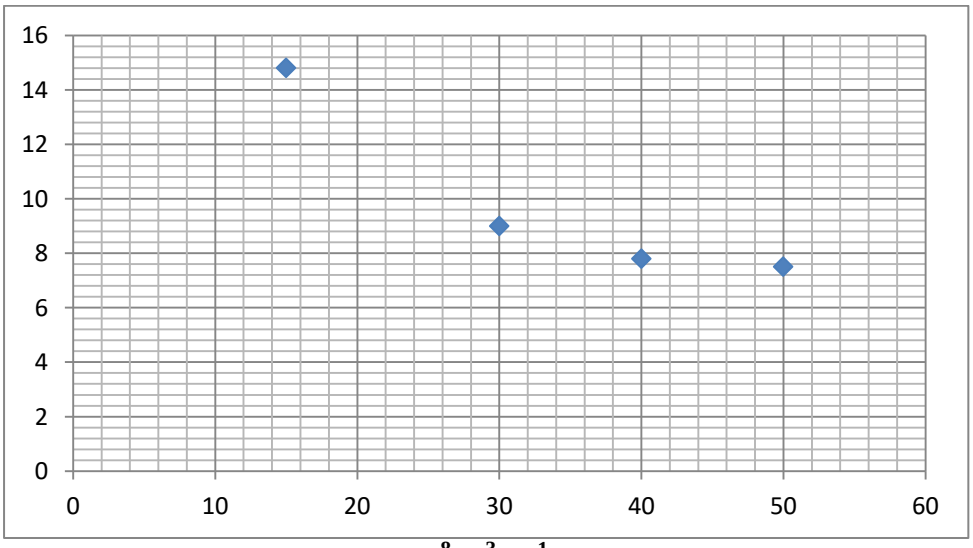


Figure 4.3h: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Gafan Sector

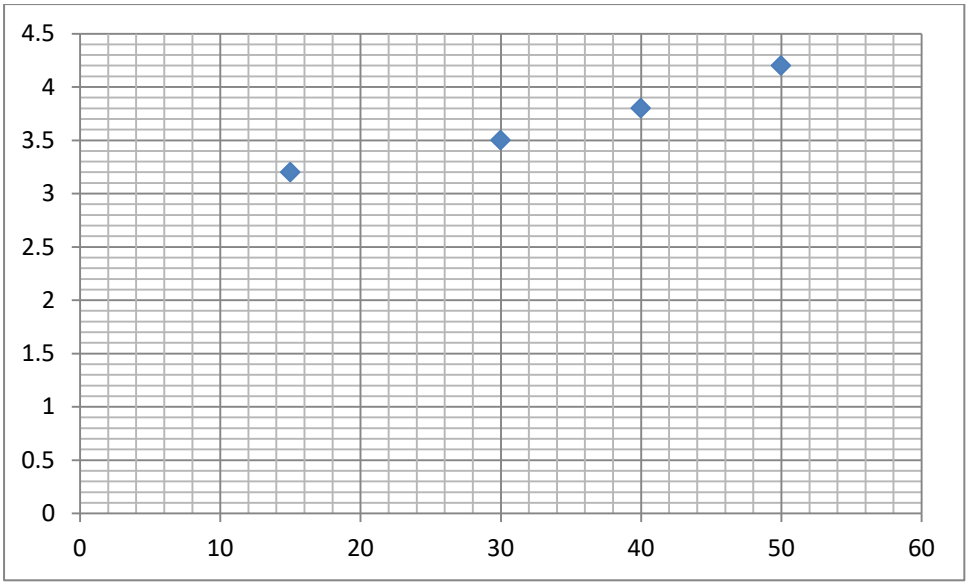


Figure 4.3i: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Samawa Sector

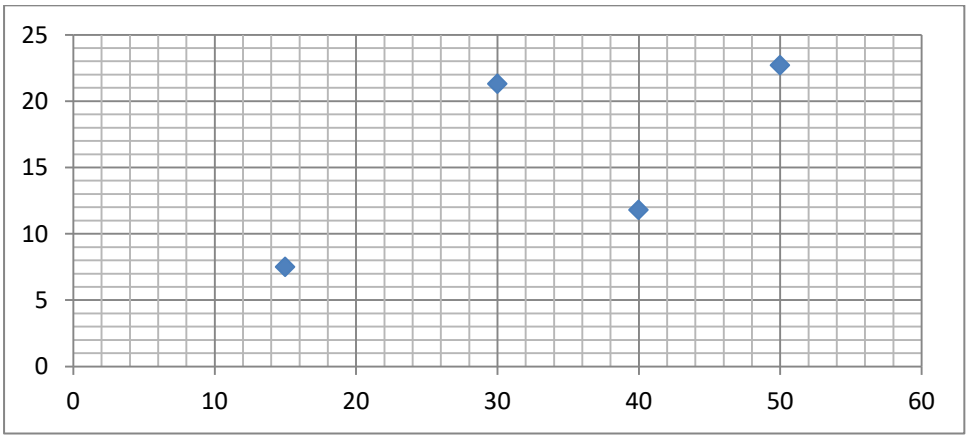


Figure 4.3j: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Yadakwari Sector

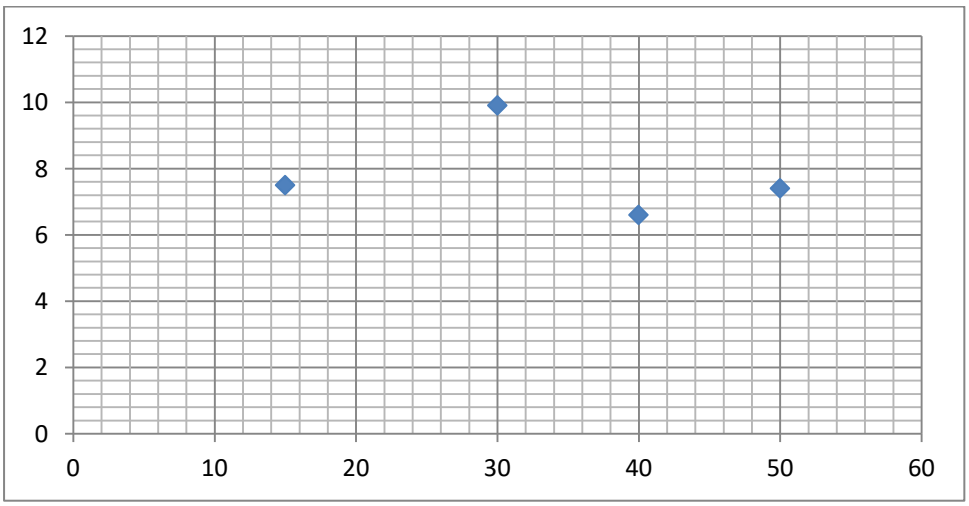


Figure 4.3k: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of M. Gabas Sector

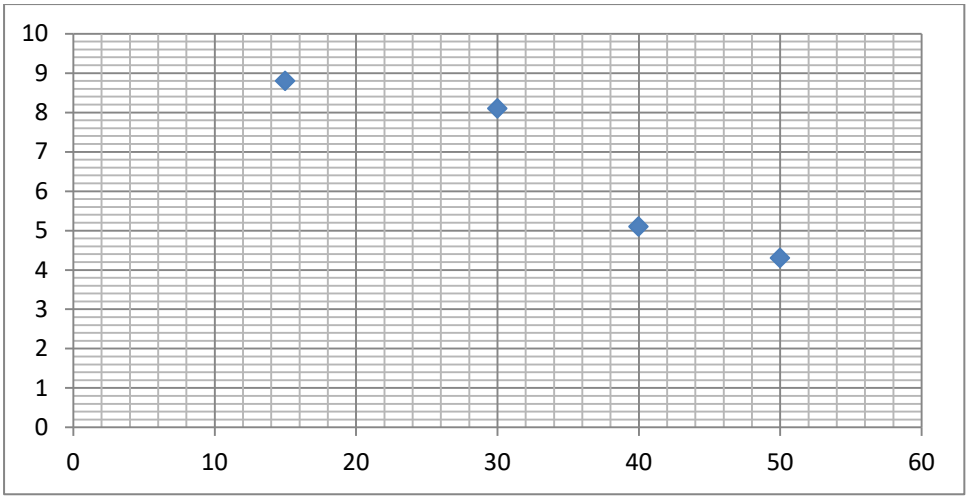


Figure 4.3l: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Batalawa Sector

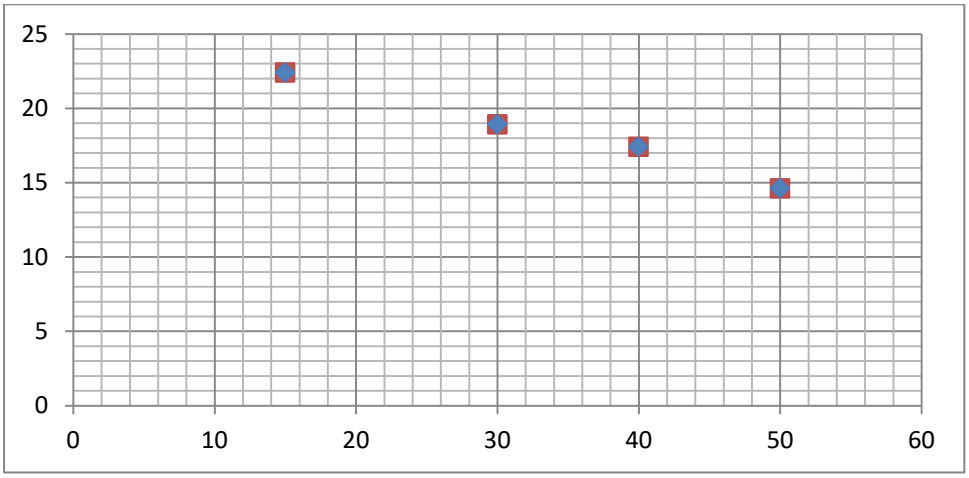


Figure 4.3m Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Kadawa Sector

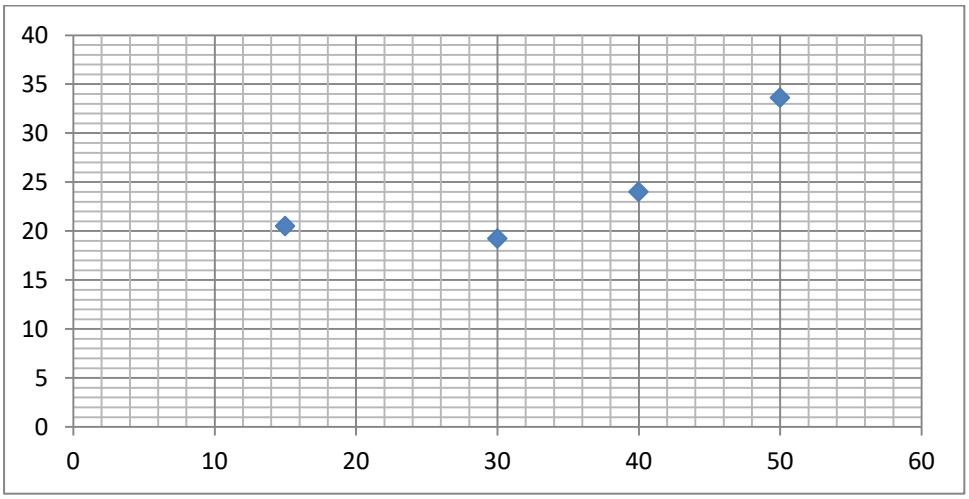


Figure 4.3n Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Tofa Sector

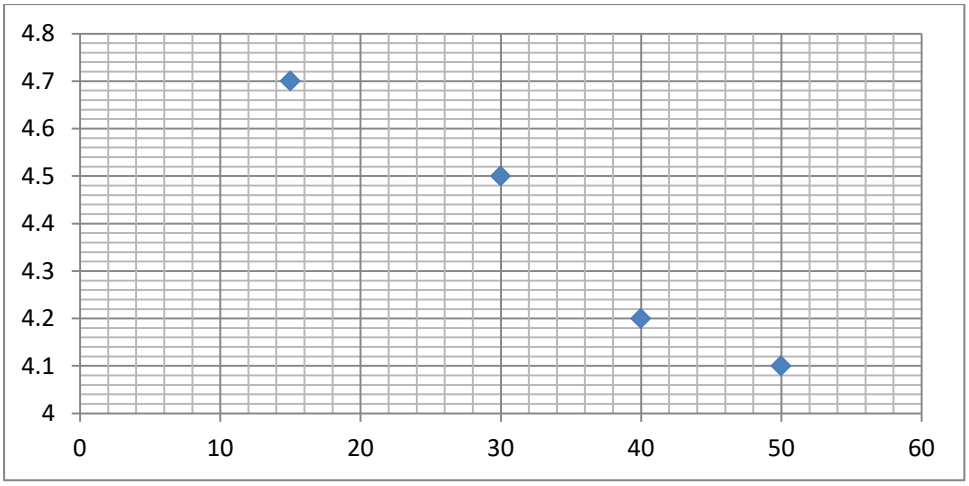


Figure 4.3o: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Rakauna Sector

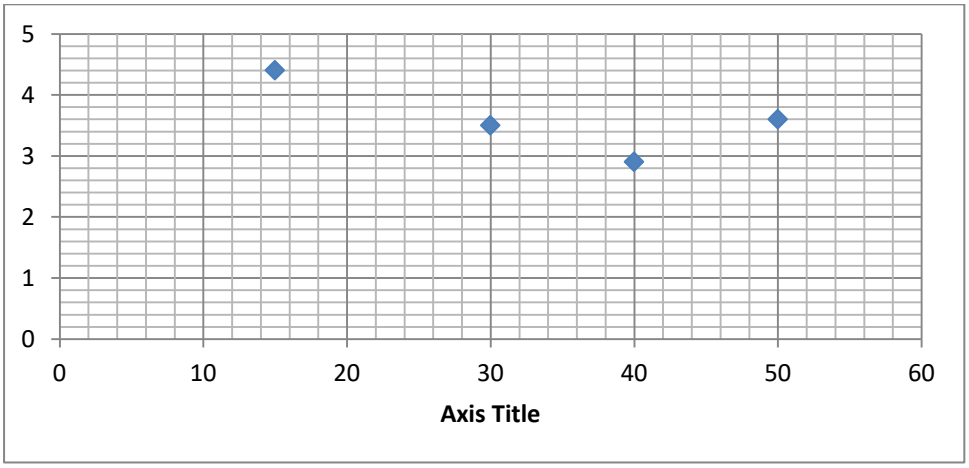


Figure 4.3p: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Karfi Sector

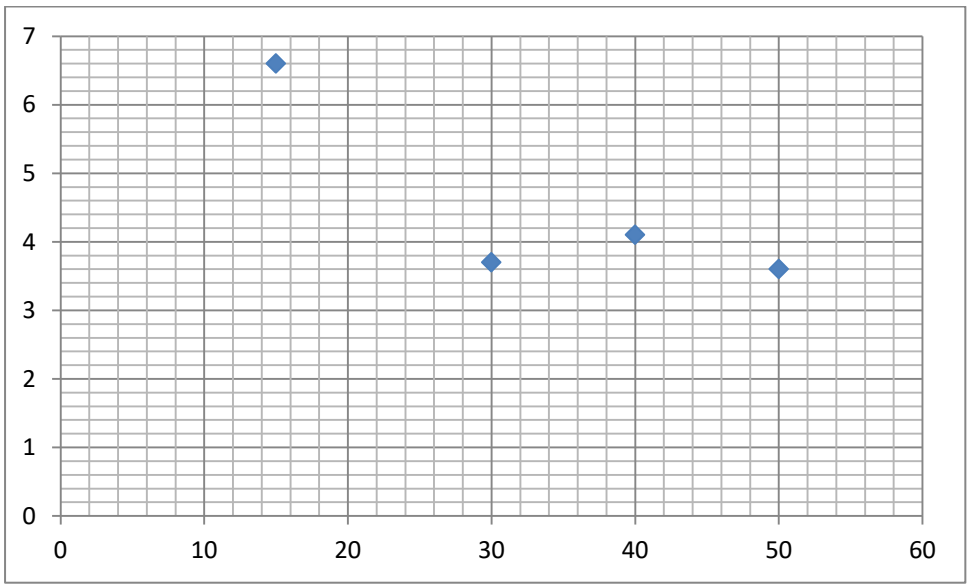


Figure 4.3q: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Kosawa Sector

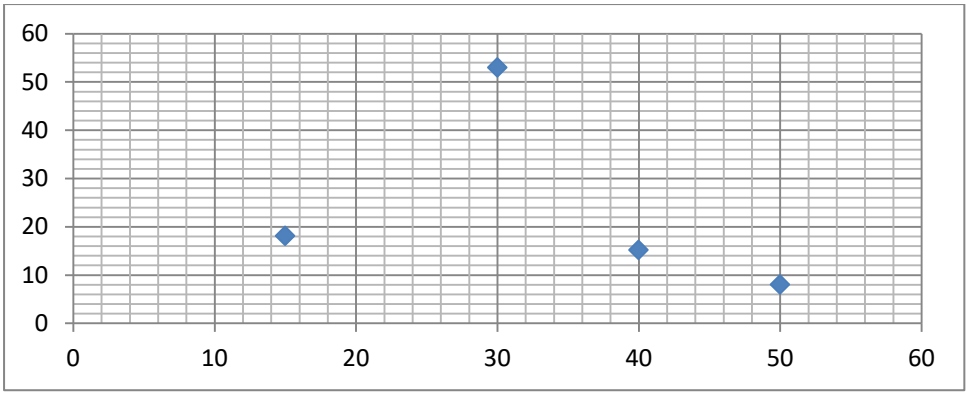


Figure 4.3r: Variation of x_{lf} (10^{-8} m^3kg^{-1}) Depth (cm) of Agolas Sector