Assessment of Potential Ecological Risks Associated with Heavy Metals in Soil of Waste Disposal Site at Khulna: A Spatial and Temporal Appraisal

by

Kanij Fahmida

A thesis submitted in partial fulfillment of the requirements for the Degree of

Master of Science in Civil Engineering

Department of Civil Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh

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Declaration

This is to certify that the thesis work entitled *"Assessment of Potential Ecological Risks Associated with Heavy Metals in Soil of Waste Disposal Site at Khulna: A Spatial and Temporal Appraisal"* has been carried out by *Kanij Fahmida* in the *Department of Civil Engineering*, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the thesis work submitted by *Kanij Fahmida* entitled *"Assessment of Potential Ecological Risks Associated with Heavy Metals in Soil of Waste Disposal Site at Khulna: A Spatial and Temporal Appraisal"* has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of *Master of Science in Civil Engineering* in the *Department of Civil Engineering*, Khulna University of Engineering & Technology, Khulna, Bangladesh in November 2017.

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I thought the time to write this section would never arrive, and often I even wondered why I had ever decided to start of M.Sc. Engineering degree. Now I have reached the end and it is time to express my gratitude to all the people who have encouraged me to finish this work. For sure, the fulfillment of this thesis is due to the cooperation of many people. Therefore I can only hope that I mention you all – and those who I forget at this moment, please forgive me and think that despite this lapse I really do appreciate you all.

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Kanij Fahmida

To

my parents

for their love, support and encouragement

Abstract

Most of the ecological and health risk occurs due to the emission of heavy metal from contaminated soil of waste disposal site. The main focus of this study was to assess the ecological risk associated with heavy metals present in soil of waste disposal site. To these endeavors, sixty soil samples were collected from different locations of a selected waste disposal site at Rajbandh, Khulna, Bangladesh. This study period covered both, dry season (March to May, 2016) and rainy season (June to August, 2016). In the laboratory, metal elements of Aluminium (Al), Arsenic (As), Barium (Ba), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Manganese (Mn), Sodium (Na), Nickel (Ni), Lead (Pb), Antimony (Sb), Scandium (Sc), Strontium (Sr), Titanium (Ti), Vanadium (V) and Zinc (Zn) in soil was measured through standard test methods. In this study, to assess the ecological risks associated with heavy metals various indices such as potential contamination index (Cp), contamination factor (CF), contamination load index (PLI), modified contamination degree (mCD), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}), ecological risk index (ER) and potential ecological risk index (PERI) were used. In addition, Pearson's correlation and principal component analysis (PCA) was performed using SPSS and XLSTAT.

The results of skewness and kurtosis revealed that the heavy metals in soil were normally distributed for both seasons. The soil sample collected from center of disposal site showed comparatively the higher concentration than the other soil samples from larger distances with respect to center of the disposal site for both seasons. Results indicated the level of contamination for soil was severe or very severe based on Cp for Cd and Sb for both seasons as well as Pb and As for dry season. In addition, CF for Cd and Sb showed very high level of contamination in both seasons. Additionally, CF for Pb and As showed moderate to considerable contamination in dry season; where, CF for same elements showed moderate to low contamination in rainy season. The results of EF for Pb, Zn, Cd, As, Hg, Co and Sb contributed the class of extremely severe enriched for dry season. Mainly, EF for Sb and Cd indicated the soil was extremely severe enrichment for dry and rainy season. Besides, ER for Cr, Cu, Pb, Zn, Ni, As, Hg and Co; and ER for Cd indicated the slightly ecological risk and extremely strong ecological risk, respectively, for dry season. Moreover, PERI for entire soil samples indicated the extremely strong ecological risk. It was observed that the soil sample of the central point of the disposal site showed comparatively the higher potential ecological risk than other soil samples collected from larger distances with respect to center of the disposal site for both seasons.

Results of Pearson's correlation and PCA indicated that most of the heavy metals were found to correlate significantly with each other indicating close association of these parameters in both seasons. The spatial distribution of heavy metals represented the same pattern for both seasons but the intensity of heavy metals decreases in relation to the increasing of lateral distance from the center of disposal site. Finally, it can be concluded that the outcome of this study will help to know the degree of contamination of soil as well as the ecological risk from the contaminated soil of a selected waste disposal site.

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Nomenclature

%	percent
a_j	eigenvectors obtained from the correlation matrix
x_j	input variables
AAS	atomic absorption spectrophotometer
Al	Aluminium
As	Arsenic
Ba	Barium
Ca	Calcium
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
CF	Contamination Factor
CLI	Contamination Load Index
Co	Cobalt
Cp	Potential Contamination Index
Cr	Chromium
Cu	Copper
EF	Enrichment Factor
ER	Ecological Risk Index
ERA	Ecological risk assessment
Fe	Iron
GIS	Geographic Information System
GPS	Global Positioning System
Hg	Mercury
I_{geo}	Geo-accumulation Index
K	Potassium
LFG	Landfill Gas
mCD	Modified Contamination Degree
ME	Metal elements
mg/kg	milligram per kilogram
mL	millilitre
Mn	Manganese
MSW	Municipal Solid Waste

Na	Sodium
Ni	Nickel
NICF	Numerical Integrated Contamination Factor
OK	Ordinary Kriging
Pb	Lead
PC	Principal Components
PCA	Principle Component Analysis
PCB	Polychlorinated biphenyl
PERI	Potential Ecological Risk Index
ppm	parts per million
Sb	Antimony
Sc	Scandium
SPSS	Statistical Package for the Social Sciences
Sr	Strontium
Ti	Titanium
TR	Toxic Response Factor
V	Vanadium
WHO	World Health Organization
Zn	Zinc

CHAPTER I

INTRODUCTION

1.1 Background Information

One of the utmost threatening environmental problems towards the world is dealing with the enormous quantity of municipal solid waste (MSW) produced in rapid growing industries, commercial places as well as households (Rafizul et al., 2012). In open dumping facilities, huge quantities of MSW and its biological and physicochemical processes makes the surrounding areas vulnerable due to the emission of toxic metal element from MSW (Srinivasa and Pradip, 2010). Most of the environmental and human health problems come from the emission of metal elements from the propagated leachate and soil in waste disposal site, landfill gas (LFG), from its non-methanic volatile organic compounds as well as hazardous air pollutants (Talib et al., 2008). In addition, metal elements from waste disposal sites can accumulate and persist in soils at an environmentally hazardous risk level or ecologically risks (Rahman et al., 2008). The effects of metal elements are found to vary with the conditions prevailing in the dumping sites and its binding forms.

In Khulna city, most of the MSWs are collected from door-to-door without any sorting and dumped in open disposal site at Rajbandh. At the present time, the disposal site at Rajbandh is only the official dumping site over 25 acres in area situated at a distance of about 7 km to the west of Khulna city corporation headquarter. Due to inadequate management practices of MSW in disposal site, the generated leachate percolates into the underlying soil, ground and surface water bodies and then contaminates the environmental components. The emission of toxic metal element from MSW, leachate and contaminated soil will be vulnerable to the environmental components (soil, air, water, etc.) and inhabitants. In present time, more concern about soil contamination by metal elements is necessary. The potential ecological risks due to metal element in soil has been occurring for centuries but its extent has increased markedly since last fifty years due to technological developments and increased consumer use of materials containing these metals (Ajah et al., 2015). The ecological risk is the actual or potential threat of adverse effects on living organisms and the

environment by wastes, effluents, emissions, resource depletion, etc., arising out of an organization's activities (Wolf, 2012).

This study was conducted to assess the ecological risks associated with metal elements in soil of waste disposal site. To these endeavors, sixty soil samples were collected from a selected waste disposal site at Rajbandh, Khulna, Bangladesh. The presence of toxic metal elements in soil in the vicinity of waste dumping site may create an acute pollution of the underlying soil layer and water as well as may pose health hazards to the city people. Therefore, this study aimed to assess ecological risks of metal elements in soil of the disposal site. In this study, the concentrations of metal element of Aluminium (Al), Arsenic (As), Barium (Ba), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Manganese (Mn), Sodium (Na), Nickel (Ni), Lead (Pb), Antimony (Sb), Scandium (Sc), Strontium (Sr), Titanium (Ti), Vanadium (V) and Zinc (Zn) in soil was measured through standard test methods in the laboratory. The concentrations of metal elements considering in this study were then compared to the allowable limit of metal concentration in soil for different countries available in the literature.

The popular soil contamination and ecological risk assessment methods can be classified into two categories: quantitative and qualitative. The qualitative methods, such as Principal component analysis (PCA), Pearson's correlation, factor analysis, and cluster analysis, are inferential and indicative. In this study, to compute the level of contamination of soil of the waste disposal site, various indices such as potential contamination (Cp), contamination factor (CF), pollution load index (PLI), modified contamination degree (mCD), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}), ecological risk index (ER) and potential ecological risk index (PERI) were used. Numerous researchers provided different limits of indices such as Cp, CF, PLI, mCD, NICF, EF, I_{geo}, ER and PERI for evaluating the level of contamination of soil. In this study, the limiting values of these indices were considered to check the level of contamination of soil of the selected waste disposal site.

In this study, the distribution of the concentration of metal elements was described in terms of mean, maximum, minimum, median, standard deviation (SD), co-efficient of variation (CV), skewness and kurtosis by performing Statistical Package for the Social Sciences

(SPSS). The Pearson's correlation coefficient of metal elements was also conducted using SPSS to determine the accumulated concentrations of metal elements irrespective to their sources which provide an effective way to reveal the correlations between the multiple variables. The interrelationship studies between different variables are very helpful tools in promoting research and opening new frontiers of knowledge. The study of correlation reduces the range of uncertainty associated with decision making (Patil and Patil, 2010). The correlation analysis is a preliminary descriptive technique to estimate the degree of association among the variables involved. The purpose of the correlation analysis is to measure the intensity of association between two variables. Such association is likely to lead to reasoning about causal relationship between the variables.

In addition, PCA was performed using XLSTAT to know how the metal elements are correlated to each other. Furthermore, geostatistical analysis such as ordinary kriging (OK) was performed using ArcGIS to examine the quantitative distribution of metal elements spatially in soil as well as the spatial distributions of various indices of CF, EF, ER and PERI. Moreover, to date, there is no comprehensive study regarding the effect of metal element concentration on soil from waste disposal site in Bangladesh. Therefore, the outcome of this study will help as a guideline to know the degree of contamination of soil as well as the ecological risk from the contaminated soil of a selected waste disposal site.

1.2 Soil and Its Contamination

Soil is one of the principal natural resources of the earth. It is a vital part of the natural environment. It mainly provides a habitat for a wide range of organisms and influences the plant species thus contribute to the diet of human and animal. Thus, soil is an indispensable to all living being in the world (Nriagu and Pacyna, 1988). Recently, open or uncontrolled dumping of MSW is considered an increasing threat to the underlying soil layer of adjoining area as well as the surrounding environment of waste disposal sites (Jiang et al., 2014). In addition, soil contamination as part of land degradation is caused by the presence of xenobiotic (human-made) chemicals or other alteration in the natural soil environment. It is typically caused by improper disposal of waste, industrial activity and agricultural chemicals.

Soil contamination occurs when the presence of toxic chemicals, pollutants or contaminants in the soil is in high enough concentrations to be of risk to plants, wildlife, humans and of course, the soil itself (SCU, 2013). Materials that find their entry into the soil system persist and accumulate in toxic concentrations becoming sources of pollution in the soil (Misra and Mani, 2009). The concentration of metal elements in soil and their impact on ecosystems can be influenced by many factors such as the parent rock, climate and anthropogenic activities (Jia et al., 2010). Among the pollutants that persist and accumulate in soils include; inorganic toxic compounds for example fertilizers, organic wastes, organic pesticides and radio cucleides (Misra and Mani, 2009; Jia et al., 2010). The soil is thus becoming increasingly contaminated with chemicals and other pollutants which can reach the food chain, surface water or groundwater and ultimately be ingested by man (Misra and Mani, 2009).

1.3 Problem Statement and Justification

The MSW management is a growing concern, as the it contributes to the degradation of the environment and pose a health hazard to populations at large (Akaeze, 2001). Most affected are the living adjacent to the dumping sites due to the potential of the MSW to polluted land, water, food sources, air and vegetation. Furthermore, large amounts of MSW include organic material; there are considerable proportions of plastic, paper, metal rubbish and batteries which are known to be real sources of metal element. Thus, uncontrolled and unmonitored disposal of MSW in open dumps has the result of contamination and subsequent pollution of the environment by metal elements. Metal elements are non-biodegradable and can accumulate in soils to toxic concentrations that affect plant and animal life.

The potential ecological risks due to metal element in soil has been occurring for centuries but its extent has increased markedly since last fifty years due to technological developments and increased consumer use of materials containing these metals (Ajah et al., 2015). There has long been concern about the issue of pollution by metal element because of their toxicity for soil, plant, animal and human beings and their lack of biodegradability (Zhuang et al., 2009). Owing to the toxicity and ill effects of metal elements on living being, the present day researchers have developed interest in the origin and fate of these elements in the environment (Islam et al., 2012).

Khulna is the third prime metropolitan city of Bangladesh. At the present time, Rajbandh waste disposal site is the only official dumping site. The presence of noxious metal elements in soil in the surrounding area of this disposal site may create an acute pollution of the underlying soil layer and water as well as also may pose health hazards to the city people. For the above mentioned reasons, there is need for a comprehensive study of metal contamination of soils of this selected waste disposal site to discover the level of soil contamination in this region. Despite this, no work has been reported on assess the risk associated with metal element content in soil of waste disposal site and its pollution potential to the environment at Khulna. Therefore, this study was conducted to assess the ecological risks associated with metal elements in soil, collected from waste disposal site at Rajbandh, Khulna, Bangladesh.

1.4 Objectives of the Study

The general and specific objectives of this study are as follows

1.4.1 General Objectives

The main aim of this study was to assess the potential ecological risks associated with heavy metals in soil of the selected waste disposal site with the implication of spatial and temporal variation.

1.4.2 Specific Objectives

The specific objectives of this study are as follows:

1. To identify the quality of soil of the waste disposal site on the basis of maximum allowable limits of heavy metal element in soil proposed by different countries.
2. To evaluate the level of contamination of soil of the waste disposal site using various indices available in the literature.
3. To assess the potential ecological risks associated with heavy metals in soil of waste disposal site.
4. To identify the correlations of heavy metals with each other in soil from statistical analysis.

5. To distribute the heavy metals and various indices spatially and to know the temporal variation of metals in soil of the waste disposal site.

1.5 Contribution to Knowledge

There is insufficient information regarding contamination of waste disposal site and its environmental effects in and around of waste disposal site in Bangladesh. This research will provide the level of knowledge about the ecological risk as well as the level of contamination of soil of a typical waste disposal site. Research needs to include ecological and toxicological studies and decisions about the risk treatment and minimization. Moreover, to date, there is no comprehensive study regarding the environmental and health effect from waste disposal site in Bangladesh. It impede the enforcement for ensuring the environmental and health safely of the inhabitants in and around of waste disposal site.

The outcome of this research will support the development of sound recommendations about risks that may need treatment. Furthermore, the overall outcome of this research will help federal government institution in confirming risks according to its mandate and responsibilities and in developing plans or necessary preparations to reduce mitigate or prevent these risks. This study will provide a stepwise guideline of the various processes to be followed in evaluating the ecological risk of contamination of a typical waste disposal site in Bangladesh for students, researchers and practitioners. Here, it can also be mentioned that the results of this study will guide more efficient management practices and adoption of suitable technological solutions for the disposal of waste in landfills to protect the surrounding environment and public health.

1.6 Significance of the Study

The study will provide an overview about the level of contamination of soil in a selected waste disposal site at Rajbandh, Khulna, Bangladesh due to the emissions of metal element from decomposed MSW, leachate, etc. The study will also be beneficial to estimate the level of risk of the studied soil for the adjoining environment. Moreover, this study will be helpful to understand the distribution patterns of metal concentration in relation to the variation of soil sampling distances and seasons. Moreover, the distributions of various indices are also

highlighted in this study. The study can inform the authorities in environment management on the level of metal element pollution in Khulna region hence providing a reference for future studies on the same. As a final point, the outcomes of this study will provide a protective approach for ecological restoration of waste disposal site all over the world.

1.7 Scope and Limitations

There are many metal elements but this study considered only twenty one metal elements which from related literature are prevalent in soils of selected waste disposal site. The study also covered only two seasons for temporal variation because of its expansiveness. Besides, some metals could be present in the underlying rocks and this could be reflected in the levels and assumed to be from anthropogenic sources.

1.8 Outline of the Study

The study has been presented in five distinct chapters comprising different aspects of this study. The outline and relations between these five chapters as depicted in Figure 1.1.

Chapter I describes general knowledge on the background of waste disposal sites, challenges of MSW management and dumping facilities, contaminated soil, metal element and the possible sources of contamination of soil in disposal site the. This chapter also deals about effect of landfill in environment and the concept of potential ecological risk assessment. In addition, the problems associated to unplanned waste disposal and its justification in context of world, objectives of the study and the scope and limitations of this study are also highlighted in this chapter.

Chapter II presents the literature review of this work. This chapter mainly deals about the MSW disposal facilities, MSW and impacts of disposal sites on the environmental components and surrounding areas. In addition, present scenario of MSW management and disposal facilities in Bangladesh, exposure pathways of waste disposal sites, approaches and challenges to MSW management and environmental risk of metal elements mobility in disposal sites are also dealt in this chapter. Soil contamination, mechanism of action of metal

elements, key concepts in understanding soil contamination, potential ecological risk assessment and relevant software's used in this study are also highlighted in this chapter.

Chapter III discusses about the overall methodology and the materials used in this study. Mainly, available information of study area, adopted sampling techniques, process of laboratory works, methods used in analysis work of this research are described in this chapter. Hence, it deals about field investigations, collection of soil samples from different locations, collection of GPS coordinate of all soil sampling point, testing in laboratory through standard test methods to analyze the concentration of metal element in soil. Furthermore, the level of contamination of soil by metal elements investigation process using various indices available in the literature described in this chapter. Besides, it describes performing statistical analysis and Pearson's correlation analysis using SPSS and XLSTAT and discussed in this chapter. This chapter also deals the geostatistical analyses of ordinary kriging (OK) used in this study to distribute the metal elements in soil spatially.

Chapter IV describes about the results of statistical analysis and index analysis as well as correlation analysis of measured heavy metals concentration in soil of Rajbandh waste disposal site. Thus, this chapter deals with the level of contamination of soil due to the presence of heavy metal in soil of a selected waste disposal site in different aspects. The statistical analysis for heavy metals in soil and discussed in this chapter. In addition, the level of contamination of soil by heavy metals was investigated using various indices available in the literature and also illustrated in this chapter. The distribution of the concentration of heavy metals in soil spatially and temporal variation of heavy metals were investigated using ArcGIS and hence discussed in the chapter. Brief discussion about the outcomes also included in this chapter.

Chapter V draws final conclusions based on logical reasoning of the laboratory data and the analysis outcomes and also provides a few recommendations for future improvement.

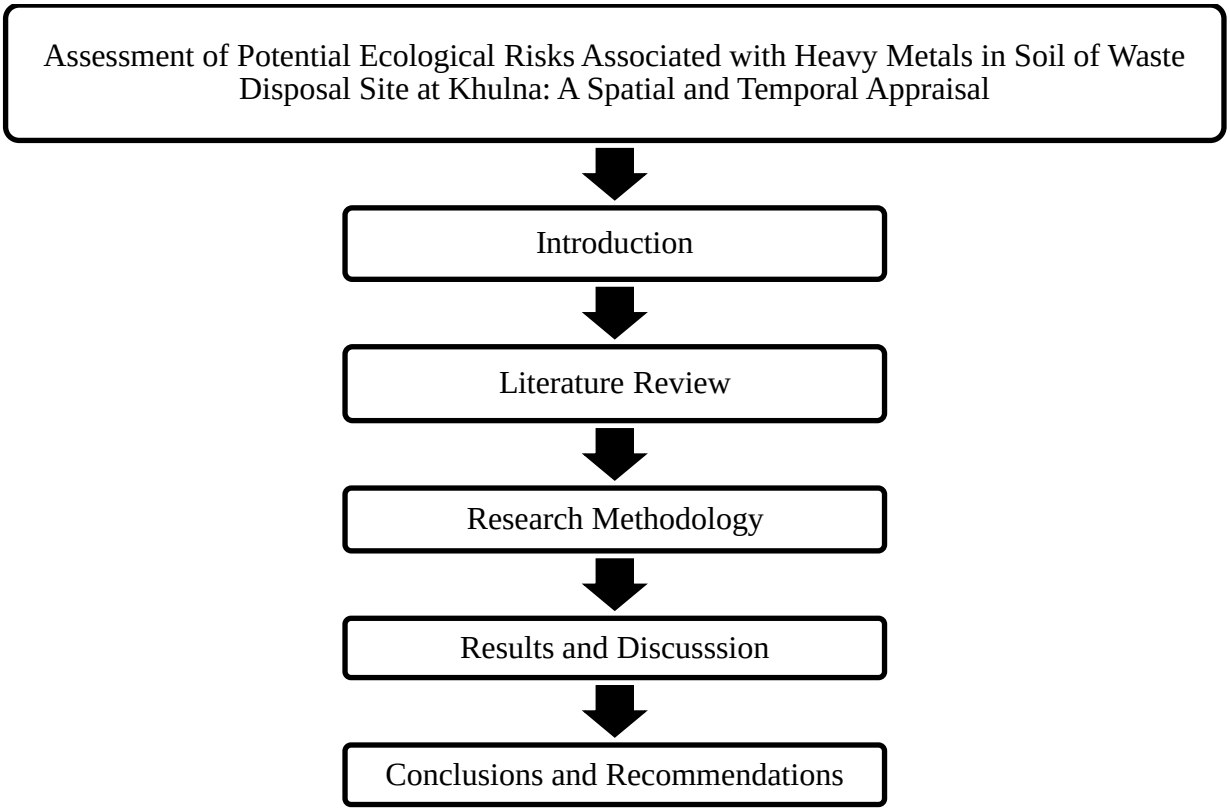


Figure 1.1: Outline and relations between five chapters of this study.

CHAPTER II

LITERATURE REVIEW

2.1 General

This chapter deals with municipal solid waste (MSW), dumping facilities and challenges of MSW management. This chapter also illustrates about the causes of soil contamination in waste disposal sites, soil contamination by metal elements, impacts of waste disposal sites, environmental effects and exposure pathways of waste disposal sites. In addition, this chapter also provides comprehensive literature review encompassing the characteristics of metal elements, soil contamination by metal elements in disposal site, soil quality standard, sources of metal elements, ecological risk assessment of soil associated with metal elements. The indices used in this study to evaluate the ecological risk are also presented in detail in this chapter. Finally, the concept of Pearson's correlation, principal component analysis (PCA) and geostatistical technique of ordinary kriging are also highlighted in this chapter.

2.2 Municipal Solid Waste

Municipal solid waste (MSW) means any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded materials including solid, liquid, semi-solid, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations (USEPA, 1989). The main sources of MSW are street rubbish (leaves, paper dust, animal dropping etc.), hospital wastes (medicine, syringe, carton, plastic etc.), domestic wastes (food wastes, paper, wood, plastic, glass etc.), industrial wastes, market refuse (vegetable and animal wastes). But the characteristics and quality of MSW varies from country to country and depends on food habits, living standard, and economic conditions (Srivastava et al., 2014). Generally, industrial countries generate more waste per inhabitant than non-industrialized countries. The characteristics of MSW are:

1. Corrosive: these are wastes that include acids or bases that are capable of corroding metal containers, tanks.
2. Ignitability: this is waste that can create fires under certain condition, e.g. waste oils and solvents.
3. Reactive: these are unstable in nature, cause explosions and toxic fumes when heated.
4. Toxicity: waste which are harmful or fatal when ingested or absorb.

Khulna is the third largest metropolitan city of Bangladesh. The major sources of MSW in Khulna city are residences, whole and retail sale market places including shopping places, streets, hotels and restaurants, private clinics and hospitals, educational institutions, cinemas, railway, bus, and launch/steamer ghats, slaughter houses, etc. (Murtaza, 2002). Table 2.1 presents sources of the generation of MSW in Khulna City. Additionally, 70-80 percent of the generated wastes are organic in nature and easily biodegradable. On the other hand, the remaining 20-30 percent of waste is inorganic and need better treatment to manage with care (Murtaza, 2002).

Table 2.1: Sources of generation of municipal waste in Khulna city.

Source/Type	Total generation (Mg/day)	Percent of total generation
Residential areas	455.50	85.87
Commercial areas	60.14	11.60
Institutional areas	5.26	1.02
Street sweeps	2.86	0.55
Other	5.00	0.96
Total	518.75 ≈ 520	100

(Source: Ahsan et al., 2015)

2.3 Dumping Facilities of Municipal Solid Waste

Landfilling practices in developing countries differ from that of the developed countries. Developed countries follow advanced landfilling practices such as sanitary landfill (engineered landfill) as opposed to open dumping practiced in the developing countries. The term ‘landfill’ describes a single action for the final abandoning of MSW on a certain plot designed and constructed aiming the minimum effect to the adjacent atmosphere (Rafizul et

al., 2012). There are two common methods for the final disposal of MSW, one is open dumping and the other is sanitary landfill (Visvanathan and Trankler, 2003).

2.3.1 Open Dumping Facilities

The open dumping facility is a disposal of MSW without compaction during placement; neither compacts nor covers with soil. The land is used without preparation of engineering planning. Thus, the open dump site characteristic are unplanned heaps of uncover waste, burning waste at the dump site, pools of standing polluted water, rat and fly infestation and waste scavenging at dump site shown in Figure 2.1. In the environment, chemicals and other contaminants found in MSW can seep into the groundwater and can also be carried by rainwater to rivers and lakes that provide essential wildlife habitat.

Figure 2.1: Open dump practice in Asian countries (Source: Ali et al., 2014).

In South and South East Asia, the open dumping approach is the most predominant waste disposal option (Ali et al., 2014). The toxic chemicals from open dump have negative effects on human life, wildlife, and environmental quality (Jia et al., 2010). Open dumping facilities have no longer acceptable from aesthetic, environment and sanitary points of view. Crude open dumping is being practiced in many developing countries as a means of final disposal of solid waste (Visvanathan and Trankler, 2003). The bad effects of open dumping reveals as: (a) health hazard; (b) public complain; (c) bad image; (d) air, soil and water contamination and (e) more space occupies.

2.3.2 Sanitary Landfill

Sanitary landfill is one of the most widely used MSW methods; however, it needs high standard of environment protection in the operation of landfill (Davis and Cornwell, 1998). The changing from dumping to high standard of environment protection needed time change technology, change in thinking and behavior. Figure 2.2 shows a cross-section of a typical engineered landfill used all over the world.

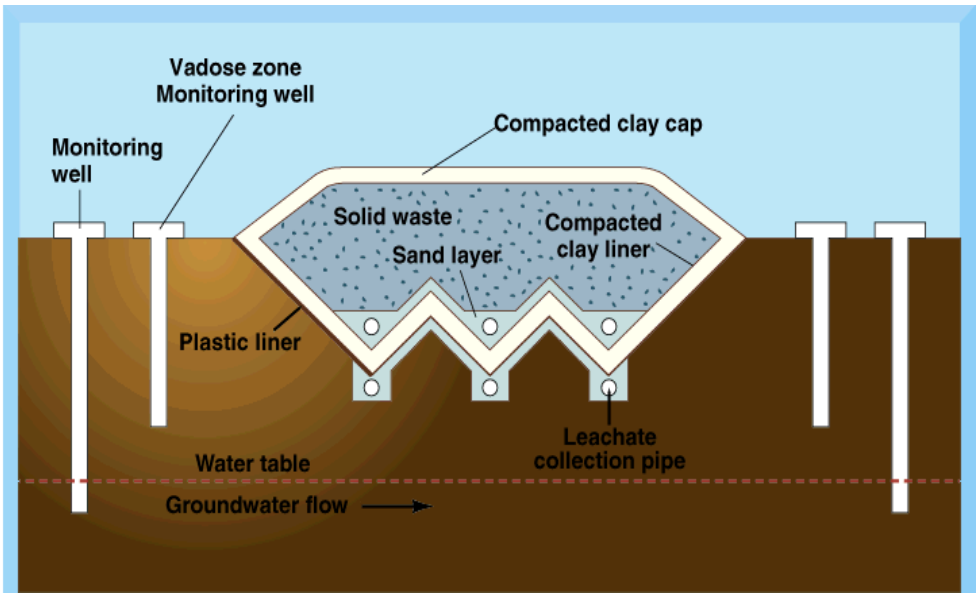


Figure 2.2: Cross section of a typical sanitary landfill (Source: earthsci.org, 2017).

The base liner is the most important component, includes a leak detection sump system, compacted clay liner, leachate collection system with a leachate collection layer. It was designed considering hydrological data of the site, the size of landfill, and suitability of construction as well as locally available of material. In addition, the final cover of sanitary landfill consists of top soils, percolation water collection layer, compacted clay liner and gas collection pipe system with gas collection layer.

The main aim of a sanitary landfill is to use it for a longer time for disposal of MSW with less negative effect to the ecosystem. There must be several monitoring wells around the landfill to monitor the movement of pollutants. There should also be a special drainage system which can help to reduce the flow over from the landfill surface. Thus, the amount of water that penetrates it will be reduced. Typically, impermeable clay cap located at the top of landfill can prevent the infiltration of water through the landfill.

2.4 Impacts of Waste Disposal Site

Deposited MSW in disposal site has serious dual implications for both the environment and the quality of life. Dumping of MSW has huge environmental impacts and can cause serious problems. Some of MSW will eventually decompose, but not all, and in the process it may smell or generate methane gas, which is explosive and contributes to the greenhouse effect (Tabassum, 2015). Flows chat with different impacts arising from open dumping shown in Figure 2.3.

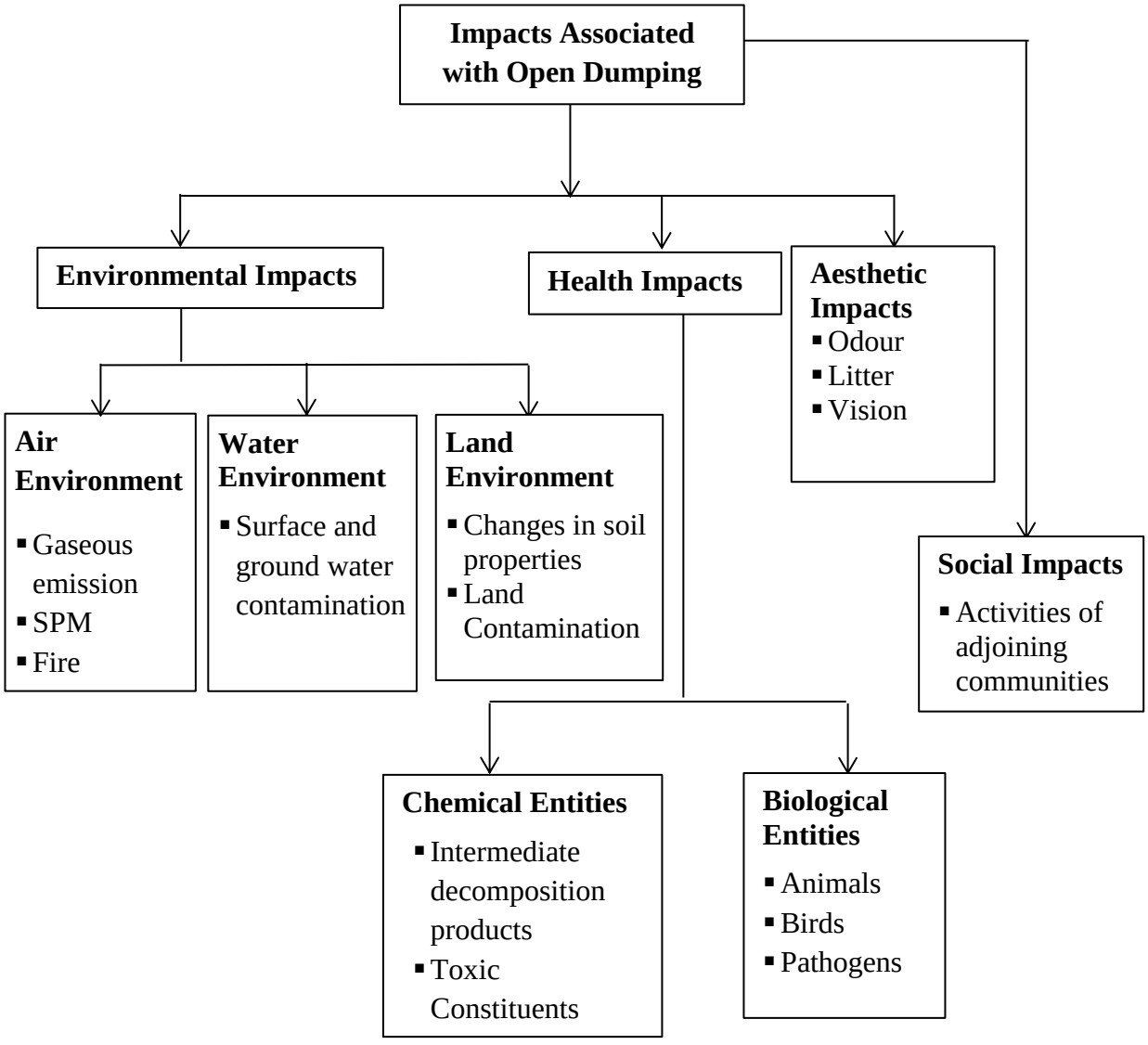


Figure 2.3: Flow chart of impacts associated with open dumping facilities (Source: Dutta, 2017).

Deposition of MSW in disposal site contaminates soil, water and air. This occurs when water from rainfall seeps through dumped waste and mixes with substances within the waste and forms a substance known as leachate. Leachate released from waste sites also poses a high risk to groundwater and surface water if it is not properly managed. Leachate produced as waste decomposes may cause contamination of underlying soil layer. Dumpsites also make the surrounding areas prone to flooding as the different components of waste can block drains, creeks and culverts (UNDP, 2006). The presence of metal elements in an open dumpsite can cause serious health problems for nearby residents as it is an ideal breeding ground for disease vectors such as rats and mosquitoes (USEPA, 1989).

The occurrence of uncontrolled dump sites not only effects health and the environment but also the quality of life. Moreover, illegal dumpsites have adverse effects on the basic human rights of people with regards to the standard of living. Because, the presence of dumpsites does not only deteriorate the quality of the environment but also breaches human rights as it has an impact on community pride. Usually, the sight and smell that emerges from illegal dumpsites is unpleasant and diminishes land value. Illegal sites that mostly constitute of flammable substances and gases are vulnerable to fires. This not only has an impact on the aesthetic appeal of landscapes but it also diminishes the value of surrounding properties significantly, forcing residents to vacate their homes to further places (USEPA, 1989).

2.5 Environmental Effects of Waste Disposal Site

Waste disposal site or landfill is the ultimate stage of MSW management as well as the easiest and lowest cost options for disposal of MSW; however, environmental concern should be addressed efficiently in this stage (Talib et al., 2008). The open dumping facilities are the lowest rank in MSW management hierarchy due to its various negative environmental impacts such as emission of CH_4, CO_2 and odor in the air, leaching of salt and metal elements in the water as well as accumulation of hazardous substances in the soil. Long lasting and continuous retention of metal elements might affect the defending ability of soil in and around of the waste disposal site (Murtaza, 2002). Besides, landfill gas has a potential behavior to pollute the main component of environment such as the atmosphere (air), the lithosphere (land) and the hydrosphere (water) (Figure 2.4).

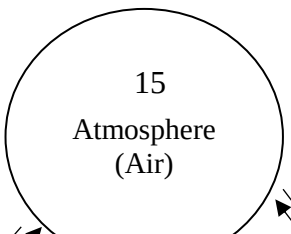


Figure 2.4: Landfill as a hazards and key environmental media (Source: Talib et al., 2008).

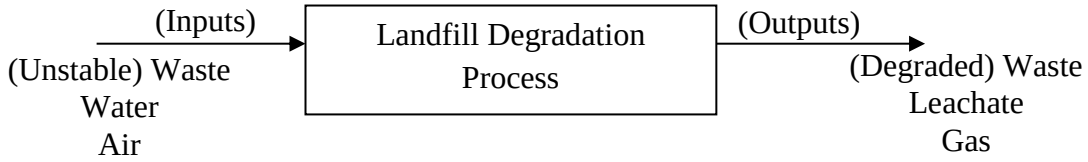
Thus, the environmental problems posed by solid waste ranges from air, soil and water contamination. The resultant of these is the degradation of our environmental quality (Abdus-Salam et al., 2011). In some dumping sites, MSW are burnt in the open and ashes abandoned at the sites, with no regard to environmental implications. This poses a direct safety threat because of the danger of explosion and air contamination. The burning of MSW gets rid of the organic materials and oxidizes the metals, leaving the ash richer in metal contents. After the processes of oxidation and corrosion, these metals get dissolved in rain water and are then leached into soil from where they are picked up by growing plants thereby entering the food chain (Benson and Ebong, 2005).

2.6 Exposure Pathways of Waste Disposal Sites

In waste disposal sites, MSW decomposes and produces three components of waste: solid (degraded waste); liquid (leachate that is infiltrating into the underlying layer) and landfill gas (LFG). In the process of MSW degradation in disposal sites, solid waste,

precipitation/water and atmospheric air are the three inputs parameters, while, leachate and LFG are the two principal outputs of landfill as shown in Figure 2.5.

Figure 2.5: Degradation process of waste disposal sites (Source: Talib et al., 2008).



These detrimental effects then impact the human health and the natural environment (aquatic, earthly flora and fauna) (Butt et al., 2008). Open dumping facilities release huge quantity of harmful as well as poisonous chemicals to the nearby groundwater, underlying soil layer as well as the atmosphere, through leachate and LFG (Lee and Jones-Lee, 1994). These chemical contains extensive ranges of possible carcinogens and toxicological compounds that signify a potential risk to public health. Ecological and health risk assessments are a necessary tool to recognize and illustrate the hazard of disposal site for the environment (Butt et al., 2008).

The exposure of waste disposal sites is the potential threat to the environment and human health risk that will happen when a person has been exposed to a particular quantity of a hazard. Communities living nearby disposal sites are directly exposed to chemicals through inhalation of LFG released during the waste degradation, but also to the combustion products (e.g. dioxins and dioxin like compounds) that can be generated when LFG is burned in flares or for energy recovery (Environment Agency, 2004). Ingestion of drinking water obtained from private wells contaminated by leachates, skin absorption and ingestion of contaminated soil particles, or ingestion of home-grown products, are other possible exposure pathways to chemicals. The exposure and exposure scenario of waste landfills is illustrated in Figure 2.6.

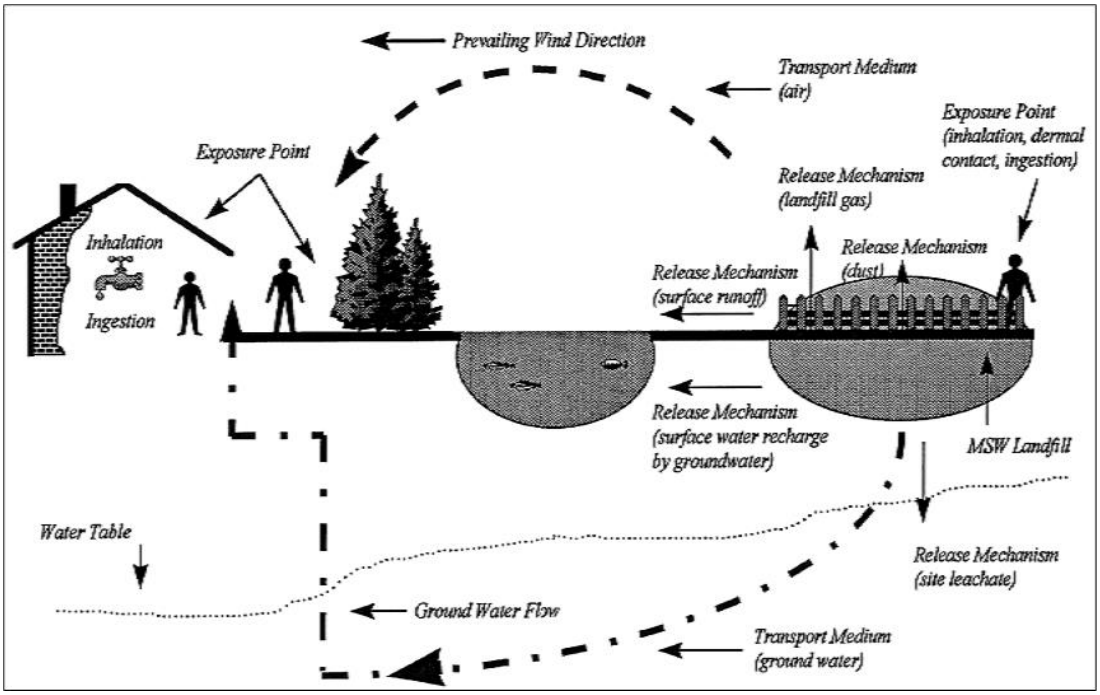


Figure 2.6: Exposure pathways of waste disposal sites in surrounding environment (Source: Butt et al., 2008)

2.7 Approaches and Challenges of MSW Management

MSW handling facilities are lacking in many highly populated areas in most developing and underdeveloped countries due to cost and lack of enforcement of relevant enactment (Håkanson, 1980). Poor regional and urban planning, lack of enforcement of relevant laws and edicts on waste disposal, lack of organized landfill sites contribute to the presence of dumping sites within living areas in developing nations. This results in the discharge of household sewage and refuse into the environment untreated. The surface run-off and leachates from dumpsites are sources of fresh water contamination (Abdus-Salam et al., 2011).

Appropriate MSW management is a large challenge for local authorities because improper solid waste management creates all types of contamination in different sectors like air, soil and water. The recent population and industrial growth has led to increasing production of domestic, municipal and industrial wastes, which are indiscriminately dumped in landfill and water bodies without treatment (Ali et al., 2014). MSW management constitutes one of the most crucial health and environmental problems. The uncollected or illegally dumped wastes constitute a disaster for human health and the environmental degradation. Thousands

of old landfills and dumpsites exist throughout the developing countries representing a threat for human health for the next decades, unless appropriate measures are taken. Most developing countries follow the practice of open dumping of solid wastes causing environmental and health risks (Ali et al., 2014). Industrialization, population growth and unplanned urbanisation have partially or totally turned our environment to dumping sites for waste materials.

2.8 Effects of MSW on the Environment

Poor MSW management poses a great challenge to the well-being of city residents, particularly those living adjacent to dumpsites due to the potential of the waste to pollute water, food sources, land, air and vegetation. The poor disposal and handling of waste thus leads to environmental degradation, destruction of the ecosystem and may cause great risks to public health. The resultant accumulation of waste poses a health hazard to urban inhabitants, and also threatens the surrounding environment (UNDP, 2006). Figure 2.7 shows the chain approach from waste generation to environmental impact through waste management and emissions.

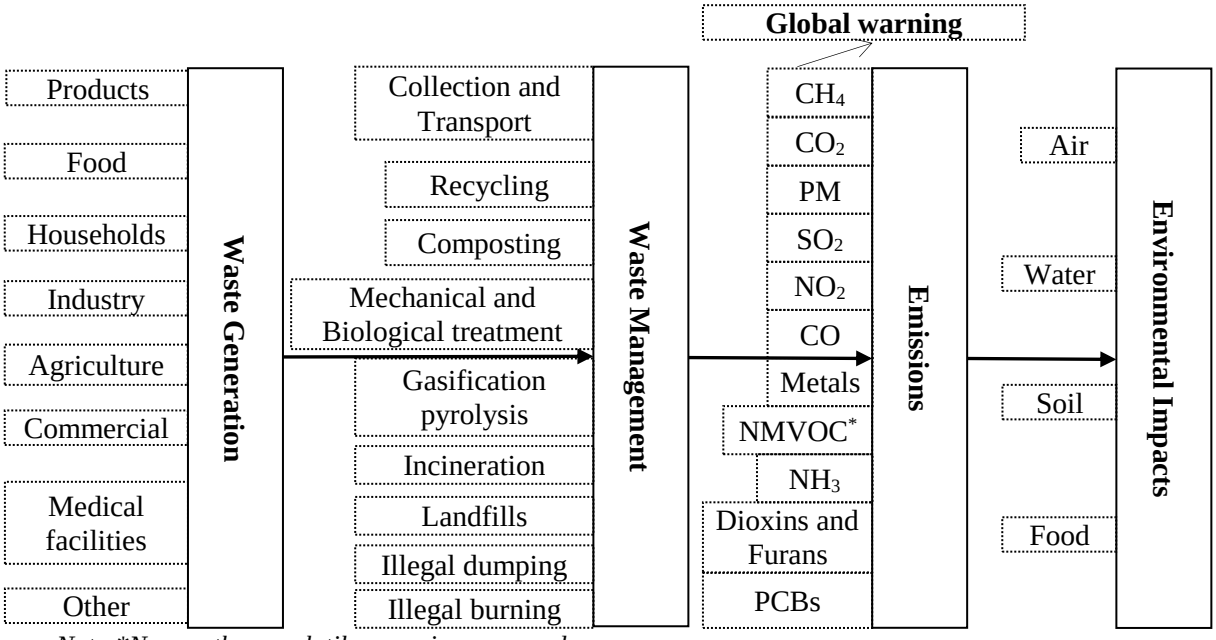


Figure 2.7: The chain approach from waste generation to environmental impact (Source: Clift et al., 2000).

Most dumping sites are located within the vicinity of living communities and wetlands. The dumping sites are often not lined nor basement prepared for selective adsorption of toxic substances. Therefore it is prone to release pollutants to nearby water and to the air through leachates and dumping site gases respectively.

Soil samples represent an excellent media to monitor metal element contamination resulting from anthropogenic activities. Metal element contaminated soil affects the ecosystem due to leaching into ground water or when they are taken up by plants and animals which results in great risks due to bioaccumulation (Bhagure and Mirgane, 2010). Metal elements and persistent organic contamination are of concern due to their potential harmful effects to humans and the environment. Metal elements are potentially toxic to crops, animals, and humans when contaminated soils are used for crop production. Contamination of the biosphere with metal elements, induced by industrial, agricultural, and domestic activities, poses serious problems for safe use of agricultural lands. Most studies of metal leaching in soil columns or field investigations conclude that trace metals are strongly bound to topsoil (Sukkariyah et al., 2005).

Metal elements concentration in the soil are associated with biological and geochemical cycles and are influenced by anthropogenic activities such as agricultural practices, industrial activities and waste disposal methods (Zukowska and Biziuk, 2008). Waste dumpsites can transfer significant levels of toxic and persistent metals into the soil environment (Udosen et al., 2006). These metals are taken up by plants and transferred into the food chain (Benson and Ebong, 2005). Cultivated plants take up these metals either as mobile ions in the soil solution through their roots (Udosen et al., 2006) or through their leaves thereby making them unfit for human consumption (Yusuf et al., 2003). Consequently, higher soil metal element concentration can result in higher levels of uptake by plants. The rate of metal uptake by a plant could be influenced by factors such as metal species, plants species, plant age and plant part (Singh et al., 2010).

2.9 Environmental Risk of Metal Elements Mobility in Waste Disposal Sites

A large amount of metal elements are contained of waste disposal sites and are considered a potential environmental risk for the future. Waste disposal sites contain a

mixture of different type of waste: household, commercial waste, industrial waste and treatment sludge. In MSW, many substances are not stable under natural conditions and especially not when they are in contact with water (Flyhammar and Hakanson, 1999). In waste disposal sites, the anaerobic state is the situation mainly present. Under this condition, metals are prevalently immobilized as sulphides or they can form complexes with the solid organic matter or, in a minor part, precipitate out as carbonates. Since the sulphur content is not sufficient to immobilize all the metals deposited organic materials retains a large fraction of metals in waste disposal sites.

During the years, the oxygen intrusion inside the waste disposal sites increases and subsequently the oxidized material increases the risk of metals being released. In fact, the intrusion of oxygen induces an increase of the cation exchange capacity causing the complex formation between metals and the organic fraction. Thus consequently metal sulphides dissolve and solid organic matter content becomes depleted. Therefore, due to these reasons, waste disposal sites usually produce leachate with metal elements concentrations.

Metal elements constitute an environmental problem, if the leachate migrates into surface water or groundwater, or a treatment issue where the leachate is collected and treated prior to discharge. In fact, once they get into groundwater or soil, it becomes extremely difficult to remove them due to the complex speciation chemistry coming into play. Furthermore, metal elements are toxic for human beings and, when they leach to aquifer and underlying soil layer, they can become bioavailable to living organisms and inhabitants.

2.10 Soil Contamination

Soil is the thin layer of organic and inorganic materials that covers the earth's rocky surface. The organic portion, which is derived from the decayed remains of plants and animals, is concentrated in the dark upper most top soil. The inorganic portion made up of rock fragments, as formed over thousands of years by physical and chemical weathering of bedrock. Productive soils are necessary for agriculture to supply the world with sufficient food (Fatoki, 2000). Open dumping for MSW is considered an increasing threat to the underlying soil layer and the surrounding environment of disposal sites (Petts and Edulgee, 1994). In addition, soil contamination as part of land degradation is caused by the presence

of xenobiotic (human-made) chemicals or other alteration in the natural soil environment. It is caused by improper disposal of MSW, industrial activity and agricultural chemicals etc. Contamination of soil in a typical waste disposal site is shown in Figure 2.8.

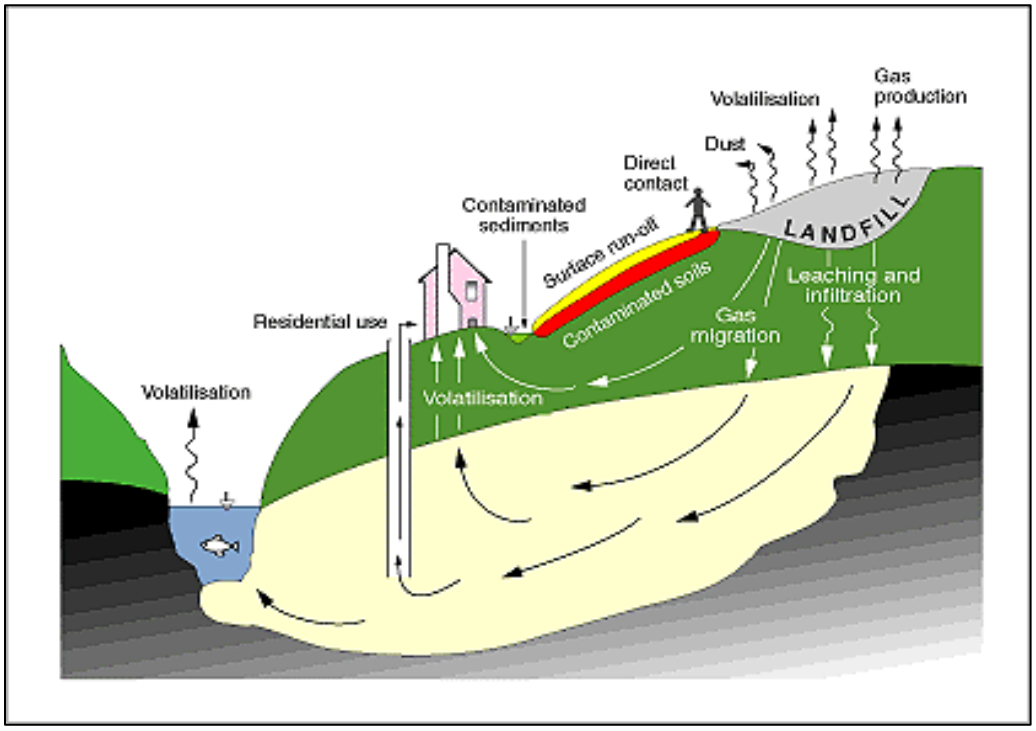


Figure 2.8: Contamination of soil of waste disposal site (Source: Petts and Edulgee, 1994).

Soil contamination occurs due to the presence of toxic chemicals, pollutants or contaminants with high concentrations in soil. It has great risk to plants, wildlife, humans and of course for the soil itself (Jia et al., 2010). Materials that find their entry into the soil system persist and accumulate in toxic concentrations becoming sources of pollution in soil (Misra and Mani, 2009). The concentration of metal elements in soil and their impact on ecosystems can be influenced by many factors such as the parent rock, climate and anthropogenic activities (Jia et al., 2010). Among the pollutants that persist and accumulate in the soils include; inorganic toxic compounds for example fertilizers, organic wastes, organic pesticides and radio cucleides (Misra and Mani, 2009). The soil is thus becoming increasingly contaminated with chemicals and other pollutants which can reach the food chain, surface water or ground water and ultimately be ingested by man (Misra and Mani, 2009).

Despite its importance, soil is often contaminated by human activities and this is reflected in the high horizontal and vertical variability brought about by the anthropogenic influence on soil formation and development (Fong et al., 2008). There are many different ways that soil

can become contaminated, such as Seepage from waste dumpsite; discharge of industrial waste into the soil; percolation of contaminated water into the soil; rupture of underground storage tanks; excess application of pesticides, herbicides or fertilizer; solid waste seepage and deforestation and soil erosion. The most common chemicals involved in causing soil contamination are petroleum; hydrocarbons; metal elements; pesticides and solvents.

2.11 Sources of Metal Elements and Its Effect

Metal elements are generally referred to as those metals which possess a specific density of more than 5 g/cm^3 and adversely affect the environment and living organisms (Järup, 2003; Misra and Mani, 2009). Heavy metals are released into the environment by both natural and anthropogenic sources. With the exception of soils derived from the physical and chemical weathering of parent materials containing elevated levels of trace elements (e.g. black shales and basic igneous rocks), the presence of elevated metal concentrations in the environment is related to man's activities (Zhuang et al., 2009). The sources of metal element generation illustrates in Figure 2.9. A metal element is not toxic per se and it is only toxic when its concentration in the plant and animal exceeds a certain threshold (the dose that makes the effect). Some elements, called trace elements or micronutrients, have essential functions in plant and animal cells (Lu et al., 2010). This has been shown for Co, Cu, Fe, Mn, Mo, Ni and Zn. Only when the internal concentration exceeds a certain threshold do they demonstrate toxic effects, and they are commonly termed ‘metal elements’.

Thus, the absence of a unanimous definition causes populate this list of metal element. Mainly the list of metal element includes As, Cd, chromium, copper, lead, nickel, molybdenum, vanadium and zinc. Some interest also exists in aluminum, cobalt, strontium and other rare metals (Khanna and Khanna, 2011). Arsenic, Antimony and Selenium are sometimes counted as metal elements, particularly in environmental chemistry (Daffus, 2002).

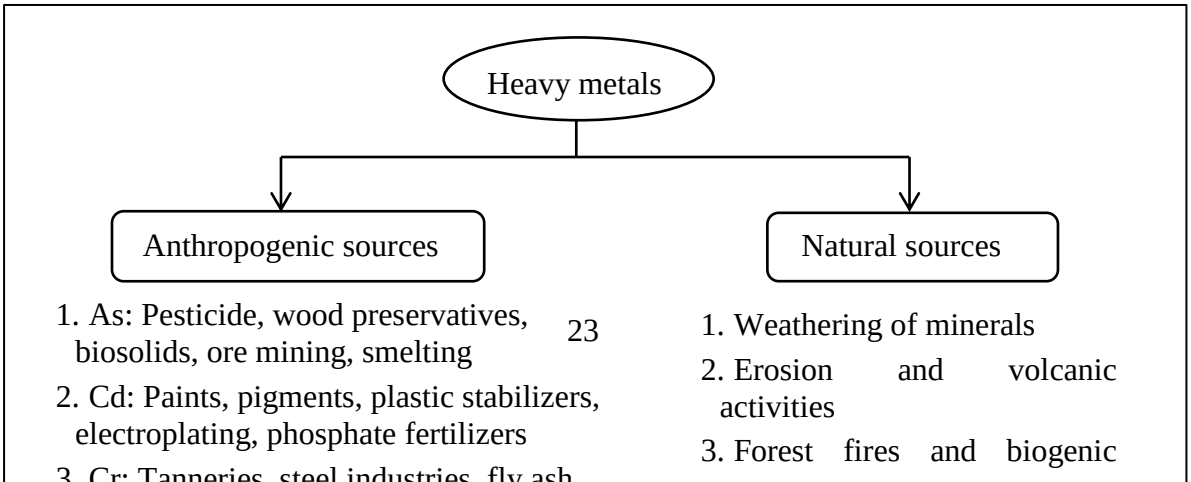


Figure 2.9: Sources of different metal element generation (Source: Dixit et al., 2015).

There are different types of contamination among which contamination caused by toxic level of metal element pollutants is called metal element contamination (Bose and Hemantaranjan, 2005). Metal element contamination has received the attention of researchers all over the world, mainly due to their harmful effects on living beings and the environmental components. Pollution of the natural environment by heavy metals is a universal problem because metals are indestructible and most of them have toxic effects on living organisms. Soils are usually regarded as the ultimate sink for heavy metals discharged into the environment. Soil heavy metal contents are not only the serious environmental issue but also frequently related to agricultural soil utilization problems. The sources of metal element in the environment are shown in Figure 2.10.

Human biology is full of instances where metal element toxicity has led to mass deaths (Shrivastav, 2001). All metal elements are toxic to living organisms at excessive concentrations, but some are essential for normal healthy growth and reproduction by plants at low but critical concentrations (Bose and Hemantaranjan, 2005). Though, essential elements to plants include Co, Cu, Fe, Mo and Zn and for animals are Cr, Ni and Sn. The metal elements Cd, Hg and Pb have not been shown to be essential for either plants or animals (Misra and Mani, 2009).

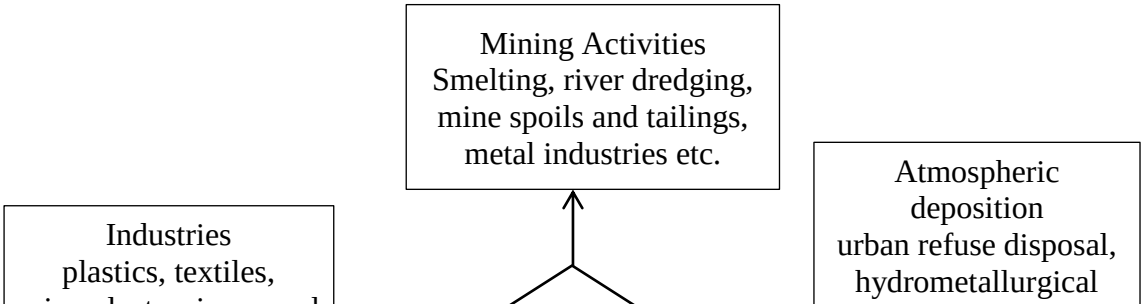
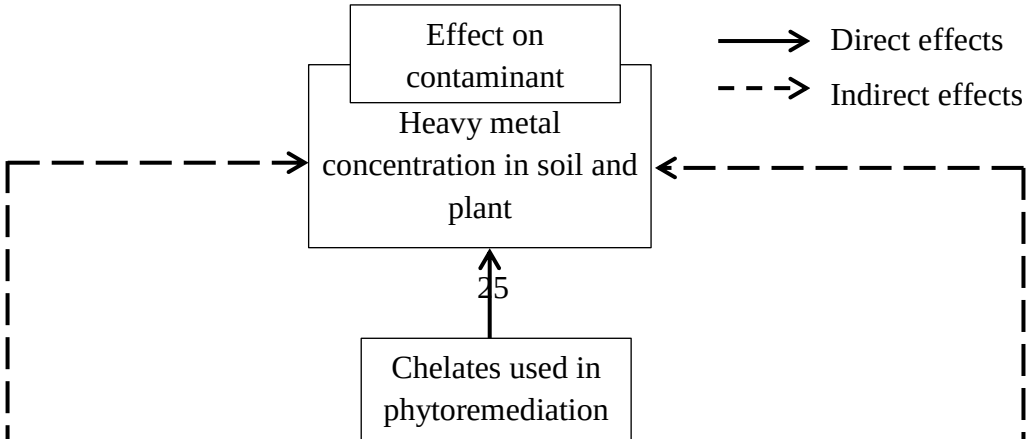


Figure 2.10: Sources of heavy metal elements in the environment (Source: Prasad, 2011).

It is important to note however that the concentrations of individual metals in living tissues must be kept very low and should be maintained within narrow limits to permit the optimum biological performance of most organisms (Misra and Mani, 2009). Metal elements are non-biodegradable and once they enter into an environment, they will stay there for a longtime. Metal elements are considered serious pollutants because of their toxicity, persistence and nonbiodegrable conditions in the environment, thereby constituting a threat to human beings and other forms of biological life (Adeleken and Abegunde, 2011). The effect of contaminated soil by heavy metal is shown in Figure 2.11.

Metal elements occur in atmosphere basically in particulate form. Hence, the transfer of airborne particles to land or water surfaces by dry, wet and occult deposition constitutes the first stage of atmospheric metal elements (Shrivastav, 2001). Adeleken and Abegunde (2011) noted that metal elements have low environmental mobility as a result of this; a single contamination could set a stage for a long term exposure of human, microbial, fauna, flora and other edaphic communities to metal elements.



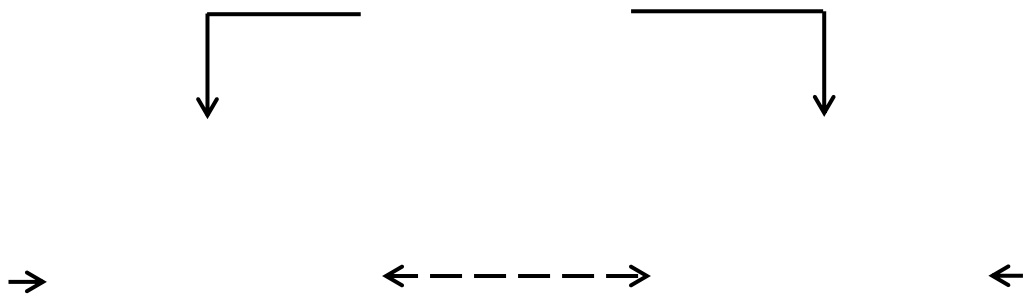


Figure 2.11: Effect of heavy metal in soil (Source: Adeleken and Abegunde, 2011).

The problem of atmospheric metal element contamination is not going to disappear overnight. On the contrary it will remain a legacy of mass industrial activity for many generations and is likely to escalate further in future. In this regard, the compilation of past and present catalogues of atmospheric metal element concentration is an activity of great importance (Shrivastav, 2001).

2.12 Mechanism of Action of Metal Elements

The metal element ions form complexes with proteins, in which carboxylic acid (–COOH), amine ($–NH_2$), and thiol (–SH) groups are involved. These modified biological molecules lose their ability to function properly and result in the malfunction or death of the cells. When metals bind to these groups, they inactivate important enzyme systems, or affect protein structure, which is linked to the catalytic properties of enzymes. This type of toxin may also cause the formation of radicals, dangerous chemicals that cause the oxidation of biological molecules (Neal and Guilarte, 2012)

2.13 Soil Contamination by Metal Elements

Soil contamination by metal elements is associated with biological and geochemical cycles and influenced by different types of anthropogenic activities (Zukowska and Biziuk, 2008). This contamination in soil refers to cases where the quantities of the elements in soils are

higher than maximum allowable concentrations and this is potentially harmful to biological life at such locations (Adeleken and Abegunde, 2011). Metal elements such as Pb, Cd, Hg and As do not have any beneficial effect on organisms and are thus regarded as the "main threats" since they are very harmful to both plants and animals. These metals are taken up by plants and transferred into the food chain (Benson and Ebong, 2005). Cultivated plants take up these metals either as mobile ions in the soil solution through their roots (Udosen et al., 2006) or through their leaves thereby making them unfit for human consumption (Yusuf et al., 2003). Consequently, higher soil metal element concentration can result in higher levels of uptake by plants. The rate of metal uptake by a plant could be influenced by factors such as metal species, plants species, plant age and plant part (Singh et al., 2010).

The toxicity and mobility of metal elements in soils depend not only on the total concentration but also on their specific chemical form, bonding state, metal properties, environmental factors, soil properties and organic matter content (Osu and Okoro, 2011). According to some research done based on soils at dumpsites, the soil contain different kinds of concentration of metal elements depending on the age, contents and location (Mustafa et al., 2015). Studies have also shown that both long term and short term contamination of soils have effects on microbial activity and enzyme activities of the soil (Adeleken and Abegunde, 2011).

Field investigations as well as soil column studies have reported rapid leaching of significant concentrations of zinc, copper, chromium and cadmium (Sukkariyah et al., 2005). Municipal waste contains such metal elements as As, Cd, Co, Cu, Fe, Hg, Mn, Pb, Ni, and Zn which end up in the soil and are leached out from the dump sites (Fatoki, 2000). Exposure of children, generally accepted as the highest risk group who have a higher adsorption rate of metal elements because of their active digestion system and sensitivity of hemoglobin, to metal elements, can greatly increase ingestion of metal laden soil particles via hand -to-mouth activities. In addition, adults may be exposed to threat since inhalation is easier pathway for toxic metals to enter their body (Fong et al., 2008).

2.14 Key Concepts in Understanding Soil Contamination

The accumulation of heavy metals in soil is of interest because of the adverse effect heavy metals may pose to food quality, soil health and the environment. At increased concentrations of metal elements is toxic to soil microorganisms and plants and may adversely affect soil fertility and crop yield. Current legislative frameworks for soil pollution focus predominantly on total metal content. However, environmental risks posed by heavy metals are a function not only of their overall presence in the soil, but also of their chemical speciation. This is because heavy metals in a soil solution constitute the soil metal fraction that is most directly available for plant uptake and could potentially be leached from the soil and contaminate groundwater or surface water and also underlying soil layer. Many authors have shown that the activity of metal ions in the soil solution is a key factor in determination of element bioavailability and its toxicity for various organisms

Soil composition is significant to human health, because parent material (the weathered rock materials from which soils are formed), topography, climate, organisms and time will lead to soils with different physical and chemical properties. Nevertheless, this unique composition of a soil will affect the amount of water it can hold, the living organisms it supports, which chemical reactions are possible to occur, and cycles process of nutrients (SCU, 2013). Generally, these factors will determine the effect of potentially harmful contaminants in soils, transported or transformed process of them, and the extent of those contaminants available in chemical forms that are harmful to human health.

Two different types of soil contamination to consider are local soil contamination; the result of intensive industrial activities and waste disposal. Contamination by metal elements and organic contaminants is probably the most serious problem as the contamination is practically irreversible. Soil pH (acidity) is of particular importance because it controls the behavior of metals and many other soil processes (Silveira et al., 2003). Besides, metal element captions (positively charged metal atoms) are most mobile in acid soils. This means that metal contaminants are more available for uptake by plants, or to move into the water supply.

2.15 Indices and Methods for the Assessment of Soil Contamination

Popular soil contamination assessment methods can be classified into two categories: quantitative and qualitative. The qualitative methods, such as Principal component analysis (PCA), Pearson's correlation, factor analysis, and cluster analysis, are inferential and indicative (Salomons and Förstner, 1984). These multivariate analyses require that each variable shows a normal distribution and that the whole dataset shows a multivariate normal distribution. Some of the most commonly used quantitative methods are potential contamination index (Cp), contamination factor (CF), modified contamination degree (mCD), contamination load index (CLI), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}), potential ecological risk factor (ER) and potential ecological risk index (PERI). In this study, some of the methods or indices were followed to evaluate the level of contamination or degree of risk in soil and hence described here.

The ecological risk assessment of soil and sediment contamination associated with heavy metals has received increasing attention in the last few decades in both developing and developed countries. A number of calculation methods have been put forward for quantifying the degree of contamination due to presence of metal elements in soil and sediments. Various authors (Müller, 1969; Håkanson, 1980) have proposed some empirical equations for evaluating level of contamination of soil and sediments. In addition, they also proposed contamination impact scales (or ranges) to convert the calculated numerical results into broad descriptive bands of pollution ranging from low to high intensity.

The level of metal contamination can be expressed by the contamination factor (CF). CF is the ratio between the metal content in the sediment to the background value of the metal. It is an effective tool for monitoring the pollution over a period of time. CF, defined by Håkanson (1980), enables an assessment of soil contamination through the use of concentrations in the surface layer of bottom sediments to preindustrial levels as a reference. In China, the CF was adopted as a pollution index (PI), which is often evaluated by comparing metal concentrations with related environmental guidelines, or with respect to relevant background values. The CF is sometimes used in equivalency to background.

In addition, contamination severity and its variation were determined with the use of contamination load index (CLI). The CLI is obtained as concentration factor. This

concentration factor is the quotient obtained by dividing the concentration of each metal. It represents the number of times by which the heavy metal concentrations in the sediment exceeded the background concentration, and give a summative indication of the overall level of heavy metal toxicity in a particular sample and is determined as the nth root of the product of nCF.

The enrichment factor (EF) in metals and geo-accumulation index (I_{geo}) are indicators used to assess the presence and intensity of anthropogenic contaminant deposition on surface soil. These indexes of potential contamination are calculated by the normalization of one metal concentration in the topsoil respect to the concentration of a reference element. A reference element is an element particularly stable in the soil, which is characterized by absence of vertical mobility and/or degradation phenomena. The constituent chosen should also be associated with finer particles (related to grain size), and its concentration should not be anthropogenically altered (Ackerman, 1980). Typical elements used in many studies are Al, Fe, Mn and Rb, and also total organic carbon and grain size are among those most used (and Ukpai, 2016). Al is a conservative element and a major constituent of clay minerals, and it has been used successfully by several scientists (Barbieri, 2016). The extent of soils contamination was also assessed using EF which was initially developed to speculate on the origin of elements in the atmosphere, precipitation, or seawater (Nweken and Ukpai, 2016) but it was progressively extended to the study of soils, lake sediments, peat, tailings, and other environmental materials. EF among other things was used to assess the relative contributions of natural and anthropogenic heavy metal inputs to soils. According to this technique metal concentrations were normalized to the textural characteristic of soils.

The I_{geo} is generally used to determine the anthropogenic contamination in sediments as introduced by Müller (1969). This index evaluates the contamination levels by comparing present concentrations with background levels. Potential Ecological Risk Index (PERI) proposed by Håkanson (1980) to evaluate the potential ecological risk of heavy metals in soil and sediments. This method comprehensively considers the toxic level, concentration of the heavy metals and ecological sensitivity of heavy metals in soil (Singh et al., 2010; Douay et al., 2013). PERI is formed by three basic parts: contamination factor (CF), toxic-response factor (TR) and potential ecological risk factor (ER).

2.16 Background Soil Quality Standards used in this Study

Preventing metal element contamination is critical because cleaning contaminated soils is extremely expensive and difficult to achieve. In order to evaluate soil quality, soil functions and response properties must be assessed taking into account influential factors (climate, hydrology etc.) (Singh et al., 2011). Soil quality guideline values published by different countries and supporting technical guidance are intended to assist professionals in the assessment of long-term risk to health from human exposure to chemical contamination in soil. There are different guidelines according to land use (residential, allotments, commercial) because people use land differently and this affects who and how people may be exposed to soil contamination. In addition, different organizations and countries provides the maximum allowable limits of metal concentrations in soil, as soil quality guidelines for the protection of environment and human health from contaminated sites.

Environmental quality standards in England are building on the 'First Soil Action plan for England (2004-2006) where the focus has become orientated towards the role of soils adapting to climate change and preventing pollution and dealing with historic contamination (Defra, 2004). There has been concern both in the UK and elsewhere that soil guidelines are frequently misused or misunderstood public confidence in environmental policy and risk management requires confidence in regulations set. Environmental quality standards help to ensure soil quality is monitored and sustained to prevent soil degradation as soil functions are both spatially and temporally changing. Soil quality is the ability of soil to provide ecosystem and society services through its capacities to perform its functions and respond to external influences (Kabata-Pendias, 1995).

Soil quality assessment is considered one of the main criteria for planning and practicing sustainable soil use. It's important to ensure the quality of soils do not degrade by promoting management practices that aid the sustainability of them achieved through ensuring the material and energy flow associated with soil processes are controlled and positively influenced. A sustainable soil is referred to as 'the use of soil as a natural resource on a way that does not exert any negative effects on the environment. In this study, soil quality guidelines from different countries like Canadian Council of Ministers of

the Environment (CCME), WHO, Poland, UK, USA, Austria, Australia, Germany and Japan were used to check the quality of soil. The maximum allowable limit of metal elements in soil mg/kg) of different countries is provided in Table 2.2.

Table 2.2: Maximum allowable limit of metal elements in soil of different sources

Metal element	WHO standard	CCME	Austria	Canada	Poland	Japan	UK	Germany	U.S.A
Fe	3000-250000	-	-	-	-	-	-	-	-
Mn	200-9000	-	-	-	-	-	-	-	-
Cr	0-85	64	100	75	100		50	200	1000
Cu	-	63	100	100	100	125	100	50	100
Pb	15-20	70	100	200	100	400	100	500	200
Zn	20-300	200	300	400	300	250	300	300	300
Ni	0-100	45	100	100	100	100	50	100	500
Cd	0-30	1.4	5	8	3	-	3	-	0.7
As	-	12	-	-	-	-	-	-	-
Hg	-	6.6	-	-	-	-	-	-	-
Co	-	40	50	25	50	50	-	-	40
Sb	-	20	-	-	-	-	-	-	-
V	-	130	-	-	-	-	-	-	-
Ba	-	750	-	-	-	-	-	-	-

CCME=Canadian Council of Ministers of the Environment. (Source: Akaeze, 2001; Anhwange and Asemave, 2013; Kabata-Pendias, 1995; USEPA, 1983; WHO, 1984).

2.17 Potential Ecological Risk Assessment

There are two major types of risk assessments as noted by Jensen et al. (2006). The first is undertaken prior to the release of a new substance, such as pesticides, to determine if it is safe to use in the natural environment. The second type of ecological risk assessment (ERA) is a description of the changes, which are observed in populations or ecosystems at sites that have become contaminated, and can therefore also be referred to as an impact assessment. This assessment can conduct using empirical equations or and other developed mechanisms (Jensen et al., 2006). The ERA is performed to evaluate the likelihood of adverse ecological effects occurring as a result of exposure to physical or chemical stressors. These stressors are defined as any biological, physical, or chemical factor that causes adverse responses in the environment (Mustafa et al., 2015).

At EPA, ecological risk assessments are used to support many types of actions, including: regulation of hazardous waste sites, industrial chemicals, and pesticides; or the management of watersheds or other ecosystems affected by multiple chemical, physical, or biological stressors. Risk assessment provides a systematic procedure for predicting potential risks to human health or the environment. The aim of a chemical risk assessment is to investigate if a chemical is being used or can be used as intended without causing detrimental effects to human health or the environment.

In several countries, the problems of contamination with metal elements are increasing; therefore the application of principal component analysis and risk index method become very useful tool for assessing the environmental impact of ecological risk of metal elements in environment (Mustafa et al., 2015). Figure 2.12 displays the procedure of environmental risk assessment and thus components of human and ecological risk assessment. From the ecological point of view the contamination indexes provides useful information to public, decision makers and managers in processing and analyzing the environmental data.

The researchers report that multivariate statistical techniques are the right tool for viewing and analyzing some of complex data (Wei et al., 2011). In addition, the potential ecological risk index (PERI) is a method that is used for the risk assessment of metal elements. This method was first suggested by Håkanson in 1980 with the aim of indicating the environmental agents and prioritizing contamination studies in hazard contamination sites, lakes and coastal systems (Håkanson, 1980). Although potential risk factor was originally used by Håkanson for the purpose of controlling water contamination, in recent years it was very successfully used for the quality of sediments and soil in the environment with metal elements using various indices.

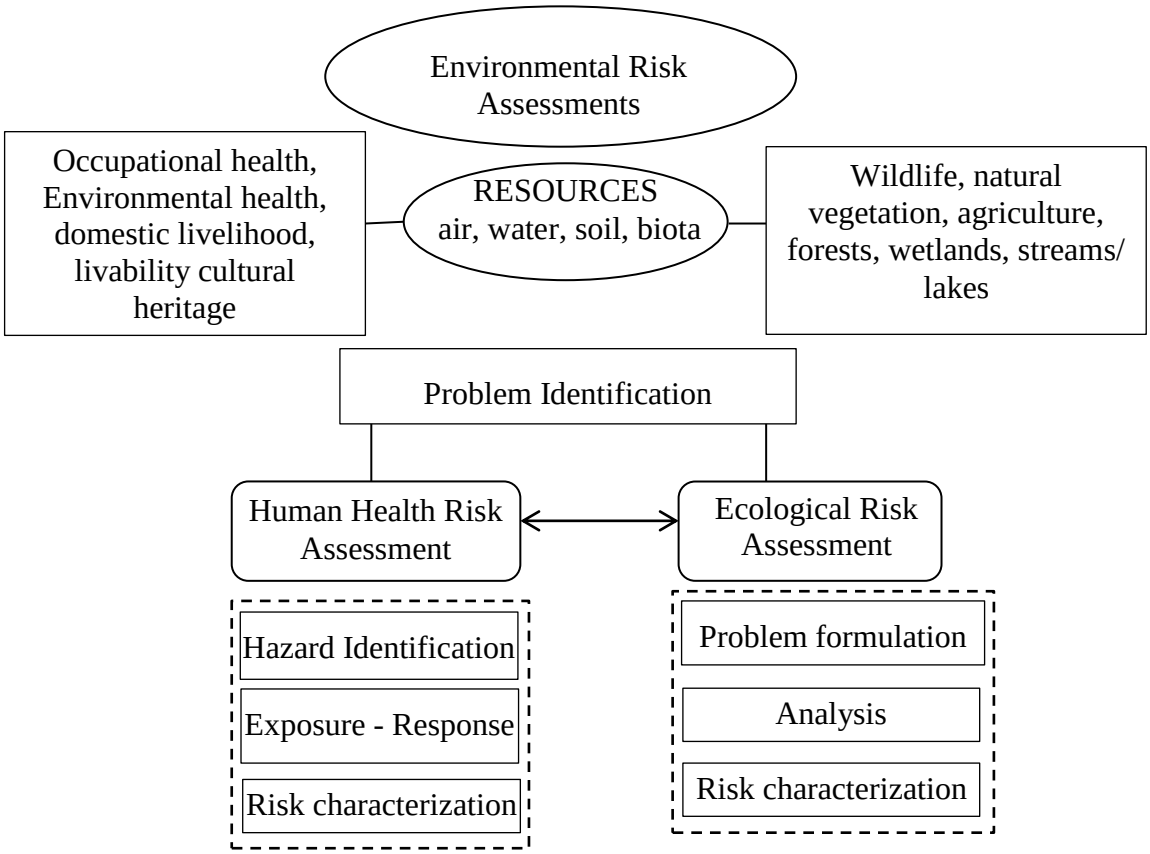


Figure 2.12: Components of human health risk and ecological risk (Source: UNEP, 1996).

In addition, assessment of metal contamination by indices including potential contamination (Cp), contamination factor (CF), contamination load index (CLI), modified contamination degree (mCD), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}), potential ecological risk factor (ER) and potential ecological risk index (PERI) are common for soil and stream sediments or surface sediment along different water bodies such as river, lake, sea (Kalender and Uçar, 2013). In the same way, analysis method being used for possible metal contaminated soil such as landfill soil, soil of industrial area, agricultural soil etc. (Mustafa et al., 2015; Wang et al., 2013).

Pearson's correlation analysis and principal component analysis (PCA) are one of unsupervised methods that estimate the correlation structure of the variables by finding hypothetical new variables (principal components-PC) that account the variance in a multidimensional data set (Wei et al., 2011). In addition, geostatistical technique like ordinary kriging (OK) is a common method to distribute metal contamination spatially.

2.18 Pearson's Correlation Analysis

The technique of Pearson's correlation is a parametric measurement developed by Karl Pearson from a related idea introduced by Francis Galton in 1880s (Galton, 1886; Pearson, 1895). The Pearson's correlation produces a sample correlation coefficient, r, which measures the strength and direction of linear relationships between pairs of continuous variables. Such affiliation is probably going to prompt thinking about causal association between the factors (Srinivasa and Pradip, 2010). The correlation analysis is a preliminary descriptive technique to estimate the degree of association among the variables involved.

The values of correlation coefficients will help in selecting proper treatment to minimize groundwater pollution from the contaminated soil. In case of metal element contamination in soil, several studies were performed to find the association between metal elements and the similarity of their contamination sources. Zou et al. (2015) studied on sources of metal elements in farmland soils of beijing suburbs, China based on pearson's correlation. It was found that some metal eelments such as Cr was moderately correlated with Cd and Zn, whereas, Hg was only correlated with As and not with the other elements as the pair. In this study, the principal of pearson's correlation was performed using XLSTAT to examine the association of metal elements in soil of the waste disposal site.

2.19 Principal Component Analysis

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (or sometimes, principal modes of variation). PCA was invented in 1901 by Karl Pearson, as an analogue of the principal axis theorem in mechanics; it was later independently developed and named by Harold Hotelling in the 1930s. The number of PCs is less than or equal to the smaller of the number of original variables or the number of observations. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding

component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors are an uncorrelated orthogonal basis set.

Multivariate statistics concerns understanding the different aims and background of each of the different forms of multivariate analysis, and how they relate to each other. PCA estimates those components that contribute most to the variation in the data sets. Large-scale investigations of metal concentrations have been conducted in China, with natural background levels and minor anthropogenic pollution sources (Liu et al., 2006). A typical interrelation between PCA and hierarchical cluster analysis (HCA) as well as the performance of these interpolation techniques are shown in Figure 2.13.

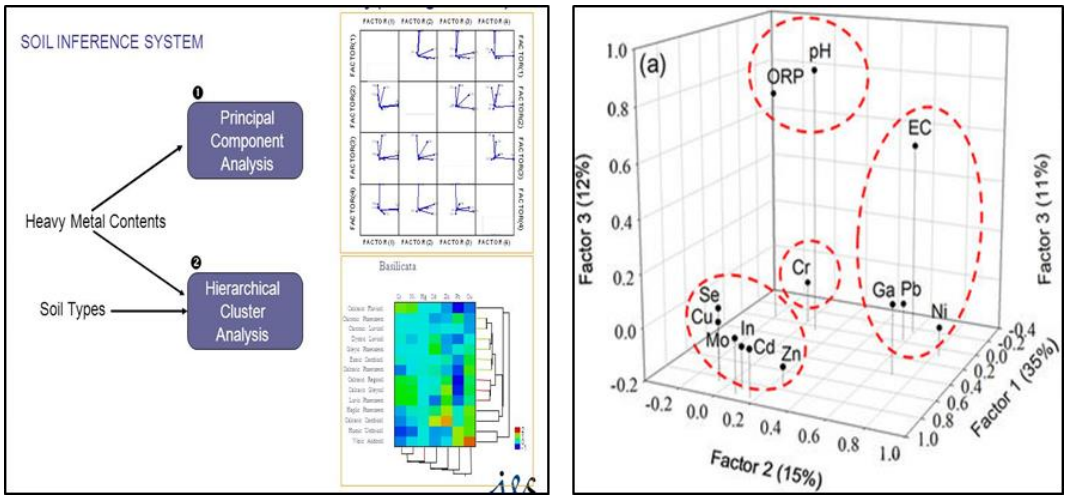


Figure 2.13: A typical interpolation of PCA and its results (Source: Hsu et al., 2016).

2.20 Geostatistical Interpolation Technique

Geostatistics is a branch of statistics focusing on spatial or spatiotemporal datasets. Geostatistical analyst also provides many supporting tools. For example, prior to mapping, exploratory spatial data analysis tools can be used to assess the statistical properties of the data. Kriging is a family of estimators used to interpolate spatial data (Olea, 2009). This family includes ordinary kriging (OK), universal kriging, indicator kriging, simple kriging are shown in Figure 2.14.

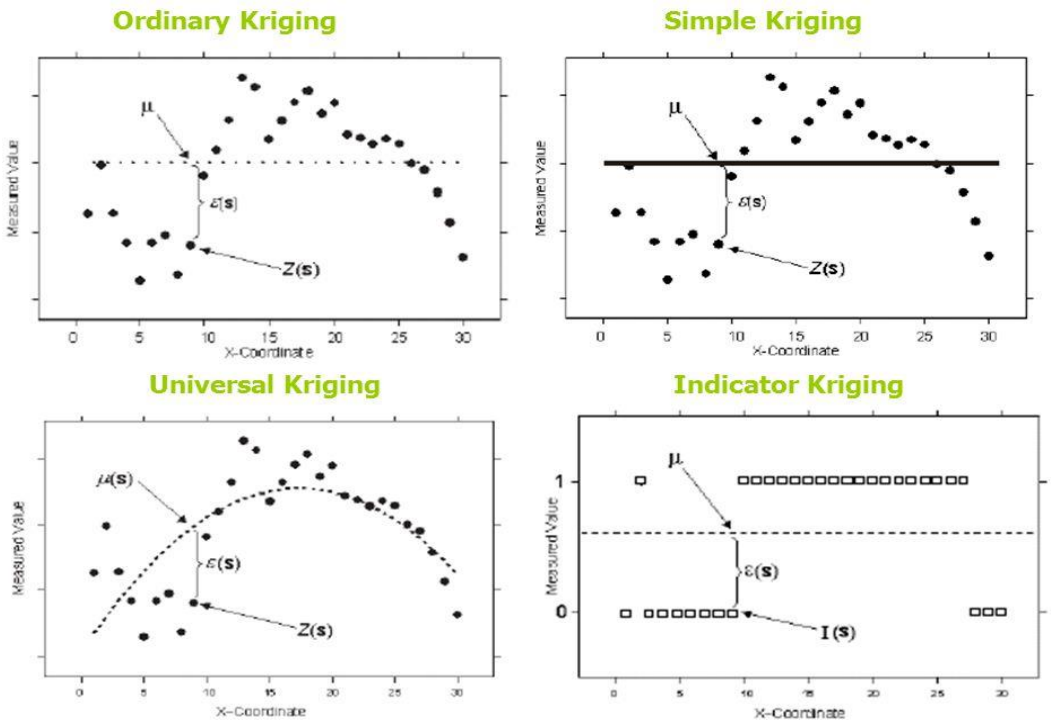


Figure 2.14: Different types of kriging commonly used for interpolation (Source: arcgis.com, 2017).

The ordinary kriging (OK) is a spatial estimation method where the error variance is minimized. OK is usually referenced with the acronym B.L.U.E. meaning best linear unbiased estimator. OK is "linear" because its estimates are weighted linear combinations of the data used in analysis; it is "unbiased" since it tries to have the mean residual error equal zero; is "best" because it aims at minimizing the variance of the errors associated with the analysis (Yamamoto, 2005). The whole idea behind OK is to find the optimal weights that minimize the mean square estimation error (Olea, 2009).

In this study, the technique of ordinary kriging (OK) was performed using ArcGIS. The interpolation technique of OK, produced a prediction surface (map) which indicated the level of contamination by different colors shown in Figure 2.15.

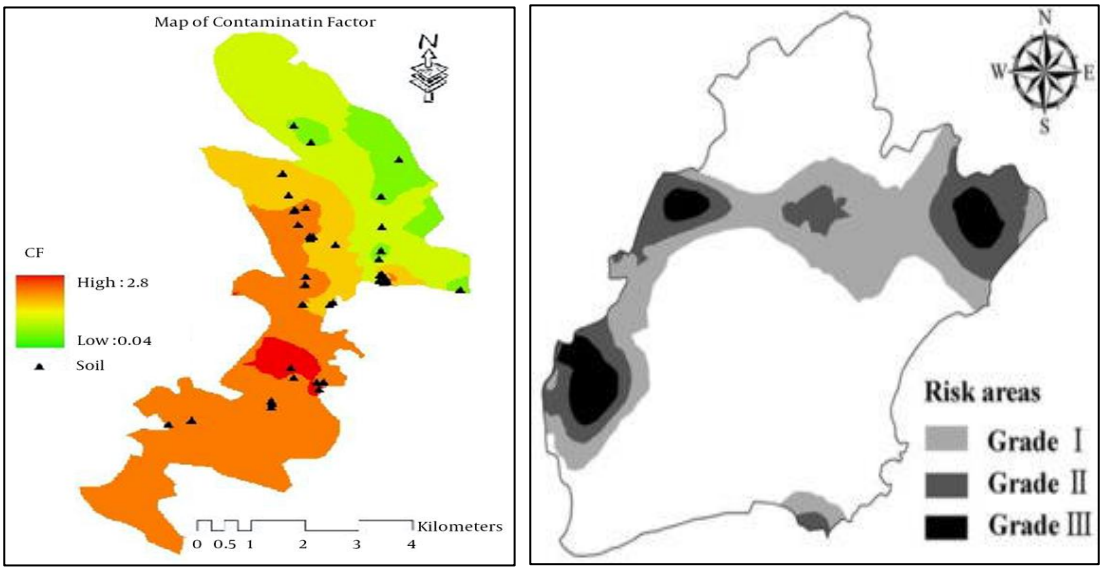


Figure 2.15: Level of contamination of soil using ordinary kriging (Source: Solgi and Konani, 2016).

CHAPTER III

RESEARCH METHODOLOGY

3.1 General

This chapter deals with municipal solid waste (MSW), waste disposal site, leachate percolation, heavy metal leaching, contamination and risk associated with heavy elements in soil. This chapter also illustrates about field investigations and collection of soil samples from different locations of the selected open dumping site at Rajbandh, Khulna. To create map pointing sampling location, GPS coordinates of all soil sampling point were recorded. In addition, in order to identify the correlations of heavy metals in soil, statistical analysis and Pearson's correlation analysis were performed using SPSS and XLSTAT and discussed in this chapter. To evaluate the ecological risk of contaminated soil various indices were used and highlighted in this chapter. This chapter represents the geostatistical analyses of ordinary kriging (OK) used in this study to distribute the metal elements in soil spatially and hence discussed in the following articles. The flow chart of the research strategy in this study is depicted in Figure 3.1.

3.2 Present Condition of the Selected Waste Disposal Site

In Khulna City, waste disposal site is situated outside the city in low-lying areas at Rajbandh, 7 km far away from the city center. The existing landfilling system in Rajbandh is the crude open dumping where there are no provisions for the leachate collection and treatment, for the groundwater/surface water pollution control (i.e. no liners and fences are used), and for the biogas management and utilization (Ahsan et al., 2015). All types of MSW in disposal site are disposed together including some portions of industrial and construction wastes. Crude open dumping of MSW is practiced all over the Asian countries, which always incompatible with the surrounding areas. There is also a pilot scale sanitary landfill (PSSL) at Rajbandh. In this study, open dumping site at old Rajbandh was selected as a case study.

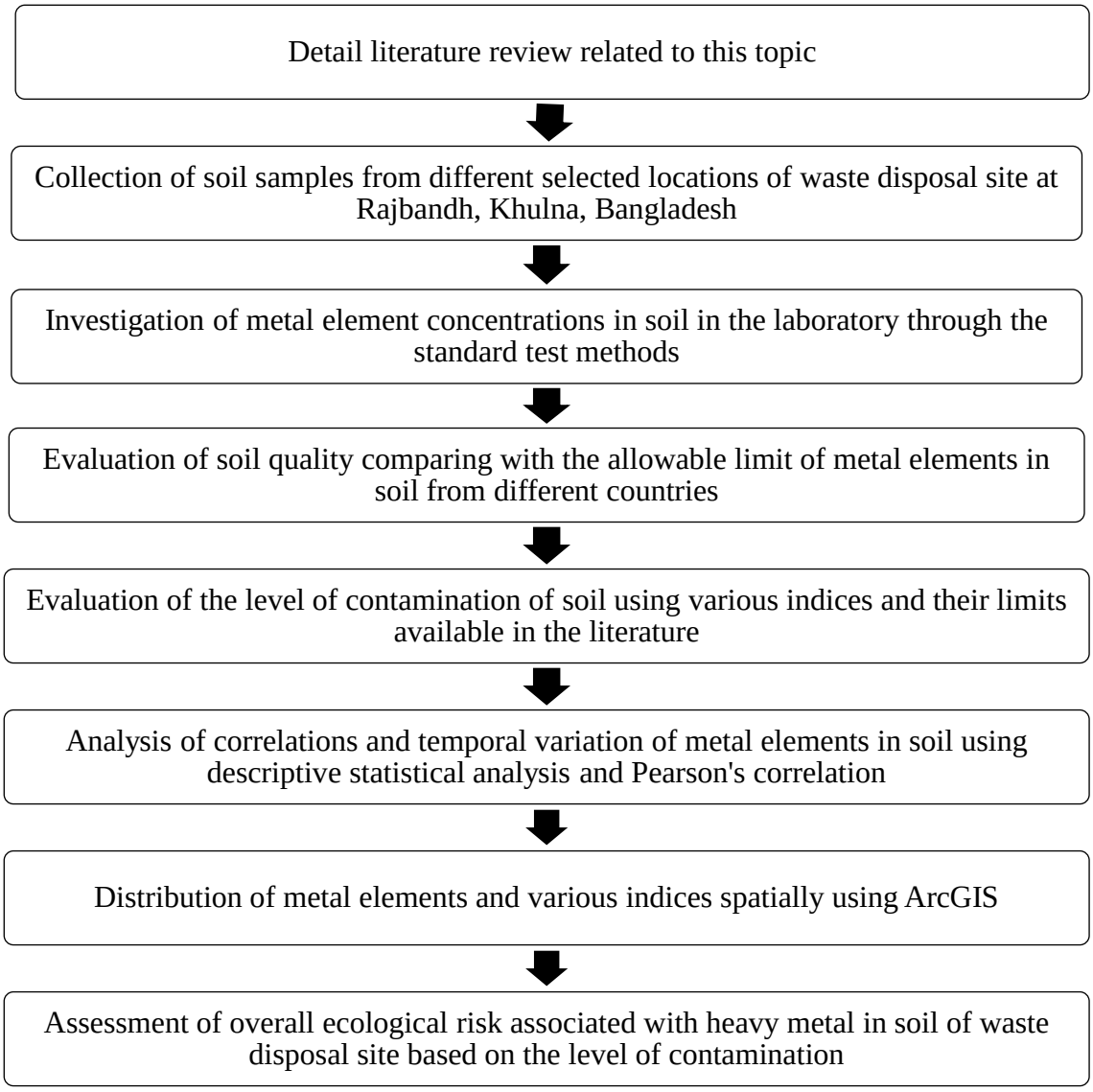


Figure 3.1: Flow chart of this study.

In the selected disposal site, MSW is dumping with neither planning nor proper operation. MSW spreads all over the site, and even to the surrounding water bodies. Figure 3.2 shows the present scenarios of the selected open dumping site at Rajbandh, practice of vegetation and fishing near to the site. The hand pumps/tube-wells are located nearby to the waste disposal site (about 300 m) and people use the groundwater for drinking, bathing and washing purposes.

Figure 3.2: (a) Waste disposal site at Rajbandh, (b) vegetation on a layer of waste in the site and (c) fishing in a pond near to the site.

3.2.1 Geological Setting of Study Area

Khulna is a district among total sixty four districts in Bangladesh. Besides, the Khulna city is in the northern part of the district, acknowledged as third largest among ten metropolitan cities of Bangladesh. Geographically, Khulna lies between 22°47'16" to 22°52'0" north latitude and 89°31'36" to 89°34'35" east longitude. This city situated on the Rupsha and Bhairab river-banks shown in Figure 3.3. The MSW of Khulna city is dumped at Rajbandh disposal site. However, in this study only the old Rajabndh waste disposal site was chosen as a case study to assess the quality, level of contamination and ecological risk of soil of this disposal site.

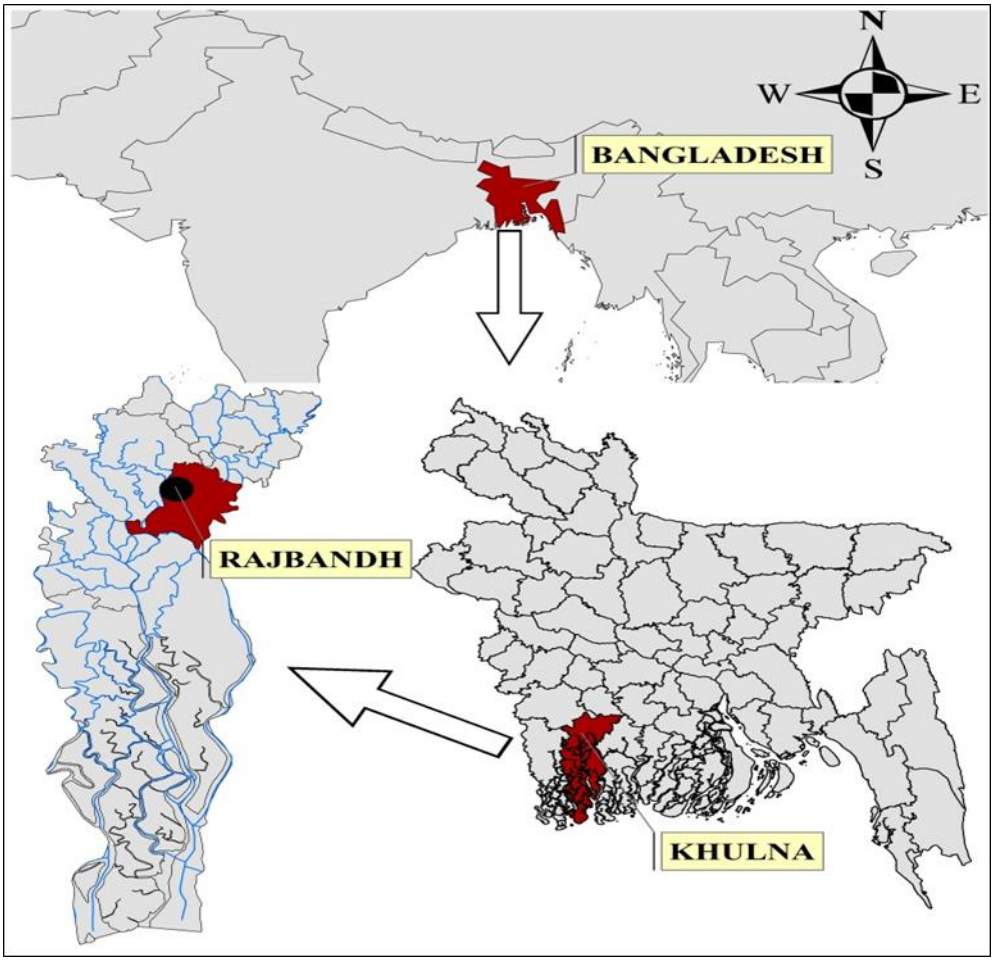


Figure 3.3: Location map of Rajbandh at Khulna city of Bangladesh.

3.3.2 Soil and MSW Condition of Waste Disposal Site

The waste disposal site is located at Rajbandh, Khulna, 7 km far from the city center i.e. Royal & Castle Salam Square of Khulna city and situated along the North-side of Khulna-Satkhira highway. It is important to know the physical and mechanical properties of underlying soils as thoroughly as possible before assessing their physico-chemical or hydro-mechanical behavior. Based on these concepts, in laboratory through standard methods, some relevant physical and mechanical properties of soil from this selected disposal site were determined by Rafizul (2014). Soil moisture content, plastic limit, liquid limit, plasticity index and shrinkage limit of soil were found 22, 22, 43, 21 and 16 %, respectively. In addition, the percentages of soil constituents were found as sand, silt and clay of 10, 56.6 and 33.4%, respectively. Then the value of soil pH, optimum moisture content, maximum dry density and coefficient of permeability were found 6.7, 18 %, 16 kN/m^3 and 1.90x10^{-7} cm/sec, respectively.

In Bangladesh, MSW mainly consist of food and vegetables waste (Rafizul, 2014). Other items are presents in negligible percentages. For a basic understanding of the nature of MSW that are generally encountered, the type distribution of particle sizes must be known. The degradation of the organic fraction from MSW in disposal site produces a number of gases which degrades environmental condition. In contrary, the MSW of the study site mainly consists of pH, volatile solids (VS), and ash residue and bulk density of 7.79, 58 %, 46 % and 1000-1066 kg /m^3, respectively. In addition, the percent finer of MSW was 100 % in 300 and 200 mm sieve openings, whereas the values were found as 76.25, 63.72, 45.22 and 24.34 % for the opening of 100, 76.2, 38.2 and 19.1 mm, respectively. Moreover, the chemical characteristics in terms of carbon (C), nitrate (N) potassium (K), phosphorous (P) and C/N ration was found as 25.63, 1.84, 1.37, 0.41% and 13.92, respectively.

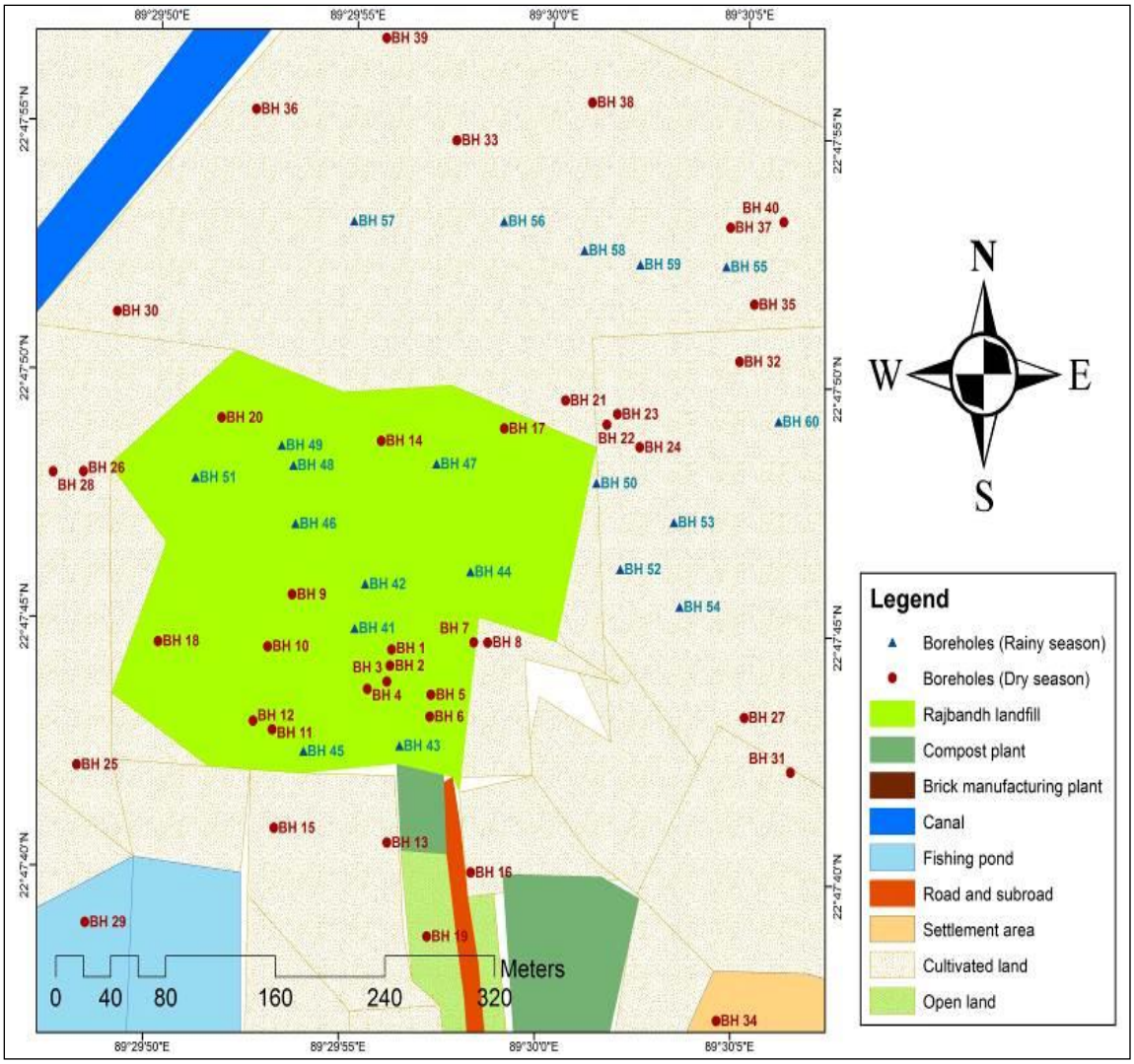


Figure 3.4: Soil sampling location in waste disposal site at Rajbandh.

3.3 Soil Sampling

In this study, sixty soil samples were collected from different selected locations of waste disposal site shown in Figure 3.5. Soil samples were collected at a depth of 0-30 cm from the existing ground surface of waste disposal site. The latitude and departure of all the soil sampling locations was recorded using GPS device. In total sixty soil samples, forty samples were collected in dry season (March to May, 2016) then rest twenty samples were collected in rainy season (June to August, 2016). In dry season, the sampling points were selected maintaining gradual addition of about 10 m distance from the 1st borehole (BH-1) by the subsequent boreholes. The first sampling point, BH-1 is located at the centre of the waste disposal site. The first borehole of rainy season (BH-41) is about 30 m apart from BH-1 which is the centre of disposal site and maintains a gradual addition of about 15 m in selecting of following boreholes. Proper care was taken to remove any loose material, debris etc. from the bottom of the excavated pit. The soil samples were collected from the bottom of the borehole by excavating the ground manually by using hand shovels. The soil samples were taken in large polythene bags and eventually transported to the laboratory.

3.4 Laboratory Investigations

The soil samples were carried out to the laboratory to measure the concentration of metal elements of Aluminium (Al), Arsenic (As), Barium (Ba), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Manganese (Mn), Sodium (Na), Nickel (Ni), Lead (Pb), Antimony (Sb), Scandium (Sc), Strontium (Sr), Titanium (Ti), Vanadium (V) and Zinc (Zn) in soil. The acid digestion and atomic absorption spectrophotometer (AAS) analysis are described in followings.

3.4.1 Acid Digestion

To measure the concentration of metal elements in soil, laboratory work was done through the standard test method. In laboratory investigation, at first 10 g of each soil sample was taken into a 100 mL conical flask. The flask had been washed with deionized water followed by adding 6 mL HNO_3/$HClO_4$ acid in ratio 2:1 and left overnight. Each sample was kept into the temperature of 150°C for about 90 minutes. Later, temperature was raised to 230°C for 30 minutes. Subsequently, HCl solution was added in ratio 1:1 to the digested sample and

re-digested again for another 30 minutes. The digested sample was washed into 100 mL volumetric flask and mixture obtained was cooled down to room temperature.

3.4.2 Analysis of Metal Elements with AAS

After performing the digestion procedure, metal elements in this digested solution were determined using AAS in the laboratory and the amount of each metal element was deduced from the calibration graph. The relevant concentrations of Al, Fe, Mn, Cr, Cu, Pb, Zn, Ni, Hg, Cd, As etc. in mg/kg were measured.

3.5 Assessment of Soil Contamination using Various Indices

The concentrations of metal elements in soil considered in this study were measured in the laboratory. To identify the quality of soil, the mean value of the metal element was compared with the allowable limit of metal elements in soil from different countries available in the literature. In this study, to assess the ecological risks associated with metal elements in soil, various indices were used. These indices were potential contamination index (Cp), contamination factor (CF), modified contamination degree (mCD), contamination load index (CLI), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}), ecological risk index (ER) and potential ecological risk index (PERI). In this study, to identify the level of contamination of soil, the values of various indices were then compared with the allowable limits published by different researchers as well as discussed in the following articles.

3.5.1 Potential Contamination

To investigate the level of contamination in terms of potential contamination index (Cp), maximum concentration of a particular metal element and its corresponding background value (concentration of the metal in unaltered granodioritic rocks) is very important. In this study, Cp was computed using Equation 1 proposed by Dauvalter and Rognerud (2001).

$$Cp = \frac{C_{\max}}{C_{background}} \qquad (1)$$

Where, C_{max} is the maximum concentration of a particular metal element in soil, and $C_{background}$ is the value of the same metal element in a reference soil or background level. In

this study, the level of contamination of soil was checked using the limiting values of Cp. The limiting values of Cp proposed by Dauvalter and Rognerud (2001) are: Cp ≤ 1 indicated low contamination; 1 < Cp ≤ 3 is moderate contamination; and Cp > 3 is severe or very severe contamination.

3.5.2 Contamination Factor

The contamination factor (CF) of a particular metal element is the ratio of metal element concentration in soil and the background value of the same metal element. In this study, CF was computed using Equation 2.

$$CF = \frac{C_{metal}}{C_{background}} \quad (2)$$

CF values were interpreted as demonstrated by Håkanson (1980). The classes according to the values of CF are as CF<1 indicates low contamination; 1 < CF < 3 is moderate contamination; 3 < CF < 6 is considerable contamination; and CF > 6 is very high contamination.

3.5.3 Contamination Load Index

In this study, the contamination load index (CLI) was calculated from contamination factor (CF). The CLI of a certain area is calculated by finding the n^{th} root of the numbers of CFs that was found for all the metal elements in soil. Hence, Equation 3 was used to compute the CLI (Tomlinson et al., 1980).

$$CLI = \sqrt[n]{CF_1 x CF_2 x CF_3 x \ldots\ldots x CF_n} \quad (3)$$

Where, CF = contamination factor, n = number of metal elements. There is two classes according to CLI value, if CLI > 1 is contaminated; whereas <1 indicates no contamination (Harikumar et al., 2009).

3.5.4 Modified Contamination Degree

The degree of contamination (CD) is an index to estimate the contamination range of soil by metal elements in soil. Equation 4 was used to calculate modified contamination degree (mCD) (Abrahim, 2005).

$$mCD = \frac{1}{n}\sum_{i=n}^{1} CF_i \qquad (4)$$

In the equation, mCD is the modified contamination degree, n means the total number of metal elements considered and CF is the contamination factor as described earlier. It is worth noting that mCD is a modified and generalized form of the degree of contamination (CD) formulated in Equation 5 proposed by Håkanson (1980).

$$CD = \sum_{i=n}^{1} CF_i \qquad (5)$$

The purpose of computing the values of CD is to offer a quantity of the degree of overall contamination of surface strata in a sampling area. The definite formula of the CD is reserved to the seven specific metals (As, Cd, Cu, Cr, Hg, Pb, Zn) and the organic chemical polychlorinated biphenyl (PCB) (Håkanson, 1980). However, mCD is more suitable for this study hence PCB was not analysed here. For classify the level of contamination based on mCD, the limiting values of mCD proposed by Abrahim (2005) was followed (Table 3.1).

Table 3.1: Classification of soil contamination based on mCD values

mCD classes	Modified degree of contamination
mCD< 1.5	Nil to very low degree of contamination
1.5 ≤ mCD< 2	Low degree of contamination
2 ≤ mCD< 4	Moderate degree of contamination
4 ≤ mCD< 8	High degree of contamination
8 ≤ mCD< 16	Very high degree of contamination
16 ≤ mCD< 32	Extremely high degree of contamination
mCD> 32	Ultra high degree of contamination

(Source: Abrahim, 2005)

3.5.5 Nemerow Integrated Contamination Factor

Nemerow integrated contamination index method is an integrated method compatible with extreme value, which is not only considers the role of single elements, but also highlights the importance of element with the most serious contamination. In this study, Nemerow integrated contamination factor (NICF) was computed using the following Equation 6.

$$NICF = \sqrt{\frac{CF_{iavg}^2 + CF_{i\max}^2}{2}} \quad (6)$$

Where NICF is the nemerow contamination index, CF_{avg} is the average value of contamination factor and CF_{max} is the maximum value of a single contamination factor in soil pollutant measured from a certain site. The classifications of contamination based on NICF are provided in Table 3.2.

Table 3.2: Nemerow integrated contamination index (NICF) classification

NICF range	Class of contamination
NICF≤ 0.7	Non-contaminated
0.7< NICF≤ 1	Warning line of contamination
1< NICF≤ 2	Low level of contamination
2< NICF≤ 3	Moderate level of contamination
NICF> 3	high level of Contamination

(Source: Dauvalter and Rognerud, 2001)

3.5.6 Enrichment Factor

Enrichment factor (EF) is used to determine the level of contamination by anthropogenic actions based on metal element accumulation by soil (Sakan et al., 2009). In this study, EF was calculated using the following Equation 7.

$$EF = \frac{(\frac{C_x}{C_{ref}})_{sediment}}{(\frac{C_x}{C_{ref}})_{background}} \quad (7)$$

Where, C_x is the concentration of metal element x, and C_{ref} is the concentration of the reference metal element in soil or the earth's crust, respectively (Kalender and Uçar, 2013). By the normalization of one metal element concentration with respect to a reference metal element concentration in soil, EF is calculated. In addition, a reference metal element is almost stable compared to other metal elements based on anthropogenic effect in the soil

(Ackerman, 1980). The elements of Al, Fe, Mn and Rb are typically used in many studies. In this study, for the assessment of EF, Al was used as the reference metal element because this normalizing metal element assumed less contamination with respect to the other studied metal elements in soil of the selected disposal site. According to Taylor (1964), the significance of EF for soil contamination is tabulated in Table 3.3.

Table 3.3: The degree of soil contamination based on EF

EF value	Designation of quality
>50	Extremely severe enrichment
25 - 50	Very severe enrichment
10 - 25	Severe enrichment
5 - 10	Moderately severe enrichment
3 - 5	Moderate enrichment
1 - 3	Minor enrichment
< 1	No enrichment

(Source: Taylor, 1964)

3.5.7 Geo-accumulation Index

The geo-accumulation index (I_{geo}) is used to evaluate the degree of contamination of soil by metal elements presences in soil. In this study, I_{geo} was computed using the following Equation 8 proposed by Järup (2003).

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (8)$$

Where, C_n is the measured concentration of a particular metal element and B_n is the geochemical background value (average shale value) of the same metal element. The numerical number of 1.5 as constant value is used in the index calculation to account the natural variations in the environment and small anthropogenic influences. In Table 3.4 represents the contamination classes of soil for different values of I_{geo}.

Table 3.4: Contamination classes of soil for I_{geo} values

I_{geo}	Value I_{geo}	Class designation of soil 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	Uncontaminated to moderately contaminated
0<	0	Uncontaminated

(Source: Järup, 2003)

3.5.8 Potential Ecological Risk Index

The potential ecological risk Index (PERI) was used as an indicator to check the ecological risk in soil (Håkanson, 1980). This strategy for assessing natural hazard considers the poisonous level, concentration of metal elements and biological affectability of those metal elements (Singh et al., 2010; Douay et al., 2013). PERI is formed by three basic parts: contamination factor (CF), toxic-response factor (TR) and ecological risk index (ER). According to this technique, in this study, the ER and PERI were calculated using the following Equation 9 and Equation 10, respectively.

$$ER = TR \times CF \quad (9)$$

$$PERI = \sum ER \quad (10)$$

Where, CF is measured by Equation 2 stated in Article No. 3.5.2. Here, ER is the ecological risk index of a particular metal element in soil, PERI is a comprehensive potential ecological risk index of a contaminated site; and TR is the toxic-response factor of a single metal element. The TR values proposed by Ajah et al. (2015) and Håkanson (1980) was used in this study provided in Table 3.5.

Table 3.5: Toxic-response factor (TR) values for several metal elements

Metals	Zn	Cr	Cu	Pb	Hg	Cd	As	Ni	Co
TR	1	2	5	5	10	30	10	5	5

(Source: Ajah et al., 2015; Håkanson, 1980)

The classic PERI method considers eight pollutants including PCBs, Hg, Cd, As, Pb, Cu, Cr and Zn. However, in this study, it was not possible to consider PCBs and Hg; but the metal elements of Ni and Co was used. The classification of the contamination of soil for various limits of ER and PERI is provided in Table 3.6.

Table 3.6: Classification of soil contamination based on potential ecological risk index (ER) and potential ecological risk index (PERI)

ER	Ecological risk degree	PERI	Ecological Risk degree
ER< 30	Slight	< 40	Slight
30≤ ER< 60	Medium	40≤ PERI< 80	Medium
60≤ ER< 120	Strong	80≤ PERI< 160	Strong
120≤ ER< 240	Very Strong	160≤ PERI< 320	Very Strong
ER≥ 240	Extremely Strong	PERI≥ 320	Extremely strong

(Source: Håkanson, 1980)

3.6 Statistical and Geostatistical Analysis

The statistical analysis such as descriptive statistical and Pearson's correlation was performed using SPSS to identify the correlations of metal elements with each other in soil of the waste disposal site. In addition, Geostatistical analysis of ordinary kriging (OK) was performed using ArcGIS to distribute the metal elements spatially and hence discussed in the following articles.

3.6.1 Descriptive Statistical Analysis

In this study, SPSS was used to calculate mean, median, 95% UCL, standard deviation (SD), standard error (SE), variance, coefficient of variance (COV), skewness and kurtosis of metal elements in soil of the selected disposal site. Steps followed for statistical analysis using SPSS were listed with screenshots in the Annex-A (A.1).

3.6.2 Pearson's Correlation Analysis

The study of Pearson's correlation reduces the ranges of uncertainty associated with decision making (Patil and Patil, 2010). The Pearson's correlation analysis is an elementary method to appraise the level of correlation among the factors included in this system. The purpose of the correlation analysis is to measure the intensity of association between two variables. The bivariate Pearson correlation produces a sample correlation coefficient, *r*, which measures the strength and direction of linear relationships between pairs of continuous variables. In this study, the value of correlation coefficient, *r*, was computed through XLSTAT using the following Equation 11 considering one dataset $\{x_1,...,x_n\}$ containing n values and another dataset $\{y_1,...,y_n\}$ containing n values.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})\,(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (11)$$

Correlation varies in the range [-1, 1]. The sign of the correlation coefficient indicated the direction of the correlations, while the magnitude of the correlation indicates the strength of the correlation (Patil and Patil, 2010). A perfectly negative linear correlation indicated by the value of -1, 0 value indicated no correlation and 1 indicated perfectly positive linear correlation. In this study, Pearson correlation was performed for both seasons.

3.6.3 Principal Component Analysis

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (PCs) (or sometimes, principal modes of variation) (Rencher, 1995). PCA is used to explain the variance-covariance structure of a set of variables through linear combinations. It is often used as a dimensionality-reduction technique. The PCs are in decreasing order based on factor loading, having the PCs with the largest variance occupying the first PC (PC1) and this follows successively to the PC with the smallest variance (PCn). In this study, the following Equation 12 was used through XLSTAT to compute the variance.

$$\left.\begin{aligned} PC1 = a_1x_1 + a_2x_2 + \cdots \ldots + a_nx_n \\ PCn = \sum_{j=1}^{n} a_{1j}x_j \end{aligned}\right\} \qquad (12)$$

where;

a_{1j} = eigenvectors obtained from the correlation matrix; x_j = input variables

In this study, PCA method was performed sequentially, first by information extraction in the input space (with n-dimensions) to determine the directions of which the input variables display the most substantial variability. The PC coefficients and the eigenvalues ($\lambda_i > 0, i = 1,2, \ldots . n$) 0 for the correlation matrix ($C = E\{xx^T\}$) with respect to their eigenvectors ($e_i > 0, i = 1,2, \ldots . n$) 0, is called the loadings were then calculated. These loading factors give a new set of variables that explains the variability in the original dataset; the first PCs retained a greater proportion of the total variance, consequently leading to effective and

practical dimensionality reduction exercise. The steps of PCA are illustrated with screenshots in the Annex-A (A.2).

3.6.4 Geostatistical Interpolation Techniques

Geostatistics is a class of statistics used to analyse and predict the values associated with spatial or spatiotemporal phenomena. Many geostatistical tools such as inverse distance weighting (IDW) and kriging were originally developed as a practical means to describe spatial patterns and interpolate values for locations where samples were not taken. Spatial interpolation is widely used when data are collected at distinct locations (e.g. soil profiles) for producing continuous information. In this study, the ordinary kriging (OK) was performed using ArcGIS to distribute the metal elements and various indices spatially. The steps for spatial distribution using OK through ArcGIS are listed with screenshots in the Annex-A (A.3).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 General

This chapter deals with the level of contamination of soil due to the presence of metal element in soil of a selected waste disposal site in different aspects. The statistical analysis was performed using Statistical Package for the Social Science (SPSS) and XLSTAT for heavy metals in soil and discussed in this chapter. In addition, the level of contamination of soil by heavy metals was investigated using various indices available in the literature and also illustrated in this chapter. The distribution of heavy metals in soil and various indices spatially and temporal variation of heavy metals were investigated using ArcGIS and hence discussed in the following articles.

4.2 Basic Statistical Analysis

The obtained concentration of metal elements were subjected to basic statistical analyses, in order to assist the interpretation of metal elements presence in soil of waste disposal site for dry season and rainy season. In this study, mean, median, 95% UCL, standard deviation (SD), standard error (SE), variance, coefficient of variance (COV), skewness and kurtosis of metal elements in soil were computed using SPSS. As the technical definition of 95% UCL demonstrated a number that one can be 95% confident and the true mean (average) concentration of the data is below that 95% UCL value (Daniels and Easterly, 2010). In this study, the 95% UCL is helpful for defining upper end or a limit of concentrations of a certain metal element in soil. Basically, 95% UCL is very useful as well as a standard way of representing exposure concentrations or risk analysis of the environmental field.

The values of skewness indicated the degree to which the analysed data are not symmetrical and kurtosis specified exactly how the peak and tails of a distribution fluctuated from the normal distribution (George and Mallery, 2010). Hence, skewness and kurtosis supports by giving primarily recognition of overall characteristics about the distribution of the concentration of metal elements in soil. According to George and Mallery (2010), the values for skewness and kurtosis between -2 and +2 are considered acceptable in order to prove normally distributed data. The COV and SD are the measure that is used to quantify the

amount of variation or dispersion of a set of data or in a distribution of data. In addition, COV is a standardized measure of dispersion of a probability distribution or frequency distribution. Higher COV means the greater the level of dispersion around the mean of the data. SD is a measure of the dispersion of values in the sample and the SE is a measure of the dispersion of values in the sampling distribution.

Table 4.1: Descriptive statistical data of metal concentrations in soil of dry season (n=40)

[a]ME	Mean	median	[b]UCL	[c]SD	[d]SE	Variance	[e]COV	[f]Skew	[g]Kurt
Fe	1363.94	1386.50	1456.95	350.15	8.75	122605.26	25.67	-0.08	-1.20
Mn	15.69	14.16	16.94	4.68	0.12	21.90	29.82	1.72	1.93
Cr	6.03	5.83	6.41	1.43	0.04	2.03	23.63	0.87	0.14
Cu	6.20	4.82	7.18	3.68	0.09	13.58	59.41	1.60	1.43
Pb	37.61	33.94	41.24	13.67	0.34	186.80	36.34	1.91	2.00
Zn	34.57	34.64	36.60	7.65	0.19	58.45	22.11	0.64	0.03
Ni	4.83	4.71	5.26	1.60	0.04	2.55	33.02	0.42	-0.95
Cd	4.55	4.4`6	4.85	1.14	0.03	1.29	24.99	0.40	-0.44
As	4.15	3.42	4.69	2.03	0.05	4.10	48.79	0.76	-0.64
Hg	4.63	4.01	5.18	2.07	0.05	4.27	44.63	0.83	-0.36
Co	7.00	6.67	7.65	2.42	0.06	5.84	34.50	0.41	-0.99
Na	68.30	77.89	76.06	29.22	0.73	853.63	42.78	-0.53	-1.34
K	292.00	316.37	319.91	105.06	2.63	11037.03	35.98	-0.43	-0.90
Ca	183.80	173.19	200.18	61.67	1.54	3803.00	33.55	0.60	-0.74
Al	490.25	458.46	542.74	197.61	4.94	39048.96	40.31	0.32	-0.66
Ti	1221.22	1223.83	1329.14	406.26	10.16	165044.80	33.27	0.17	-1.20
Sb	6.07	5.76	6.66	2.19	0.05	4.79	36.04	0.82	0.73
Sc	12.16	11.67	13.03	3.27	0.08	10.70	26.89	0.47	-0.52
Sr	27.53	26.62	29.75	8.35	0.21	69.69	30.33	0.90	1.11
V	43.44	40.83	47.29	14.49	0.36	209.88	33.35	0.77	0.47
Ba	65.25	60.61	71.73	24.38	0.61	594.31	37.36	0.69	-0.64

[a]Metal element, [b]95% UCL (normal), [c]Standard deviation, [d]Standard error, [e]Coefficient of variance, [f]Skewness, [g]Kurtosis

The descriptive statistical data for concentration of metal elements in soil of waste disposal site for dry season and rainy season are provided in Table 4.1 and Table 4.2, respectively. In this study, the results obtained from laboratory indicated very clearly the preponderance of metal elements in soil of disposal site. The metal elements considered in this study in soil for dry season can be ordered as Fe> Ti> Al> K> Ca> Na> Ba> V> Pb> Zn> Sr> Mn> Sc> Co> Cu> Sb> Cr> Ni> Hg> Cd> As. In addition, the values of skewness and kurtosis of the metals in soil for dry season indicated the data represented that the data was distributed

normally. The values of COV and SD for the metal element of Ti were found to be greater than that of other metal elements, thus, indicated highest dispersion range of Ti within the soil sampling area in dry season. In addition, the highest COV was found for Cu, represented high level of scattering around the mean value of Cu in the data set.

Table 4.2: Descriptive statistical data of metal concentration in soil of rainy season (n=20)

[a]ME	Mean	median	[b]UCL	[c]SD	[d]SE	Variance	[e]COV	[f]Skew	[g]Kurt
Fe	365.79	287.65	434.66	179.06	8.95	32062.53	48.95	0.46	-1.46
Mn	5.41	3.88	7.02	4.18	0.21	17.47	77.24	0.59	-1.11
Cr	1.94	1.54	2.45	1.32	0.07	1.74	67.98	1.62	1.88
Cu	2.55	2.43	3.05	1.29	0.06	1.65	50.37	1.21	1.97
Pb	17.54	16.34	19.03	3.88	0.19	15.04	22.12	0.34	-0.72
Zn	17.58	17.23	18.81	3.21	0.16	10.30	18.25	0.50	0.29
Ni	2.58	2.70	3.01	1.11	0.06	1.24	43.05	0.53	-0.06
Cd	2.03	1.88	2.31	0.74	0.04	0.54	36.23	1.12	0.75
As	1.56	1.11	1.90	0.88	0.04	0.78	56.63	1.45	0.69
Hg	1.72	1.12	2.22	1.29	0.06	1.67	75.26	1.79	1.92
Co	5.11	4.95	6.09	2.54	0.13	6.44	49.65	0.21	-1.56
Na	25.74	21.68	31.08	14.42	0.72	207.81	56.01	0.74	-0.32
K	126.86	110.52	152.49	66.64	3.33	4440.56	52.53	0.99	-0.24
Ca	100.16	105.32	112.61	32.39	1.62	1048.98	32.34	-0.18	-1.18
Al	239.76	224.02	275.06	91.77	4.59	8421.38	38.27	0.43	-1.09
Ti	707.89	696.70	822.45	297.85	14.89	88715.74	42.08	0.68	0.76
Sb	3.41	3.35	4.05	1.66	0.08	2.75	48.60	0.14	-1.09
Sc	7.73	7.87	8.74	2.63	0.13	6.92	34.03	-0.14	-0.84
Sr	16.92	16.20	19.13	5.75	0.29	33.03	33.96	0.72	0.19
V	21.43	20.15	25.10	9.53	0.48	90.87	44.48	0.37	-0.66
Ba	39.58	39.92	45.63	15.74	0.79	247.67	39.77	0.33	-0.52

[a]Metal element, [b]95% UCL (normal), [c]Standard deviation, [d]Standard error, [e]Coefficient of variance, [f]Skewness, [g]Kurtosis

Furthermore, the mean concentrations of metal elements displayed slight seasonal variation of rainy season in the order of Ti> Fe> Al> K> Ca> Ba> Na> V> Zn> Pb> Sr> Sc> Mn> Co> Sb> Ni> Cu> Cd> Cr> Hg>As in soil through the study area. According to the values of skewness and kurtosis of metal elements in soil during rainy season, results represented the data set was normally distributed. The highest COV was found for Cr, represented the high level of dispersal around the mean value of Cr. Furthermore, the COV and SD of Ti was found to be greater than that of other metal elements, thus, indicated highest dispersion range of Ti within the selected soil sampling area in rainy season.

The order of metal element presence in soil of waste disposal site of this study as well as from other researchers for similar cases from different countries available in the literature is summarized in Table 4.3. Based on Table 4.3, it can be observed that the concentration of Fe was found comparatively higher than that of other counter metal elements for dry season and similar results for Fe was also observed by Haque et al. (2013) and Mamtaz and Chowdhury (2008) for soil samples collected from waste disposal site in Matuail, Dhaka, Bangladesh. In addition, this consequence for the concentration of Fe was also supported by Islam et al. (2012) in soil of waste disposal site in Gazipur, Bangladesh.

Table 4.3: Order of metal element in soil in this study and from other researchers

Location	**Order of metal concentrations**	**Reference**
Rajbandh, Khulna	Fe> Ti> Al> K> Ca> Na> Ba> V> Pb> Zn> Sr> Mn> Sc> Co> Cu> Sb> Cr> Ni> Hg> Cd> As (dry season) Ti> Fe> Al> K> Ca> Ba> Na> V> Zn> Pb> Sr> Sc> Mn> Co> Sb> Ni> Cu> Cd> Cr> Hg>As (rainy season)	Present Study
Enugu, Nigeria	Pb>Fe>As>Cu>Zn>Co>Ni>Cd>Cr>Mn (dry season) Pb>Fe>As>Co>Zn>Ni>Cu>Cd>Cr>Mn (rainy season)	Ajah et al., 2015
Matuail, Dhaka, Bangladesh	Fe>Ni>Cu>Cr>Cd	Haque et al., 2013
Matuail, Dhaka, Bangladesh	Fe>Zn>Pb>Cu>Mn>Ni>Cd	Mamtaz and Chowdhury, 2008
Gazipur, Bangladesh	Fe>S>P>Zn>Pb>Cu> Cd	Islam et al., 2012
Hyderabad, India	Pb>Cr>Zn>As>Cu>Ni	Parth et al., 2011
Islamabad, Pakisthan	Mg>K>Ca>Zn>Na>Pb>Ni>Cd>Cu>Cr	Ali et al., 2014
Changchun, Chaina*	Cr>Zn>Cu>Pb>Cd	Jiang et al., 2014
Stepanovice, Czeck Republic	Mn>Cr>Ni>Cu>Zn>Co>Pb>Cd>Hg	Adamcová et al., 2016

**coal gangue dumpsite*

In addition, the quantitative distribution of the range of metal elements present in soil during the dry and rainy seasons is depicted in Figure 4.1 and Figure 4.2, respectively. Among all studied metal elements in soil, Fe was the main dominant with concentration ranges from

1785.77 to 733.20 mg/kg in dry season (Figure 4.1). Besides, Ti was the main dominant with ranges from 1445.65 to 243.88 mg/kg in rainy season (Figure 4.2).

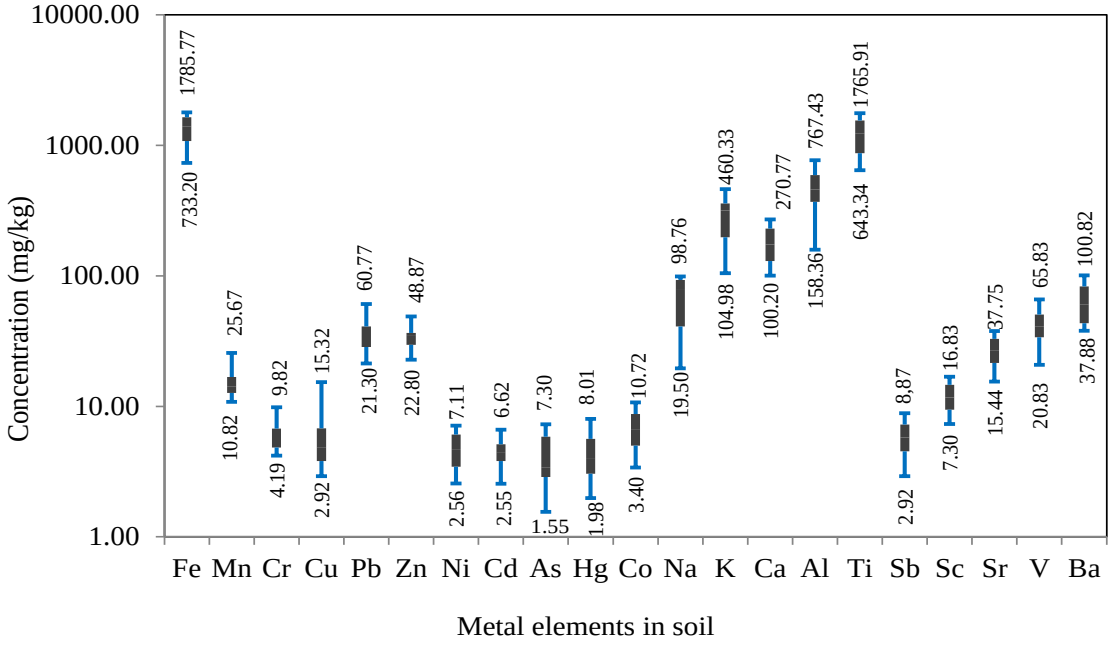


Figure 4.1: Range of metal element concentrations in soil of disposal site for dry season.

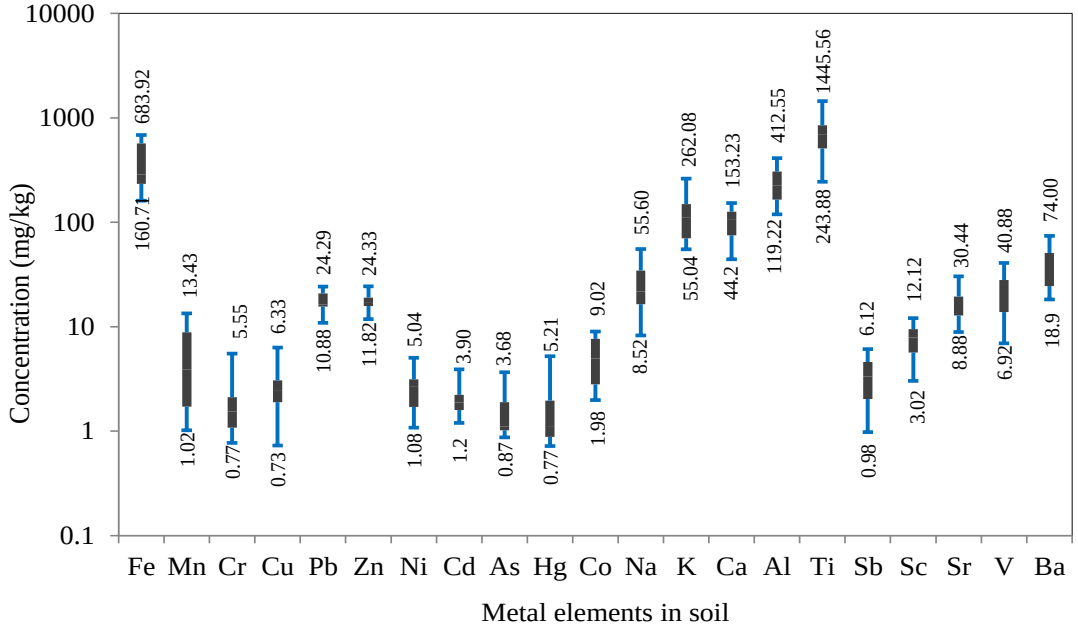


Figure 4.2: Range of metal element concentrations in soil of disposal site for rainy season.

The basic statistical analysis reveals that the soil of the selected waste disposal site was highly contaminated by Fe. This statement also supported by the other researchers for waste disposal site of Bangladesh (Haque et al., 2013; Mamtaz and Chowdhury, 2008 and Islam et al., 2012). But compared to those research data, the concentration of Fe was comparatively lower for the present study. Eddy et al. (2006) suggested that any pollution of the

environment by Fe cannot be conclusively linked to waste materials alone but other natural sources of Fe. According to world health organization (WHO, 1984) the deficiency of Fe in man can cause weak muscular coordination, vomiting, diarrhea and other serious health defects.

Another metal abundance in the soil of the sampling site was Ti. Naturally, Ti presented in the earth in a big proportion since the crustal abundance value of Ti is 5700 ppm (Krauskopf and Bird, 1995). It is extensively used as a pigment in house paint, plastics, enamels and paper. In addition, a former study investigating metal elements present in soils and vegetables collected from different agricultural fields of Dacope, Khulna, illustrated Ti concentration in that collected soil was 3000 to 8000 ppm (Rahman et al., 2016). Therefore, abundance of Ti in the waste disposal site soil was not only for MSW dumped there but also for the natural components of soil of the site. Variation in concentration of metal elements in two different seasons was discovered in the above analysis. Most of the elements had greater concentration in soil during dry season but less in rainy season. Such variation was caused by the metal element infiltrates in soil through rain water and different soluble capacity of metals in rainy season (Rahman et al., 2012).

4.3 Evaluation of Soil Quality Comparing with Allowable Limit

In this study, 95% UCL of the arithmetic mean of metal elements in soil for both, dry season and rainy season were compared with the maximum allowable limits for soil published by different countries available in literature is listed in Table 4.4. In this analysis, 95% UCL of mean was considered to avoid the uncertainly associated with estimating the true average concentration at a site stated in USEPA (1989). Different organizations and countries provides the maximum allowable limits of metal concentrations in soil, as soil quality guidelines for the protection of environment and human health from contaminated sites. In the present study, the soil sample for dry and rainy seasons showed comparatively the lower concentration of Cr, Cu, Pb, Zn, and Ni than that of maximum allowable limits proposed by different countries except WHO (Table 4.4). Furthermore, the soil sample for dry and rainy seasons showed comparatively the lower concentration of Co than that of maximum allowable limits proposed by different countries. Besides, the concentration of Cd for dry season exceeds the allowable limits stated by WHO, CCME, Poland, UK and USA except

Austria. In addition, the soil sample for rainy season showed comparatively the lower concentration of Cd than that of maximum allowable limits proposed by different countries except WHO and CCME (Table 4.4).

Table 4.4: Concentration of metal elements in soil in the present study as well as maximum allowable limit of metals in soil (mg/kg) of different sources

Metal element	WHO standard	CCME	Austria	Canada	Poland	Japan	UK	Germany	U.S.A	Present study	
										Dry season	Rainy season
Fe	3000-250000	-								1456.95	434.66
Mn	200-9000	-								16.94	7.02
Cr	0-85	64	100	75	100		50	200	1000	6.41	2.45
Cu	-	63	100	100	100	125	100	50	100	7.18	3.05
Pb	15-20	70	100	200	100	400	100	500	200	**41.24**	**19.03**
Zn	20-300	200	300	400	300	250	300	300	300	36.60	18.81
Ni	0-100	45	100	100	100	100	50	100	500	5.26	3.01
Cd	0-30	1.4	5	8	3	-	3	-	0.7	**4.85**	**2.31**
As	-	12								4.69	1.90
Hg	-	6.6								5.18	2.22
Co	-	40	50	25	50	50	-	-	40	7.65	6.09
Sb	-	20								6.66	4.05
V	-	130								47.29	25.10
Ba	-	750								71.73	45.63

CCME=Canadian Council of Ministers of the Environment. (Source: Akaeze, 2001; Anhwange and Asemave, 2013; Kabata-Pendias, 1995; USEPA, 1983; WHO, 1984).

The Figure 4.3 illustrates the comparison of Pb concentration in soil in this study with allowable limits from different countries available in the literature. The Figure 4.3 reveals that the mean concentration of Pb in dry and rainy season satisfied the maximum allowable limit of metal elements in soil of different countries except WHO. In dry season, the seasonal concentration of Pb was not found within the range of WHO.

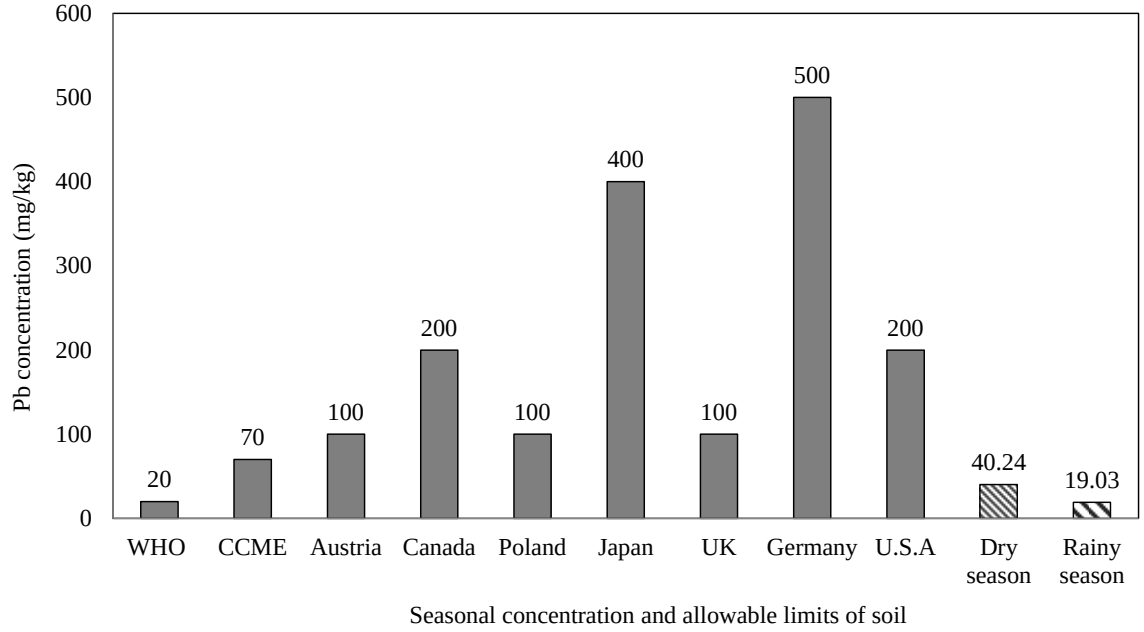


Figure 4.3: Comparison of Pb in this study with allowable limits from different sources.

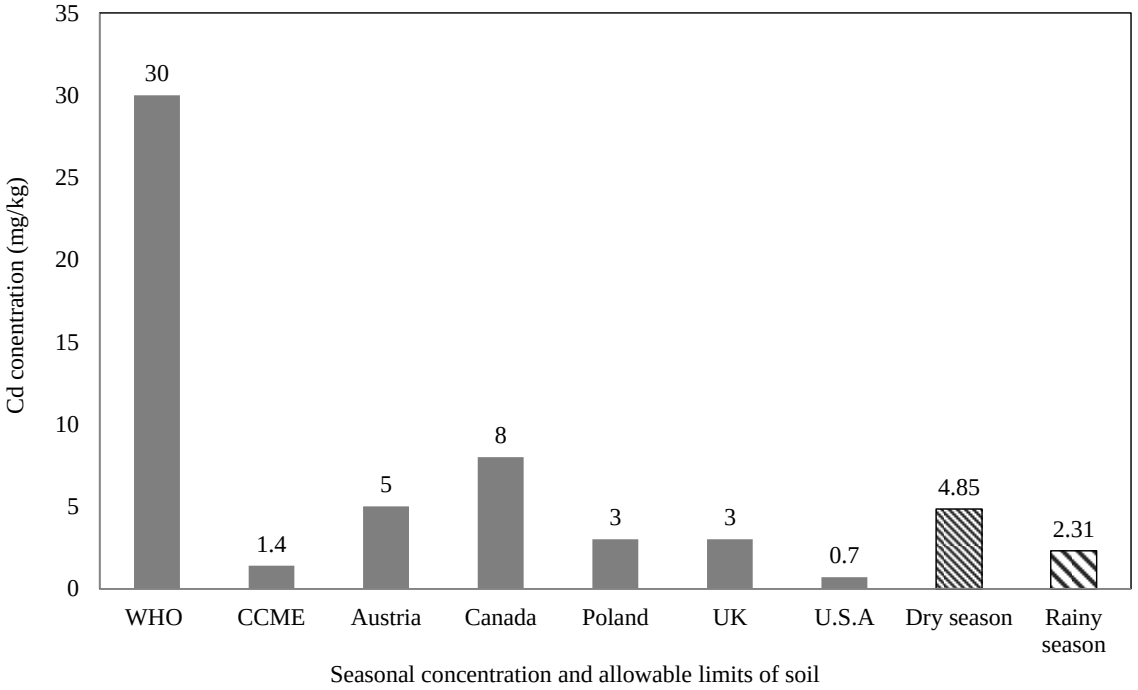


Figure 4.4: Comparison of Cd concentration in the present study with allowable limits from different sources.

The Figure 4.4 illustrates the comparison of Cd concentration in the present study and maximum allowable limits from different countries available in the literature. The mean

concentrations of Cd in both the dry and rainy season were found within the standard range provided by WHO and maximum allowable limit of Austria and Canada (Table 4.4). However, from Table 4.4 and Figure 4.4 it was observed that the mean concentration of Cd in soil for dry and rainy season exceed the maximum allowable limit, 0.3 mg/kg of USA and 1.4 mg/kg of CCME. In this study, the value of Cd in soil for dry season only goes over maximum allowable limit of metals in soil of Poland and UK.

The concentration of Pb and Cd can easily accumulate in the bodies of soil organisms. In fact, they are particularly very dangerous chemical, as they can accumulate in individual organisms, but also in entire food chains (Singh et al., 2011). Moreover, soil functions are disturbed by Pb and Cd intervention, where extreme concentrations are present. Toxicological effects of Pb and Cd on soil microbes lead to the decrease of their numbers and activities though it depend largely on the type and concentration of metal and incubation time (Khan et al., 2010). The main sources of Pb and Cd in municipal solid waste are lead-acid batteries, household batteries, consumer electronics, glass and ceramics, plastics, soldered cans Pigments etc. (Korzun and Heck, 1990). The value of Pb is one out of four metals that have the most damaging effects on human health like anaemia, high blood pressure, kidney damage, brain damage, etc.

4.4 Variation of Metal Content in Soil

The concentration of different metal elements in soil of the study area for dry season and rainy season are provided in Table 4.1 and Table 4.2, respectively. Moreover, the variation and comparison of the concentration of metal elements of Fe, Mn, Cu, Pb, Ni and Co in soil in relation to the changing of soil sampling distances from the centre of disposal site as well as for two sampling period are analysed and hence discussed in the following articles. Moreover, the spatial and seasonal variation of the metal elements of Cr, Zn, As, Cd, Hg, Na, K, Ca, Al, Ti, Sb, Sc, Sr, V and Ba in soil are presented in Figure C.1 to Figure C.15, respectively in the Annex-C.

4.4.1 Iron

The variation of Fe concentration in soil in relation to the changing of soil sampling distances from approximate the central point of waste disposal site during both seasons was shown in

Figure 4.5. In the early stage, the magnitudes of Fe were found to be higher and then it comparatively dropped until the end of the dry and rainy seasons (Figure 4.5). The Figure 4.5 reveals the concentration of Fe decreases in relation to the increasing of soil sampling distances for both the dry and rainy season. Here, it can be noted that the soil sample in case of dry season showed comparatively the higher values of Fe concentration than that of rainy season for the infiltration and dilution of metal content in rain water. This statement was also supported by Yahaya et al. (2009) and Rahman et al. (2012). Moreover, the concentration of Fe was found to be approximately 2.5, 5.0 and 6.0 times higher in dry season than that of rainy season for the sampling distances of 30, 180 and 300m, respectively. Based on the experimental results, it can be concluded that the magnitude of Fe concentrations during dry season were combatively higher than that of rainy season.

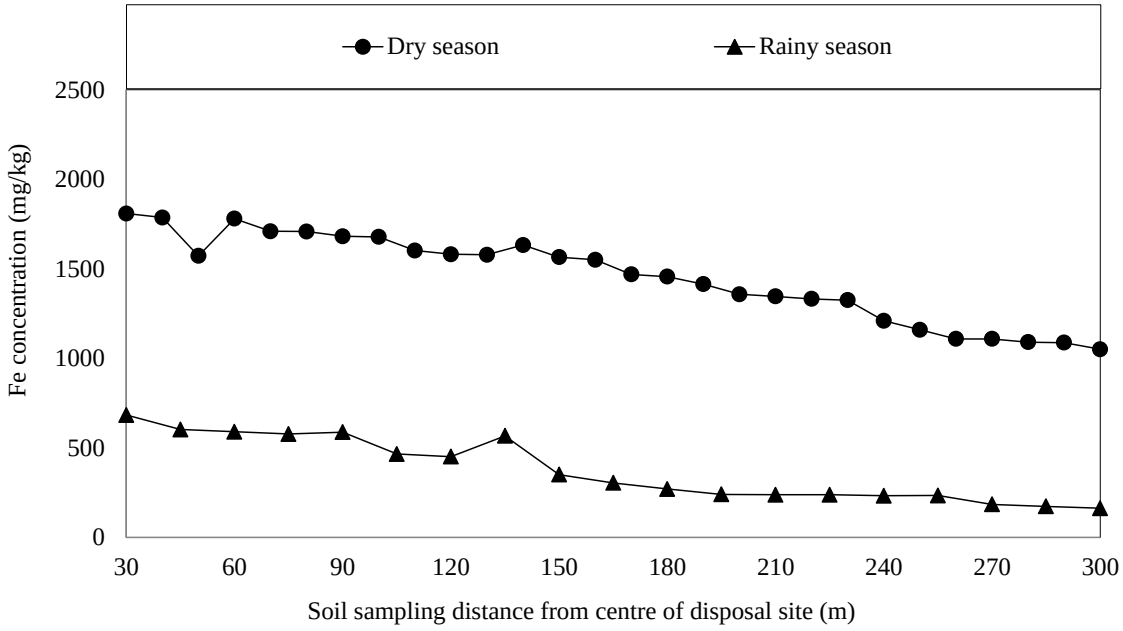


Figure 4.5: Spatial and seasonal variation of Fe concentration in soil.

The comparison of Fe concentration in soil for dry and rainy season in the present study with other researchers for similar cases is shown in Figure 4.6 and Figure 4.7, respectively. A study conducted by Yahaya et al. (2009) in Enugu landfill of Nigeria and presented the distribution of Fe in soil in both seasons and it was showing a similar pattern as reported in this study but showed a higher concentration during dry season. In dry season, distribution of Fe reported by Rahman et al. (2012) in case of Dhaka EPZ area had also a steady decrease in Fe concentration with distance as like the present study but the concentration range was excessive compared to the present study. However, distribution pattern of Fe concentration

during rainy season was found to be the different because of having a dramatic fall in Fe concentration in 110 to 150 m.

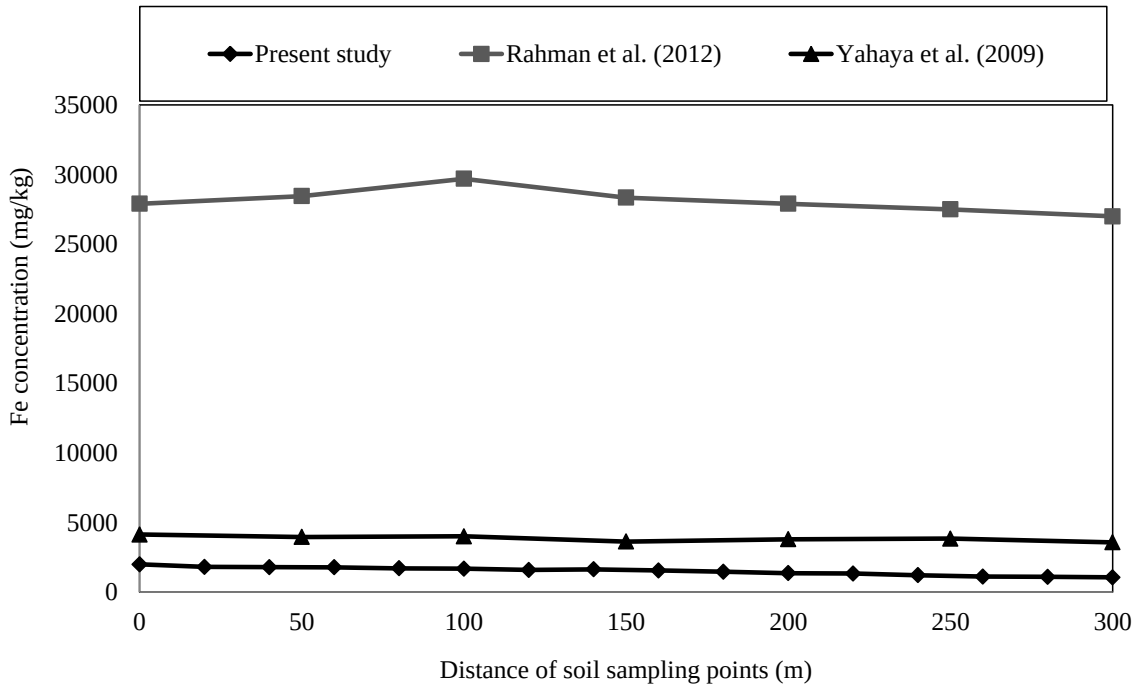


Figure 4.6: Comparison of Fe concentration in soil during dry season with other researchers for similar cases.

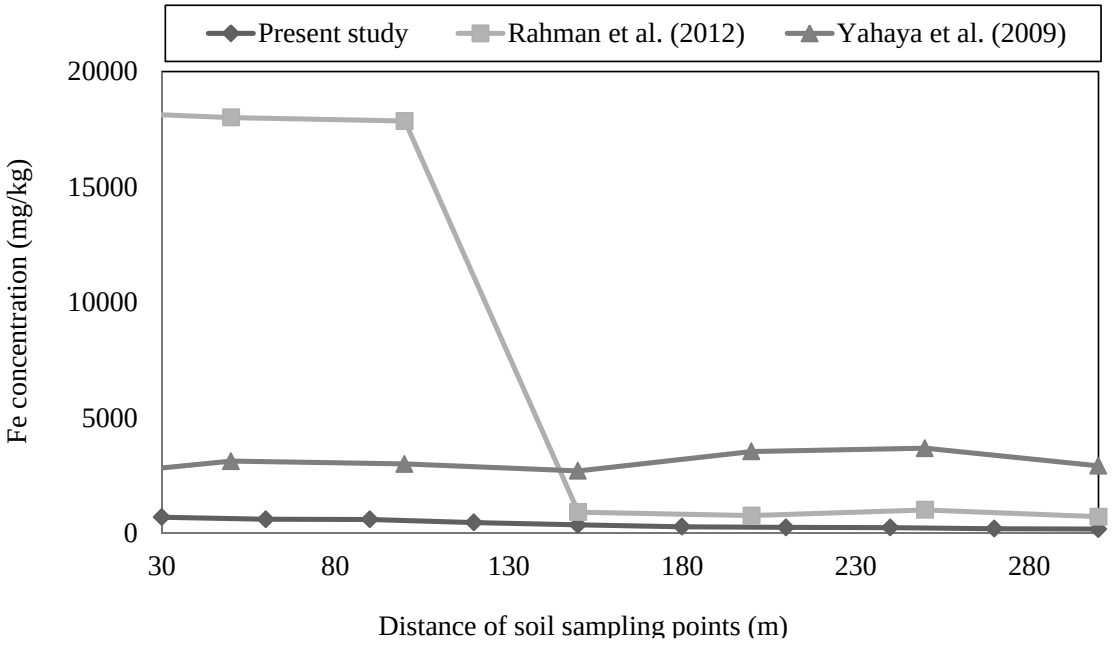


Figure 4.7: Comparison of Fe concentration in soil during rainy season with other researchers for similar cases.

4.4.2 Manganese

The variation of Mn concentration in soil, respect to soil sampling distances from approximately the central point of waste disposal site during dry season and rainy season are shown in Figure 4.8. Figure 4.8, respectively. The figures reveal that the concentration of Mn displayed dramatic rise and fall in spatial distribution for dry season, while steady decrease occurred during rainy season. Moreover, the concentration of Mn was found to be approximately 2.5, 4.0 and 11.5 times higher in dry season than that of rainy season for the sampling distances of 30, 180 and 300m, respectively.

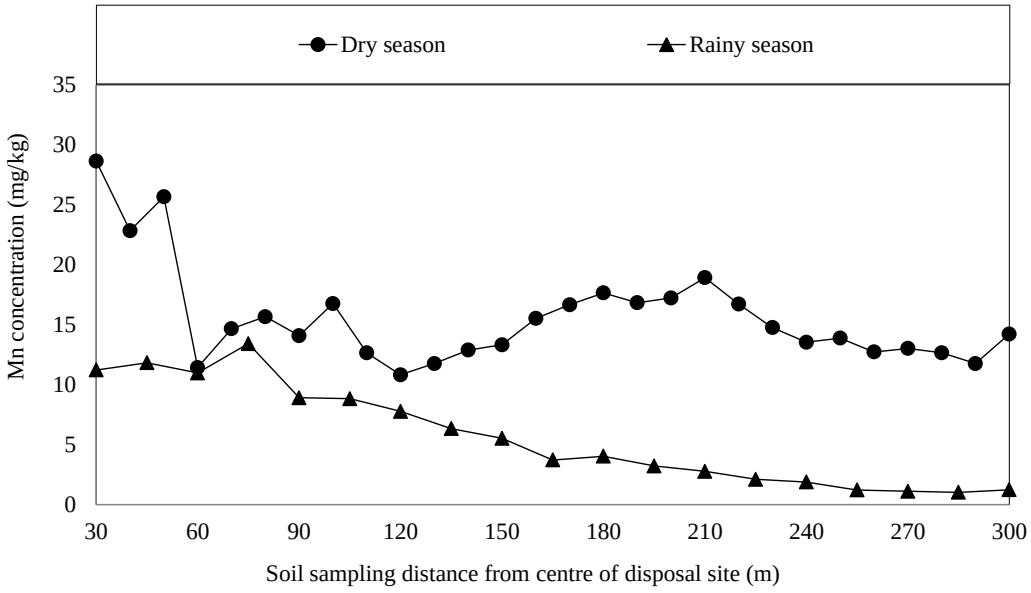


Figure 4.8: Spatial and seasonal variation of Mn concentration in soil.

The comparison among present study and similar studies of other researchers based on Mn concentration in soil for both the dry and rainy season is illustrated in Figure 4.9 and Figure 4.10, respectively. Here, the concentration of Mn was relatively lower in present study than the reported values by Rahman et al., (2012) and Yahaya et al. (2009). Moreover, the distribution pattern of the Mn was steadier in both seasons than the distribution patterns for the same seasons represented by Rahman et al., (2012) and Yahaya et al. (2009).

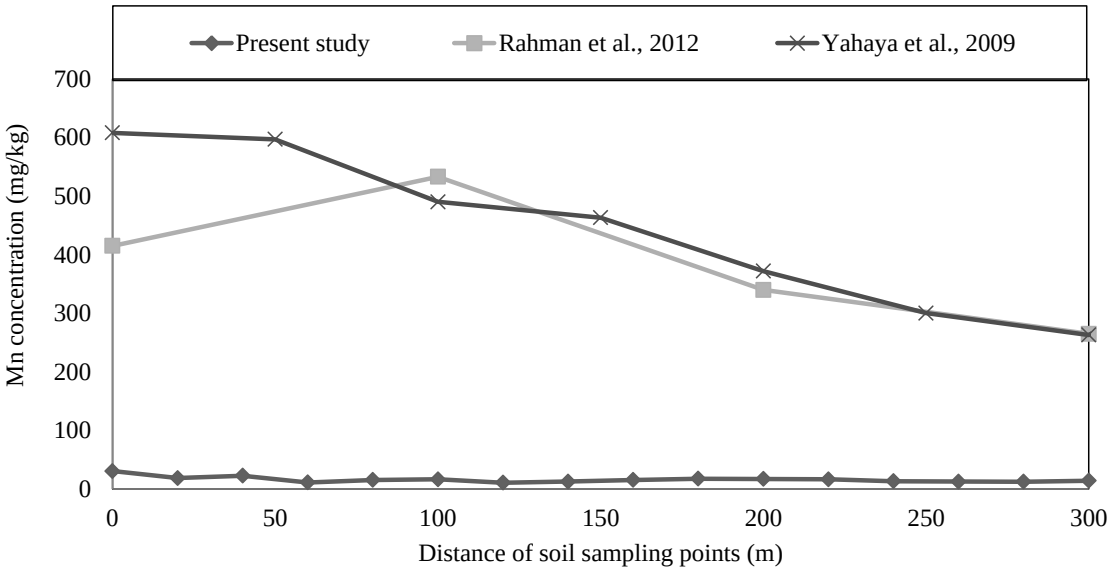


Figure 4.9: Comparison of Mn concentration in soil during dry season with other researchers for similar cases.

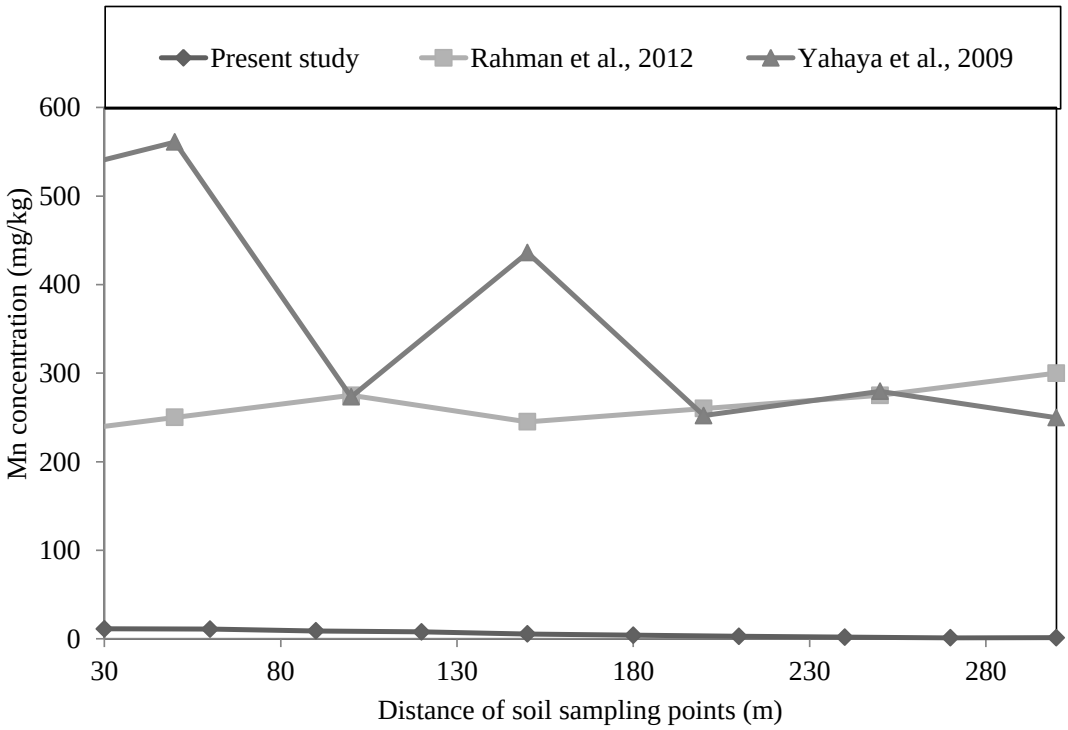


Figure 4.10: Comparison of Mn concentration in soil during rainy season with other researchers for similar cases.

4.4.3 Copper

The line graphs in Figure 4.11 demonstrates the change of the concentration level of Cu in soil samples collected within 30 to 300 m distance from approximate central point of the

selected disposal site during dry and rainy seasons. In Figure 4.11, the distribution of Cu showing steady decrease in concentration with the changing of soil sampling distances. Moreover, the concentration of Cu was found to be approximately 2.0, 2.3 and 4.0 times higher in dry season than that of rainy season for the sampling distances of 30, 180 and 300m, respectively (Figure 4.11).

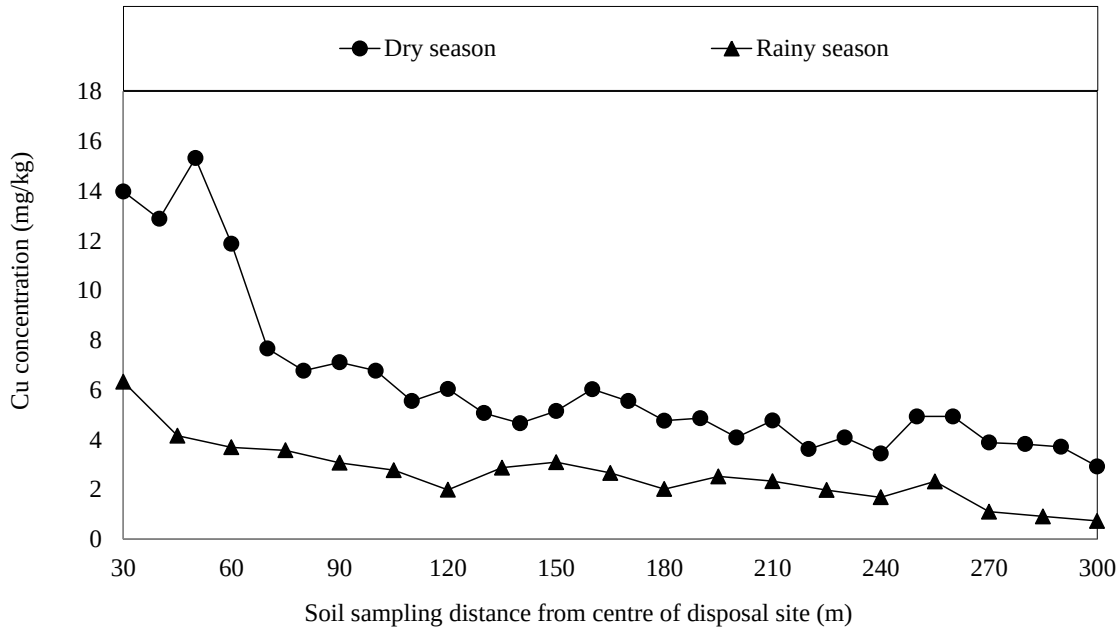


Figure 4.11: Spatial and seasonal variation of Cu concentration in soil

The Figure 4.12 and the Figure 4.13 describes the Cu distribution pattern along soil sampling distance of present study with other two analogous studies during dry and rainy season, respectively. According to Figure 4.12, Cu distribution pattern in present study is similar to Rahman et al. (2009) in dry season except a study reported by Yahaya et al. (2009). Besides, in rainy season, the Cu distribution pattern is similar in three research findings (Figure 4.13). However, the soil samples of this study have lower concentration of Cu than the two parallel studies considered in this article.

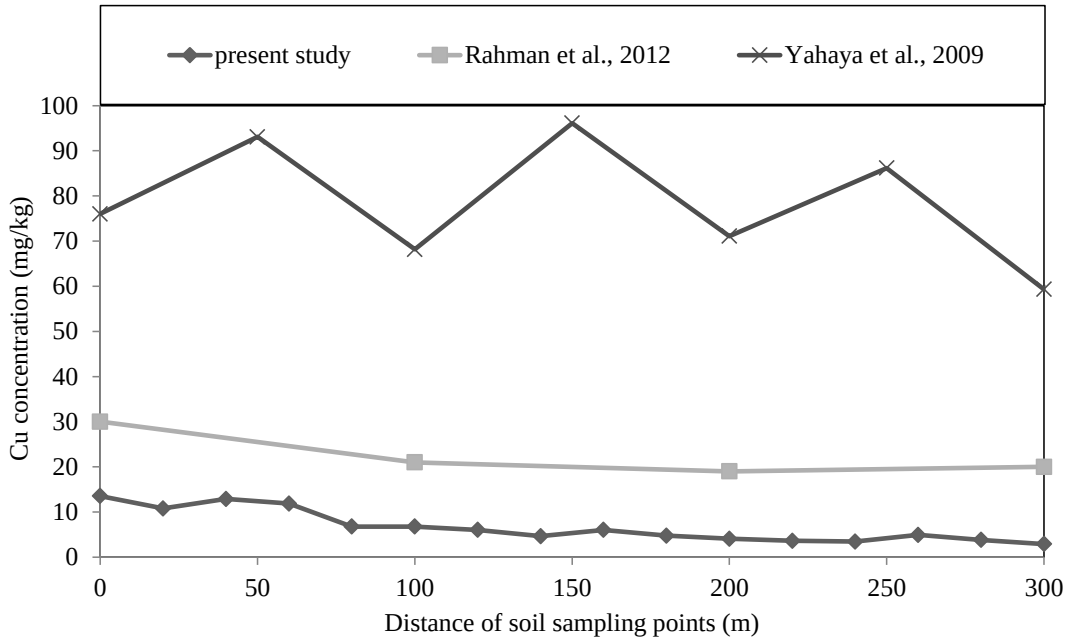


Figure 4.12: Comparison of Cu concentration in soil during dry season with other researchers for similar cases.

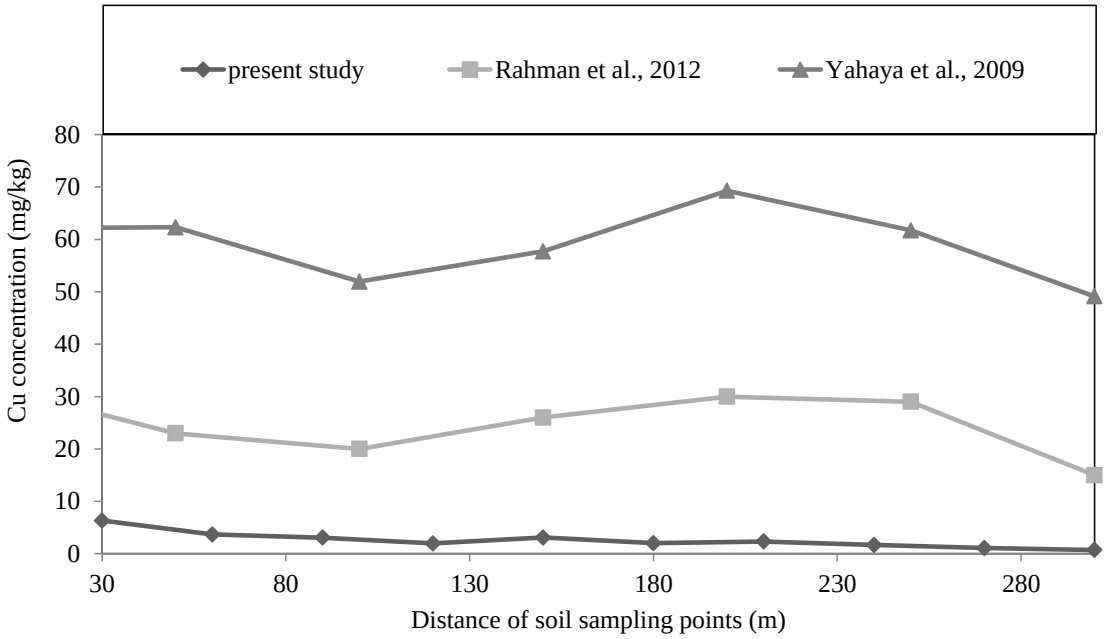


Figure 4.13: Comparison of Cu concentration in soil during rainy season with other researchers for similar cases.

4.4.4 Lead

Figure 4.14 shows the pattern of Pb distribution in soil within 30 to 300 m distance from central point of the waste disposal site during both the dry and rainy season. In dry season, the line diagram shows some fluctuation in Pb concentration in soil laterally. Moreover, the concentration of Pb was found to be approximately 3.0, 2.4 and 2.4 times higher in dry season than that of rainy season for the sampling distances of 30, 180 and 300m, respectively. Thus, rainy seasonal Pb concentration shows about half of the values than that of dry season. Comparing the Pb concentration of the present study with two other researches of similar case available in the literature during dry and rainy season, are presented in Figure 4.15 and Figure 4.16, respectively. The distribution of Pb shows fairly similar pattern and more or less similar values of Pb concentration in soil for both seasons.

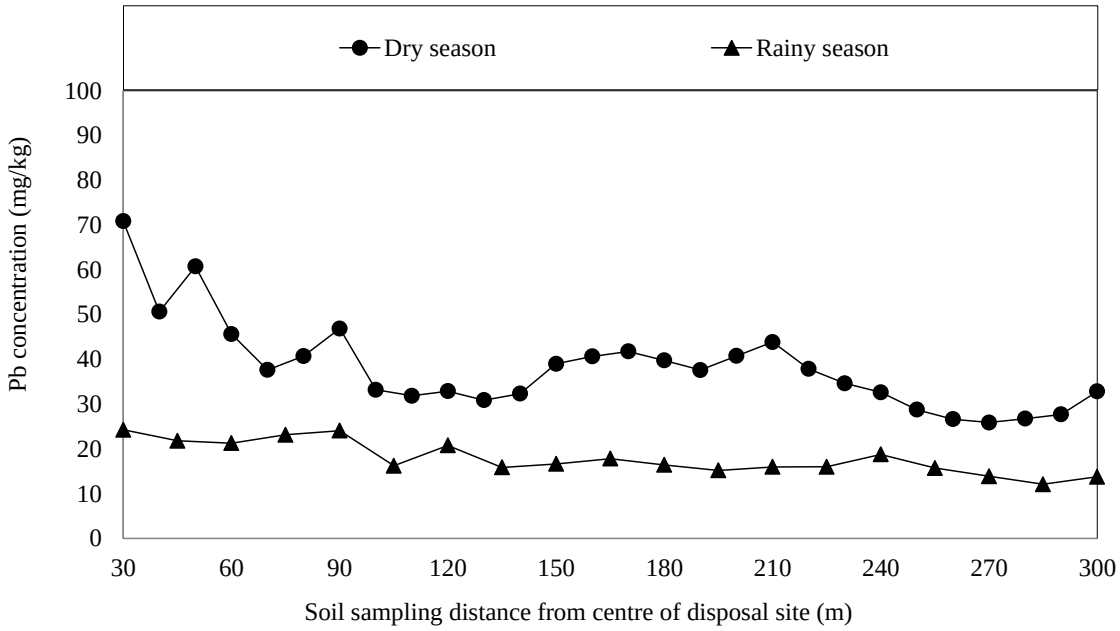


Figure 4.14: Spatial and seasonal variation of Pb concentration in soil.

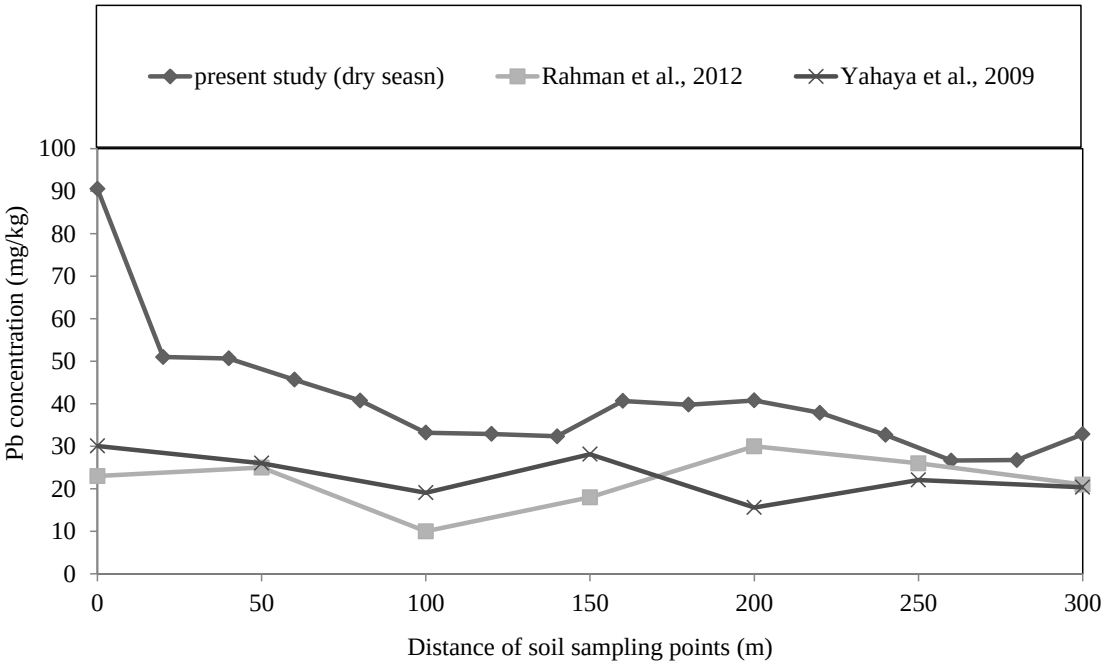


Figure 4.15: Comparison of Pb concentration in soil during dry season with other researchers for similar cases.

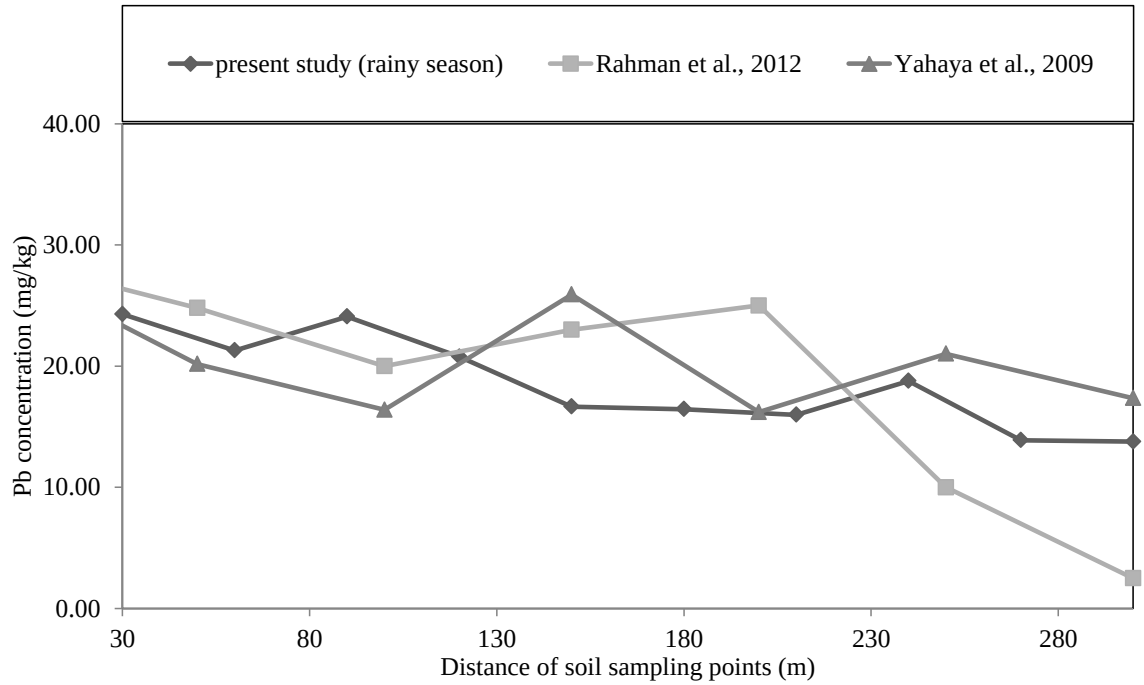


Figure 4.16: Comparison of Pb concentration in soil during rainy season with other researchers for similar cases.

4.4.5 Nickel

The line graphs in Figure 4.17 illustrate the changes of concentration level of Ni in soil collected within 30 to 300 m distance from approximately centre of the disposal site during dry season and rainy season. In Figure 4.17, Ni concentration decreases in relation to the increasing of soil sampling distances with slight fluctuations at some points during both seasons. Moreover, the concentration of Ni was found to be approximately 1.5, 1.5 and 2.2 times higher in dry season than that of rainy season for the sampling distances of 30, 180 and 300m, respectively.

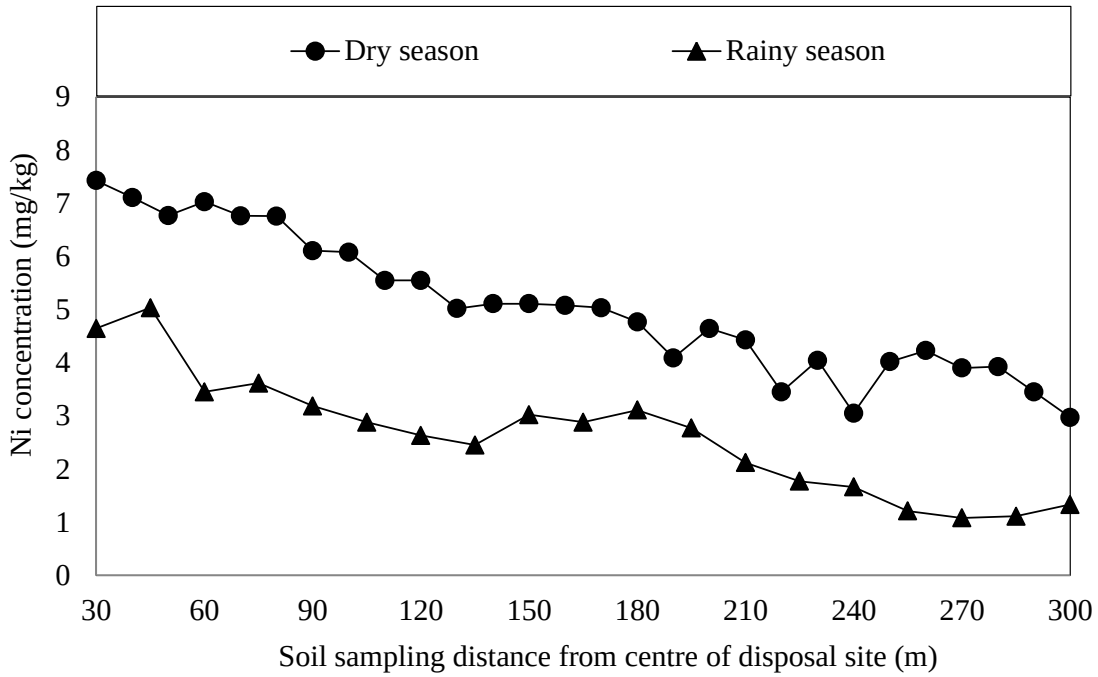


Figure 4.17: Spatial and seasonal variation of Ni concentration in soil.

The Figure 4.18 and Figure 4.19 describes the distance wise Ni distribution pattern of present study with other two corresponding studies during dry and rainy season, respectively. The seasonal Ni concentrations were very low and steady in compared to other two researchers.

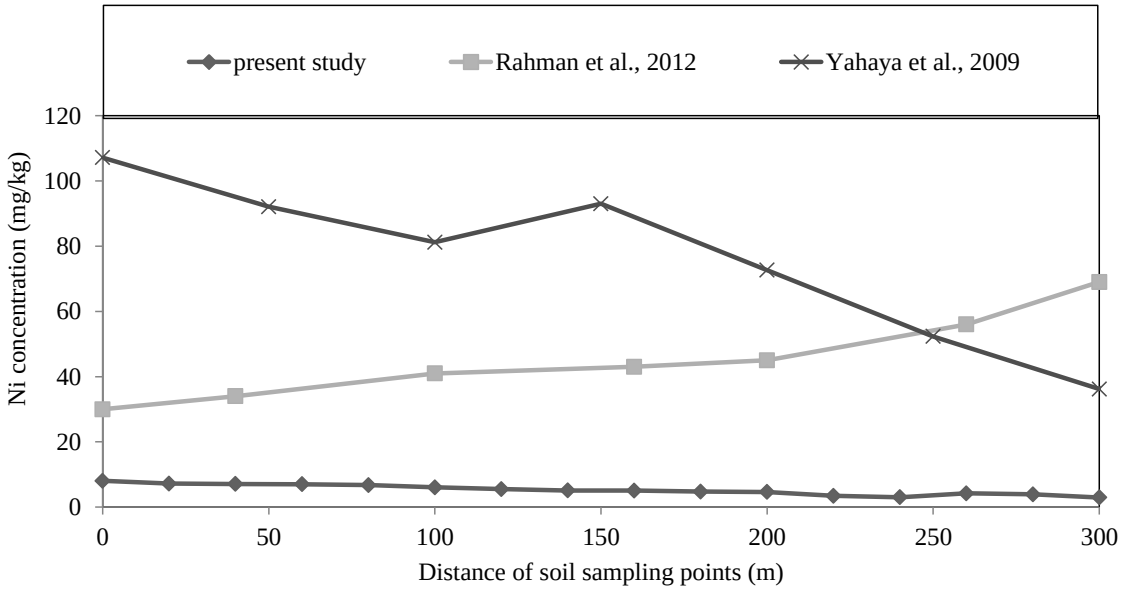


Figure 4. 18: Comparison of Ni concentration in soil during dry season with similar studies.

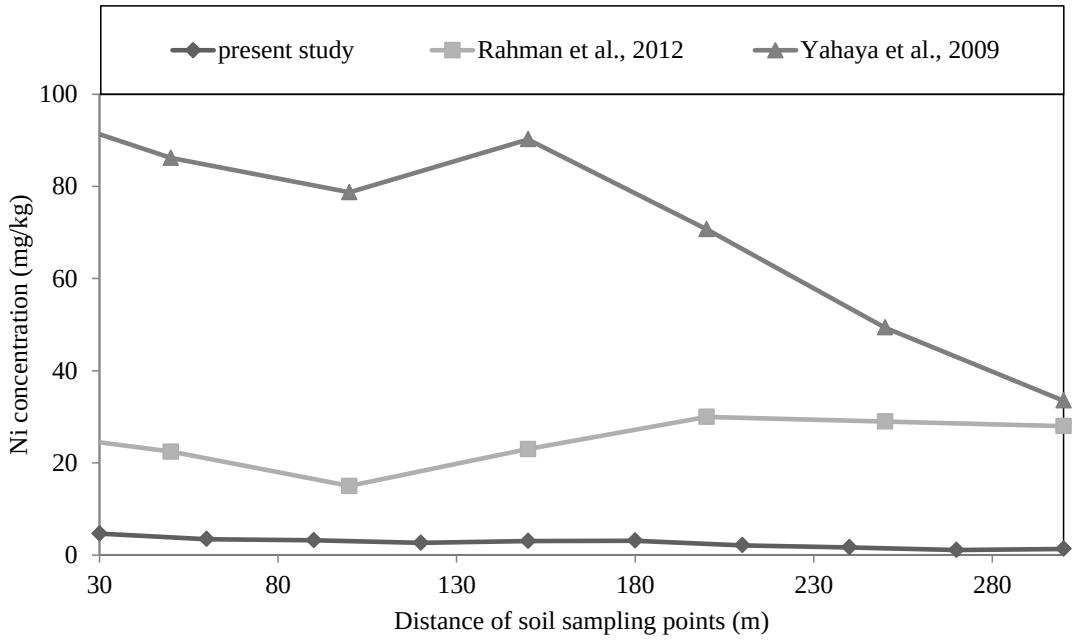


Figure 4.19: Comparison of Ni concentration in soil during rainy season with other researchers for similar cases.

4.4.6 Cobalt

The line graphs in Figure 4.20 explains the changes of concentration level of Co in soil collected within 30 to 300 m distance from approximate centre of the waste disposal site during two seasons. In Figure 4.20, Co concentration is showing gradual decreasing trend during both seasons with respect to the increasing of soil sampling distances with slight fluctuations at some points. Additionally, the concentration of Co was found to be approximately 1.25, 1.5 and 2.3 times higher in dry season than that of rainy season for the sampling distances of 30, 180 and 300m, respectively.

The Figure 4.21 and Figure 4.22 represent the Co distribution pattern of the present study with other two corresponding studies during dry and rainy season, respectively. The concentrations of Co in soil of the present study were slightly higher than that of a study conducted by Yahaya et al. (2009) during both seasons. But concentrations of the present study were more fluctuated in compared with other researcher of Ajah et al. (2015).

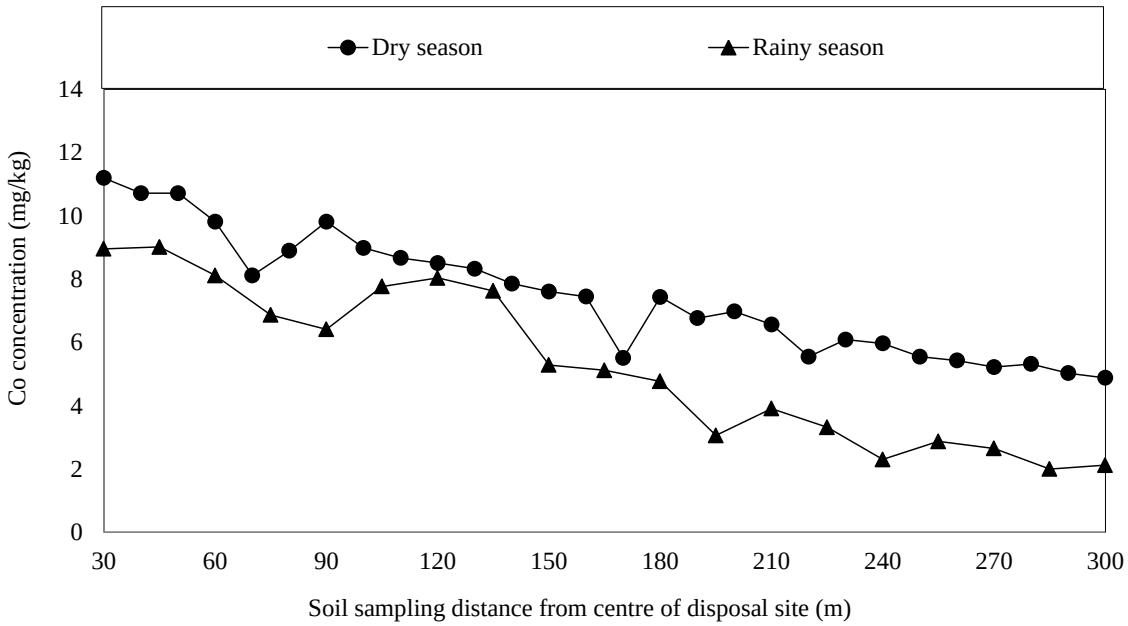


Figure 4.20: Spatial and seasonal variation of Co concentration in soil.

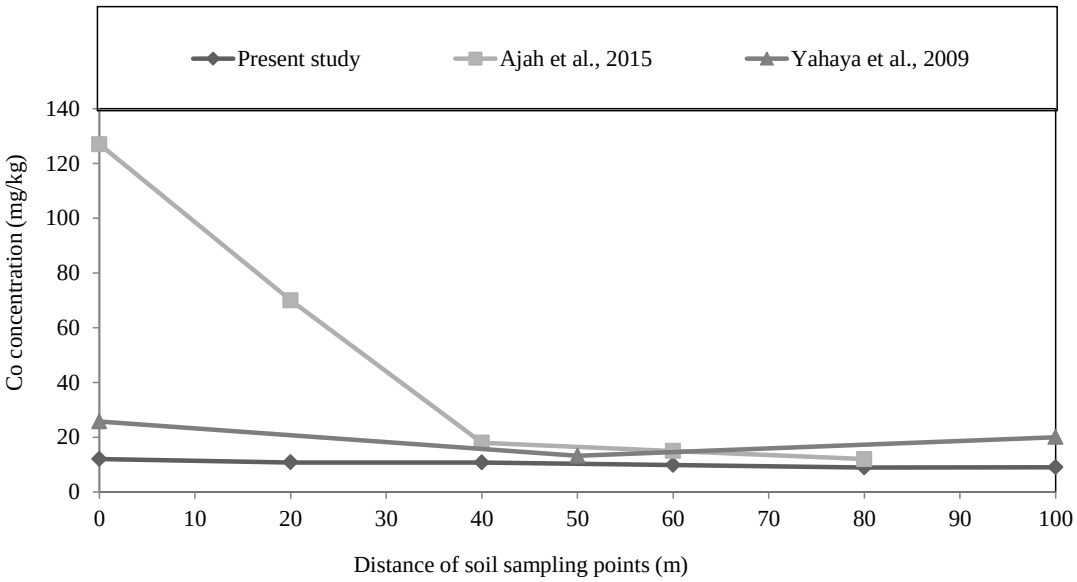


Figure 4.21: Comparison of Co concentration in soil during dry season with other researchers for similar cases.

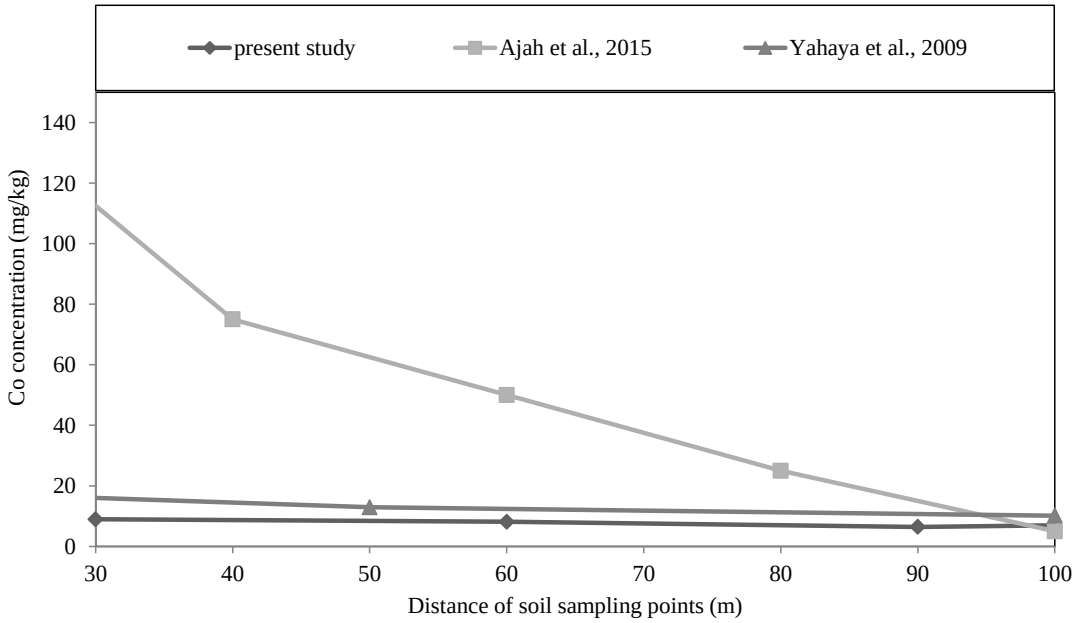


Figure 4.22: Comparison of Co concentration in soil during rainy season with other researchers for similar cases.

4.5 Spatial Distribution of Metal Concentration in Soil

Spatial distribution is the arrangement of a phenomenon across the earth's surface and a graphical display of such an arrangement is an important tool in geographical and environmental statistics. A graphical display (produced prediction surface) of a spatial distribution may summarize raw data directly or may reflect the outcome of more sophisticated data analysis. Many different aspects of a phenomenon can be shown in a single graphical display by using a suitable choice of different colours to represent differences. Moreover, in this distribution, different color segments were considered which represented the various ranges of the metal concentration in soil. In the produced prediction surface, green with yellow color region represented the level of less contamination, whereas, deep blue color area represented the level of highly contaminated soil (Yasrebi et al., 2009). To these attempts, in this study, the spatial distribution was performed using ordinary kriging (OK) through ArcGIS of different metal elements in soil for both the dry and rainy season to represent the level of different concentration and hence discussed in the following articles. The spatial distribution of the metal elements are described in the following figures except Mn, Cu, Pb, Ni, Co, Na, K, Ca, Al, Sc, Sr, V and Ba in soil which are presented in Figure D.1 to Figure D.13, respectively, in the Annex-D.

4.5.1 Iron

The surface spatial distributions of the concentration of Fe in soil (forty soil samples) for dry and rainy season (twenty soil samples) are presented in Figure 4.23 (a) and 4.23 (b), respectively. In Figure 4.23, the deep blue colour indicated that the soil was highly contaminated with the high concentration of Fe in soil, while, the green with yellow colour indicated that the soil was comparatively less contaminated with low concentration of Fe in soil of the waste disposal site. The magnitude of the concentration of Fe for soil sample from central point (approximately 0 m) ranges from 1745 to 1986 mg/kg, while, for soil sample from farthest point (390m from central point) ranges from 733 to 900 mg/kg for dry season. Besides, Fe ranges from 625-683 mg/kg for soil sample from near to centre (approximately 30 m) and 160-218 mg/kg for soil sample from farthest point (315m from central point) in rainy season. Produced prediction surface showed most of the contaminated hotspots was found near the central point of the disposal site for dry season. The distribution patterns indicated that the concentration of Fe in the selected site gradually decreases from the centre

to the outer side area of the waste disposal site during both seasons. In addition, Fe concentration is higher in dry season than rainy season.

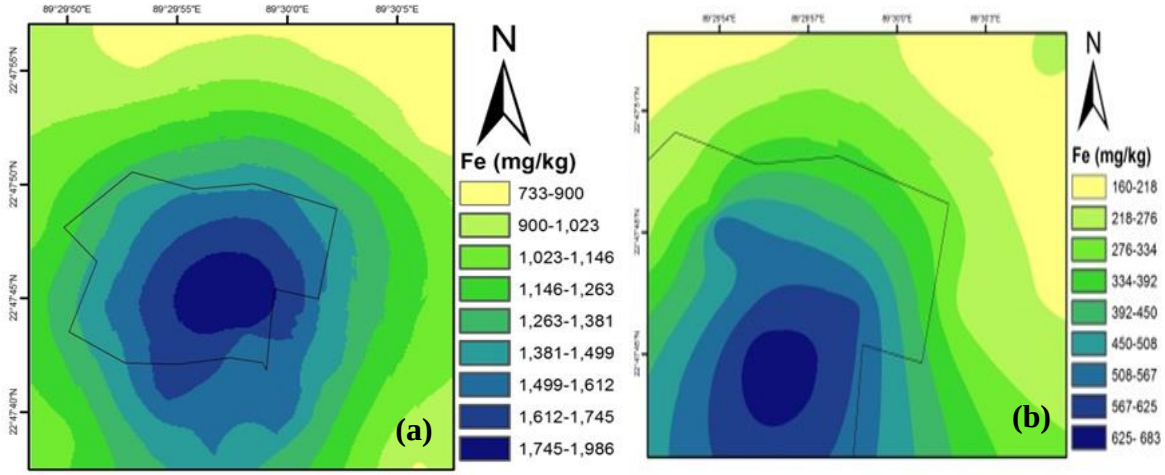


Figure 4.23: Spatial distribution of Fe concentration in soil for (a) dry and (b) rainy season.

4.5.2 Chromium

The surface spatial distributions of the concentration of Cr in soil for dry season and rainy season are presented in Figure 4.24 (a) and Figure 4.24 (b), respectively. The value of the concentration of Cr for soil sample from central point (approximately 0 m) ranges from 7.67 to 8.22 mg/kg, while, for soil sample from farthest point (390m from central point) ranges from 4.36 to 4.91 mg/kg for dry season. Moreover, Cr concentration ranges from 4.93 to 5.52 mg/kg for soil sample from near to centre (approximately 30 m) and 0.77-1.36 mg/kg for soil sample from farthest point (315m from central point) in rainy season. In figures, the deep blue colour indicated that the soil was highly contaminated with the high concentration of Cr in soil, while, the green with yellow colour indicated the soil was less contaminated with the concentration of Cr in soil of that sampling point was comparatively very low. Form figure, it is clear that the maximum concentration range in dry season not only covers the centre point of the disposal site but also the surrounding area of the site. The distribution patterns are similar in both season but the intensity of Cr is decreasing with lateral distance from the centre point of the area. The ranges of concentration in both season shows, the dry seasonal Cr concentration in soil was higher than rainy season.

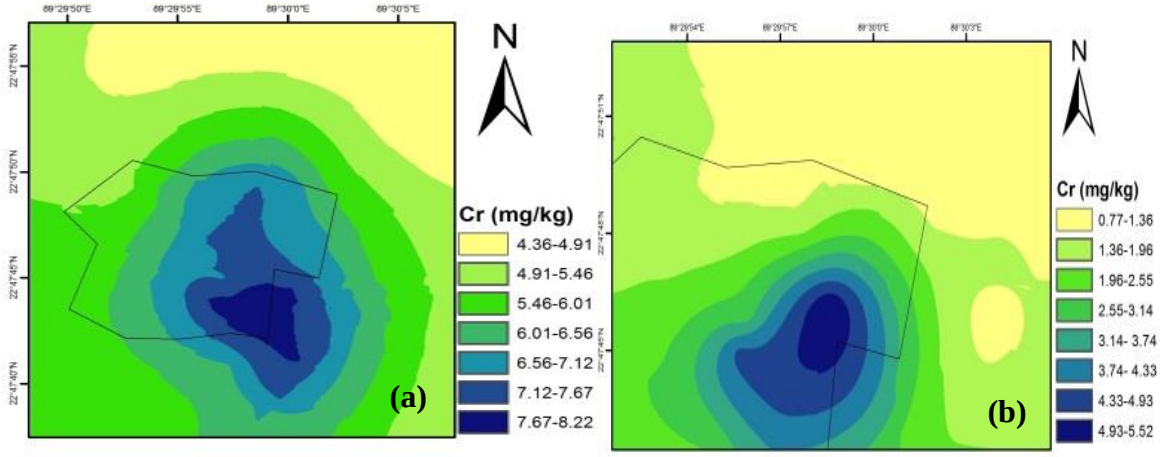


Figure 4.24: Spatial distribution of Cr concentration in soil for (a) dry and (b) rainy season.

4.5.3 Zinc

Figure 4.25(a) and Figure 4.25(b) illustrate the surface spatial distribution of the concentration of Zn in soil for dry season and rainy season respectively. In spatial distribution, the deep blue color indicated the concentration of Zn in soil of that sampling point was very high, while, the green with yellow color indicated the concentration of Zn in soil of that sampling point was comparatively very low. The magnitude of the concentration of Zn for soil sample from central point (approximately 0 m) ranges from 46 to 48 mg/kg, while, for soil sample from farthest point (390m from central point) ranges from 23 to 26 mg/kg for dry season. In addition, Zn ranges from 21.91 to 24.29 mg/kg for soil sample from near to center (approximately 30 m) and 11.82 -13.21 mg/kg for soil sample from farthest point (315m from central point) in rainy season. The distribution patterns are similar in both season but the intensity of Zn in soil was higher in dry season. In addition, the concentration of Zn was decreasing with lateral distance from the centre. point of the area.

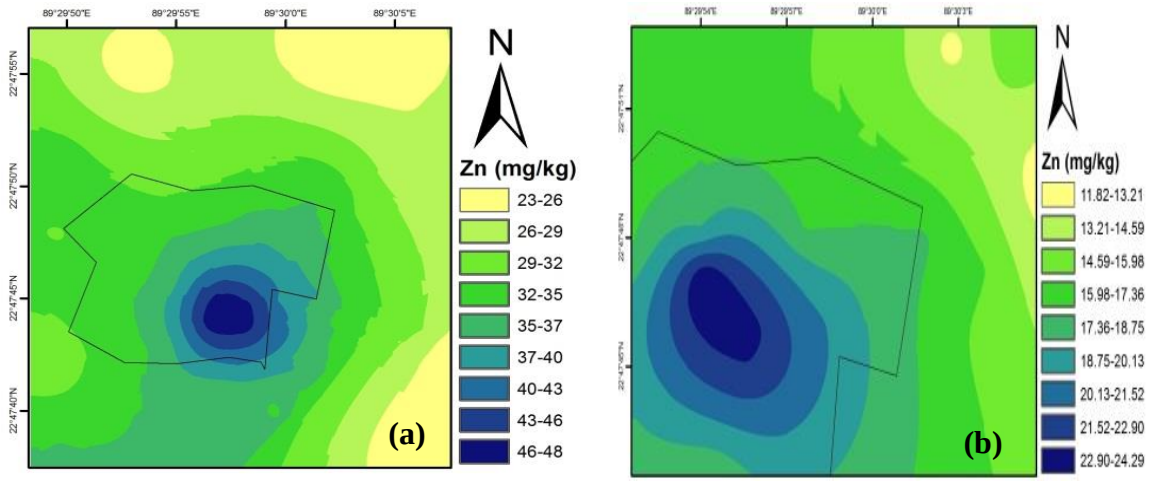


Figure 4.25: Spatial distribution of Zn concentration in soil for (a) dry and (b) rainy season.

4.5.4 Cadmium

Figure 4.26 (a) and Figure 4.26 (b) demonstrate the map containing surface spatial distribution of the concentration of Zn in soil for dry season and rainy season respectively. The magnitude of the concentration of Cd for soil sample from central point (approximately 0 m) ranges from 6.50 to 6.99 mg/kg as well for soil sample from farthest point (390 m from central point) ranges from 2.55 to 3.04 mg/kg for dry season. Further, in rainy season, Cd concentration ranges from 3.41 to 2.72 mg/kg for soil sample from near to center (approximately 30 m) and 1.24 to 1.55 mg/kg for soil sample from farthest point (315 m from central point). Outcome of the distribution depicted that the concentration of metal elements decreases in relation to the increasing of soil sampling distances from approximately the central point of waste disposal site. Comparing seasonal concentration of Cd, dry seasonal Cd concentration was high.

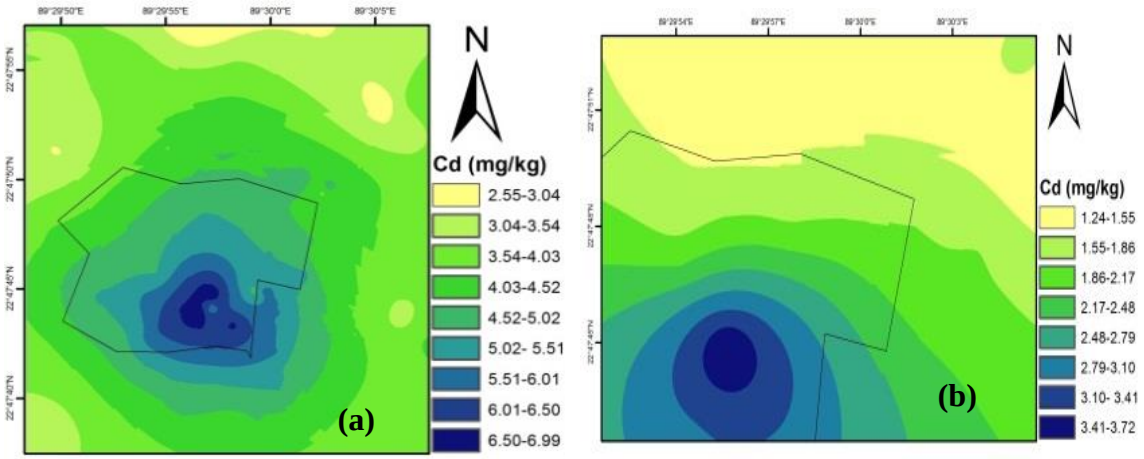


Figure 4.26: Spatial distribution of Cd concentration in soil for (a) dry and (b) rainy season.

4.5.5 Arsenic

The surface spatial distribution of the concentration of As in soil for dry and rainy season (twenty soil samples) is presented in Figure 4.27 (a) and Figure 4.27 (b), respectively. Here, the ranges of As concentration in dry season and rainy season were categorized in 9 and 8 classes respectively as well as distinguished by different shades of deep blue and green with yellow colors. The magnitude of the concentration of As for soil sample from central point (approximately 0 m) ranges from 7.94 to 8.74 mg/kg, while, for soil sample from farthest point (390 m from central point) ranges from 1 to 2 mg/kg for dry season. Besides, As ranges from 3.32 to 3.67 mg/kg for soil sample from near to center (approximately 30 m) and 0.87-1.22 mg/kg for soil sample from farthest point (315 m from central point) in rainy season. Thus, it is clear that the concentration of As was higher in soil of the center and decreases gradually to outer side soil of the disposal site. Figure also shows the range of As concentration was slightly greater in dry season than that of rainy season.

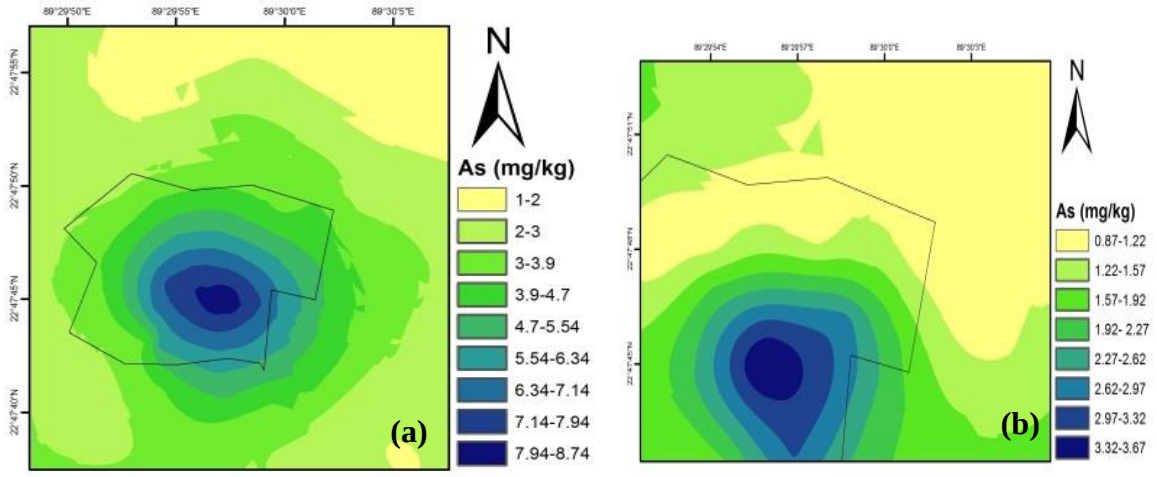


Figure 4.27: Spatial distribution of As concentration in soil for (a) dry and (b) rainy season.

4.5.6 Mercury

The following figure (Figure 4.28(a) and Figure 4.28(b)) show the surface spatial distribution of Hg concentration in soil of the selected waste disposal site for dry season and rainy season, respectively. Here, the ranges of Hg concentration in both seasons distinguished by different shades of deep blue and green with yellow colors. Figure shows the magnitude of the concentration of Hg for soil sample from central point (approximately 0 m) ranges from 8 to 9 mg/kg, while, for soil sample from farthest point (390 m from central point) ranges from 1 to 2 mg/kg for dry season. Maximum of the total sampling site is covered concentration 2 to 4 mg/kg of Hg depicted by figure in dry season. Similarly, Cd ranges from 3.57 to 3.93 mg/kg for soil sample from near to center (approximately 30 m) and 0.85 -1.30 mg/kg for soil sample from farthest point (315 m from central point) in rainy season. In addition, not only the farthest point, the area slightly far from center had Hg concentration 0.85 -1.30 mg/kg also. The distribution pattern in dry season was irregular where in rainy season pattern shows uniform distribution along the area. From the figure it can be said that the extreme level of Hg was present in the soil of central point where it decreases along the lateral distance. Moreover, Dry season shows the high range of Hg concentration.

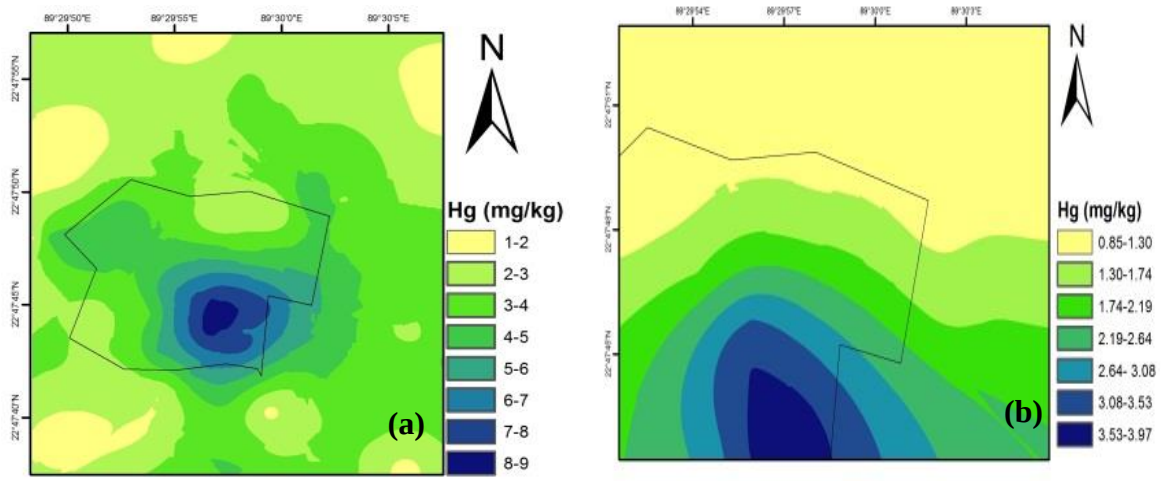


Figure 4.28: Spatial distribution of Hg concentration in soil for (a) dry and (b) rainy season.

4.5.7 Titanium

The surface spatial distribution of the concentration of Ti in soil for dry and rainy season are offered in Figure 4.29(a) and Figure 4.29(b), respectively. The concentration of Ti for soil sample from central point (approximately 0 m) ranges from 1791 to 1935 mg/kg, while, for soil sample from farthest point (390 m from central point) ranges from 636 to 780 mg/kg for dry season. Besides, Ti ranges from 1308 to 1441 mg/kg for soil sample from near to center (approximately 30 m) and 244 to 377 mg/kg for soil sample from farthest point (315 m from central point) in rainy season.

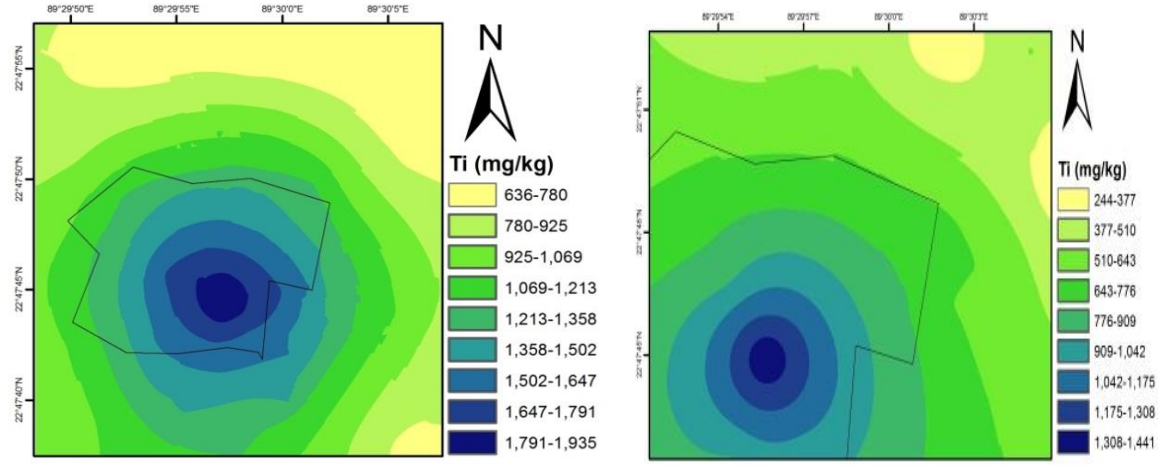


Figure 4.29: Spatial distribution of Ti concentration in soil for (a) dry and (b) rainy season.

The distribution patterns tell that concentration of metal is large in dry season than rainy season. Though the two seasonal distribution patterns does not cover the same geometric area, but it is clear from the figure that metal concentration is decrease along increasing distance from the center point of the waste disposal site.

4.5.8 Antimony

Figure 4.30(a) and Figure 4.30(b) represented the surface spatial distribution of the concentration of Sb in soil of waste disposal site during dry season and rainy season respectively. In figure, the deep blue color indicated the concentration of Sb in soil of that sampling point was very high, while, the green with yellow color indicated the concentration of Sb in soil of that sampling point was comparatively very low. The magnitude of the concentration of Sb for soil sample from central point (approximately 0 m) ranges from 11 to 12 mg/kg, and for soil sample from farthest point (390 m from central point) ranges from 2 to 3 mg/kg for dry season. In addition, Sb ranges from 5.54 to 6.11 mg/kg for soil sample from near to center (approximately 30 m) and 0.98 to 1.55 mg/kg for soil sample from farthest point (315 m from central point) in rainy season. Figure of distribution reveals that the concentration of Sb in soil collected from the central point of the waste disposal site showed higher magnitude than the others. Mainly, along the distances the Sb concentration decreases and during dry season the ranges was higher than rainy season.

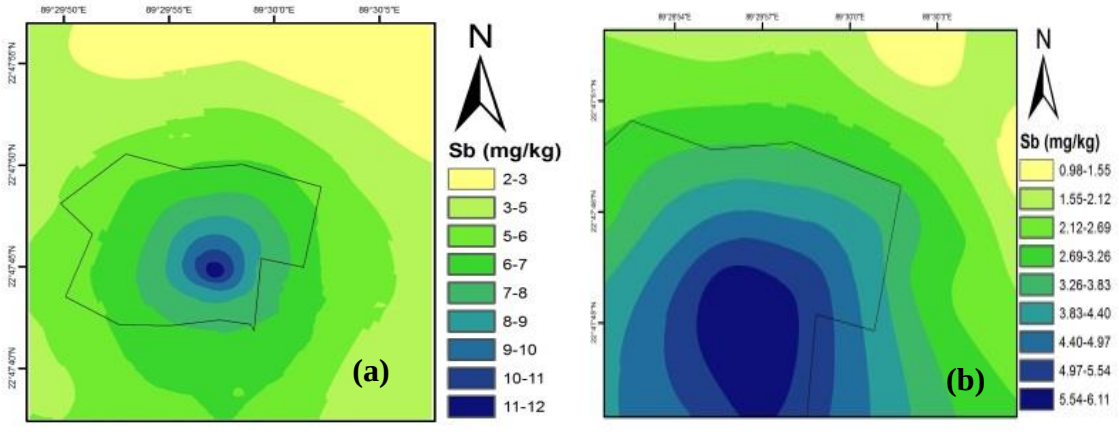


Figure 4.30: Spatial distribution of Sb concentration in soil for (a) dry and (b) rainy season.

From the above articles, it is sure that all the metal elements considered in the study had a greater concentration in the soil of the studied waste disposal site during dry season than rainy season. Though the two seasonal distribution patterns do not cover the same geometric area, but it is clear that the concentration was decrease along increasing distance from the

centre point of the waste disposal site. The reduction of concentration is caused by the effect of leaching by infiltrating water. Besides, during heavy rainfall, soluble metal content get diluted and runoff from the dumpsite spreads to the surrounding soil.

4.6 Analysis of Various Indices

To assess the ecological risks associated with metal elements in soil of the study area, various index analyses was done. The indices were potential contamination index (Cp), contamination factor (CF), modified contamination degree (mCD), contamination load index (CLI), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}), ecological risk index (ER) and potential ecological risk index (PERI). In this study, the analysis was accomplished by calculating various indices for all the studied metal elements in soil and then identified the level of contamination based on the ranges of various indices published by different researchers as well as discussed in the following articles.

4.6.1 Potential Contamination Index

To investigate the level of contamination in terms of potential contamination index (Cp), maximum concentration of a particular type of metal element and its corresponding background value was considered. The value of Cp was computed using an empirical equation proposed by Dauvalter and Rognerud (2001). The computed values of Cp for all the studied metal elements in soil during two seasons provided in Table 4.5 and depicted in Figure 4.31.

In this study, to identify the level of contamination of soil, the limit values of Cp proposed by Dauvalter and Rognerud (2001) was considered. When the value of $Cp \leq 1$ indicates low contamination; $1 < Cp \leq 3$ is moderate contamination; and $Cp > 3$ is severe or very severe contamination of soil. In Figure 4.63, the computed values of Cp for Cd and Sb in soil for both the seasons as well as of Pb and As in soil for dry season indicated the level of contamination of soil was severe or very severe condition. It also demonstrated that during rainy season, for Pb and As, the soil of the disposal site was moderately contaminate. In this study, the value of Cp for the metal element of Sb was found to be 62.74 and 30.60 for dry and rainy season, respectively. Similarly, the value of Cp was found to be 35.15 and 19.50

for Cd in soil for dry season and rainy season, respectively. In addition, based on the computed values of Cp, other investigated metal elements of Al, Fe, Mn, Cr, Cu, Zn, Ni, Co, Sc and Hg in soil showed the lower level of contamination of soil. A research conducted by Nouri and Haddioui (2016) in case of soil from iron mine site and found the highest value of Cp for Pb, while in the present study, the value of Cp was found highest for Sb. Sb is used in many parts of a vehicle, such as the brake device, fire retardant and battery. Consequently, the study area was in a frightening situation for Cd and Sb during both the seasons based on the value of Cp.

Table 4.5: Potential contamination index of metal elements in soil of different seasons

Metal elements	Potential contamination index (Cp)	
	Dry season	Rainy season
Fe	0.04	0.01
Mn	0.03	0.01
Cr	0.10	0.06
Cu	0.30	0.12
Pb	**4.53**	1.21
Zn	0.73	0.35
Ni	0.11	0.07
Cd	**35.15**	**19.50**
As	**4.87**	2.04
Hg	0.92	0.52
Co	0.48	0.36
Na	0.00	0.00
K	0.02	0.01
Ca	0.01	0.00
Al	0.01	0.01
Ti	0.34	0.25
Sb	**62.74**	**30.60**
Sc	0.93	0.55
Sr	0.14	0.08
V	0.62	0.30
Ba	0.29	0.17

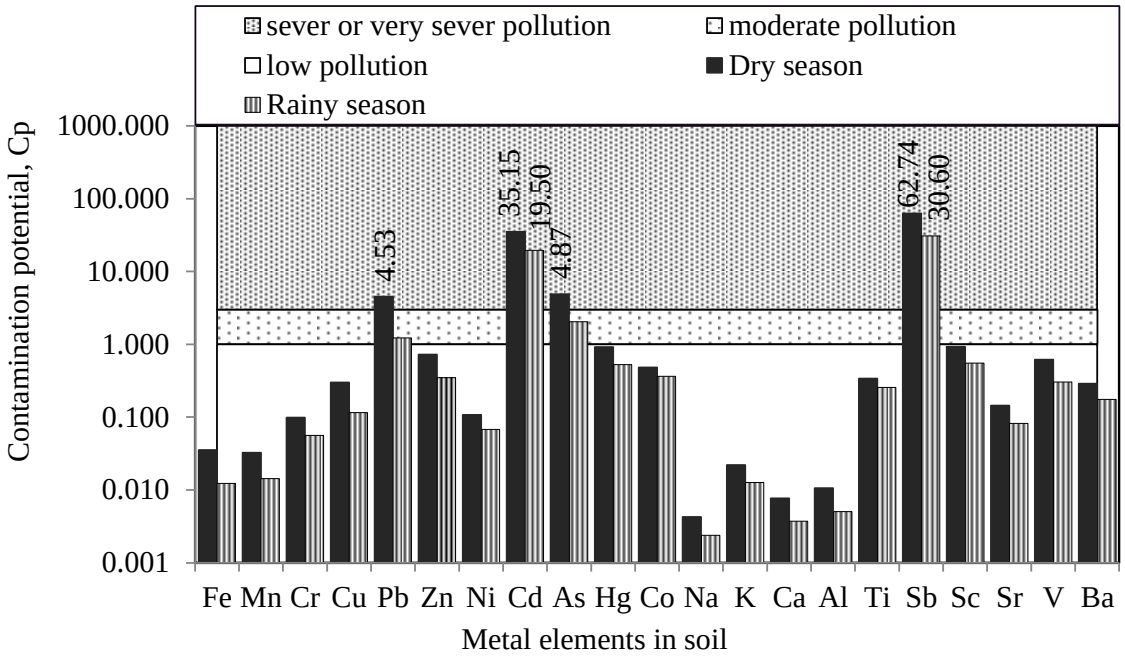


Figure 4.31: Variation of Cp of metal elements in soil for dry and rainy seasons.

4.6.2 Contamination Factor

In this study, the value of contamination factor (CF) was computed based on the empirical equation demonstrated by Håkanson (1980). The computed mean values of CF of all studied metal elements in soil are provided in Table 4.6. Results showed the highest value of CF was for Sb and lowest was for Na (Table 4.6).

Table 4.6: Mean value of CF of metal elements in soil of different seasons.

Metal elements	Contamination factor (CF)		Metal elements	Contamination factor (CF)	
	Dry season	Rainy season		Dry season	Rainy season
Fe	0.02	0.01	Na	0.003	0.001
Mn	0.02	0.01	K	0.01	0.01
Cr	0.06	0.02	Ca	0.004	0.002
Cu	0.11	0.05	Al	0.006	0.003
Pb	1.88	0.88	Ti	0.21	0.12
Zn	0.49	0.25	Sb	30.37	17.06
Ni	0.06	0.03	Sc	0.55	0.35
Cd	22.76	10.15	Sr	0.07	0.05
As	2.31	0.87	V	0.32	0.16
Hg	0.46	0.17	Ba	0.15	0.09
Co	0.28	0.20			

The values of CF for each metal element in soil for all the soil sampling points during both seasons are provided in Table B.1 and Table B.2 in the Annex-B.

The statistics of the computed values of CF in soil are presented in Figure 4.32 and Figure 4.33, respectively, for dry and rainy season. Figure 4.32 represents, CF values of the metals of Fe, Mn, Cr, Cu, Zn, Ni, Hg, Co Na, K, Ca, Al, Ti, Sc, Sr, V and Ba in soil were found to be less than 1 and hence indicated the low level of contamination in dry season. The values of CF for Pb indicated the contamination of soil ranges from moderate (1<CF<3) to considerable (3<CF<6) due to presence of Pb. Similarly, the values of CF indicated the contamination of soil by As ranges from low (CF<1) to considerable (3<CF<6) though the mean of CF stands in moderate contamination class. Accordingly, the entire values of CF for Cd and Sb indicated the high level of contamination of soil (CF>6). Similarly, a study conducted by Rahman et al. (2012) and found the soil was highly contaminated by As and Hg according to CF in dry season In the same way, research by Wang et al. (2013) in an opencast coal mine shows highest CF for Hg and a class of severe contamination.

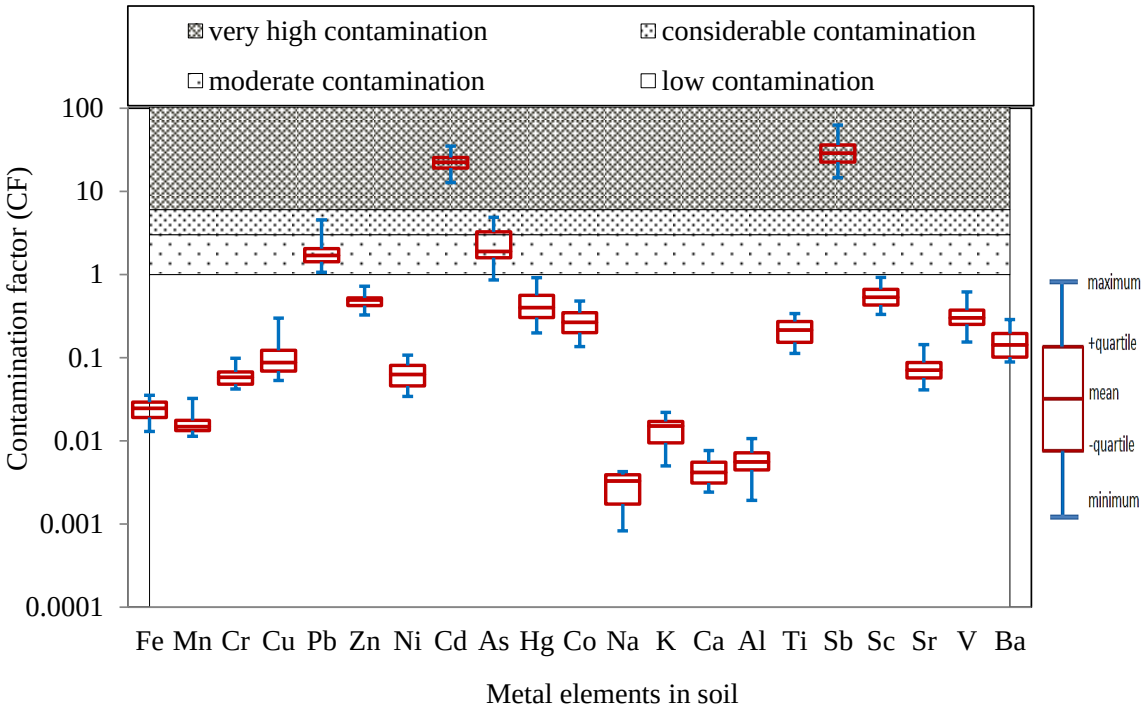


Figure 4.32: Statistics of CF of metal elements in soil for dry season.

Figure 4.33 represents the CF values for the metal elements of Fe, Mn, Cr, Cu, Zn, Ni, Hg, Co Na, K, Ca, Al, Ti, Sc, Sr, V and Ba in soil for rainy season indicated the low level of

contamination of soil against of dry season. Although, most of the values of CF indicated the low level of contamination of soil, nevertheless, the maximum value of CF for Pb and As indicated the soil was moderately contaminated of the selected waste disposal site. Accordingly, all the computed values of CF for Cd and most of the CF values of Sb indicated the high level of contamination of soil, while, the minimum CF of Sb indicated the considerable level of contamination of soil of the selected disposal site.

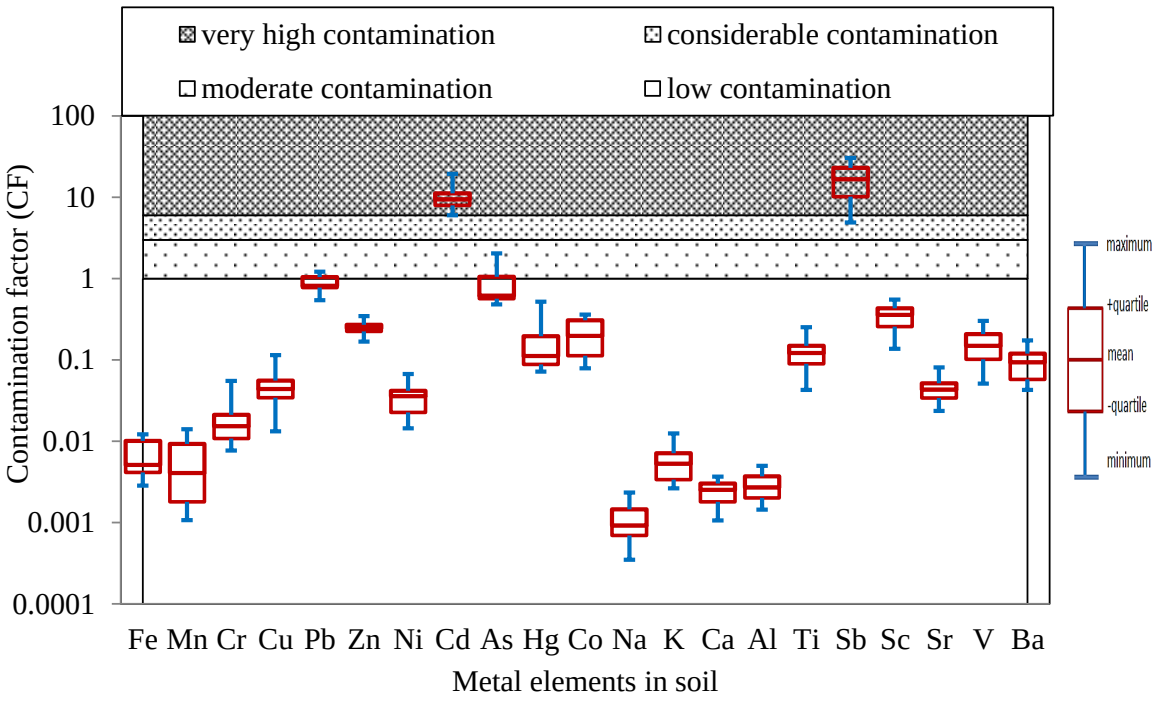


Figure 4.33: Statistics of CF of metal elements in soil for rainy season.

The concentrations of Cd and Sb were in alarming ranges in both seasons according to this indices. Besides, Pb and As content in soil of the selected waste disposal site should be considered as shocking because of the high range in dry season. Hence, considering two seasons, there was very slight change in the overall situation depending on class of contamination which showed similarity with a research done by Rahman et al., (2012).

4.6.3 Nemerow Integrated Contamination Factor

The nemerow integrated contamination factor (NICF) for twenty one studied metal elements in soil for both dry and rainy season is presented in Table 4.7. Then NICF for dry and rainy season are depicted in Figure 4.34 and Figure 4.35, respectively. Based on these figures, all the studied metal element showed the NICF values greater than 3, which indicated the heavy

contamination in soil for the two seasons considered here. Same contamination index methods were used to evaluate the soil environmental quality for Changchun municipal waste landfill, Chaina was within warning category (0.7<NICF<1) considering eight metal elements (Cd, As, Pb, Cr, Cu, Zn, Ni, Mn) (Xu-dan et al., 2015).

Table 4.7: Computed values of NICF for metal elements in soil for both seasons.

Dry season				Rainy season	
Boreholes	NICF	Boreholes	NICF	Boreholes	NICF
1	44.53	21	19.94	41	21.30
2	38.21	22	19.48	42	21.71
3	34.37	23	19.00	43	20.22
4	31.51	24	18.51	44	18.90
5	31.49	25	18.08	45	17.46
6	28.40	26	17.38	46	15.96
7	28.22	27	17.32	47	14.57
8	27.88	28	17.08	48	13.76
9	27.58	29	17.08	49	13.33
10	26.91	30	16.52	50	12.87
11	25.36	31	14.65	51	10.86
12	25.28	32	14.54	52	10.65
13	24.43	33	14.51	53	10.01
14	24.38	34	14.25	54	8.91
15	24.25	35	13.09	55	7.28
16	23.86	36	13.58	56	7.03
17	23.64	37	12.52	57	5.86
18	21.65	38	11.02	58	4.98
19	21.52	39	10.73	59	4.41
20	20.98	40	13.74	60	4.26

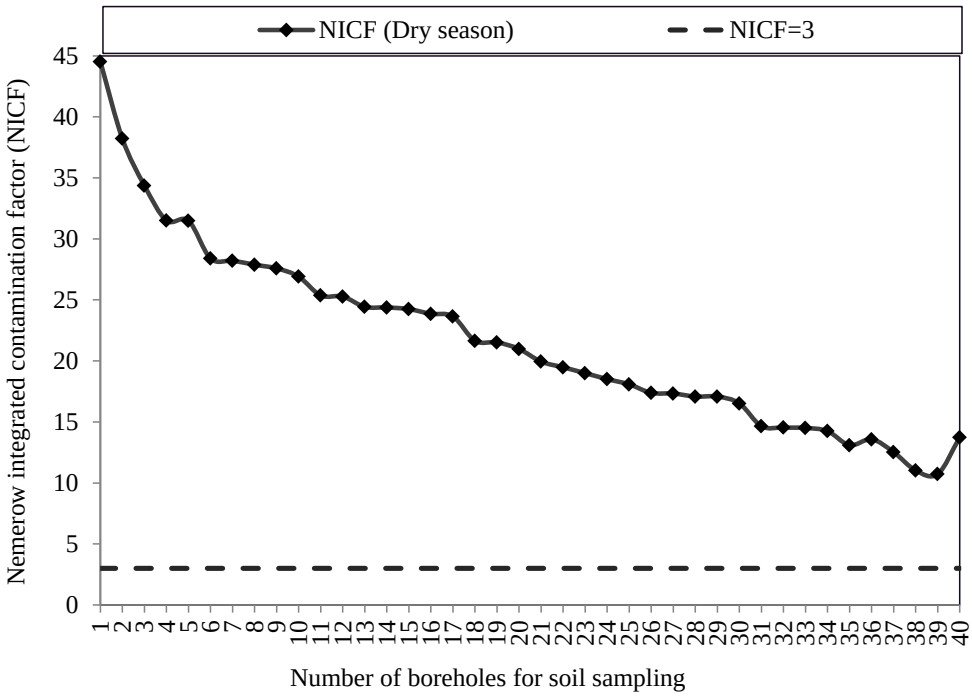


Figure 4.34: Computed values of NICF of studied metal element in soil of dry season.

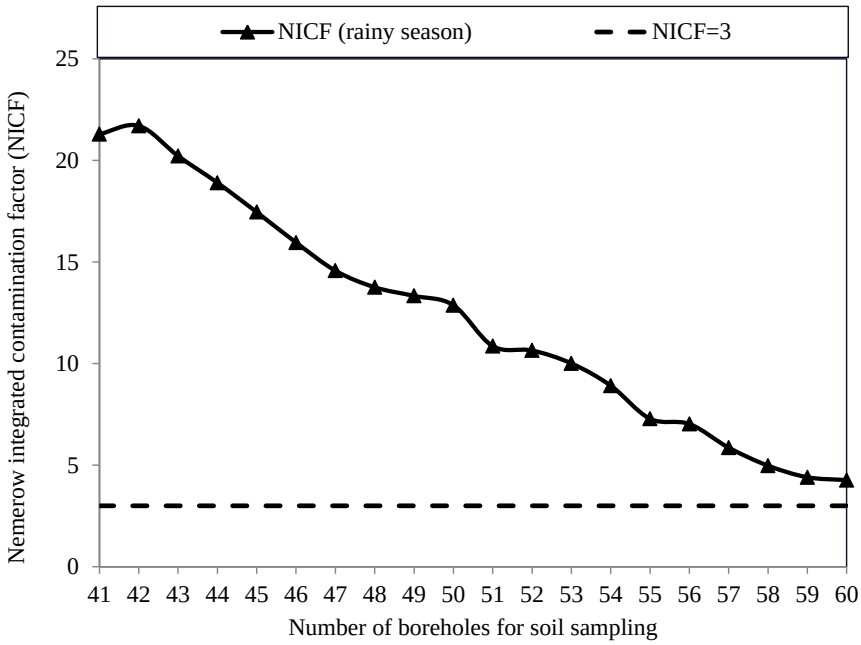


Figure 4.35: Computed values of NICF of studied metal elements in soil for rainy season.

4.6.4 Contamination Load Index

Pollution severity and its variation along the sites were determined with the use of contamination load index (CLI). This index is a quick tool in order to compare the pollution

status of different places. The CLI was calculated based on contamination factor (CF) for all studied metal elements in soil. CLI is an integrated index and combination of contamination factor (CF) of all metal elements. Results of the present study showed that the values of CF was low (<1) for almost all the metal elements of Fe, Mn, Cr, Cu, Zn, Ni, Hg, Co Na, K, Ca, Al, Ti, Sc, Sr, V and Ba in soil. But, CF values was found to be higher (>1) for metal elements like Sb, Cd, As and Pb in soil due to the influence of external discrete sources thus anthropogenic inputs. The computed values of CLI for all the studied metal elements in soil of study area for both dry and rainy season is presented in Table 4.8. Since, CLI in soil for both dry and rainy season was found to be less than 1 indicated that the soil was uncontaminated in the study area. Finally, it can be noted that the values of CLI were found to be generally low (<1) in soil for all the studied borehole points (Table 4.8). In this study, considering all the studied numbers of metal elements and low values of CF was the reason behind a smaller value of CLI in soil.

Table 4.8: Computed values of CLI for metal elements in soil for both dry and rainy season

dry season				rainy season	
No of BH	CLI	No of BH	CLI	No of BH	CLI
1	0.2751	21	0.1552	41	0.1394
2	0.2500	22	0.1501	42	0.1253
3	0.2377	23	0.1402	43	0.1176
4	0.2485	24	0.1399	44	0.1102
5	0.2352	25	0.1320	45	0.0971
6	0.2339	26	0.1349	46	0.0865
7	0.2135	27	0.1273	47	0.0790
8	0.2018	28	0.1237	48	0.0781
9	0.1977	29	0.1197	49	0.0718
10	0.1929	30	0.1137	50	0.0676
11	0.1880	31	0.1127	51	0.0648
12	0.1745	32	0.1127	52	0.0603
13	0.1735	33	0.1129	53	0.0596
14	0.1657	34	0.1039	54	0.0562
15	0.1608	35	0.0992	55	0.0495
16	0.1634	36	0.0938	56	0.0449
17	0.1623	37	0.0912	57	0.0401
18	0.1562	38	0.0898	58	0.0355
19	0.1577	39	0.0848	59	0.0344
20	0.1520	40	0.0833	60	0.0324

4.6.5 Modified Contamination Degree

The degree of contamination (CD) is an index to estimate the pollution range of soil by metal elements (Abrahim, 2005). In this study, to check the level of contamination of soil, the modified contamination degree (mCD) was computed based on empirical equation proposed by Abrahim (2005). The "mCD" and "CD" are integrated indices thus calculated by combining all studied metal elements for different soil sampling points for both the dry and rainy season and presented in Table 4.9.

Table 4.9: Computed values of CD and mCD for metal elements in soil for dry and rainy season

Dry season						Rainy season		
No. of Borehole	CD	mCD	No. of Borehole	CD	mCD	No. of Borehole	CD	mCD
1	112.23	5.34	21	58.74	2.80	41	55.52	2.64
2	95.55	4.55	22	54.14	2.58	42	51.50	2.45
3	88.97	4.24	23	56.19	2.68	43	49.22	2.34
4	91.25	4.35	24	53.52	2.55	44	44.14	2.10
5	85.67	4.08	25	50.68	2.41	45	43.41	2.07
6	84.04	4.00	26	49.95	2.38	46	36.84	1.75
7	73.88	3.52	27	46.56	2.22	47	32.77	1.56
8	76.46	3.64	28	47.59	2.27	48	30.77	1.47
9	73.57	3.50	29	45.86	2.18	49	30.30	1.44
10	75.28	3.58	30	43.47	2.07	50	30.41	1.45
11	73.33	3.49	31	46.54	2.22	51	28.17	1.34
12	68.67	3.27	32	45.08	2.15	52	27.06	1.29
13	67.34	3.21	33	44.01	2.10	53	26.40	1.26
14	66.21	3.15	34	42.40	2.02	54	25.20	1.20
15	64.93	3.09	35	38.55	1.84	55	21.18	1.01
16	65.28	3.11	36	41.03	1.95	56	18.45	0.88
17	63.05	3.00	37	35.64	1.70	57	17.22	0.82
18	62.15	2.96	38	34.43	1.64	58	15.08	0.72
19	58.62	2.79	39	31.58	1.50	59	13.31	0.63
20	57.08	2.72	40	37.61	1.79	60	12.62	0.60
Maximum mCD					5.34	Maximum mCD		2.64
95% UCL of mCD					3.14	95% UCL of mCD		1.72

In Table 4.9, the maximum mCD was found to be 5.34 and 2.64 for dry season and rainy season, respectively. Both the maximum mCD values were found in the soil, collected from

the central point (BH 1) of the waste disposal site. Result reveals the values of mCD for rainy season was comparatively less than that of dry season. Here, it can be noted that the high degree of contamination of soil was found at the central borehole point (BH 1) of the disposal site with maximum values of mCD for dry season, while, during rainy season it was found as moderate degree of contamination.

In addition, as it is a pollution or risk index, 95% UCL was also used for computing overall mCD of the selected disposal site. The value of mCD for 95% UCL for dry season was found to be 3.14 and classified as high degree of contamination, while, in rainy season, mCD was found 1.72 indicated low degree of contamination of soil. So during dry season, the overall scenario of the site was same as showing high degree of contamination in the centre and around of the study area. The variation mCD and thence the level of contamination of soil happened in two seasons because of the heavy rainfall, dilution and other run-off in the rainy season makes the metals flushed out from the upper layer of the soil to some extent through the adjoining flood zone. A study conducted by Rahman et al. (2012) and found the high degree of contamination with mCD values of 575.13 and 244.44, respectively, in dry and wet season. Therefore, the findings of this study are agreed well with the postulation stated by Rahman et al. (2012).

The variation of mCD values in soil for forty soil samples in dry season is shown in Figure 4.36 to identify the level of contamination of soil. The lowest value of mCD was to be found 1.50 for BH-39 in the selected disposal site area, belongs to the class of low level of contamination of soil (1.5< mCD< 2). On the other hand, the highest value of mCD was observed as 5.34 in case of BH-1 in the selected area, which lies in the class of high degree of contamination of soil (4< mCD< 8). Most of the mCD values lie in the class of moderate degree of contamination of soil. Here, it can be concluded that the collected soil sample from the central point (BH 1) of the waste disposal site showed the higher concentrates for most of metal elements with respect to BH-39 which consequently implied the higher values of mCD for BH 1 than that of BH 39.

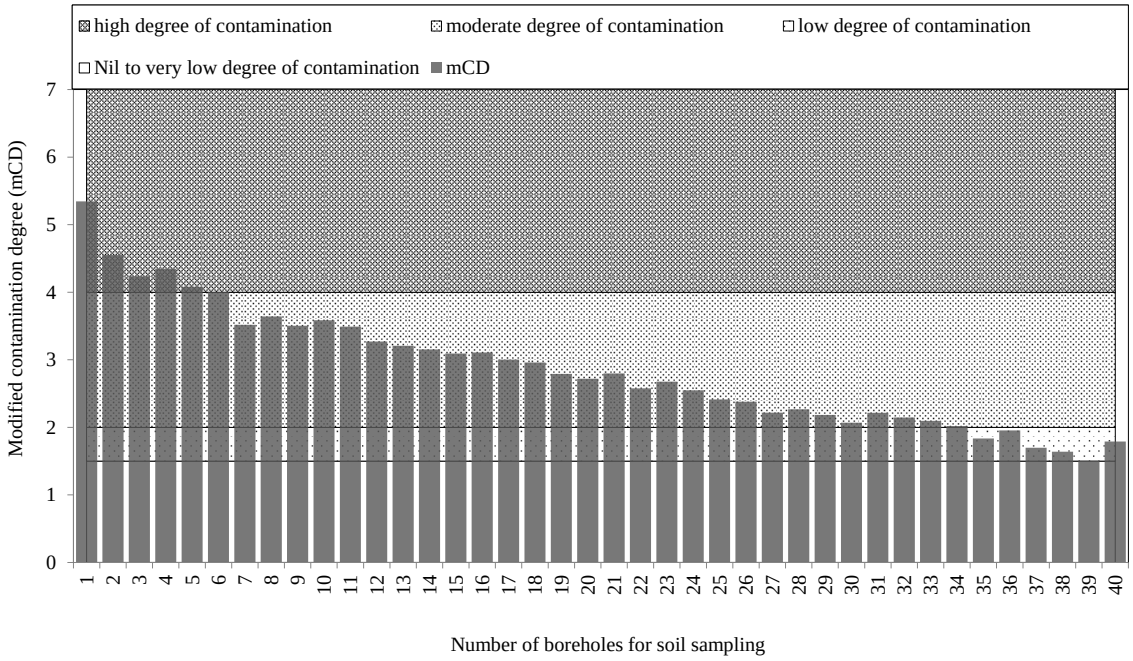


Figure 4.36: Classify level of contamination based on mCD values in soil for dry season.

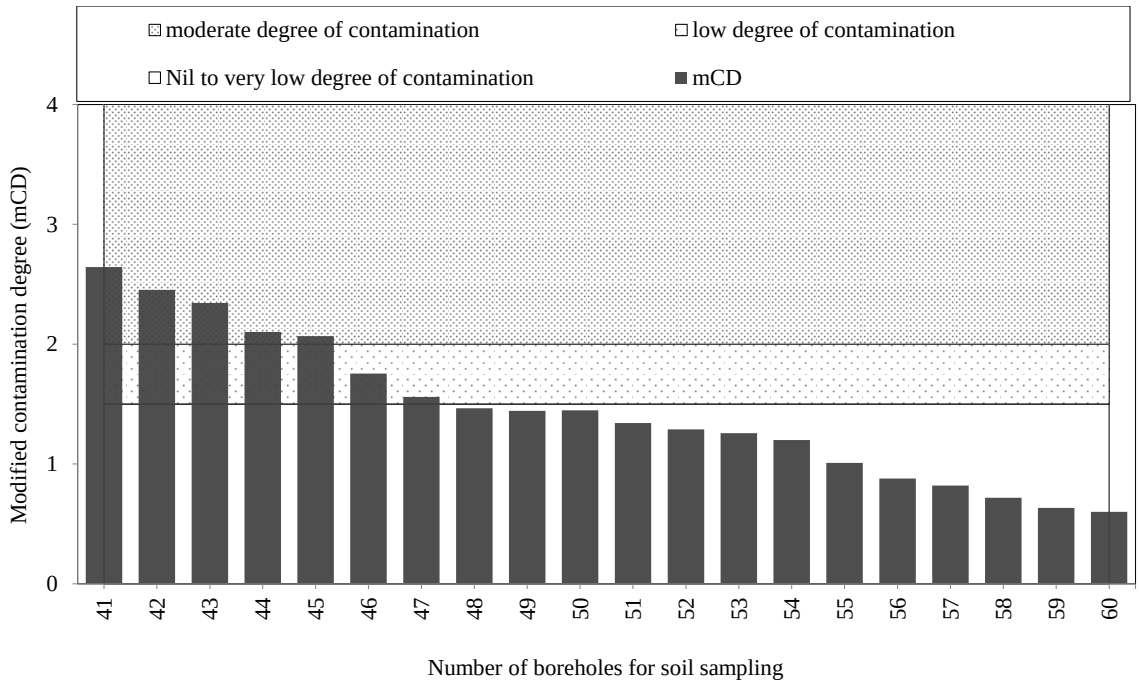


Figure 4.37: Classify level of contamination based on mCD values in soil for rainy season.

The Figure 4.37 represents the mCD for twenty soil samples in rainy season with the classification of the contamination of soil. The lowest value of mCD was to be found as 0.60 in case of BH-39 in studied area belongs to the class of nil to very low contamination (1.5< mCD). On the other hand, the highest value of mCD was recorded 2.64 for BH-41 in the

area belongs to the class of moderate degree of contamination (2< mCD< 4). However, most of the computed value of mCD lies in the class of nil to very low contamination of soil in the waste disposal site.

4.6.6 Enrichment Factor

In the assessment of enrichment factor (EF), Aluminum (Al) was used as the reference metal element because this normalizing element assumed less contamination with respect to the other study metal elements in soil of the selected disposal site. In this work, Al was chosen as the conservative element for normalization. As, Al was selected as reference element hence EF of Al was found to be 1 for both dry and rainy seasons. The average values of EF of all studied metal elements are presented in the Table 4.10. Additionally, the values of EF for each metal element in soil for all the soil sampling points during dry season and rainy season are provided in Table B.3 and Table B.4, respectively, in the Annex-B.

Table 4.10: Computed EF for metal elements in soil for both dry and rainy season

Metal elements	EF	
	dry season	rainy season
Fe	4.39	2.15
Mn	3.13	1.68
Cr	11.28	6.26
Cu	18.93	15.61
Pb	339.18	323.11
Zn	92.87	93.68
Ni	11.46	11.78
Cd	4202.11	3588.91
As	380.58	294.01
Hg	80.64	56.17
Co	49.07	67.26
Na	0.48	0.35
K	2.38	2.01
Ca	0.78	0.84
Ti	37.53	42.19
Sb	5287.86	5589.45
Sc	100.12	122.08
Sr	13.13	15.81
V	56.53	53.10
Ba	26.89	31.79

The value of EF varies across the sites following the sequence of Sb>Cd>As>Pb>Sc>Zn>Hg>V>Co>Ti>Ba>Cu>Sr>Ni>Cr>Fe>Mn>K>Ca>Na in dry season. In rainy season, the EF varied with the sequence of Sb>Cd>Pb>As>Sc>Zn>Co>Hg>V>Ti>Ba>Sr>Cu>Ni>Cr>Fe>K>Mn>Ca>Na. Figure 4.38 shows the mean value of EF of twenty elements measured for dry season and rainy season. In dry season, EF was calculated based on forty soil samples (BH-1 to BH-40) where in rainy season EF for twenty soil samples (BH-41 to BH-60). To make a comparison of EF for all the studied metal elements and it can be concluded that the values of EF were found to be very close in both seasons. However, the dry season showed the highest value of EF than that of rainy season as well as vice versa. Figure 4.38 shows that the value of EF for the metal elements of Pb, Zn, Cd, As, Hg, Co and Sb were greater than 50 and lies in the class of extremely severe enriched. Furthermore, the value of EF for Sb and Cd showed very high EF values indicated the soil was extremely severe enrichment for both seasons. The values of EF for Ti and Ba as well as for Fe showed the class was very severe enriched and moderately enrichment, respectively, for dry season. In addition, the value of EF for Fe, Mn and K indicated the minor enrichment as well as Na and Ca indicated no enrichment in soil of the selected waste disposal site for rainy season.

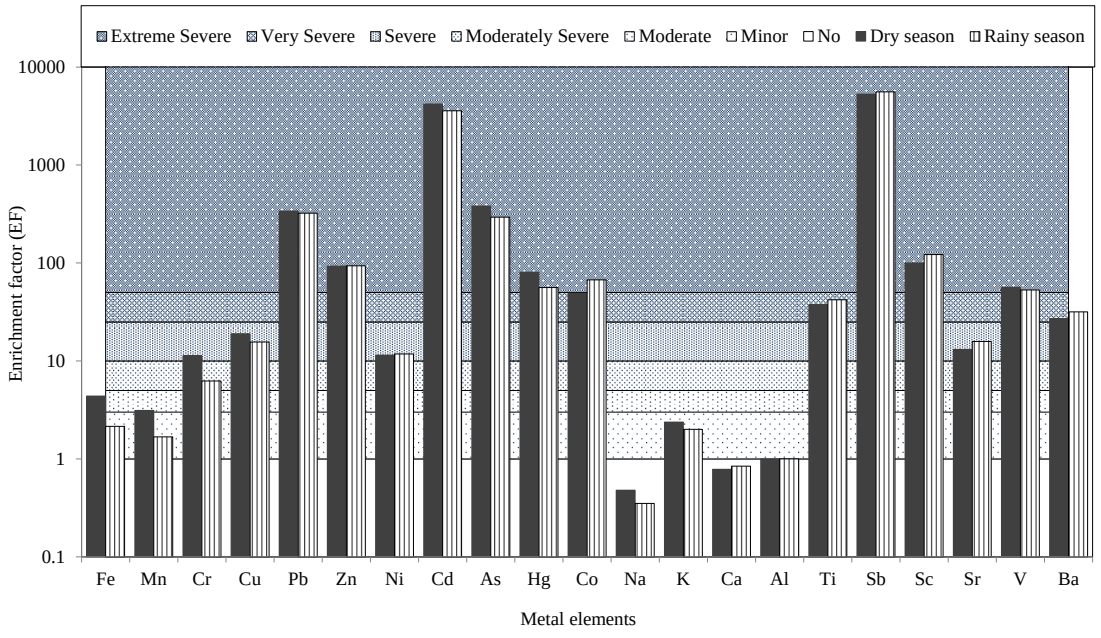


Figure 4.38: Classify the level of contamination of soil based on EF for dry and rainy seasons.

4.6.7 Geo-accumulation Index

In this study, to compute the values of geo-accumulation index (I_{geo}), 95% UCL was considered and the level of contamination for different metal elements in soil are provided in the Table 4.11. In addition, the values of I_{geo} for each metal element in soil for all the soil sampling points are provided in Table B.5 and Table B.6 in the Annex-B for dry and rainy season, respectively.

Table 4.11: Computed values of I_{geo} and contamination levels of soil in dry and rainy season

Metals	Dry season		Rainy season	
	I_{geo} value	Contamination level	I_{geo} value	Contamination level
Fe	-5.88	Uncontamineted	-7.70	Uncontamineted
Mn	-6.44	Uncontamineted	-7.97	Uncontamineted
Cr	-4.57	Uncontamineted	-6.16	Uncontamineted
Cu	-3.71	Uncontamineted	-4.86	Uncontamineted
Pb	0.39	Uncontamineted to Moderately contamineted	-0.67	Uncontamineted
Zn	-1.54	Uncontamineted	-2.49	Uncontamineted
Ni	-4.47	Uncontamineted	-5.29	Uncontamineted
Cd	3.99	Strongly contamineted	2.89	Moderately to strongly contamineted
As	0.67	Uncontamineted to moderately contamineted	-0.67	Uncontamineted
Hg	-1.64	Uncontamineted	-3.03	Uncontamineted
Co	-2.35	Uncontamineted	-2.72	Uncontamineted
Na	-8.95	Uncontamineted	-10.28	Uncontamineted
K	-6.67	Uncontamineted	-7.81	Uncontamineted
Ca	-8.33	Uncontamineted	-9.13	Uncontamineted
Al	-7.90	Uncontamineted	-8.86	Uncontamineted
Ti	-2.73	Uncontamineted	-3.44	Uncontamineted
Sb	4.41	Strongly to extremely contamineted	3.67	Strongly contaminated
Sc	-1.37	Uncontamineted	-1.94	Uncontamineted
Sr	-4.28	Uncontamineted	-4.92	Uncontamineted
V	-2.15	Uncontamineted	-3.08	Uncontamineted
Ba	-3.22	Uncontamineted	-3.86	Uncontamineted

The Figure 4.39 and Figure 4.40 show the overall statistics of I_{geo} in soil over two seasons. Result reveals that the value of I_{geo} for Pb and As showed the soil was uncontaminated to moderately contaminated for dry season, while, these metals (Pb and As) showed the soil was uncontaminated for rainy season. In consideration of the metal of Cd, the value of I_{geo}

for Cd showed the soil was strongly contaminated as well as moderately to strongly contaminated for dry and rainy season, respectively. Correspondingly, the mean value of I_{geo} for the metal element of Sb indicated the strongly to extremely contaminated as well as strongly contaminated level for dry and rainy season, respectively. In overall, I_{geo} is distinctly variable and the soil around the waste disposal site ranges from uncontaminated to strongly and extremely contaminate with respect to analysed metal, which is also supported by (Rahman et al., 2012).

In the Figure 4.39 demonstrations the values of I_{geo} for Fe, Mn, Cr, Cu, Zn, Ni, Hg, Co, Na, K, Ca, Al, Sc, Sr, V and Ba in soil for dry season found to be less than zero indicated the soil was uncontaminated by these metals for the selected disposal site.

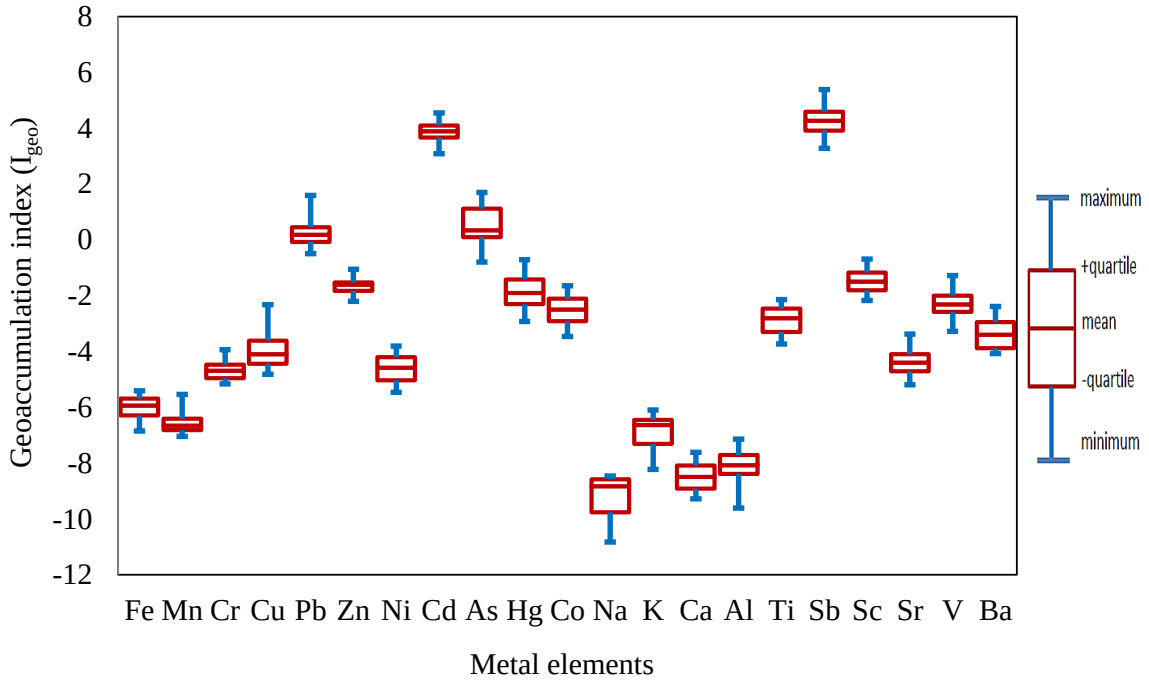


Figure 4.39: Statistics of I_{geo} for metal elements in soil for dry season.

Furthermore, the values of I_{geo} for Fe, Mn, Cr, Cu, Pb, Zn, Ni, Hg, Co, Na, K, Ca, Al, Sc, Sr, V and Ba in soil were found to be less than zero indicated the soil was uncontaminated for rainy season showed in the Figure 4.40. Moreover, only the metal element of As showed the maximum value of I_{geo} which was greater than zero.

The computed values of I_{geo} for the metal elements of Pb, Cd and As in the present study were then compared with the other researches for similar cases of studies provided in Table

4.12. The comparison of I_{geo} for Pb, Cd and As in soil presented in Figure 4.41, Figure 4.42 and Figure 4.43, respectively. These figures depicts that, I_{geo} for Cd was found higher in compare with Rahman et al. (2012) and Ajah et al. (2015).

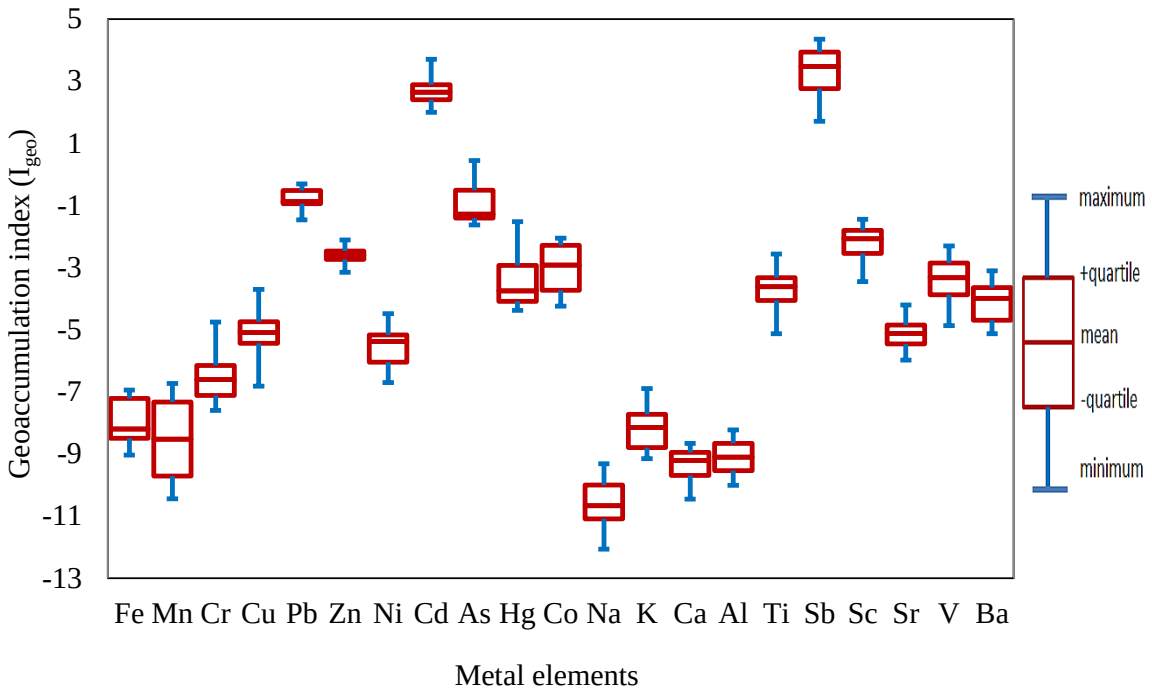


Figure 4.40: Statistics of I_{geo} for metals in soil for rainy season.

Table 4.12: Comparison of I_{geo} of present study with other researchers for dry and rainy season

Parameters	I_{geo}					
	Present study		Rahman et al. (2012)		Ajah et al. (2015)	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
Pb	0.39	-0.67	0.06	-0.1 9	0.4	0.05
Cd	3.99	2.89	-0.03	-0.53	-1.3	-0.7
As	0.67	-0.67	3.23	2.16	0.9	0.6

The values of I_{geo} was computed based on the concentration of metal elements in soil. In the present study for dry season, soil samples showed comparatively the higher concentration of Pb than that of rainy season. For this reason, in dry season the soil samples showed comparatively the higher values (+values) of I_{geo} than that of rainy season (-values) (Figure 4.41). The present study showed comparatively the lower values of I_{geo} than that of published by Rahman et al. (2012) and Ajah et al. (2015) in rainy season. In addition, Ajah et al. (2015) found (+ values) of I_{geo} in case of rainy season.

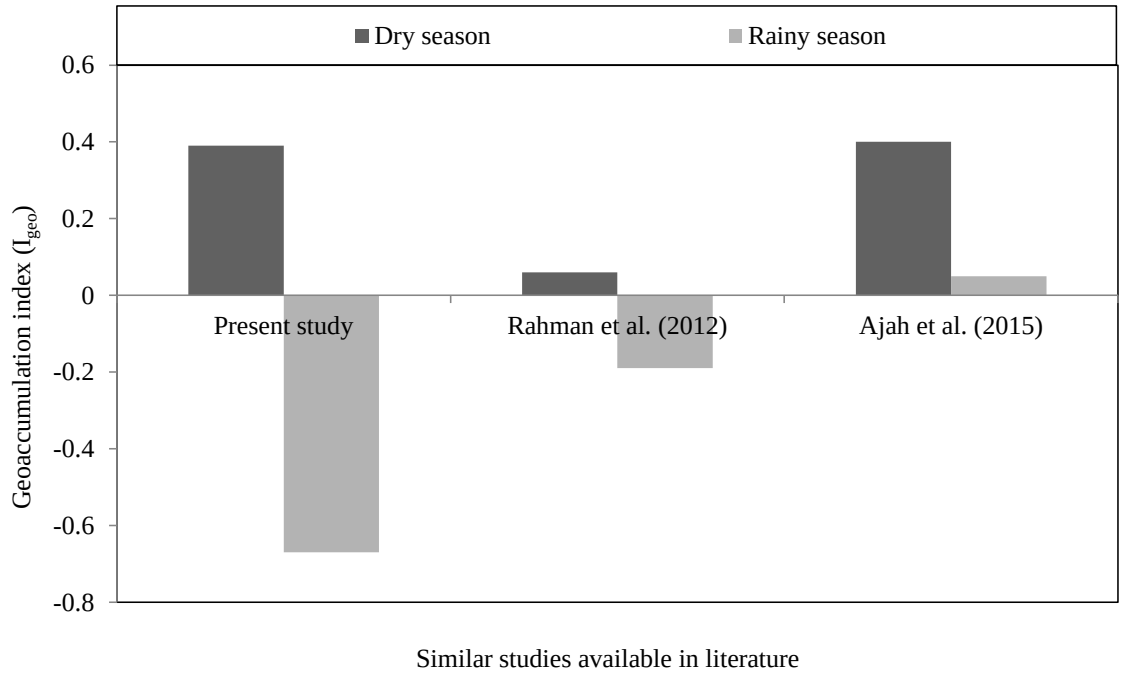


Figure 4.41: Comparing I_{geo} for Pb in the present study with other researchers for similar cases of studies.

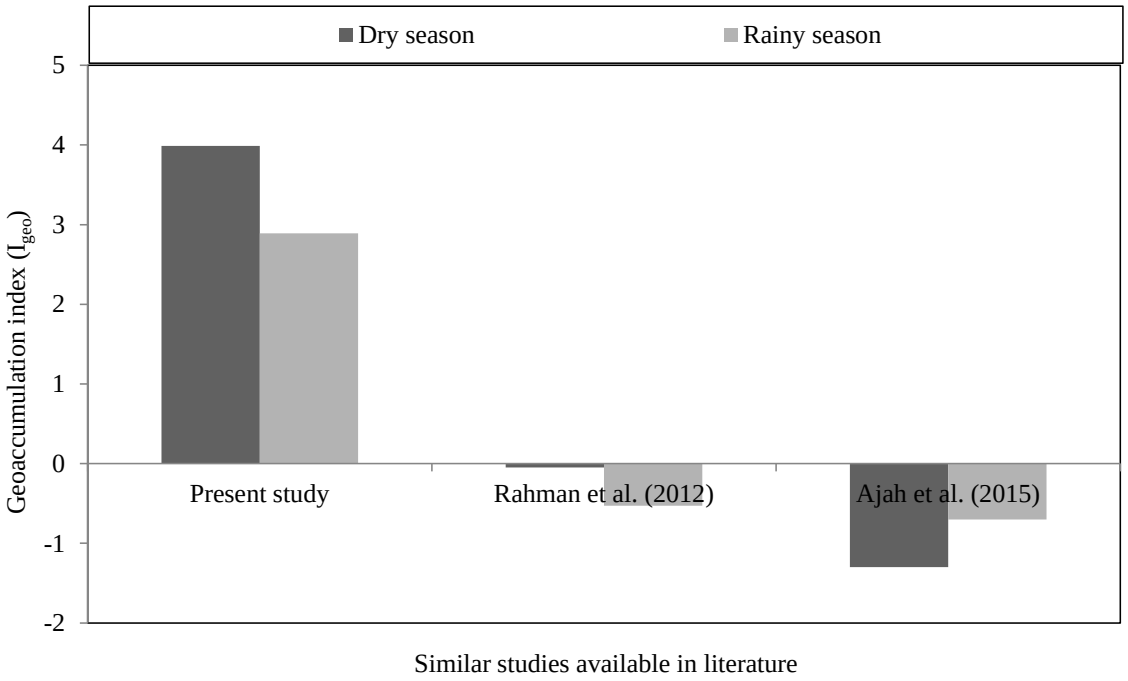


Figure 4.42: Comparing I_{geo} for Cd in the present study with other researchers for similar cases of studies.

In the present study for dry season, soil samples showed comparatively the higher concentration of Cd than that of rainy season implied the higher values of I_{geo} than that of

rainy season (Figure 4.42). The present study showed comparatively the higher values of I_{geo} than that of published by Rahman et al. (2012) and Ajah et al. (2015) for both the dry and rainy season. In addition, Rahman et al. (2012) and Ajah et al. (2015) found (- values) of I_{geo} for both, dry season and rainy season (Figure 4.42). However, Ajah et al. (2015) found comparatively the lower values of I_{geo} than that of obtained by Rahman et al. (2012).

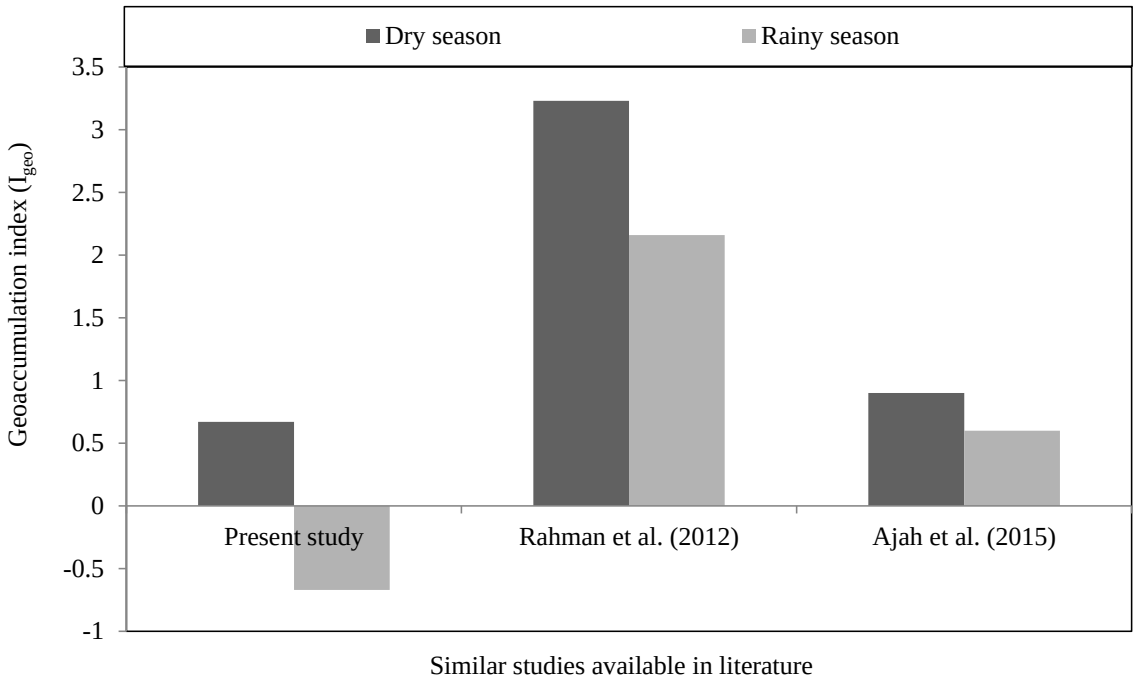


Figure 4.43: Comparing I_{geo} for As in the present study with other researchers for similar cases of studies.

In addition, Figure 4.43 reveals that Rahman et al. (2012) was found comparatively the higher values (+ values) of I_{geo} for As than that of results of present study and result of Ajah et al. (2015) for both seasons. The present study only showed the lowest values (-values) of I_{geo} for As.

4.6.8 Potential Ecological Risk Index

With regard to the assessment method proposed by Håkanson (1980), ecological risk index (ER) of a single heavy metal as well as potential ecological risk index (PERI) was computed by adding ER for each heavy metal. In addition, ER is computed from contamination factor (CF) and toxic-response factor (TR) for each heavy metal. The computed results of ER for heavy metal and PERI in soil for all sampling points (boreholes) for dry season are provided

in Table 4.13. In addition, the value of ER for heavy metals in soil for dry season is illustrated in Figure 4.44.

Table 4.13: Variation of ER and PERI for heavy metals in soil during dry season

Boreholes	ER									PERI
	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	
1	0.12	1.23	22.64	0.73	0.54	1054.50	48.72	35.48	2.40	1166.36
2	0.12	1.50	12.72	0.73	0.52	903.00	43.83	36.80	2.10	1001.31
3	0.18	0.98	12.75	0.65	0.48	880.50	42.56	33.28	2.15	973.52
4	0.18	1.27	17.72	0.72	0.50	1042.50	41.06	34.36	2.24	1140.54
5	0.20	1.17	12.67	0.70	0.47	919.50	38.61	28.88	2.14	1004.34
6	0.16	1.39	15.19	0.65	0.45	993.00	37.22	32.04	2.14	1082.26
7	0.16	1.08	11.42	0.63	0.47	720.00	38.44	30.60	1.96	804.76
8	0.14	0.70	9.42	0.54	0.45	843.00	35.17	28.56	1.62	919.59
9	0.14	0.62	10.19	0.50	0.45	754.50	40.56	24.56	1.78	833.29
10	0.13	0.65	11.72	0.52	0.41	843.00	35.83	19.04	1.96	913.27
11	0.13	0.62	8.30	0.48	0.41	883.50	31.67	22.56	1.80	949.47
12	0.12	0.50	7.97	0.51	0.37	781.28	22.33	19.92	1.73	834.75
13	0.11	0.55	8.23	0.50	0.37	762.45	27.11	19.92	1.70	820.94
14	0.15	0.46	7.72	0.47	0.33	743.62	26.56	12.36	1.67	793.33
15	0.12	0.42	8.08	0.53	0.34	724.79	21.56	11.48	1.57	768.89
16	0.17	0.47	9.76	0.48	0.34	744.00	21.50	10.48	1.52	788.72
17	0.15	0.55	10.17	0.49	0.34	687.12	20.42	12.12	1.49	732.85
18	0.11	0.50	10.44	0.50	0.34	750.00	19.17	14.00	1.10	796.16
19	0.12	0.43	9.94	0.52	0.32	649.46	18.78	16.56	1.49	697.62
20	0.10	0.44	9.41	0.48	0.27	630.63	18.50	20.12	1.35	681.30
21	0.12	0.37	10.19	0.51	0.31	708.00	21.67	22.48	1.40	765.05
22	0.09	0.43	10.97	0.50	0.30	592.96	20.39	19.28	1.31	646.23
23	0.12	0.33	9.47	0.47	0.23	700.50	17.33	14.64	1.11	744.20
24	0.12	0.37	8.67	0.44	0.27	645.00	17.28	16.36	1.22	689.72
25	0.12	0.31	8.17	0.41	0.20	585.00	17.17	15.08	1.19	627.65
26	0.11	0.45	7.19	0.43	0.27	595.50	16.78	19.68	1.11	641.51
27	0.11	0.45	6.66	0.44	0.28	504.00	16.47	14.64	1.09	544.14
28	0.11	0.35	6.47	0.53	0.26	549.00	16.22	11.08	1.04	585.07
29	0.11	0.35	6.69	0.51	0.26	499.50	16.06	8.36	1.06	532.90
30	0.10	0.34	6.93	0.50	0.23	453.00	16.00	7.92	1.01	486.02
31	0.10	0.27	8.21	0.33	0.20	616.50	15.94	18.82	0.98	661.34
32	0.10	0.34	9.46	0.39	0.23	573.00	15.36	14.62	0.94	614.43
33	0.10	0.42	5.89	0.40	0.32	564.00	14.78	15.68	0.93	602.51
34	0.10	0.36	7.56	0.33	0.18	532.50	12.33	9.68	0.96	564.00
35	0.08	0.34	7.93	0.38	0.20	462.00	11.61	13.80	0.93	497.28
36	0.09	0.27	6.57	0.33	0.19	573.00	10.31	12.20	0.81	603.76
37	0.09	0.27	6.07	0.38	0.24	418.50	9.89	13.56	0.78	449.78
38	0.09	0.35	5.45	0.33	0.21	465.00	9.83	11.58	0.78	493.63
39	0.08	0.34	5.32	0.43	0.19	382.50	9.00	9.50	0.75	408.12
40	0.08	0.32	5.79	0.39	0.17	580.50	8.61	8.30	0.68	604.85
95% UCL	0.13	0.67	10.46	0.53	0.36	735.62	26.55	21.07	1.55	795.92

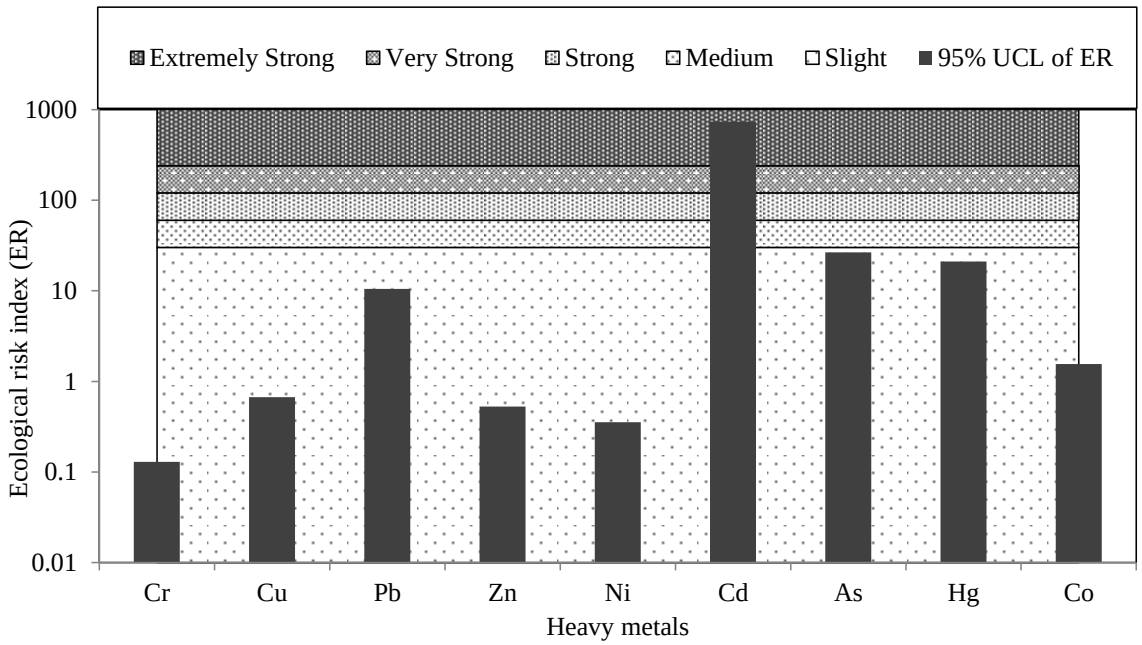


Figure 4.44: Classification of risk based on ecological risk index for heavy metals in soil during dry season.

The ecological risk index (ER) arrayed in the order of ER(Cd)> ER(As)> ER(Hg)> ER(Pb)> ER(Co)> ER(Cu)> ER(Zn)> ER(Ni)> ER(Cr) for 95% UCL value of these nine heavy metals in soil (Figure 4.56). Håkanson (1980) stated that soil sample having the value of ER less than 30; 30 to 60; 60 to 120; 120 to 240 and greater than 240 indicated contamination risk degree is slight, medium, strong, very strong and extremely strong, respectively. Based on this postulation, the studied heavy metals of Cr, Cu, Pb, Zn, Ni, As, Hg and Co having the ER values less than 30 indicated the slightly ecological risk while the heavy metal of Cd having the 95% UCL value of 735.62 indicated the extremely strong ecological risk. Furthermore, result depicted that the heavy metal of Cd showed the maximum value of ER of 735.62 (Figure 4.44) with respect to the other counter heavy metals in soil and it can be revealed that Cd was the key influence factor to cause the potential ecological risk in soil of waste disposal site. Results indicated that about 92 to 95% of this potential ecological risk (ER) is contributed by the heavy metal of Cd, whereas, the risk posed by the other heavy metals had comparatively very lower values. This statement was similar with risk of municipal central dumpsite in Enugu, Nigeria where Cd posed 91% of total risk stated by Ajah et al. (2015). Furthermore, the entire soil samples have extremely strong potential ecological risk for Cd, whereas, other heavy metals only showed slightly ecological risk except As and Hg. These two heavy metals has medium to slight ecological risk in soil in

the present study. In addition, Figure 4.45 represents the variation of computed PERI for all soil sampling points (boreholes) during dry season. Håkanson (1980) stated that soil sample having the value of PERI less than 40, 40 to 80, 80 to 160, 160 to 320 and greater 320 indicated the ecological risk is slight, medium, strong, very strong and extremely strong, respectively. Figure 4.45 depicts that the magnitude of PERI for entire soil samples were found above 320 indicated extremely strong ecological risk by the heavy metals present in soil for all the soil sampling points (boreholes) of the selected waste disposal site.

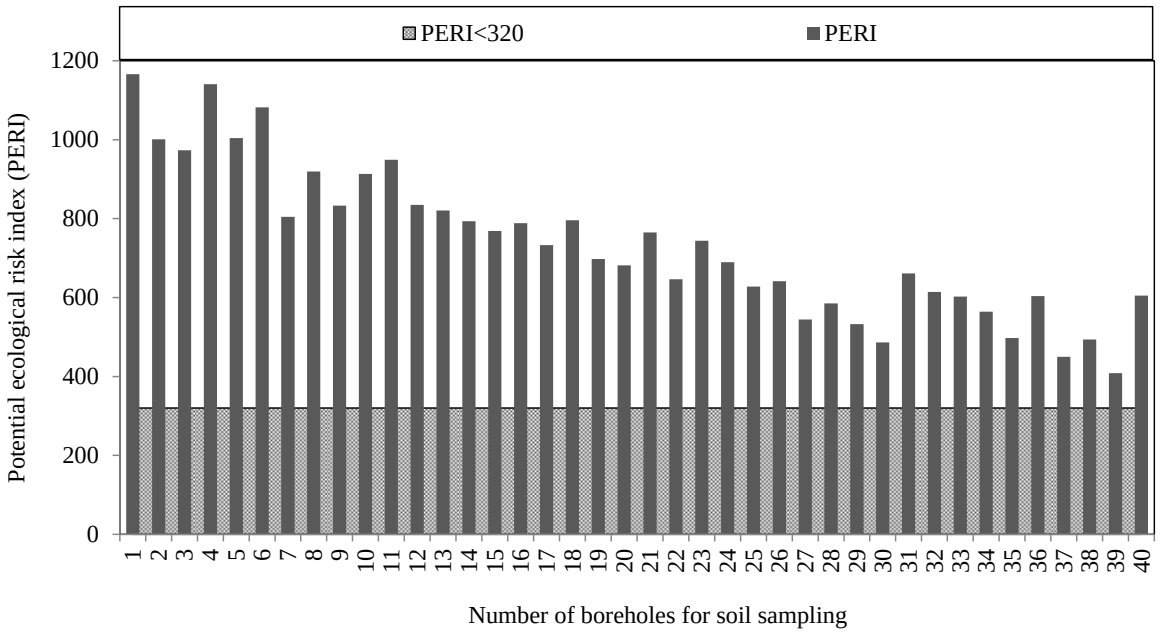


Figure 4.45: Variation of computed potential ecological risk index for heavy metals in soil during dry season.

In addition, the values of ER for each heavy metals and PERI for all soil sampling points were also computed for rainy season and provided in Table 4.14. The classification of contamination degree according to the values of ER of heavy metals in soil of rainy season is depicted in Figure 4.46. In rainy season, the potential ecological risk was found as similar as the dry season in the order of ER(Cd) > ER(As)> ER(Hg)> ER(Pb)> ER(Co)> ER(Cu)> ER(Zn)> ER(Ni)> ER(Cr) in terms of the 95% UCL of potential ecological risk indices of these metals. The soil samples have extremely strong potential ecological risk for Cd, while, other metals showed only slightly ecological risk in soil.

Table 4.14: Variation of ER and PERI for heavy metals in soil during rainy season

No of borehole	ER									PERI
	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	
41	0.09	0.58	6.07	0.33	0.31	585.00	20.42	18.08	1.79	632.66
42	0.06	0.38	5.45	0.33	0.34	465.00	17.97	14.76	1.80	506.09
43	0.08	0.34	5.32	0.28	0.23	467.25	16.67	20.84	1.62	512.62
44	0.11	0.32	5.79	0.28	0.24	382.50	15.36	9.32	1.37	415.31
45	0.05	0.28	6.02	0.25	0.21	441.75	10.44	7.66	1.28	467.95
46	0.04	0.25	4.06	0.35	0.19	318.00	10.69	4.48	1.55	339.62
47	0.03	0.18	5.19	0.25	0.18	265.50	6.17	4.44	1.61	283.54
48	0.03	0.26	3.97	0.27	0.16	247.50	5.89	5.80	1.53	265.41
49	0.03	0.28	4.17	0.26	0.20	256.50	5.67	4.08	1.06	272.24
50	0.03	0.24	4.46	0.25	0.19	282.00	4.89	4.44	1.02	297.52
51	0.03	0.18	4.11	0.25	0.21	303.00	5.67	3.48	0.95	317.88
52	0.03	0.23	3.80	0.24	0.18	282.00	6.17	3.52	0.61	296.78
53	0.03	0.21	4.00	0.23	0.14	288.00	5.67	6.68	0.78	305.74
54	0.02	0.18	4.00	0.22	0.12	298.50	6.17	8.40	0.66	318.27
55	0.02	0.15	4.69	0.23	0.11	249.00	6.22	5.04	0.46	265.93
56	0.02	0.21	3.93	0.22	0.08	184.50	5.72	3.96	0.57	199.22
57	0.02	0.10	3.47	0.24	0.07	199.50	6.72	3.52	0.53	214.17
58	0.02	0.08	3.03	0.21	0.07	210.00	5.67	2.88	0.40	222.35
59	0.02	0.07	3.44	0.18	0.09	186.00	6.17	3.08	0.42	199.47
60	0.02	0.12	2.72	0.17	0.11	180.00	4.83	3.08	0.40	191.45
95% UCL	0.05	0.28	4.81	0.27	0.20	352.94	10.81	9.15	1.24	379.15

Figure 4.47 represents the variation of PERI for all soil sampling points (boreholes) during rainy season. Figure 4.47 reveals that the computed values of PERI for soil samples from boreholes 41 to BH 46 were almost above 320, while PERI for soil samples from boreholes 47 to BH 60 ranges from 160 to less than 320. Håkanson (1980) stated that soil sample having the value of PERI ($160 \leq PERI < 320$) indicated the ecological risk is very strong, while, greater than 320, indicated the ecological risk is extremely strong. Based on this statement, it can be depicted that for soil from boreholes BH 41 to BH 46, the ecological risk was extremely strong, while, for boreholes BH 47 to BH 60, ecological risk was very strongly. A study conducted by Ajah et al. (2015) of waste dumping site in Enugu and postulated that the PERI in soil for both seasons revealed the potential ecological risk is very strongly contaminated. In the present study, the soil sample of showed very strong to extremely contaminated in risk for both season. In addition, from the Table 4.13 and Table 4.14, it is depicted that the values of ER and PERI was declining in relation to the increasing of soil sampling distances from central point of the waste disposal site. Hence, Risk due to

heavy metals was more severe in case of dry season according to the variation of PERI and ER against rainy season.

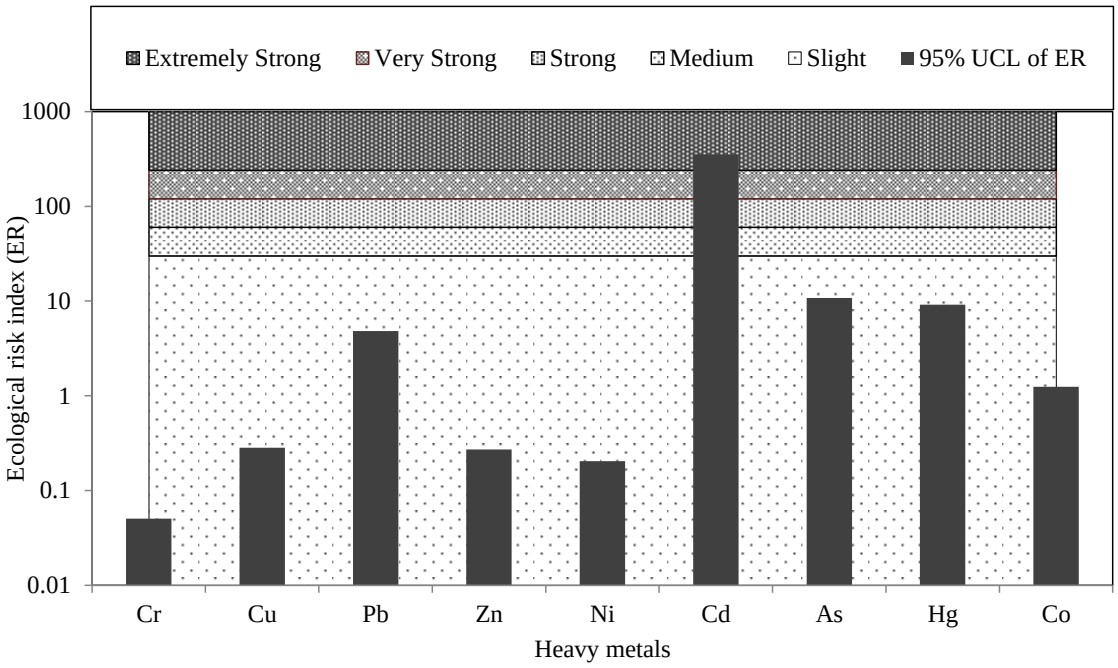


Figure 4.46: Classification of risk based on ecological risk index for heavy metals in soil of rainy season.

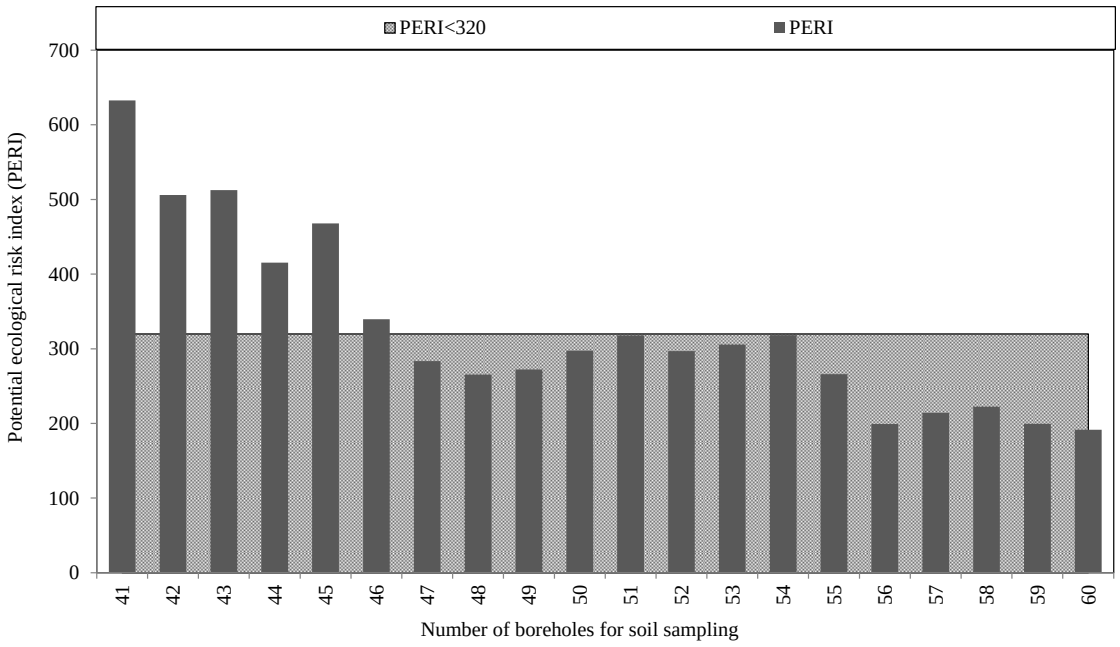


Figure 4.47: Variation of computed Potential ecological risk index for heavy metals in soil from boreholes during rainy season.

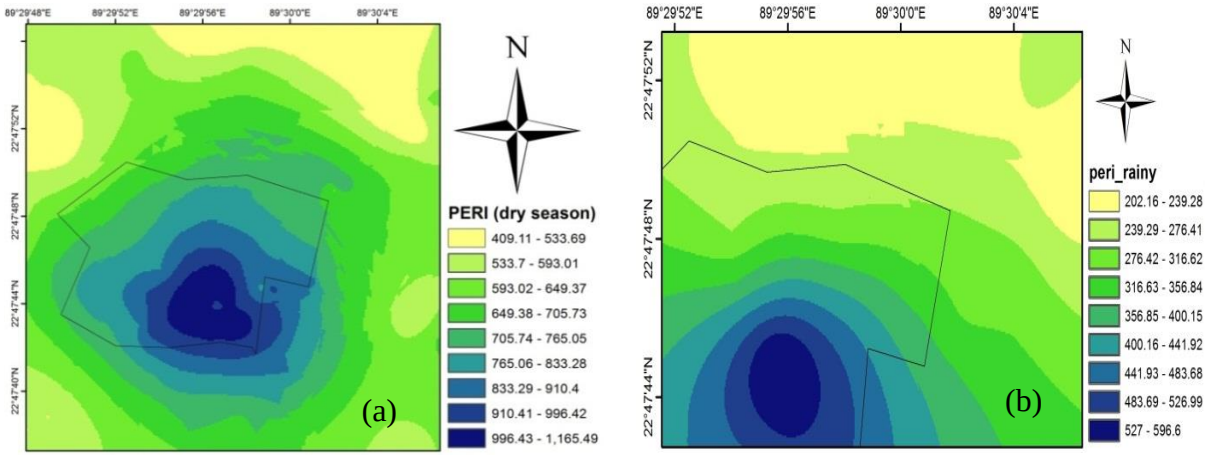


Figure 4.48: Spatial distribution of PERI during (a) dry and (b) rainy season.

The spatial distribution of PERI in soil (forty soil samples) for dry and rainy season (twenty soil samples) is presented in Figure 4.48 (a) and Figure 4.48 (b), respectively. Moreover, in this distribution, different shades of deep blue and yellow color segments were considered which represents the various ranges of the PERI value in soil. In the produced prediction surface, green with yellow color region represented the less degree of ecological risk of soil, whereas, deep blue color area represented the high degree of ecological risk (Yasrebi et al., 2009). In this study, the magnitude of PERI for soil sample from central point (approximately 0 m) ranges from 1165.49 to 996.43, while, for soil sample from farthest point (390m from central point) ranges from 533.69 to 409.11 for dry season. Here, it can be noted that the soil of near to central borehole points was extremely strong ecological risk, while, soil of followed other borehole points was very strongly ecological risk.

In addition, PERI ranges from 527 to 596.6 for soil sample from near to center (approximately 30 m) and to 202.16 to 239.28 for soil sample from farthest point (315m from central point) in rainy season. Here, it can be noted that the soil of near to central borehole points (BH 47 to BH 60) was extremely strong ecological risk, while, soil of other borehole points (BH 47 to BH 60) was very strongly ecological risk. Result reveals that the values of PERI based on the heavy metal concentration was found to be higher at central point of the waste disposal site and then it decreases in relation to the increase to soil sampling distances. Moreover, the magnitudes of PERI were comparatively higher for dry season against the rainy season.

4.6.9 Overall Risk identified by Indicies in this Study

To evaluate the level of contamination of soil of the selected waste disposal site, various indices such as Cp, CF, I_{geo}, mCD, EF, NICF, CLI, ER and PERI were used. In this study, the level of contaminaton of soil were evaluated based on the limit of these indices suggested by the different researchers stated earlier. The soil of dry season showed comparativle the higher values of Cp, CF, I_{geo}, mCD, EF, NICF, CLI, ER and PERI in soil than that of rainy season. Thus, for overall results of various indices, the maximum values of for dry season were considered. The overall results of indices with contmination level and responsible heavy metals for risk are provided in Table 4.15.

Table 4.15: Overall results of indices with contmination level and responsible heavy metals.

Serial No.	Indices	Computed Values	Highest class of soil contamination	Responsible heavy metals for risk
1	Cp	>3	Severe or very sever contamination	Sb, Cd
2	CF	>6	Very high contamination	Cd, Sb
3	I_{geo}	3 - 4	Strongly contaminated	Cd, Sb
5	mCD	2-4	Moderate degree of contamination	---
6	NICF	> 3	Heavy level of contamination	---
7	CLI	<1	uncontaminated	---
8	ER	≥ 240	Extremely Strong ecological risk	Cd
9	PERI	≥ 320	Strongly ecological risk	---

The values of Cp for the heavy metals of Sb and Cd were found to be greater than 3 indicated the level of contamination of soil was sever or very sever. The two heavy metals of Pb and As with comparatively the higher concentrations in soil was also contributed for higher values of Cp. In addition, Cd and Sb were predominant among all the studied heavy metals and these heavy metals offered the highest values of CF and I_{geo}. In contrast, result reveals that EF indicated the extremely severe enriched by the heavy metals of Cd, As, Pb, Zn, Sc, Hg and Sb in soil and varied across the sites following the sequence of Sb> Cd> As> Pb> Sc> Zn> Hg> Co in soil of the waste disposal site. The value of CLI indicated the soil was uncontaminated. Other two indices of NICF, mCD represented the heavy level of contamination and moderate degree of contamination of soil, respectively. In addition, the results of ER indicated the extremely strong ecological risk especially for Cd as well as the

heavy metals of Cr, Cu, Pb, Zn, Ni, As, Hg and Co indicated the slightly ecological risk. PERI indicated the soil of the disposal site was strongly ecological risk.

Here, it can be demonstrated that the contamination of soil of the selected waste disposal site was found mainly due to the presence of Sb and Cd in soil. The heavy metals of Sb and Cd comes into the waste disposal site from dumping of the following items in the disposal site such as batteries, bearing metals, cable covering, solder, sheet and pipes, flame retardants used in consumer electrical and electronic equipment, polyester manufacture, semiconductors, applications in the production of specialty glasses as decolonzers and opacifiers and in the use of pigments (Velzen et al., 1998). Plastic is also a source of Cd and Sb in MSW (NIIR, 2005). The most likely sources of Cd are plastics and pigments.. In this study, the soil was also contaminated due to presence of Pb and As. The Pb emissions appeared to be derived from both discards of batteries, plastics, and pigment, paper coatings etc. (Korzun and Heck, 1990). Moreover, food waste, newspaper, and polyethylene bag etc. are the sources of Pb in MSW. In addition, Arsenic was also used in various agricultural insecticides and poisons and eventually it found in soil media.

4.7 Spatial Distribution of Various Indices

In this study, the various indices such as potential contamination index index (Cp), contamination factor (CF), contamination load index (CLI), modified contamination degree (mCD), numerical integrated contamination factor (NICF), enrichment factor (EF), geo-accumulation index (I_{geo}) and potential ecological risk index (PERI) for soil in waste disposal site for both seasons were analysed. Moreover, the surface spatial distribution of these indices using ordinary kriging (OK) through ArcGIS were also performed and hence discussed in the following articles.

4.7.1 Contamination Factor

The spatial distribution of contamination factor (CF) for twenty one metal elements during dry season and rainy season were performed. According to the definition of CF, the magnitude of CF for an element mainly depends on the values of metal concentration in soil and the background concentration of the metal. Earth crustal values were considered as the background of a metal element in this research work and the values are constant in all

sampling stations. So the CF values are different than metal concentration but the distribution pattern for metal element based on concentration and CF values. The spatial distribution of CF for the metal elements are described in the following figures except Mn, Cu, Pb, Ni, Co, Na, K, Ca, Al, Sc, Sr, V and Ba in soil which are presented in Figure E.1 to Figure E.13, respectively, in the Annex-E.

4.7.1.1 Iron

The spatial distribution of contamination factor (CF) for the metal element of Fe in soil for dry and rainy season is presented in Figure 4.49 (a) and Figure 4.49 (b), respectively. The magnitude of the CF of Fe for soil sample from central point (approximately 0 m) ranges from 0.0329 to 0.0353, while, for soil sample from farthest point (390m from central point) ranges from 0.013 to 0.0155 for dry season. In rainy season, CF ranges from 0.0112 to 0.0121 for soil sample from near to centre (approximately 30 m) and 0.0029 to 0.0039 for soil sample from farthest point (315m from central point). The distribution patterns indicate that the CF of Fe in the selected site gradually decreases from the centre to the outer side area in both seasons. The ranges of concentration in both season show, the dry seasonal CF values in soil was higher than rainy season.

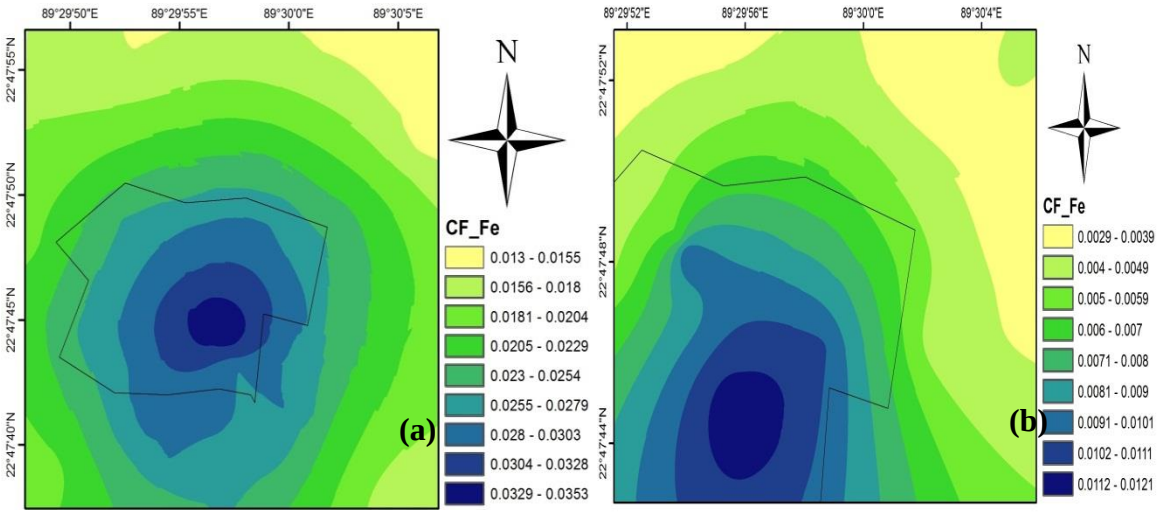


Figure 4.49: Spatial distribution of CF of Fe in (a) dry season and (b) rainy season.

4.7.1.2 Chromium

Figure 4.50 (a) and Figure 4.50 (b) illustrate, metal enhancement maps plotted CF distribution for Cr during dry and rainy season, respectively. The magnitude of the CF of Cr for soil sample from central point (approximately 0 m) ranges from 0.078 to 0.0822, while,

for soil sample from farthest point (390 m from central point) ranges from 0.0437 to 0.048 for dry season. Besides, CF of the same metal ranges from 0.0501 to 0.0553 for soil sample from near to centre (approximately 30 m) and 0.0077 to 0.0-13 for soil sample from farthest point (315 m from central point) in rainy season. In figures, the deep blue colour indicated the CF of Cr in soil of that sampling point was very high, while, the yellow colour indicated the CF of Cr in soil of that sampling point was comparatively very low. Form figure, it is clear that the maximum values of CF range in dry season not only covers the centre point of the disposal site but also the surrounding area of the site. The distribution patterns are similar in both season but the CF of Cr is decreasing with lateral distance from the centre point of the area. The ranges of concentration in both season show, the dry seasonal CF values in soil was higher than rainy season.

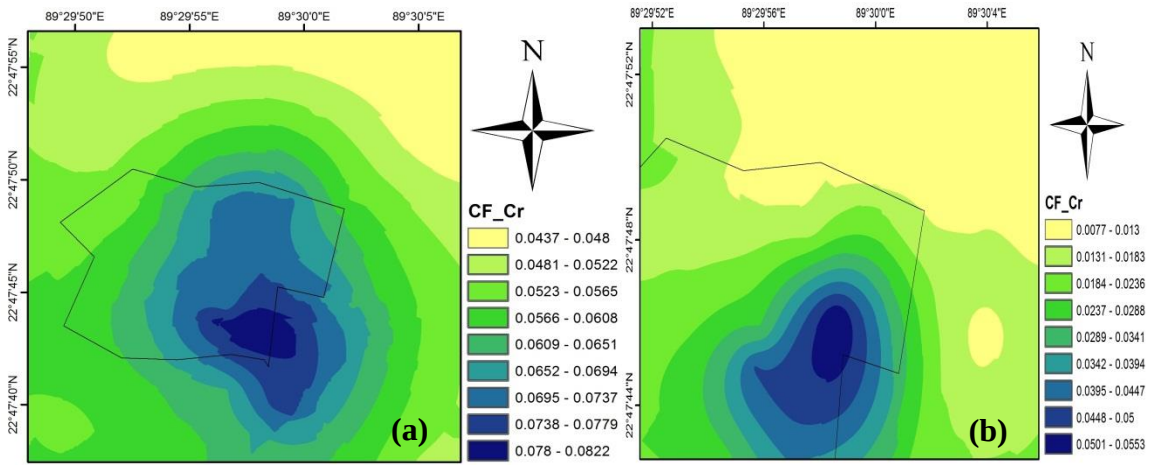


Figure 4.50: Spatial distribution of CF of Cr in (a) dry season and (b) rainy season.

4.7.1.3 Zinc

The spatial distribution of contamination factor (CF) for the metal elements of Zn in soil (forty soil samples) for dry and rainy season is presented in Figure 4.51 (a) and Figure 4.51 (b), respectively. The CF of Zn for soil sample from central point (approximately 0 m) ranges from 0.66 to 0.699, while, for soil sample from farthest point (390m from central point) ranges from 0.343 to 0.382 for dry season. Besides, CF of the same metal ranges from 0.328 to 0.347 for soil sample from near to centre (approximately 30 m) and 0.169 to 0.189 for soil sample from farthest point (315 m from central point) during rainy season. The distribution patterns of CF were similar in both season but the magnitude of CF caused by Zn in soil was

higher in dry season. In addition, the CF of Zn was decreasing with lateral distance from the centre point of the area.

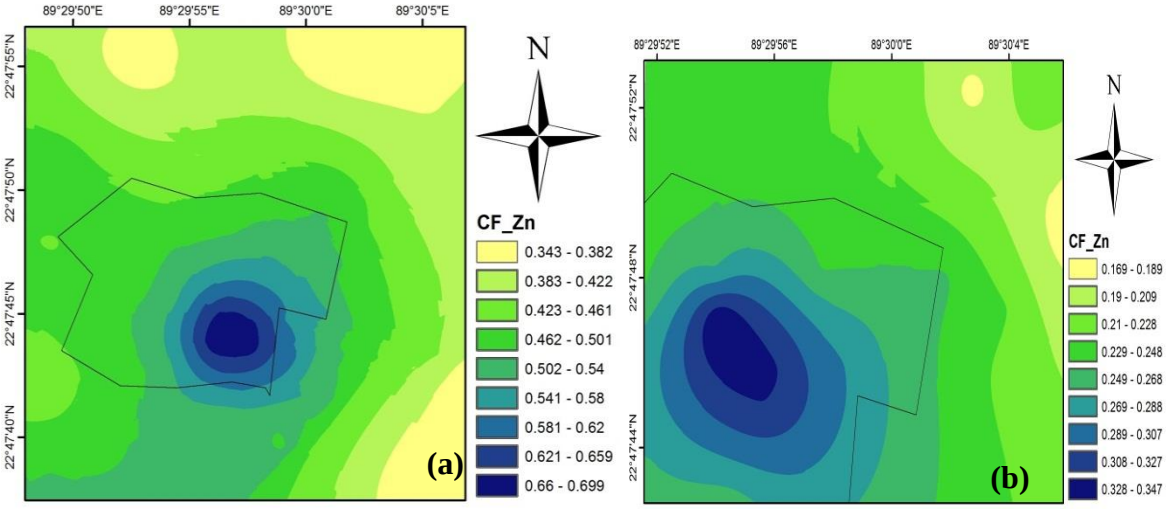


Figure 4.51: Spatial distribution of CF of Zn in (a) dry season and (b) rainy season.

4.7.1.4 Cadmium

Figure 4.52 (a) and Figure 4.52 (b) show the distribution pattern of CF of Cd along the waste disposal site for dry and rainy, respectively. The magnitude of the CF of Cd for soil sample from central point (approximately 0 m) ranges from 32.53 to 34.99, while, for soil sample from farthest point (390m from central point) ranges from 12.77 to 15.24 for dry season. Besides, CF of the same metal ranges from 17.29 to 15.66 for soil sample from near to centre (approximately 30 m) and 6.23 to 7.61 for soil sample from farthest point (315m from central point) in rainy season. Outcome of the CF distribution depicted that the magnitude of CF decreases in relation to the increasing of soil sampling distances from approximately the central point of waste disposal site. Comparing seasonal CF of Cd, dry seasonal Cd concentration was high.

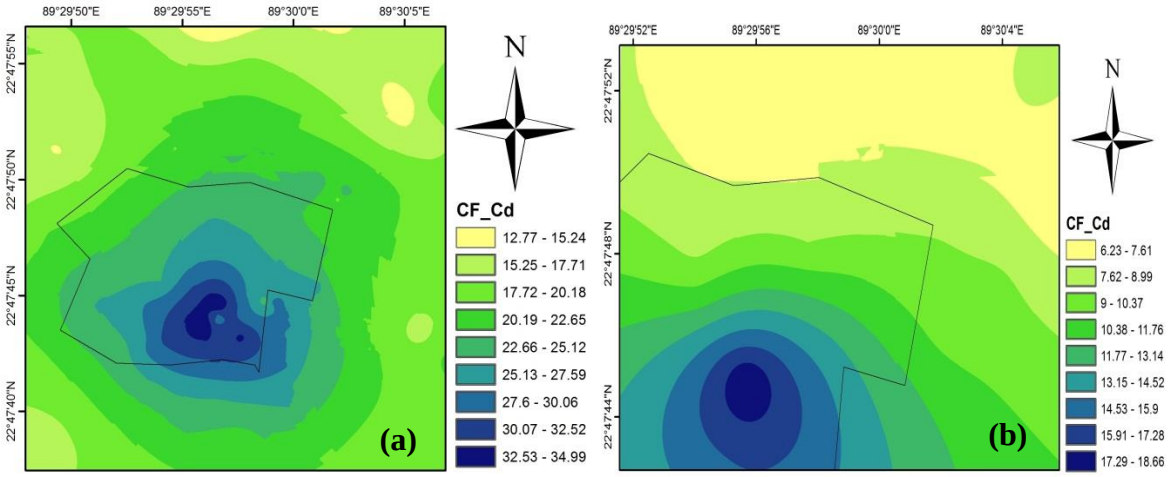


Figure 4.52: Spatial distribution of CF of Cd in (a) dry season and (b) rainy season.

4.7.1.5 Arsenic

The spatial distribution of contamination factor (CF) for the metal elements of As in soil for dry and rainy season is represented in Figure 4.53 (a) and Figure 4.53 (b), respectively. During dry season, the value of the CF of As for soil sample from central point (approximately 0 m) ranges from 4.42 to 4.56, while, for soil sample from farthest point (390 m from central point) ranges from 0.86 to 1.3. Besides, during rainy season the CF of the same metal ranges from 1.88 to 2.04 for soil sample from near to centre (approximately 30 m) and 0.48 to 0.66 for soil sample from farthest point (315 m from central point). Thus, it is clear that the CF of As was higher in soil of the centre and decreased gradually to outer side soil of the disposal site. Figure also shows the range of CF caused by As was slightly greater in dry season than rainy season.

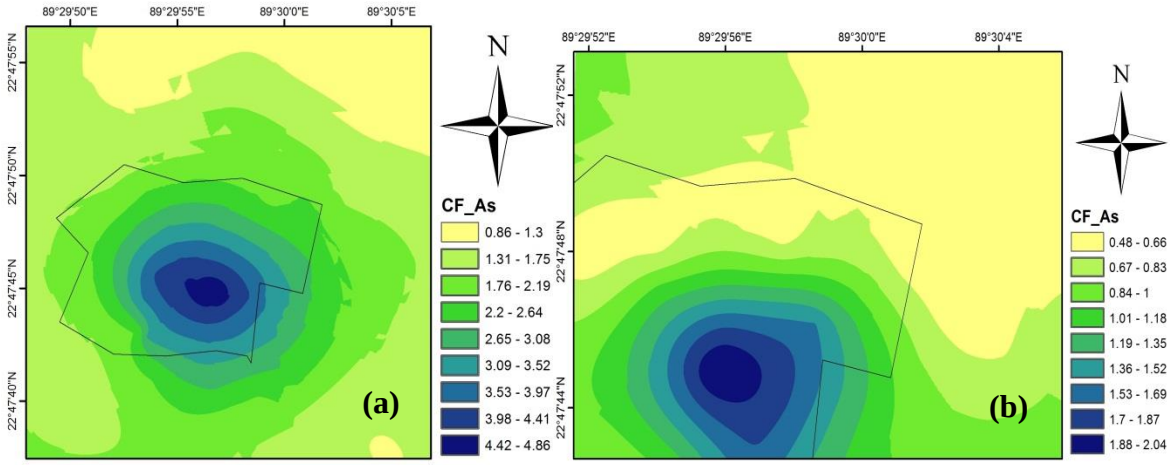


Figure 4.53: Spatial distribution of CF of As in (a) dry season and (b) rainy season.

4.7.1.6 Mercury

Figure 4.54 (a) and Figure 4.54 (b) illustrate the distribution map of CF for Hg in soil for the durations of dry season and rainy season, respectively. The magnitude of the CF of Hg for soil sample from central point (approximately 0 m) ranges from 0.837 to 0.916, while, for soil sample from farthest point (390 m from central point) ranges from 0.199 to 0.279 for dry season. In addition, CF of the same metal ranges from 0.37 to 0.4 for soil sample from near to centre (approximately 30 m) and 0.09 to 0.12 for soil sample from farthest point (315 m from central point) in rainy season. The distribution pattern of CF in dry season was irregular where in rainy season pattern shows uniform distribution along the area. From the figure it can be said that the high level of CF caused by Hg was present in the soil of central point where it was decreased along the lateral distance. Moreover, Dry season shows the high range of CF (Hg) values.

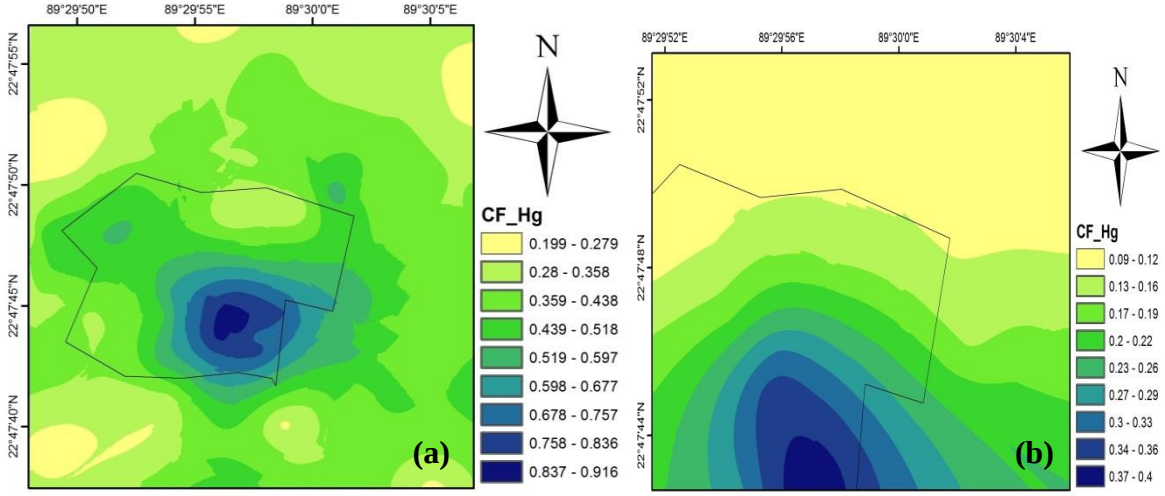


Figure 4.54: Spatial distribution of CF of Hg in (a) dry season and (b) rainy season.

4.7.1.7 Titanium

The spatial distribution of CF of Ti in the sample soil for dry and rainy season is presented in Figure 4.55 (a) and Figure 4.55 (b), respectively. The extent of the CF of Ti for soil sample from central point (approximately 0 m) ranges from 0.315 to 0.34, while, for soil sample from farthest point (390 m from central point) ranges from 0.112 to 0.137 for dry season. Besides, CF of the same metal ranges from 0.231 to 0.253 for soil sample from near to centre (approximately 30 m) and 0.043 to 0. 066 for soil sample from farthest point (315 m from central point) in rainy season. The distribution patterns tell that CF of metal is larger values in dry season than rainy season. Though the two seasonal distribution patterns does not cover

the same geometric area, but it is clear from the figure that CF got decrease along increasing distance from the centre point of the waste disposal site.

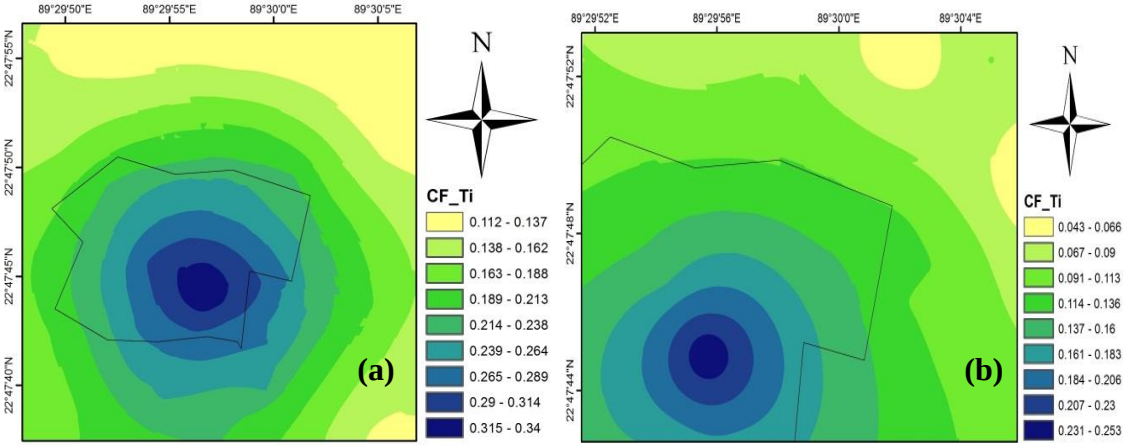


Figure 4.55: Spatial distribution of CF of Ti in (a) dry season and (b) rainy season.

4.7.1.8 Antimony

Figure 4.56 (a) and Figure 4.56 (b) show the distribution pattern of CF for the metal elements of Sb in soil along the sampling site during dry and rainy season, respectively. The magnitude of the CF of Sb for soil sample from central point (approximately 0 m) ranges from 57.09 to 62.39, while, for soil sample from farthest point (390 m from central point) ranges from 14.6 to 19.91 for dry season. Besides, CF of the same metal ranges from 27.75 to 30.59 for soil sample from near to centre (approximately 30 m) and 4.91 to 7.79 for soil sample from farthest point (315 m from central point) in rainy season. Figure of distribution reveals that the CF of Sb in soil collected from the central point of the waste disposal site showed higher magnitude than the others. Mainly, along the distances the CF of Sb decreased and during dry season the ranges was higher than rainy season.

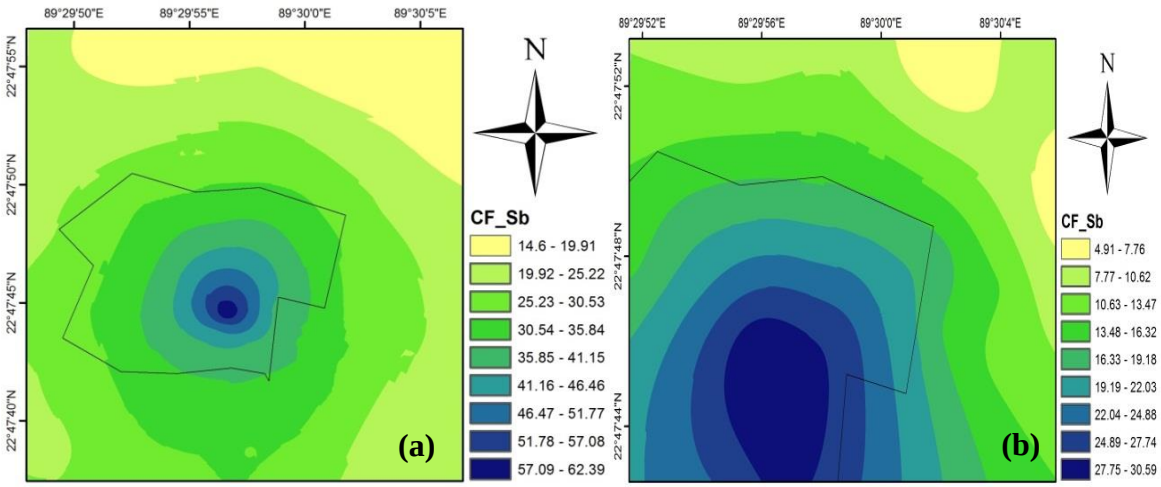


Figure 4.56: Spatial distribution of CF of Sb in (a) dry season and (b) rainy season.

From the above articles, it is sure that all the metal elements considered in the distribution study of CF had a greater magnitude in the soil of the studied waste disposal site during dry season than rainy season. In case of most of the elements considered here, the distribution pattern for CF was quite uniform in both seasons. Though the two seasonal CF distribution patterns for different metals do not cover the same geometric area, but it is clear that the range of magnitude was decrease along increasing distance from the centre point of the waste disposal site. This reduction of this index was caused by the effect of leaching by infiltrating water. Besides, during heavy rainfall, soluble metal content get diluted and runoff from the dumpsite spreads to the surrounding soil.

4.7.2 Enrichment Factor

In this article, surface spatial distribution of EF during dry season and rainy season, for twenty (20) metals considered in the study by the method of OK using ArcGIS. The distribution patterns are formed by EF values for those metal elements in soil (forty soil samples) for dry and rainy season, respectively. Moreover, distribution patterns are formed by the point concentration of different boreholes. Thus, these distribution patterns are not uniform for this index. Moreover, in this distribution, different colour segments represent the various ranges of the EF in soil. The spatial distributions of EF for Fe, Mn, Cr, Pb, Cd, As, Hg and Sb are presented in this section, however, the EF for Cu, Zn, Ni, Co, Na, K, Ca, Ti, Sc, Sr, V and Ba are shown in Figure F.1 to Figure F.12, respectively, in the Annex-F.

4.7.2.1 Iron

The spatial distribution of EF for the metal elements Fe in soil (forty soil samples) for dry and rainy season is presented in Figure 4.57(a) and Figure 4.57(b), respectively. In dry season, the maximum range EF is 7.07 to 7.56 which indicates moderately severe enrichment in the soil. But the most of the area lies in the class of moderate enrichment (EF = 3 to 5) according to EF ranges. On the other hand, the maximum EF range for Fe is 2.383 to 2.437 close to the centre point of the disposal site which indicates minor enrichment. Comparing the both seasons EF for Fe, the enrichment grade is low in rainy season than dry season.

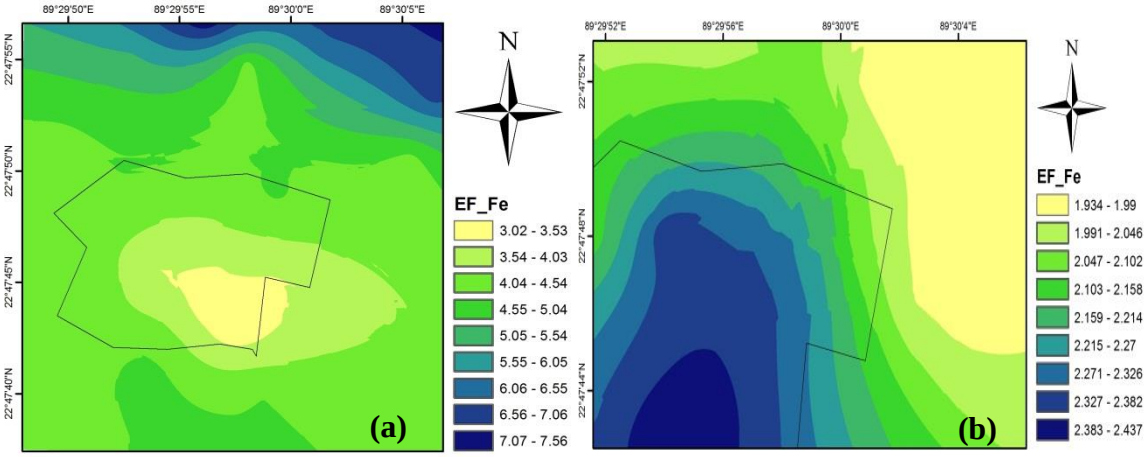


Figure 4.57: Spatial distribution of EF for Fe during (a) dry season and (b) rainy season.

4.7.2.2 Manganese

Figure 4.58(a) and Figure 4.58(b) depicted the spatial distribution of EF for Mn in soil for dry season and rainy season respectively. In both seasons, most of the sampling site lies in the class of minor enrichment (EF = 1 to 3) according to EF ranges. The maximum range of this index for Mn in dry season was 6.68 to 7.34 and 3.06 to 3.36 during rainy season. Therefore, there was reducing discrepancy in EF due to the change of dry to rainy season.

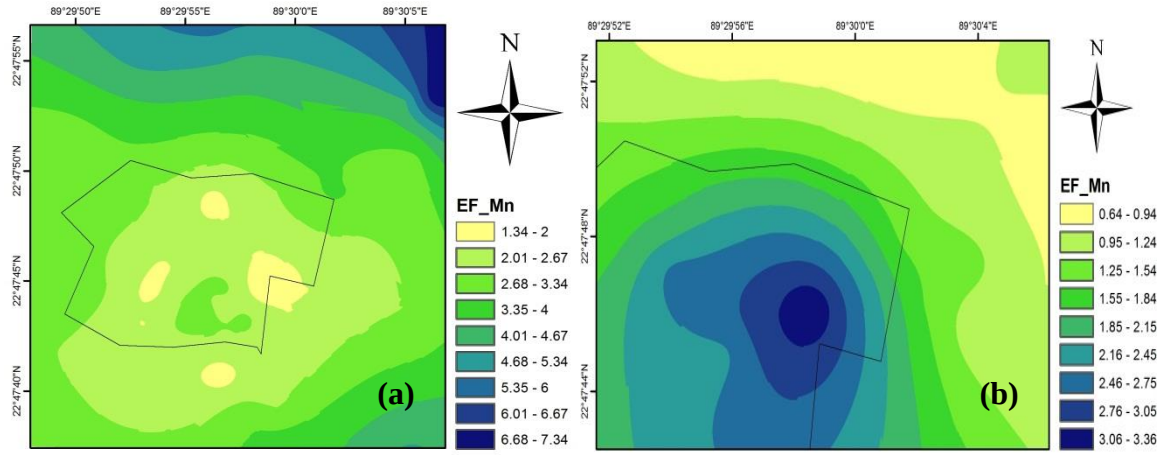


Figure 4.58: Spatial distribution of EF for Mn during (a) dry season and (b) rainy season.

4.7.2.3 Chromium

Figure 4.59(a) and Figure 4.59(b) illustrate, metal enrichment maps plotted EF distribution for Cr during dry and rainy season respectively. In dry season, the maximum range EF is 20.49 to 22.33 which indicates severe enrichment in the soil for Cr where reference element is Al. Moreover, the area undergoes moderately severe enrichment to severe enrichment in dry season. On the other hand, the maximum EF range for Cr is 12.196 to 13.159 in rainy season but most of the area lies in the class of moderately severe enrichment. Analysing the figures it is sure the enrichment status was found slight in dry season compared to dry season.

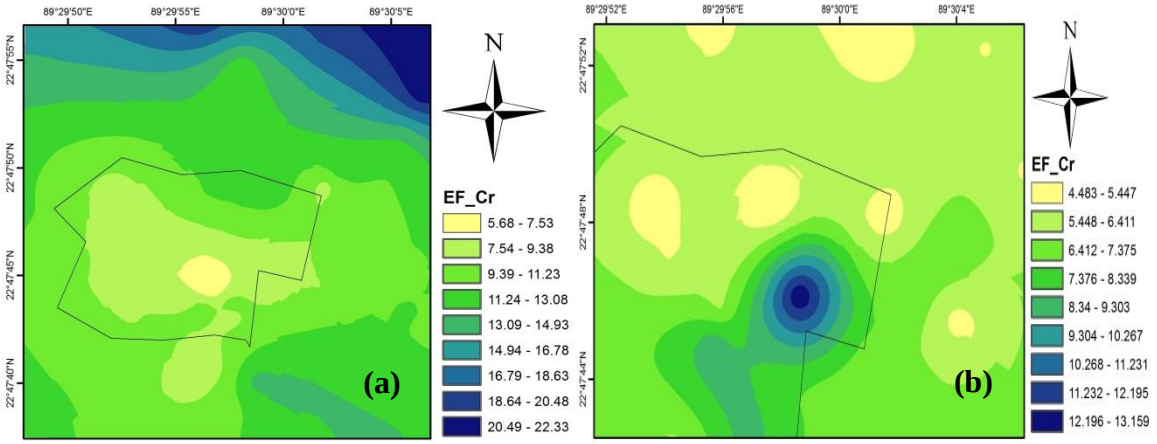


Figure 4.59: Spatial distribution of EF for Cr during (a) dry season and (b) rainy season.

4.7.2.4 Lead

Figure 4.60(a) and Figure 4.60(b) illustrate, metal enrichment maps plotted EF distribution for Pb during dry and rainy season respectively. In dry season, the maximum range EF is 556.99 to 600.23 which indicates extremely severe enrichment in the soil for Pb where reference element is Al. On the other hand, the maximum EF range for Pb is 432.37 to 458.41 in rainy. Analysing the figures it is sure the enrichment value ranges was found less in rainy season compared to dry season. But, the total sampling area shows extremely sever enrichment for this metal in both seasons.

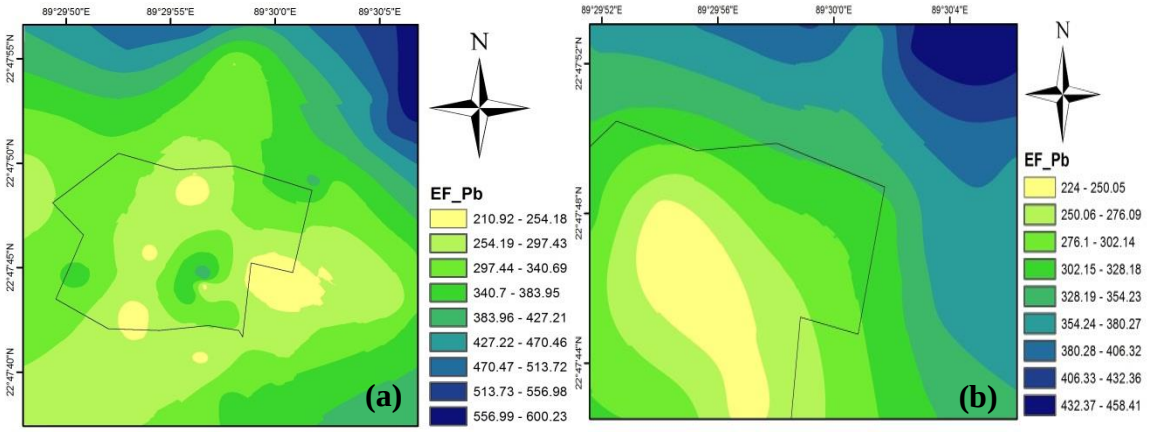


Figure 4.60: Spatial distribution of EF for Pb during (a) dry season and (b) rainy season.

4.7.2.5 Cadmium

The spatial distribution of EF for the metal elements Cd in soil for dry season and rainy season is demonstrated in Figure 4.61 (a) and Figure 4.61 (b), respectively. In dry season, the maximum range EF is 9217.91 to 10043 which indicates extremely severe enrichment in the soil. Besides, the maximum range EF is 4244.13 to 4437.69 which also directs to extremely severe enrichment for Cd during rainy season. Moreover, all the area lies in the extremely severe enrichment (EF > 50) according to EF ranges in both seasons.

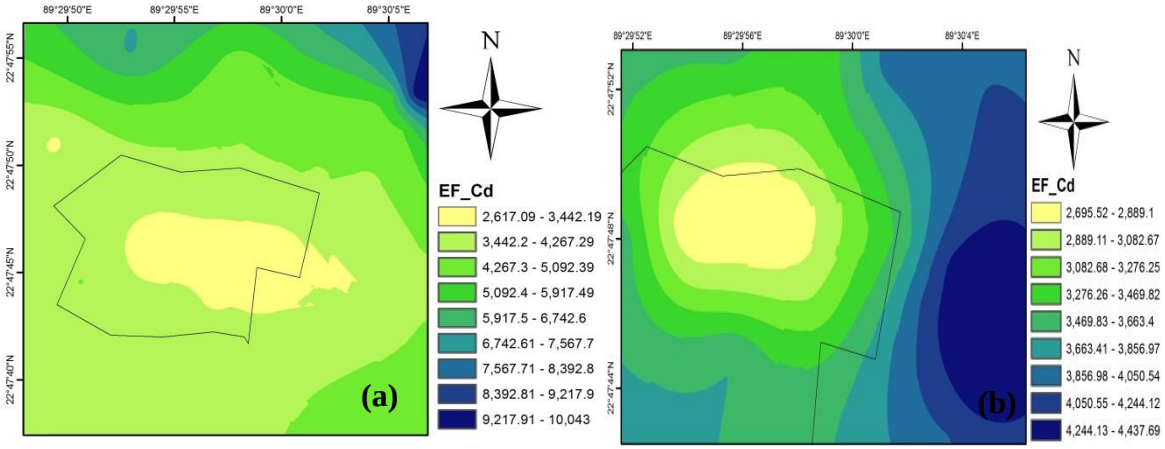


Figure 4.61: Spatial distribution of EF for Cd during (a) dry season and (b) rainy season.

4.7.2.6 Arsenic

Figure 4.62(a) and Figure 4.62(b) demonstrate metal enrichment maps plotted EF distribution for As during dry and rainy season respectively. In dry season, the maximum range EF is 441.95 to 456.17 which indicates extremely severe enrichment in the soil for As where reference element is Al. Similarly, during rainy season the maximum EF range for As

is 381.22 to 406.96 indicating extremely severe enrichment .Analysing the figures it is sure the enrichment value ranges was found less in rainy season compared to dry season. But, the total sampling area shows extremely sever enrichment for this metal in both seasons.

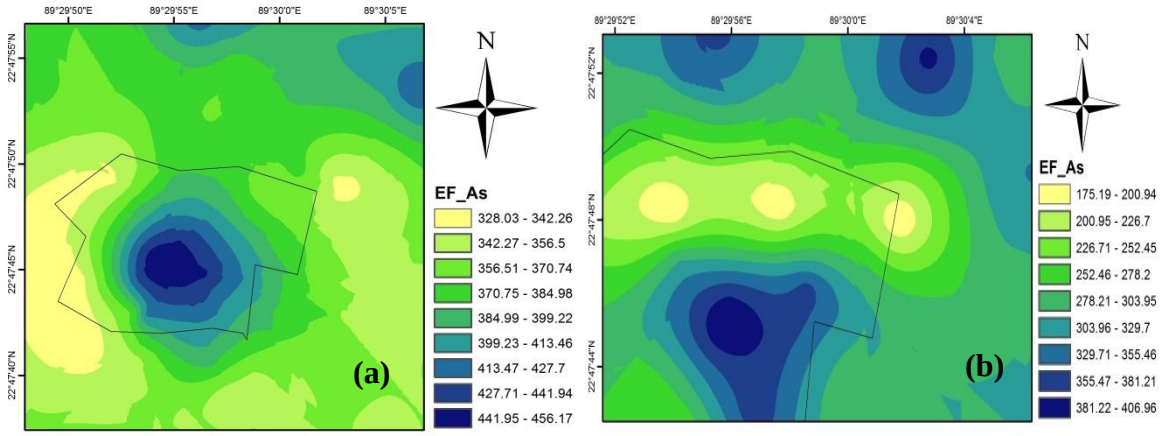


Figure 4.62: Spatial distribution of EF for As during (a) dry season and (b) rainy season.

4.7.2.7 Mercury

Figure 4.63(a) and Figure 4.63(b) show EF distribution for Hg in dry season and rainy season respectively. The maximum ranges of EF in dry and rainy season were 124.08 to 134.2 and 78.33 to 83.06, respectively, thus indicated extremely severe enrichment (EF > 50). On the other hand, the minimum EF ranges for Hg were found to be very similar in magnitude (43.03-53.16 in dry and 40.34-45-08 in rainy season). Hence, the total sampling area shows extremely sever enrichment to very sever enrichment for this metal in both seasons.

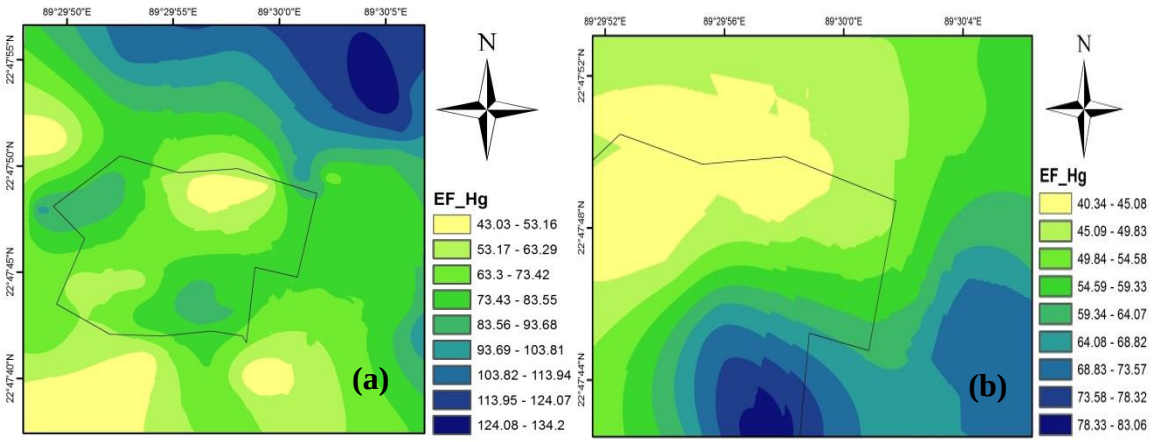


Figure 4.63: Spatial distribution of EF for Hg during (a) dry season and (b) rainy season.

4.7.2.8 Antimony

Figure 4.64(a) and Figure 4.64(b) illustrate, metal enrichment maps plotted EF distribution for Sb during dry and rainy season respectively. In dry season, the maximum range EF was 7226.93 to 7592.73 which indicated extremely severe enrichment in the soil for Sb where reference element is Al. Similarly, the maximum EF range for Sb was 6235.14 to 6610.38 in rainy season but most of the area lied in the class of moderately severe enrichment class. Analysing the figures it is sure the enrichment status was found slight less in rainy season compared to dry season.

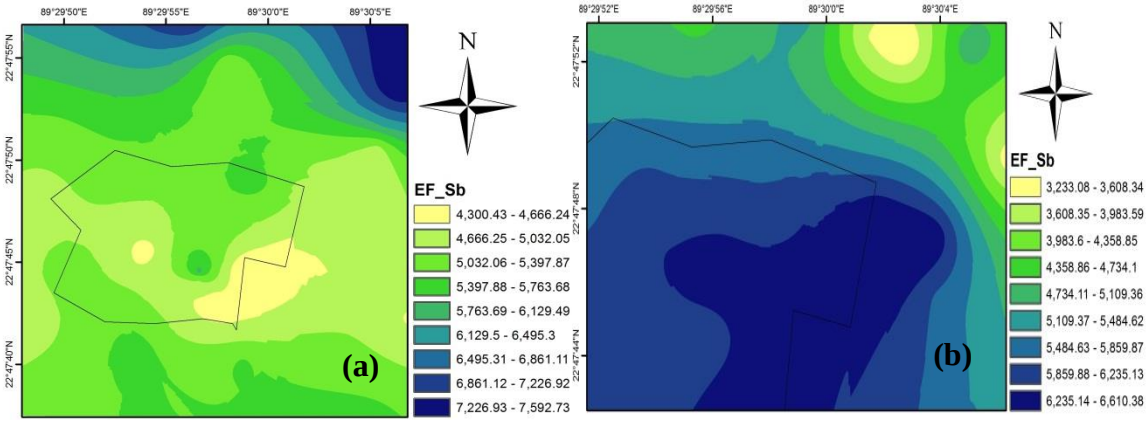


Figure 4.64: Spatial distribution of EF for Sb during (a) dry season and (b) rainy season.

From the above articles, it is sure that EF of all the metal elements had irregular shape of distribution patterns. Because all EF values are calculated using a reference element, Al. This index value depends on the concentration of the metal, the Al concentration of the certain sampling point as well as the background values of Al and the certain element. Moreover, distribution patterns are formed by the point concentration of different boreholes. Thus, these distribution patterns are not same uniform for this index. From the distribution figures, the change of EF values with distance from the central point was not uniform, but it is clear that the maximum range of EF values were greater in the soil of the studied waste disposal site during dry season than rainy season. The reduction of concentration is caused by the effect of leaching by infiltrating water. Besides, during heavy rainfall, soluble metal content get diluted and runoff from the dumpsite spreads to the surrounding soil.

4.7.3 Ecological Risk Index

Figure 4.65 to Figure 4.73 depict surface spatial distribution of Ecological Risk Index (ER) of some toxic metal elements during dry season (forty soil samples) and rainy season (twenty

soil samples), respectively. Distribution was done for total nine (9) metals considered for this index analysis in this study by the method of OK using ArcGIS. All patterns are more or less similar for different elements. The value of ER of any particular metal element of any sampling point mainly depends on the metal concentration of the certain sampling point, the background value of the metal, as well as the toxic response factor of the metal. Moreover, distribution patterns for ER are formed by ER of different boreholes. Moreover, in this distribution representation, different colour segments indicate the various ranges of the ER in soil.

4.7.3.1 Chromium

The spatial distribution of ecological risk index (ER) for Cr in soil sample along the selected site during dry season and rainy season is presented in Figure 4.65(a) and Figure 4.65(b), respectively. The ER values of the of Cr for soil sample from central point (approximately 0 m) ranges from 0.155 to 0.164, while, for soil sample from farthest point (390 m from central point) ranges from 0.087 to 0.095 for dry season. Besides, ER of the same metal ranges from 0.101 to 0.111 for soil sample from near to centre (approximately 30 m) and 0.015 to 0.025 for soil sample from farthest point (315 m from central point) in rainy season. Thus the figure represent that the ecological risk due to the metal concentration was high in the central portion of the waste disposal area compared to the farthest distance area from the centre in addition the ranges of the magnitude of ER for Cr was higher in dry season.

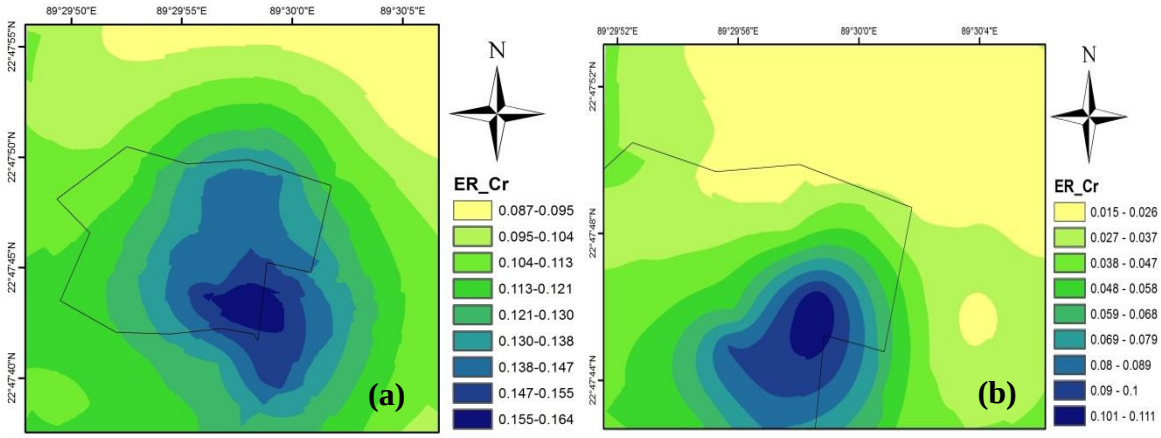


Figure 4.65: Spatial distribution of ER for Cr during (a) dry season and (b) rainy season.

4.7.3.2 Copper

Figure 4.66(a) and Figure 4.66(b) show the spatial distribution pattern of ER for Cu in the waste disposal site soil for dry season and rainy season, respectively. The magnitude of the ER of Cu for soil sample from central point (approximately 0 m) ranges from 1.33 to 0.1.46, while, for soil sample from farthest point (390 m from central point) ranges from 0.26 to 0.40 for dry season. Besides, ER of the same metal ranges from 0.43 to 0.46 for soil sample from near to centre (approximately 30 m) and 0.09 to 0.14 for soil sample from farthest point (315 m from central point) in rainy season. In case of seasonal analysis based on ER, the range of values of ER was comparatively higher in the same sampling area in dry season. Figure also reveals that the magnitude of ER of Cu in soil collected from the central point of the waste disposal site showed the higher magnitude than that of other soil sampling from different points. Result also depicted that this index of Cu had greater value in dry season than rainy season.

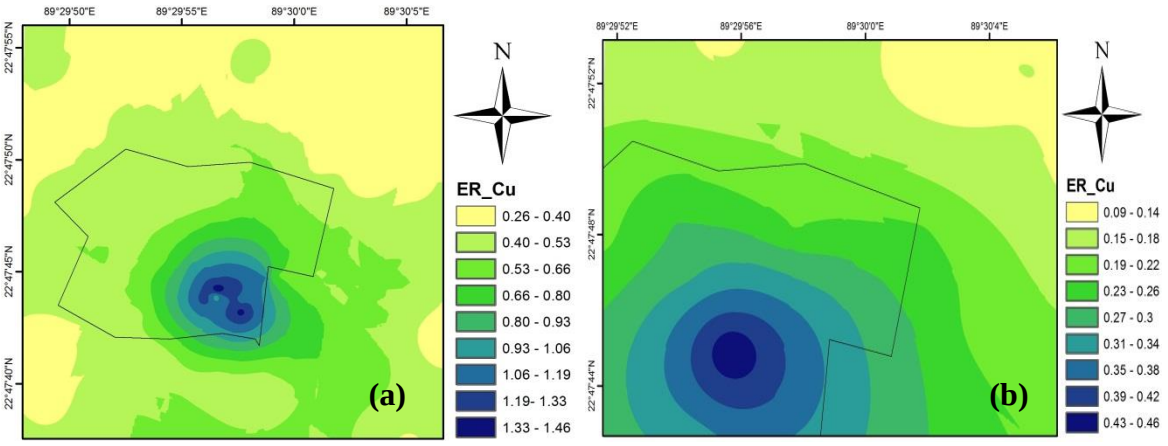


Figure 4.66: Spatial distribution of ER for Cu during dry season and rainy season.

4.7.3.3 Lead

Figure 4.67(a) and Figure 4.67(b) illustrate map containing the spatial distribution pattern of ER for Pb concentration in the soil of the selected site for dry season and rainy season is presented in respectively. During dry season, the value of the ER of Cu for soil sample from central point (approximately 0 m) ranges from 15.07 to 16.13 and for soil sample from farthest point (390 m from central point) ranges from 6.57 to 7.63. In addition, ER of the same metal ranges from 5.53 to 5.82 for soil sample from near to centre (approximately 30 m) and 0.09 to 0.14 for soil sample from farthest point (315 m from central point) during rainy season. Though the geometric area for the spatial distribution during both seasons were not same but it is clear from the figure, the ranges of magnitude of ER of the soil during dry season are higher than rainy season.

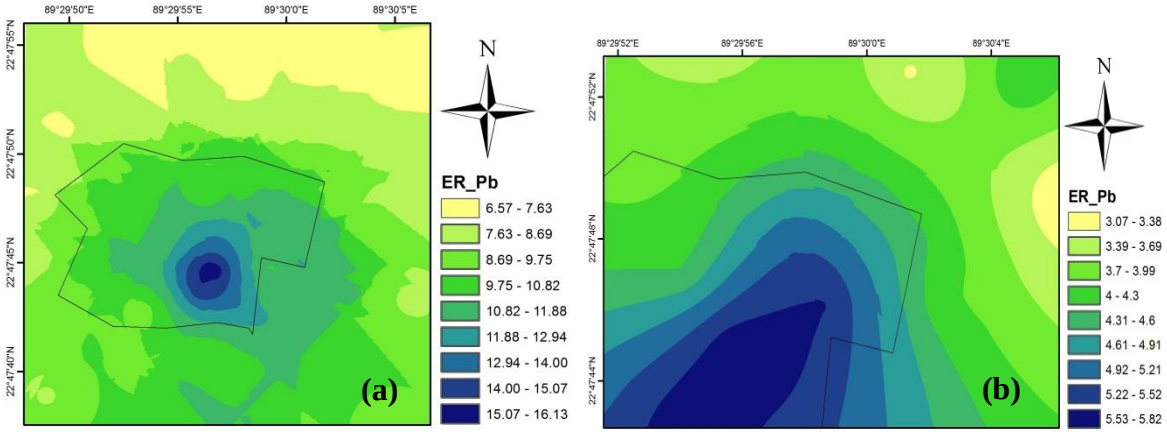


Figure 4.67: Spatial distribution of ER for Pb during (a) dry season and (b) rainy season.

4.7.3.4 Zinc

The spatial distribution of ecological risk index (ER) for the metal elements of Zn in soil (forty soil samples) for dry and rainy season is presented in Figure 4.68(a) and Figure 4.68(b), respectively. The magnitude of the ER of Zn for soil sample from central point (approximately 0 m) ranges from 0.67 to 0.7, while, for soil sample from farthest point (390 m from central point) ranges from 0.34 to 0.35 for dry season. Besides, ER of the same metal ranges from 0.34 to 0.38 for soil sample from near to centre (approximately 30 m) and 0.17 to 0.19 for soil sample from farthest point (315 m from central point) in rainy season. Analysing the spatial distribution maps, the magnitude of the index ER for Zn was greater in dry season. In addition, figures depicted that ER of Zn decreases in relation to the increasing of soil sampling distances from approximately the central point of waste disposal site.

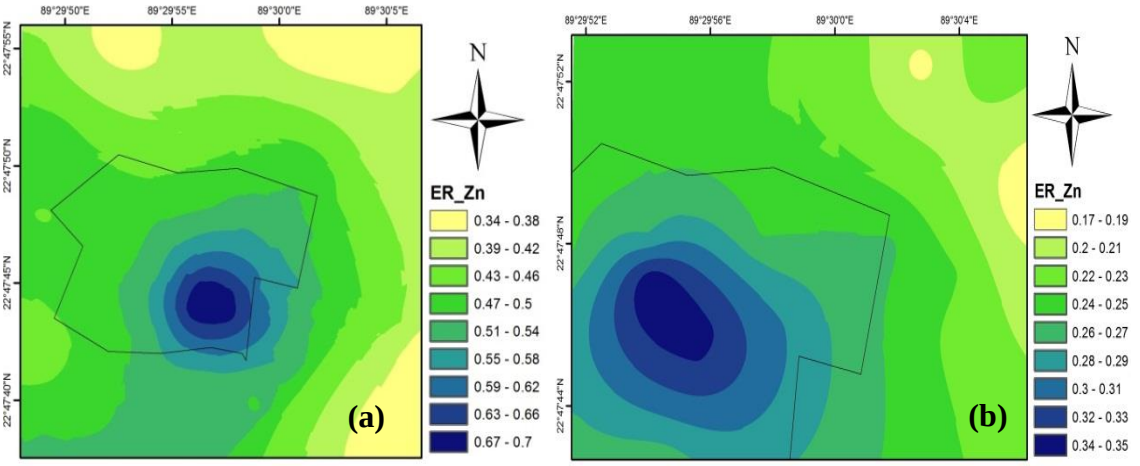


Figure 4.68: Spatial distribution of ER during for Zn (a) dry season and (b) rainy season.

4.7.3.5 Nickel

The spatial distribution pattern of ER for Ni present in soil for dry and rainy season is presented in Figure 4.69(a) and Figure 4.69(b), respectively. The magnitude of the ER of Ni for soil sample from central point (approximately 0 m) ranges from 0.5 to 0.54, while, for soil sample from farthest point (390 m from central point) ranges from 0.17 to 0.21 for dry season. Besides, ER of the same metal ranges from 0.32 to 0.33 for soil sample from near to centre (approximately 30 m) and 0.072 to 0.1 for soil sample from farthest point (315 m from central point) in rainy season. Thus the figure represent that the ecological risk due to the Ni concentration was high in the central portion of the waste disposal area compared to the farthest distance area from the centre in addition the ranges of the magnitude of ER for Ni was higher in dry season compared to rainy season.

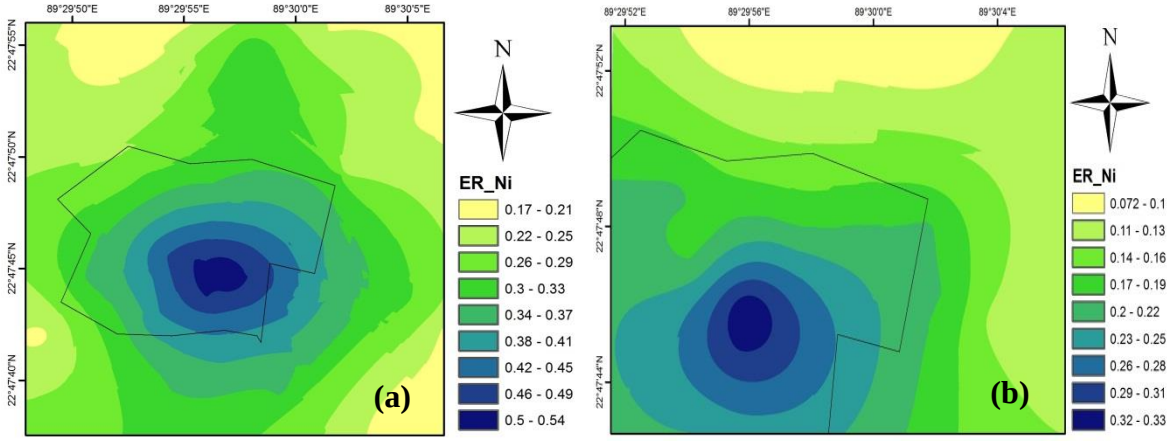


Figure 4.69: Spatial distribution of ER during for Ni (a) dry season and (b) rainy season.

4.7.3.6 Cadmium

Figure 4.70(a) and Figure 4.70(b) illustrate map containing the spatial distribution pattern of ER for Cd concentration in the soil of the selected site for dry season and rainy season is presented in respectively. In case of dry season, the value of the ER of Cd for soil sample from central point (approximately 0 m) ranges from 973.41 to 1047.18, while, for soil sample from farthest point (390 m from central point) ranges from 383.18 to 456.95. Moreover, ER of the same metal ranges from 518.48 to 559.91 for soil sample from near to centre (approximately 30 m) and 156.88 to 228.33 for soil sample from farthest point (315m from central point) in case of rainy season. Figure also reveals that the magnitude of ER of Cd in soil collected from the central point of the waste disposal site showed the higher magnitude

than that of other soil sampling from different points. Result also depicted that this index of Cd had greater value in dry season than rainy season.

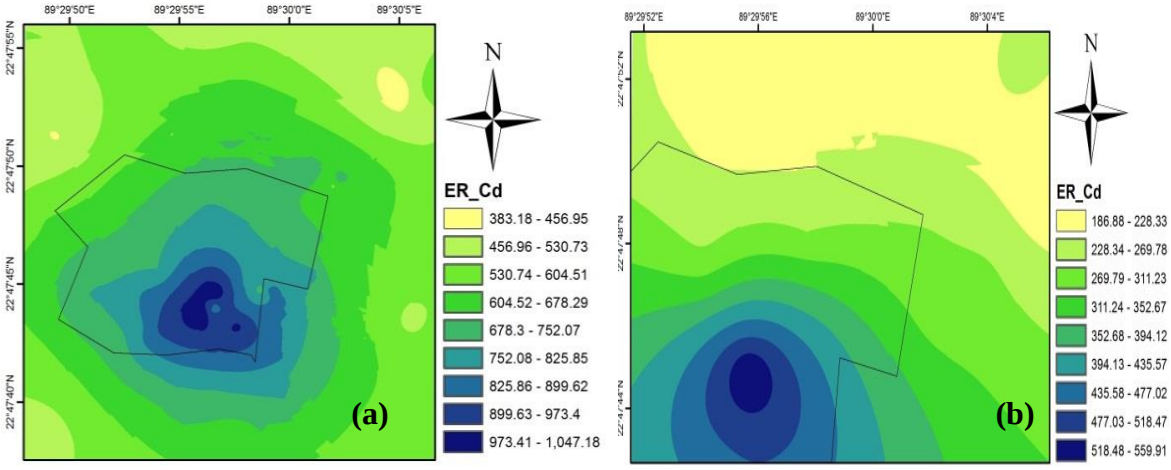


Figure 4.70: Spatial distribution of ER during for Cd (a) dry season and (b) rainy season

4.7.3.7 Arsenic

Figure 4.71(a) and Figure 4.71(b) show the distribution pattern of ER for As concentration in the soil of the waste disposal site during dry season and rainy season, respectively. During dry season, the distribution shape of ER for As for soil sample from central point (approximately 0 m) ranges from 44.12 to 48.56 as well as for soil sample from farthest point (390 m from central point) ranges from 8.59 to 13.03. Besides, ER of the same metal ranges from 18.63 to 20.34 for soil sample from near to centre (approximately 30 m) and 4.89 to 6.56 for soil sample from farthest point (315 m from central point) during rainy season. Though the geometric area for the spatial distribution during both seasons were not same but it is clear from the figure, the ranges of magnitude of ER of the soil during dry season are higher than rainy season. Distribution patterns show that ER values are maximum at the central points if the area and decreases when the distance is greater from the central point.

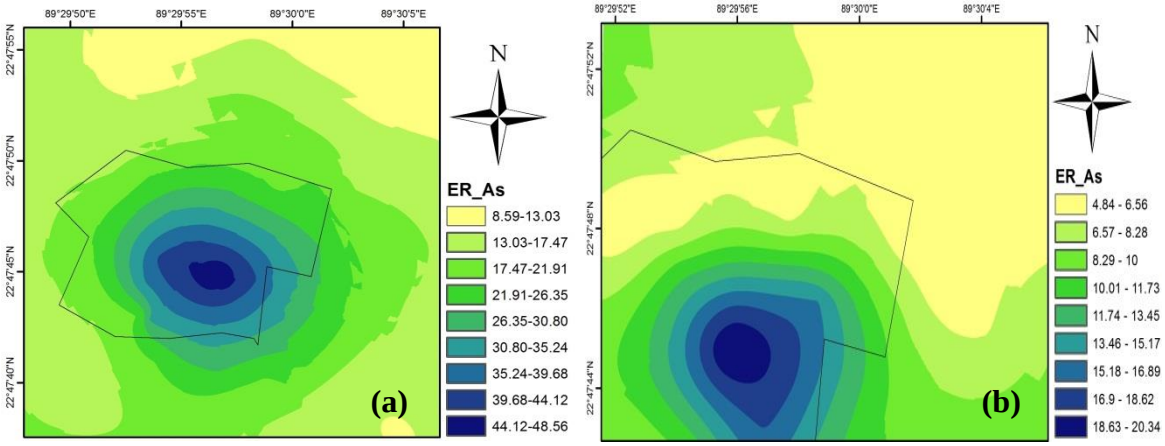


Figure 4.71: Spatial distribution of ER during for As (a) dry season and (b) rainy season.

4.7.3.8 Mercury

The spatial distribution of ER for the metal elements of Hg in soil for dry and rainy season is presented in Figure 4.72(a) and Figure 4.72(b), respectively. The magnitude of the ER of Hg for soil sample from central point (approximately 0 m) ranges from 33.44 to 36.63, while, for soil sample from farthest point (390 m from central point) ranges from 7.96 to 11.15 for dry season. Besides, ER of the same metal ranges from 14.54 to 15.92 for soil sample from near to centre (approximately 30 m) and 3.43 to 4.82 for soil sample from farthest point (315m from central point) in rainy season. Result reveals that the concentration of ER of Hg in soil collected from the central point of the waste disposal site showed the higher magnitude than that of other soil sampling from different points. Result also depicted that this index of metal elements decreases in relation to the increasing of soil sampling distances from approximately the central point of waste disposal site.

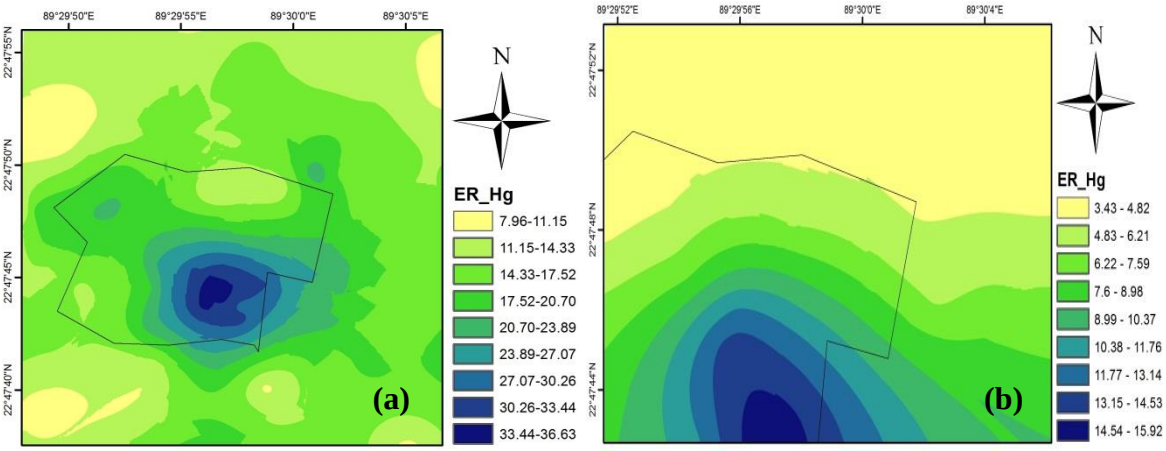


Figure 4.72: Spatial distribution of ER during for Hg (a) dry season and (b) rainy season.

4.7.3.9 Cobalt

The surface spatial distribution of ER for the metal elements of Co in soil for dry season and rainy season is demonstrated in Figure 4.73(a) and Figure 4.73(b), respectively. The value of the ER of Co for soil sample from central point (approximately 0 m) ranges from 2.20 to 2.39, while, for soil sample from farthest point (390 m from central point) ranges from 0.67 to 0.86 during dry season. Further, ER of the same metal ranges from 1.65 to 1.8 for soil sample from near to centre (approximately 30 m) and 0.38 to 0.54 for soil sample from farthest point (315 m from central point) during rainy season. Analysing the spatial distribution maps, the magnitude of the index ER for Zn was greater in dry season. In addition, figures depicted that ER of Zn decreases in relation to the increasing of soil sampling distances from approximately the central point of waste disposal site.

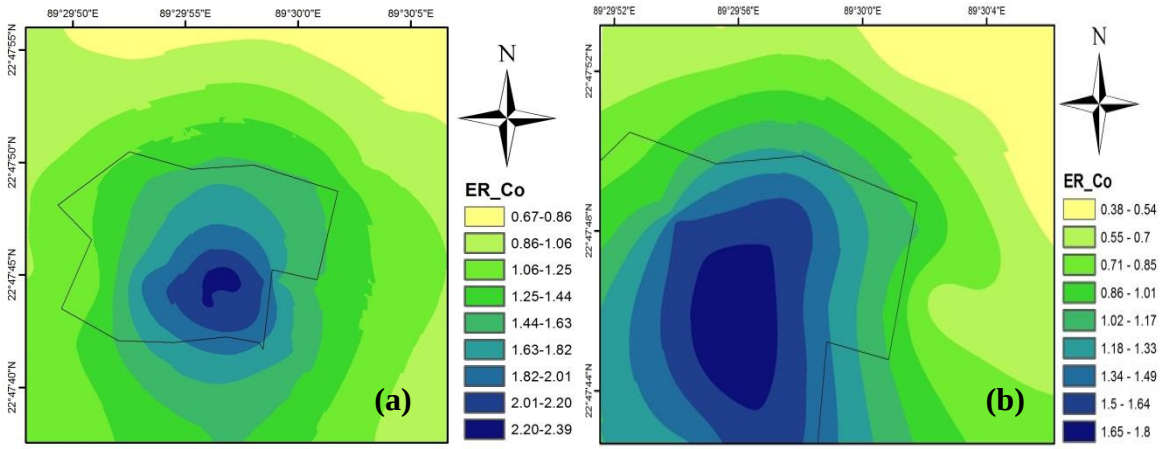


Figure 4.73: Spatial distribution of ER during for Co (a) dry season and (b) rainy season.

From the above articles, it is sure that all the metal elements considered in the study had a greater ER value in the soil of the studied waste disposal site during dry season than rainy season. Though the two seasonal distribution patterns do not cover the same geometric area, but it is clear that the ER value was decrease along increasing distance from the centre point of the waste disposal site. The reduction of concentration is caused by the effect of leaching by infiltrating water. Besides, during heavy rainfall, soluble metal content get diluted and runoff from the dumpsite spreads to the surrounding soil.

4.8 Pearson's Correlations

The Pearson's correlation is a preliminary descriptive technique to estimate the degree of association among the variables involved in any system. Such association is likely to lead to reasoning about causal relationship between the variables (Srinivasa and Pradip, 2010). Therefore, the values of correlation coefficients for soil parameters in case of waste disposal site will help in selecting proper treatment to minimize soil contamination. In this research, correlation matrixes between various metal elements in soil of selected waste disposal site for dry season and rainy season are provided in Tables 4.16 and Table 4.17, respectively. Result reveals that most of the metal elements were found to bear statistically significant correlation with each other. Moreover, this correlation also indicates close association of these parameters with each other in both seasons. In addition, the correlation matrix of metal elements in dry season is depicted in the Table 4.16 and indicated the positive correlations (r^2>0.5) among the all metal elements without Cr-Mn (0.449). A research conducted by Ajah et al. (2015) in a waste dumping site in Enugu, Nigeria, in case of dry season and revealed that all the metal elements were significantly correlated except for Co-Pb, Co-As, Zn-As, and Co-Mn. Moreover, in another research conducted by Jiang et al. (2014) in coal gangue damp in China, there were significantly positive relationships between pH, Cd, Cu, Pb and Zn, as well as a very significant correlation between Cr-Pb and Ni-Zn in waste landfill, hydrabad, India (Parth et al., 2011).

Based on the results of Pearson's correlations matrix on metal elements in soil during dry season, it was observed that the most significant viz. high positively correlated values between Fe and Ti (0.983), Mn and Pb (0.872), Cr and Co (0.797), Cu and Ba (0.888), Pb and Sr (0.867), Zn and V (0.906), Ni and Ba (0.963), Ca and Ba (0.926), As and Ca (0.975), Hg and Ca (0.882), Co and Sc (0.977), Na and K (0.950), K and Ti (0.963), Ca and Ba (0.992), Al and Sc (0.980), Ti and Sc (0.987), Sb and Sr (0.988), Sc and Sr (0.986), Sr and V (0.984) and V and Ba (0.968).

A research conducted by Rahman et al. (2012) in case of soil of Dhaka EPZ and stated that in dry season the trend of correlation was found to be Fe-Ni, As-Pb, Cu-Zn, Cu-Cr,Cu-Cd, Zn-Pb, Zn-Cd and Cr-Cd.

Similarly, the correlation matrix of metal elements in soil for rainy season is depicted in Table 4.17 and indicated the positive correlations (r^2>0.5) among the all studied metal elements. Based on the results of Pearson's correlations matrix on metal elements in soil during rainy season, it was observed that the most significant viz. high positively correlated values between Fe and Al(0.971), Mn and Ca (0.895), Cr and As (0.879), Cu and Ti (0.947), Pb and Al (0.879), Zn and V (0.883), Ni and Ba (0.936), Ca and Na (0.942), As and Na (0.907), Hg and K (0.884), Co and V (0.961), Na and Sr (0.984), K and Al (0.949), Ca and Sc (0.985), Al and V (0.985), Ti and Sr (0.991), Sb and Sc (0.988), Sc and Sr (0.981), Sr and V (0.984) and V and Ba (0.982). Compared to recent study, in the wet season the correlation around DEPZ area trends was Fe-As, Fe-Cr, Fe-Ni, As-Cr, Cu-Zn, Cu-Cr, Cu-Ni, Cr-Pb, Cr-Ni and Pb-Ni (Rahman et al., 2012).

Significant correlation between metal elements might be attributed to commonality of source and their common tendency to persist in the environment (Ajah et al., 2015). Perfect positive relationship signifies that the two variables being compared have a relation like when one variable moves higher or lower, the other variable moves in the same direction with the same magnitude. In this study, since most of the metal elements were found to bear statistically significant correlation with each other in soil of the selected waste disposal site indicating close association of these parameters with each other in both seasons.

Table 4.16: Pearson correlation analysis comprising studied metal elements in sample soil in dry season

ME[a]	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
Fe	1																				
Mn	0.554	1																			
Cr	0.768	0.449	1																		
Cu	0.756	0.762	0.669	1																	
Pb	0.739	**0.872**	0.567	0.805	1																
Zn	0.845	0.708	0.711	0.887	0.800	1															
Ni	0.928	0.632	0.753	0.875	0.761	0.886	1														
Cd	0.889	0.741	0.747	0.815	0.825	0.797	0.880	1													
As	0.914	0.656	0.740	0.880	0.810	0.867	0.959	0.892	1												
Hg	0.760	0.727	0.575	0.882	0.789	0.789	0.855	0.807	0.886	1											
Co	0.949	0.653	**0.797**	0.856	0.811	0.879	0.942	0.918	0.955	0.832	1										
Na	0.942	0.462	0.738	0.633	0.621	0.753	0.818	0.817	0.785	0.635	0.880	1									
K	0.967	0.570	0.774	0.745	0.738	0.857	0.887	0.867	0.882	0.744	0.926	**0.950**	1								
Ca	0.948	0.658	0.750	0.884	0.812	0.881	0.958	0.920	**0.975**	**0.882**	0.970	0.850	0.919	1							
Al	0.952	0.645	0.776	0.866	0.799	0.888	0.952	0.902	0.974	0.868	0.960	0.862	0.948	0.979	1						
Ti	**0.983**	0.598	0.797	0.823	0.760	0.881	0.955	0.914	0.954	0.816	0.974	0.916	**0.963**	0.979	0.977	1					
Sb	0.952	0.687	0.713	0.852	0.841	0.895	0.943	0.901	0.953	0.830	0.956	0.848	0.926	0.972	0.965	0.967	1				
Sc	0.967	0.651	0.766	0.853	0.815	0.893	0.958	0.923	0.965	0.839	**0.977**	0.885	0.946	0.986	**0.980**	**0.987**	0.987	1			
Sr	0.938	0.709	0.701	0.849	**0.867**	0.883	0.946	0.912	0.966	0.862	0.957	0.832	0.915	0.975	0.968	0.959	**0.988**	**0.986**	1		
V	0.929	0.727	0.741	0.879	0.857	**0.906**	0.940	0.916	0.958	0.876	0.959	0.823	0.921	0.970	0.974	0.956	0.984	0.980	**0.984**	1	
Ba	0.943	0.668	0.753	**0.888**	0.814	0.887	**0.963**	**0.926**	0.971	0.867	0.971	0.835	0.903	**0.992**	0.964	0.976	0.975	0.983	0.973	**0.968**	1

[a]Metal element

Table 4.17: Pearson correlation analysis comprising studied metal elements in sample soil in rainy season

ME	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
Fe	1																				
Mn	0.947	1																			
Cr	0.818	0.896	1																		
Cu	0.846	0.803	0.803	1																	
Pb	0.846	0.843	0.803	0.774	1																
Zn	0.800	0.812	0.653	0.782	0.637	1															
Ni	0.831	0.874	0.772	0.873	0.773	0.787	1														
Cd	0.840	0.835	0.830	0.889	0.852	0.721	0.873	1													
As	0.809	0.853	**0.879**	0.825	0.753	0.732	0.790	0.899	1												
Hg	0.733	0.718	0.763	0.783	0.696	0.569	0.695	0.873	0.886	1											
Co	0.943	0.917	0.710	0.792	0.762	0.856	0.844	0.767	0.726	0.664	1										
Na	0.938	0.949	0.859	0.897	0.872	0.845	0.930	**0.942**	**0.907**	0.827	0.910	1									
K	0.909	0.918	0.853	0.848	0.861	0.721	0.893	0.930	0.900	**0.884**	0.855	0.959	1								
Ca	0.922	**0.895**	0.712	0.844	0.837	0.854	0.890	0.818	0.691	0.641	0.957	0.917	0.858	1							
Al	**0.971**	0.969	0.847	0.883	**0.876**	0.850	0.911	0.898	0.856	0.772	0.949	0.979	**0.949**	0.956	1						
Ti	0.913	0.891	0.807	**0.947**	0.865	0.861	0.927	0.928	0.847	0.785	0.904	0.971	0.915	0.943	0.961	1					
Sb	0.946	0.955	0.831	0.879	0.870	0.861	0.922	0.886	0.814	0.754	0.941	0.969	0.937	0.967	0.986	0.959	1				
Sc	0.927	0.916	0.779	0.883	0.855	0.870	0.918	0.867	0.759	0.708	0.935	0.950	0.901	**0.985**	0.969	0.967	**0.988**	1			
Sr	0.940	0.925	0.852	0.944	0.870	0.855	0.924	0.934	0.881	0.819	0.914	**0.984**	0.946	0.937	0.979	**0.991**	0.973	0.965	1		
V	0.948	0.940	0.812	0.901	0.847	**0.883**	0.913	0.879	0.830	0.761	**0.961**	0.973	0.920	0.971	**0.986**	0.978	0.982	**0.981**	**0.984**	1	
Ba	0.928	0.935	0.843	0.918	0.853	0.850	**0.936**	0.910	0.820	0.745	0.927	0.967	0.909	0.961	0.976	0.977	0.978	0.976	0.979	**0.982**	1

[a]Metal element

4.9 Principle Component Analysis

To interpret the mechanisms that govern the behaviour of the metal elements in soil of waste disposal site, the soil parameters were subjected to a principal component analysis (PCA). In PCA, the principal components (PCs) with variables, the high loadings (eigenvalues) depicted greater importance from the contamination sources. On the other hand, lower loadings (eigenvalues) point to lower importance with regards the sources of these contaminations. A research conducted by Olawoyin (2012) and stated when the eigenvalues less than unique, the PCs as considered of insignificant. Based on this postulation, in PCA, for cut off of PCs, eigenvalues of 1 was considered as reference value. In this study, PCA was performed using XLSTAT to understand the behaviours of these metals in the environment and comprehend the mechanisms that govern the behaviours of these metals. The results of PCA for dry season was discussed in this section, while, results of PCA for rainy season is provided in the Annex-G.

The eigenvalue of PCA for the metal elements in soil of waste disposal site during dry season is provided in Table 4.18. The larger eigenvalue obtained for PC1 or F1 (18.267) indicated large proportion of variability (86.988%) for dry season (Table 4.18). The eigenvalues upto the second extracted principal components (PC2 or F2) were all greater than 1.0. Moreover, as the eigenvalues for the PCs (F3 to F21) were found less than 1 for dry season, these PCs were depicted as very negligible contribution in the analysis. Besides, PC2 to PC19 were considered as negligible contribution because these components were found less than 1 for rainy season (Table G.1, Annex-G). Thus, the variables could be reduced to 2 components model (dry season) with 92.106% variation as well as 1 component model (rainy season) that accounts for 88.251% variation. In addition, the larger eigenvalue obtained for F1 (18.5331) that indicated large proportion of variability (88.251%) for rainy season (Table G.1, Annex-G). According to the results of the initial eigenvalues, two principal components were considered, which account for over 92.106% of the total variance and can present the soil heavy metal contamination levels in study area. Moreover, for variability calculation based on eigenvector and factor loadings, PCs of 21 were considered for the metal elements for dry season and results provided in Table 4.19. In addition, for variability calculation based on eigenvector and factor loadings, PCs of 19

were considered for the metal elements for rainy and results provided in Table G.1 in the Annex-G.

Table 4.18: Eigenvalue of PCA analysis for metal variables in dry season

PCs	Eigenvalue	Variability (%)	Cumulative %
F1	18.267	86.988	86.988
F2	1.075	5.118	92.106
F3	0.416	1.980	94.086
F4	0.391	1.861	95.947
F5	0.230	1.094	97.041
F6	0.162	0.774	97.815
F7	0.119	0.565	98.380
F8	0.076	0.362	98.742
F9	0.058	0.277	99.019
F10	0.051	0.244	99.263
F11	0.042	0.202	99.465
F12	0.035	0.167	99.633
F13	0.026	0.122	99.755
F14	0.016	0.077	99.832
F15	0.013	0.063	99.895
F16	0.008	0.036	99.931
F17	0.004	0.021	99.952
F18	0.004	0.018	99.970
F19	0.003	0.013	99.983
F20	0.002	0.010	99.993
F21	0.001	0.007	100.000

A scree plot displays the eigenvalues associated with a component or factor in descending order versus the cumulative variability for the PCA. The scree plot for the factor variability (eigenvalues, cumulative variability and PCs) of metal elements in soil for dry season is presented in Figure 4.74, while for rainy season is shown in Figure G.1 in the Annex-G. The scree plots of PCs were represented in a form of simple line segment plot that shows the fraction of total variance in the data. In Figure 4.74, the bar of blue color represented eigenvalues and red line segment represented cumulative variability. In dry season, result reveals that PC1 showed the highest eigenvalue (18.267) and variability (86.988), while, PC21 showed the lowest eigenvalue (0.001) and variability (0.007), however, finally the scree plot reaches to 100 %

variability (Table 4.18). Moreover, similar trend was also observed for rainy season (Table G.1 and Figure G.1, Annex-G).

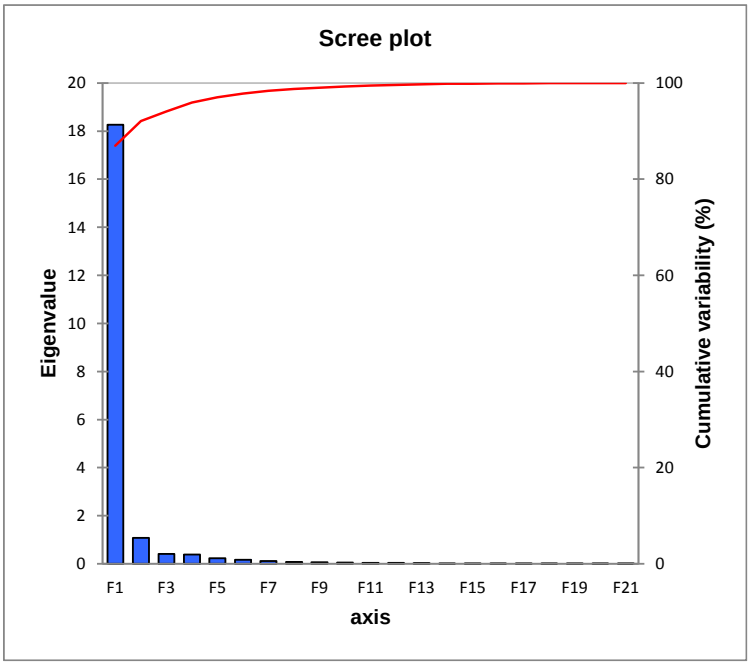


Figure 4.74: Scree plot of the PCA analysis for metal variables in dry season.

The correlation circle (axis F1-F2 plan) for different sampling points in dry season is shown in Figure 4.75. In this study, metal elements were distributed in a correlation circle which indicated four distinct quadrants relative to the PCs for dry season. This circle exhibited a graphical representation of loading vectors for metal elements in order to determine the most influential variables (metal elements) interaction in this model. According to Figure 4.75, all metal elements were more or less positively correlated as the appearance of variables on the two close quadrants (Lu et al., 2010). The impact of any individual variable to the entire PCA model was measured by the distance by how far the variable is from the origin (Olawoyin, 2012).

Variables that showed longer distances from origin of circle have larger impacts on the general architecture of the model than variables with shorter distances (Olawoyin, 2012). In the loading plot corresponding to the first two factors in Figure 4.132 showed the following ten metal elements of Ca, Al, Ti, Sb, Sc, Sr, V,Ni, As and Ba showed clear positive correlation because they were in the at the same distance from the center and very close to each other. Besides, the

metal elements of Mn, Pb, Hg, Cu, Zn, Fe, K, Cd, Cr, Na which also positively correlated with less stronger impact because they were comparative in shorter distance from origin. Moreover, the metal elements of Mn and Cr having the least impact on the PCA model because they were far from each other. It was noticed that Cu, Hg, Mn, Pb and Zn in soil were located at a distance from origin of circle than that of other metal elements. This indicated the origin of these metal elements was differing from other metal elements. In addition, the correlation circle (axis F1-F2 plan) for different sampling points in rainy season is shown in Figure G.2 in the Annex-G.

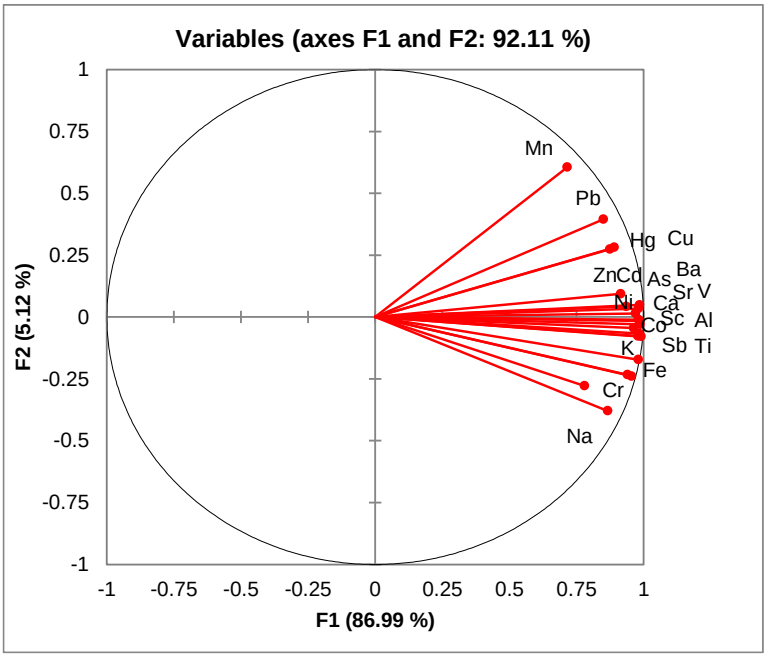


Figure 4.75: Correlation circle (axis F1-F2 plan) for different sampling points in dry season.

The magnitude of the correlation with F1 and other metal parameters are so close that in the Figure 4.76, they are almost overlapped. Going from left to right the pollution increases from BH 1 to BH 40. Most of the soil sampling points were closed together. From the Figure 4.76, BH1 to BH19 showed more pollution than that of BH-20 to BH-40. The results have nothing contradictory to the situation identified by index analysis. The biplots (Figure 4.77) represent the observations and variables simultaneously in the new space. Figure 4.77 illustrates the correlation between the observation locations, indicating central pattern for the most of locations to depict the correlation between the variables and how strongly they impacted the overall model with respect to the observations during dry season. The biplots of sampling points on the factorial plane in rainy season is shown in Figure G.3 in the Annex-G.

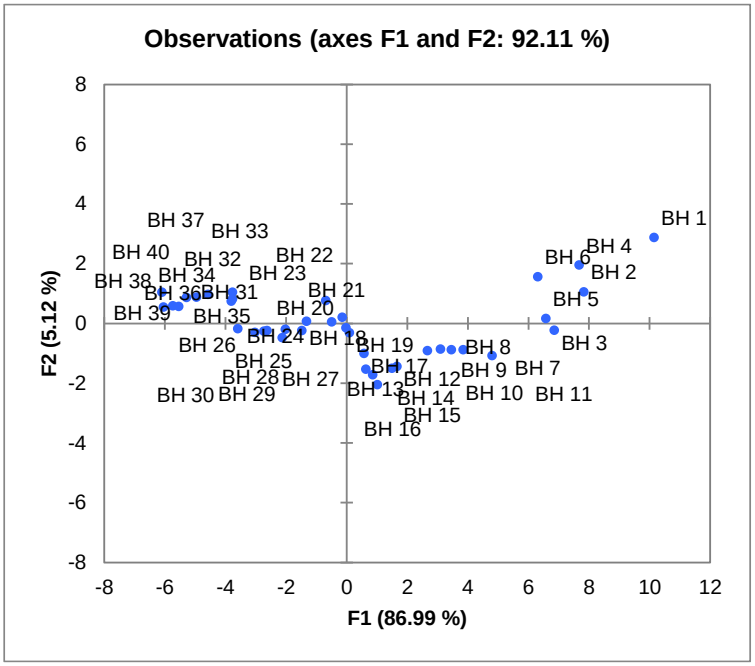


Figure 4.76: Projection of sampling points on the factorial plane in dry season.

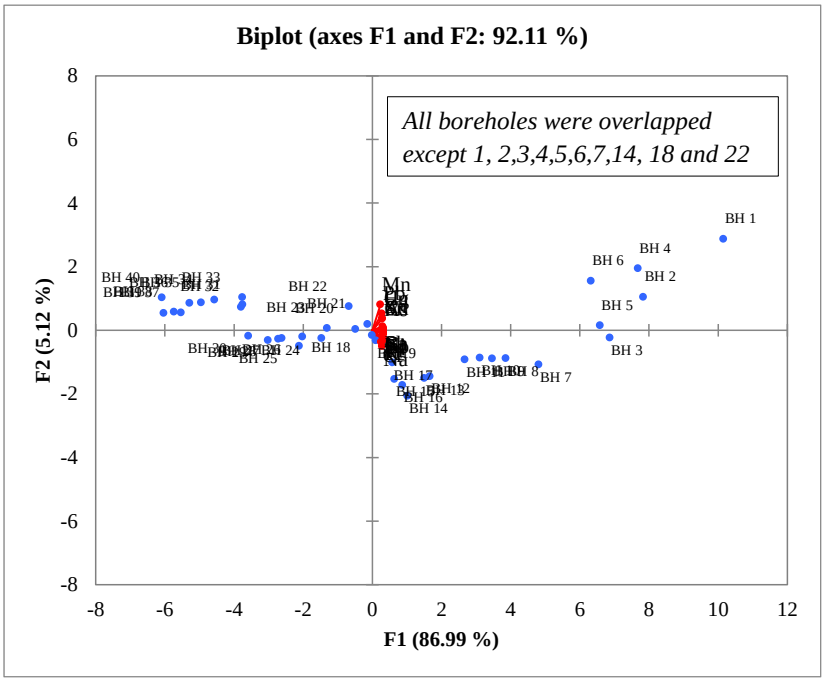


Figure 4.77: Biplots of sampling points on the factorial plane in dry season.

4.10 Concluding Remarks

The main focus of this study, to assess the ecological risk associated with heavy metals present in soil of waste disposal site. To these endeavors, total sixty soil samples were collected from different locations of a selected waste disposal site at Rajbandh, Khulna, Bangladesh. The statistical analysis such as basic statistics, Pearson's correlation and PCA was performed using SPSS and XLSTAT. In addition, to assess the ecological risks associated with heavy metals in soil, various indices such as Cp, CF, CLI, mCD, NICF, EF, I_{geo}, ER and PERI were used. The values of skewness and kurtosis of the metals in soil for dry season indicated the data was distributed normally for both the dray and rainy seasons. In addition, the values of COV and SD for the metal element of Ti were found to be greater than that of other heavy metals, thus, indicated highest dispersion ranges of Ti within the soil sampling area for dry and rainy season. In addition, the highest COV was found for Cu represented the high level of scattering around the value of Cu in the data set for both seasons.

In addition, the soil sample of dry season showed comparatively the higher concentration for almost all the heavy metals than that of rainy season. This variation was caused by the metal element infiltrates in soil through rain water and different soluble capacity of metals in rainy season (Rahman et al., 2012). In the present study, the soil sample for dry and rainy seasons showed comparatively the lower concentration of Cr, Cu, Pb, Zn, and Ni in soil than that of maximum allowable limits proposed by different countries except WHO. Besides, the concentrations of Cd for dry season exceed the allowable limits stated by WHO, CCME, Poland, UK and USA except Austria. In addition, the soil sample for rainy season showed comparatively the lower concentration of Cd than that of different countries except WHO and CCME. The concentration of heavy metals of Pb and Cd can easily accumulate in the bodies of soil organisms. In fact, they are particularly very dangerous chemical, as they can accumulate in individual organisms, but also in entire food chains (Singh et al., 2011). The main sources of Pb and Cd in municipal solid waste are lead-acid batteries, household batteries, consumer electronics, glass and ceramics, plastics, soldered cans Pigments etc. (Korzun and Heck, 1990).

The values of Cp for the heavy metals of Cd and Sb for both seasons as well as Cp for Pb and As for dry season indicated the level of contamination of soil of the disposal site was severe or very severe condition. It also demonstrated that during rainy season, Cp for Pb and As

contributed the soil was moderately contamination. In dry season, the values of CF for Fe, Mn, Cr, Cu, Zn, Ni, Hg, Co Na, K, Ca, Al, Ti, Sc, Sr, V and Ba; CF for Pb; CF for As as well as CF for Cd and Sb in soil indicated the low level of contamination; moderate to considerable; low to considerable as well as high level of contamination, respectively. In contrast, the values of CF for Fe, Mn, Cr, Cu, Zn, Ni, Hg, Co Na, K, Ca, Al, Ti, Sc, Sr, V and Ba; CF for Pb and As as well as CF for Cd and Sb in soil indicated the low level of contamination; moderately contamination and high level of contamination, respectively, for rainy season. Here, it can be noted that the high degree of contamination of soil was found at the central borehole point (BH 1) of the disposal site with maximum values of mCD for dry season, while, during rainy season it was found as moderate degree of contamination.

The results of EF for Pb, Zn, Cd, As, Hg, Co and Sb in soil contributed the class of extremely severe enriched for dry season. Furthermore, EF for Sb and Cd indicated the soil was extremely severe enrichment for both, dry season and rainy season. The values of EF for Ti and Ba as well as for Fe showed the class was very severe enriched and moderately enrichment, respectively, for dry season. In addition, EF for Fe, Mn and K indicated the minor enrichment as well as Na and Ca indicated no enrichment in soil for rainy season. The results of I_{geo} for Pb and As showed the soil was uncontaminated to moderately contaminated for dry season, while, same metals showed the soil was uncontaminated during rainy season. I_{goe} for Cd showed the soil was strongly contaminated as well as moderately to strongly contaminated for dry and rainy season, respectively. Correspondingly, I_{geo} for Sb indicated the strongly to extremely contaminated as well as strongly contaminated for dry and rainy season, respectively. In overall, I_{geo} was distinctly variable and the soil around the waste disposal site ranges from uncontaminated level to strongly and extremely contaminate.

The ER arrayed in the order of ER(Cd)> ER(As)> ER(Hg)> ER(Pb)>ER(Co)> ER(Cu)> ER(Zn)> ER(Ni)> ER(Cr) in soil for dry season. The ER for Cr, Cu, Pb, Zn, Ni, As, Hg and Co; and Cd indicated the slightly ecological risk and extremely strong ecological risk, respectively for dry season. Furthermore, result depicted that Cd showed the maximum value of ER with respect to the other counter metals in soil and it can be noted that Cd was the key influence factor to cause the potential ecological risk in soil. In addition, results indicated that about 92 to

95% of this potential ecological risk is contributed by Cd, whereas, the risk posed by the other heavy metals was comparatively very lower values. In dry season, the magnitude of PERI for entire soil samples indicated the extremely strong ecological risk by the heavy metals presence in soil for all the soil sampling points (boreholes) of the selected waste disposal site. In contrast, the ER arrayed in the order of ER(Cd) > ER(As)> ER(Hg)> ER(Pb)> ER(Co)> ER(Cu)> ER(Zn)> ER(Ni)> ER(Cr) for rainy season. The soil samples have extremely strong potential ecological risk for Cd, while, other metals showed only slightly ecological risk in soil. It can be noted that for soil samples from boreholes BH 41 to BH 46, the ecological risk was extremely strong, while, for boreholes BH 47 to BH 60, ecological risk was very strongly.

Result reveals that the maximum concentration was found for all the studied heavy metals for soil collected from central point than that of farthest points with respect to the centre of waste disposal site for both seasons. In addition, produce predicted surface showed most of the contaminated hotspots was found near the central point of the disposal site. The distribution patterns indicated that the concentration of all the metal elements gradually decreases from the centre to the outer side of the selected disposal site during dry season and rainy season. In this study, the magnitudes of PERI were found higher for soil sample of central point than that of followed boreholes (each farthest point with respect to center of disposal site) for both seasons. Here, it can be noted that the soil of near to central borehole points was extremely strong ecological risk, while, soil of followed borehole points was very strongly ecological risk for both seasons. In addition, the values of PERI in soil decreases in relation to the increasing of soil sampling distances from the center of waste disposal site. In this study, for Pearson's correlation, most of the metal elements were found to bear statistically significant correlation with each other in soil of the selected waste disposal site indicating close association of these parameters with each other in both seasons. In addition, results of PCA indicated that most of the metal elements were significantly correlated with each other in soil of the waste disposal site.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In waste disposal site, heavy metals are spreading through leachate and MSW may subsequently be accumulated in the underlying soil and then become sensitivity indicator for the surrounding areas, water bodies and the environmental components. This study was conducted to assess the potential ecological risks associated thus the level of contamination based on heavy metals in soil of the selected waste disposal site with the implication of spatial and temporal variation. The study has shown that there was considerable amount of heavy metals in soil of the selected site. However, the extreme ecological risk was identified for Cd and Sb according to the outcomes. Based on the observed results; the following conclusions have been drawn:

1. Result reveals that Cd exceeds the allowable limits proposed by WHO, CCME, Poland, UK and USA except Austria for dry season. In contrast, Cd showed comparatively the lower concentration than that of Poland, UK, Germany, Japan and USA, Austria except WHO and CCME for rainy season.
2. The soil sample of dry season showed comparatively the higher concentration than that of soil sample for rainy season.
3. Results of potential contamination index (Cp) for Cd and Sb during both seasons as well as Cp for Pb and As for dry season indicated severe or very severe level of contamination of soil in disposal site.
4. The values of contamination factor (CF) for Cd and Sb showed very high level of contamination in both seasons. Additionally, CF for Pb and As showed moderate to considerable contamination in dry season.
5. The results of enrichment factor (EF) for Pb, Zn, Cd, As, Hg, Co and Sb in soil contributed the class of extremely severe enriched for dry season. Furthermore, Sb and Cd indicated the highest values of EF for both seasons.
6. Result of ecological risk index (ER) indicated that about 92 to 95% of the potential ecological risk (PERI) is contributed by Cd where the risk posed by the other heavy metals was comparatively very lower.

7. The magnitude of PERI for entire soil samples indicated the extremely strong ecological risk by the heavy metals presence in soil for all the soil sampling points (boreholes) of the selected waste disposal site for dry season.
8. It can be noticed that the soil sample of the central point of the disposal site showed comparatively the higher ecological risk than that of other soil samples collected from larger distances with respect to centre of the disposal site for both seasons.
9. Results of Pearson's correlation and PCA indicated that most of the heavy metals were found to bear statistically significant correlation with each other in soil of the selected waste disposal site indicating close association of these parameters with each other in both seasons.
10. The spatial distribution of heavy metals in soil represented the same pattern of distributions both seasons but the intensity of heavy metal decreases in relation to the increasing of lateral distance from the centre point of the waste disposal site.

5.2 Recommendations for Future Study

The following may be recommended from this research and should be taken to the researchers in this area.

1. This study demonstrations that there is environmental contamination around dumping area and put emphasis on the necessity for a comprehensive public health approach to address environmental extortions in local communities.

2. The soil contamination and ecological risk assessment methods can be classified into two categories of quantitative and qualitative. The qualitative methods, such as Principal component analysis (PCA), Pearson's correlation, factor analysis, and cluster analysis should be used to analyze the ecological risk elaborately.

3. The levels of Sb, Cd, Pb and As in the soil should be continuously monitored to check on their levels. These heavy metals are very poisonous even in their smallest quantities.

4. Sources of heavy metals in waste disposal site like hospital waste, electronic waste, industrial waste, polythene and plastics etc. need to be controlled.

5. A systematic and constant monitoring for metal pollution should be established and certain remediation steps should be taken to decrease the rate and extent of pollution problems in future. Further research similar to this one carried out in other areas of the county, especially where industrial waste production is higher.

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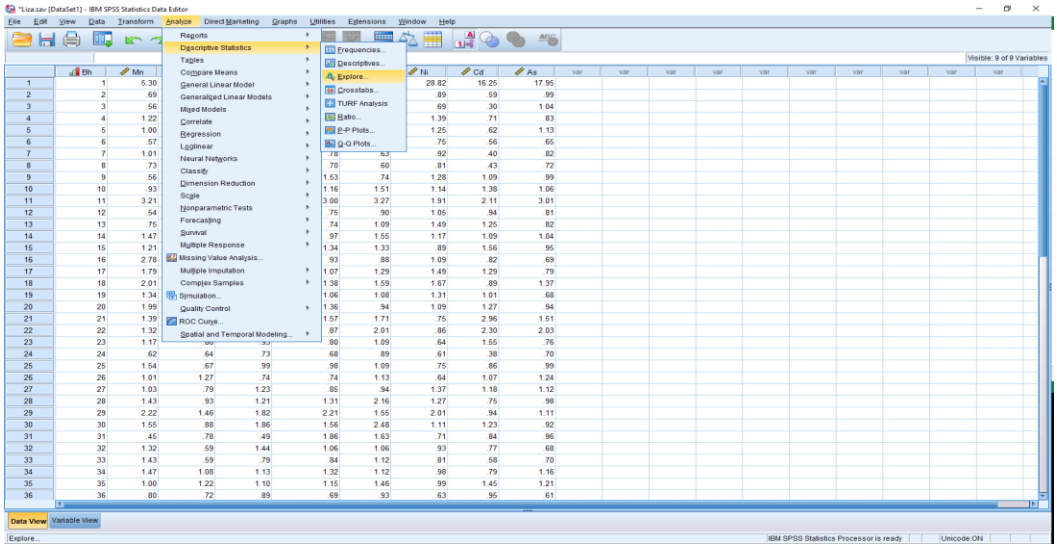
Annex-A

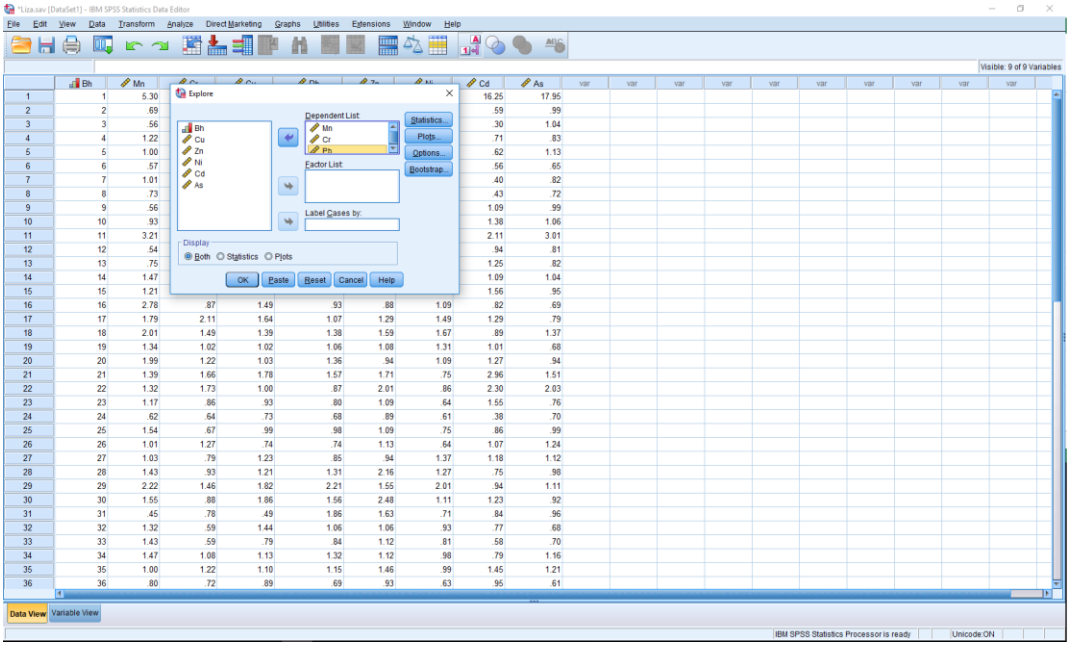
Steps of Statistical and Geostatistical Analysis

A.1: Steps for the descriptive statistical analysis by SPSS with screenshots of the work are as follows.

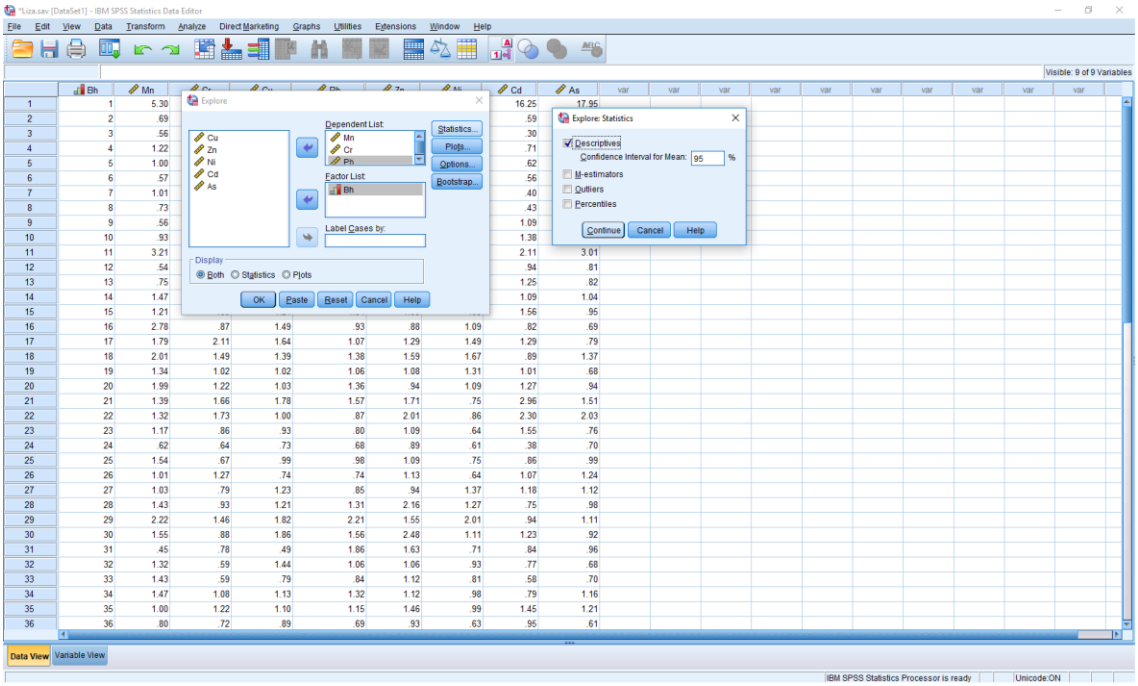
Step 1: IBM SPSS Statistics 24 is launched and data are imported to SPSS. First Click on "Analyze", "Descriptive Statistics" and "Explore"



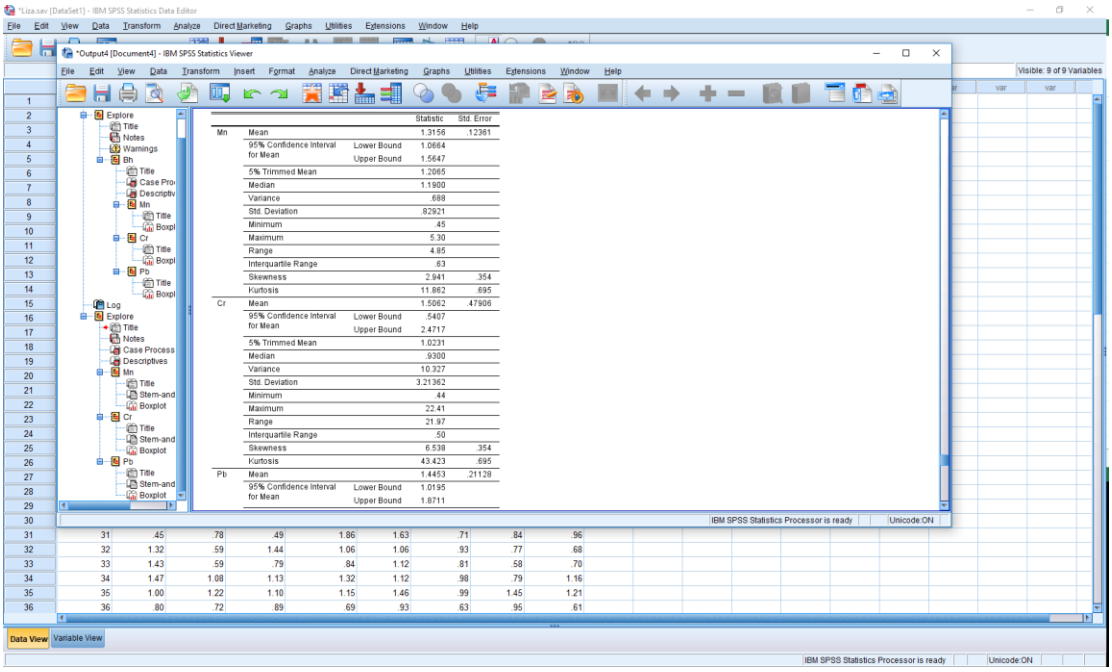
Step 2: A new window named “Explore” is appeared. Then desired field is selected in “Dependent List” and “Factor List”.



Step 3: Click on “Statistics” button. Then select “Descriptives” and click “Continue”& “ok”

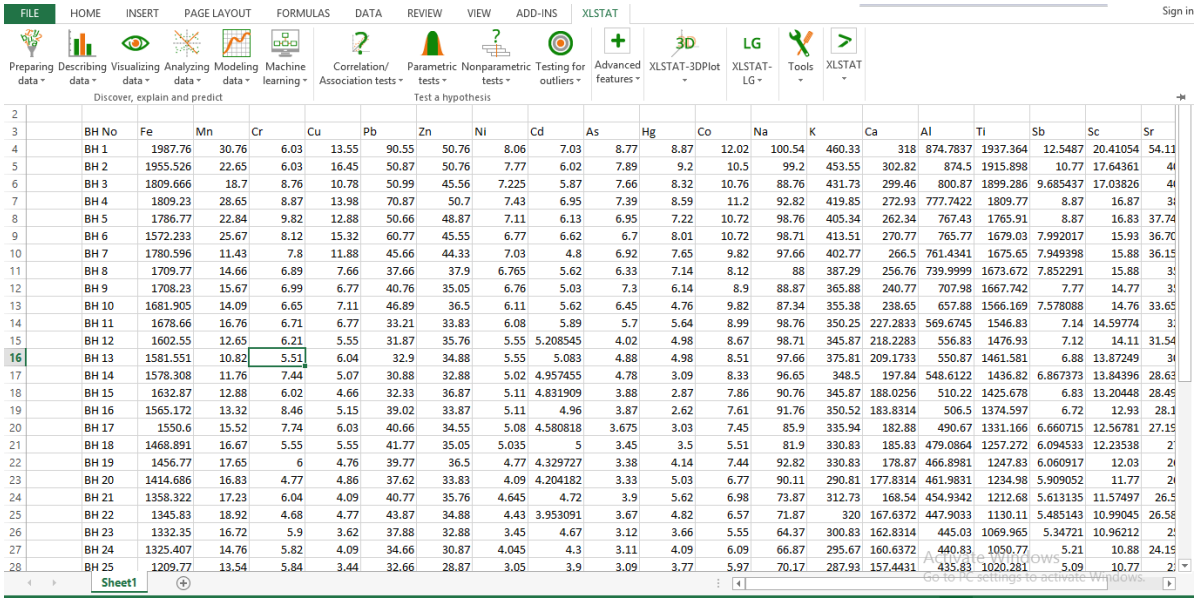


Step 4: Results are appeared in a new window named “Output”

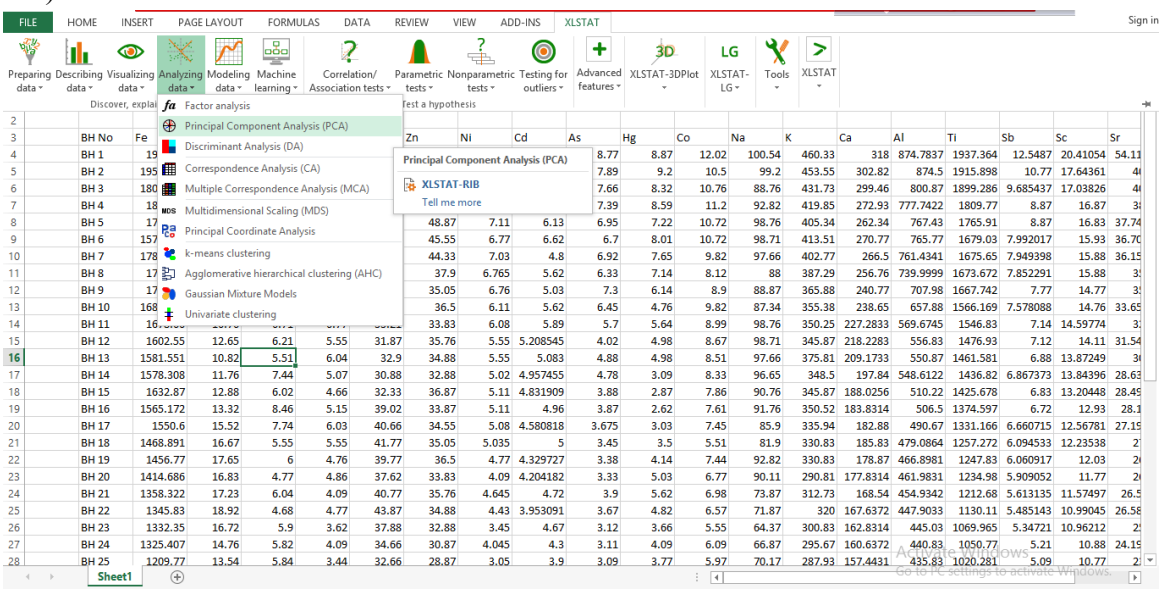


A.2: Steps for the Principle Component analysis (PCA) by SPSS with screenshots of the work are as follows.

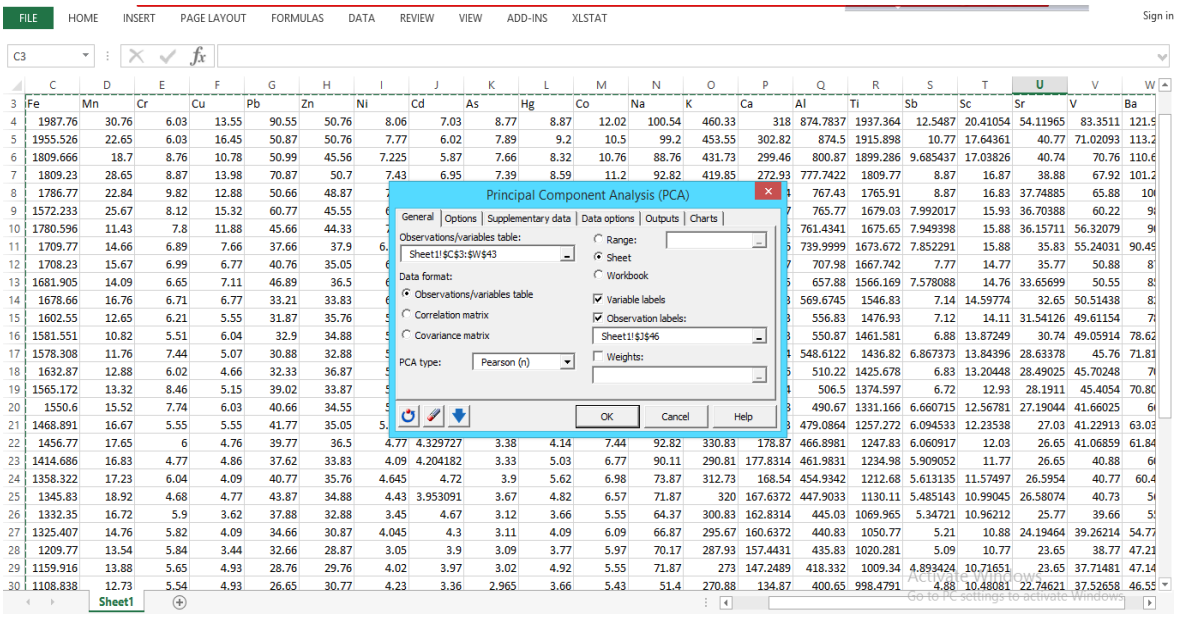
Step 1: In a excel sheet required data was tabulated and launched XLSTAT by clicking the add-in “XLSTAT” on the sheet.



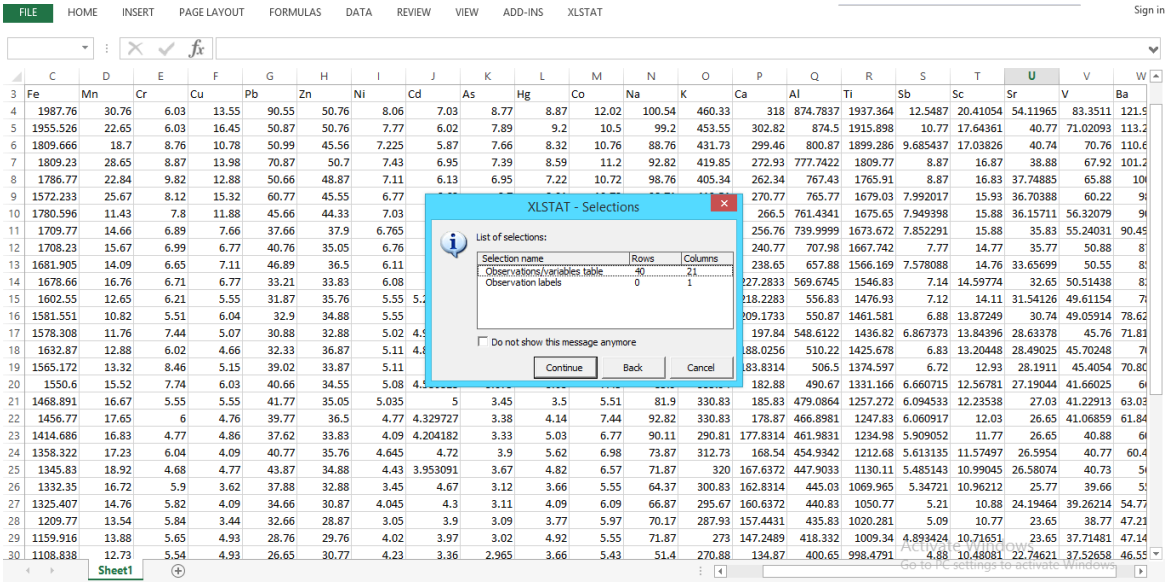
Step 2: Clicked on ‘Analyzing Data’ and then clicked on ‘Principle component analysis (PCA)’**.**



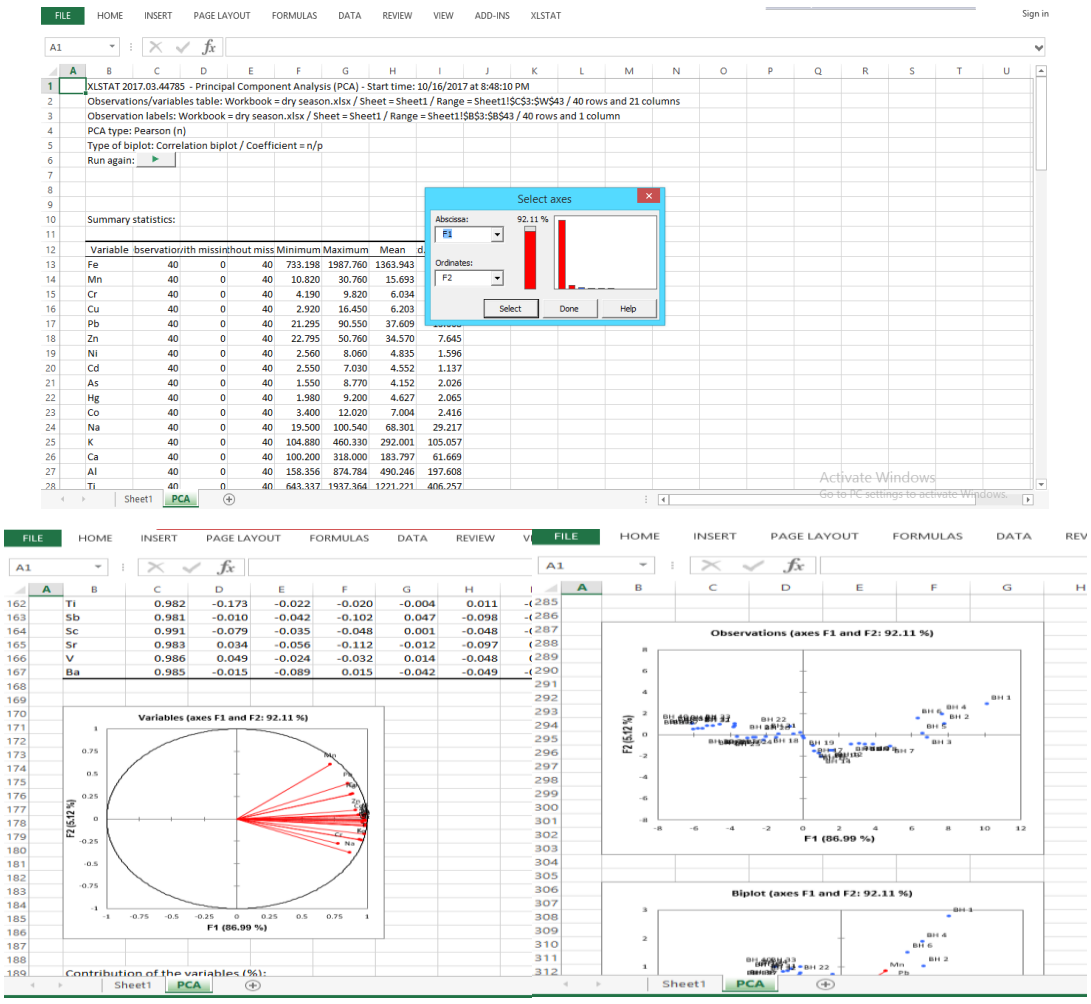
Step 3: After a new window named ‘Principle component analysis (PCA)’is appeared, desired field is selected in “General” and “Output” and “Charts”. After that, clicked on “OK”.



Step 4: A new window named “XLSTAT- selection” is appeared and clicked “Continue”.

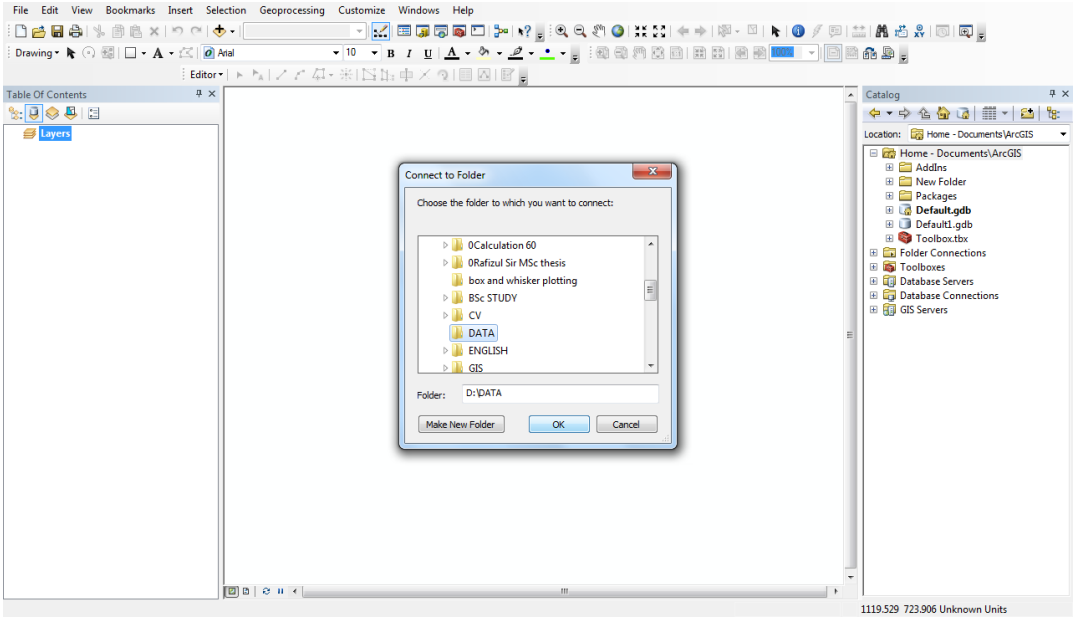


Step 5: Results are appeared in a new window named “PCA”



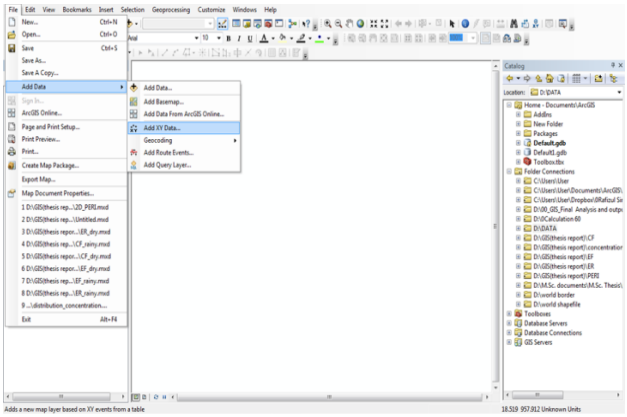
A.3: The common steps for spatial distribution using OK through ArcGIS were illustrated in followings.

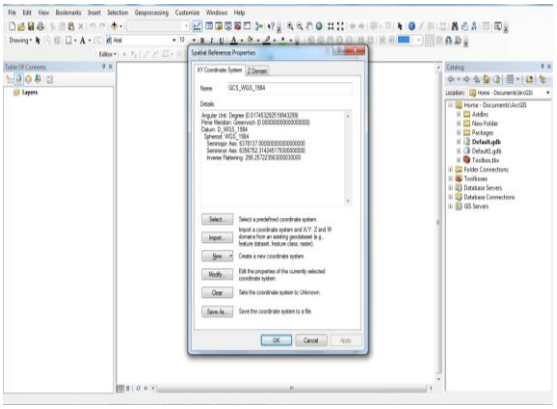
Step 1: ArcMap 10 is launched and after that, the required excel sheet (contain latitudes, longitudes and variables) connected through browsing “Folder connection” from “Catalog” window.

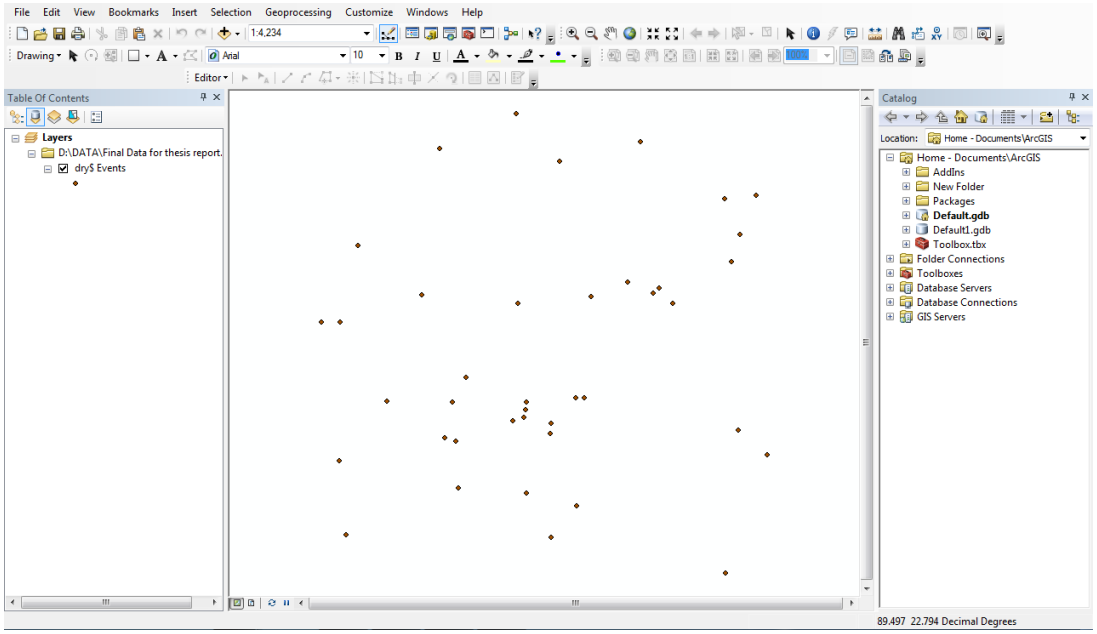


Step 2: Data added clicking “File” > “Add XY data” then the excel sheet previously added by “Folder connection”. Then selected required fields appeared window of “Add XY data”

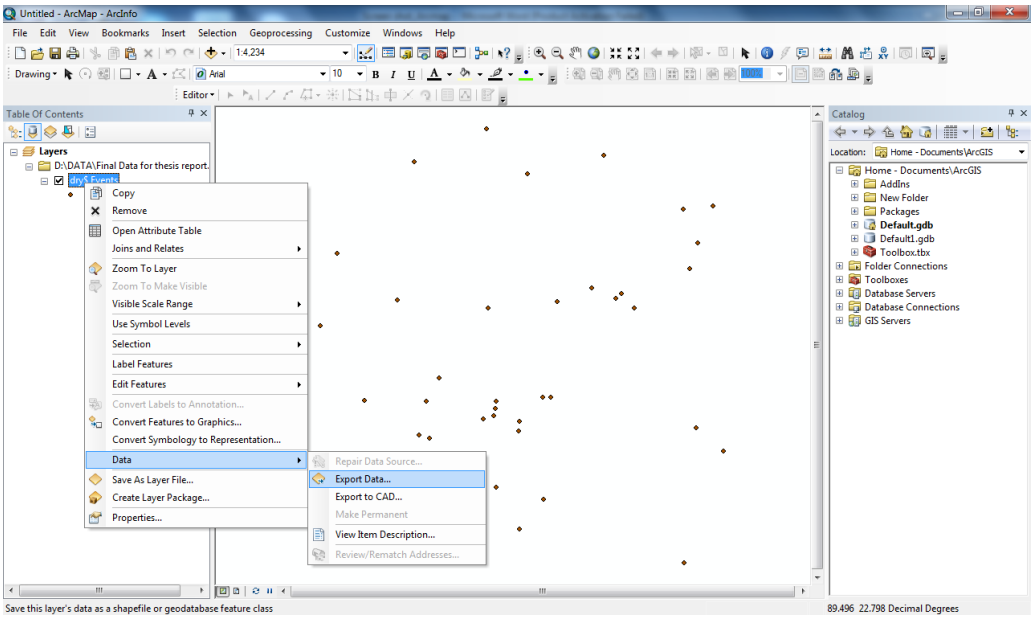
including “XY coordinate system” by selecting “geographic coordinate system” and clicked “OK”. Then the borehole appeared in the “Data View” window as points and a new layer in “Table of contents”.

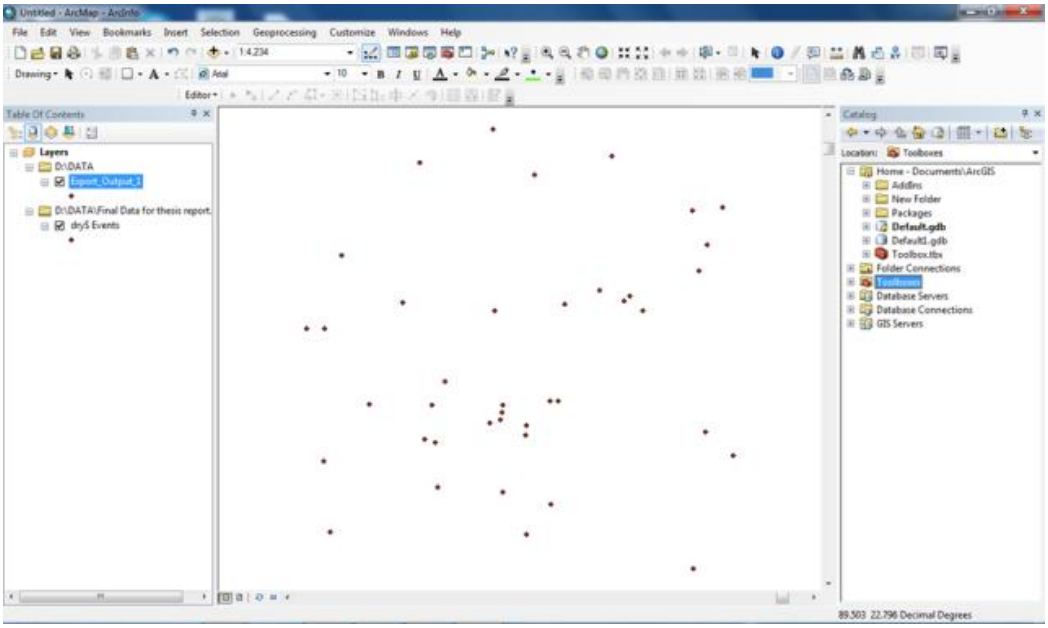






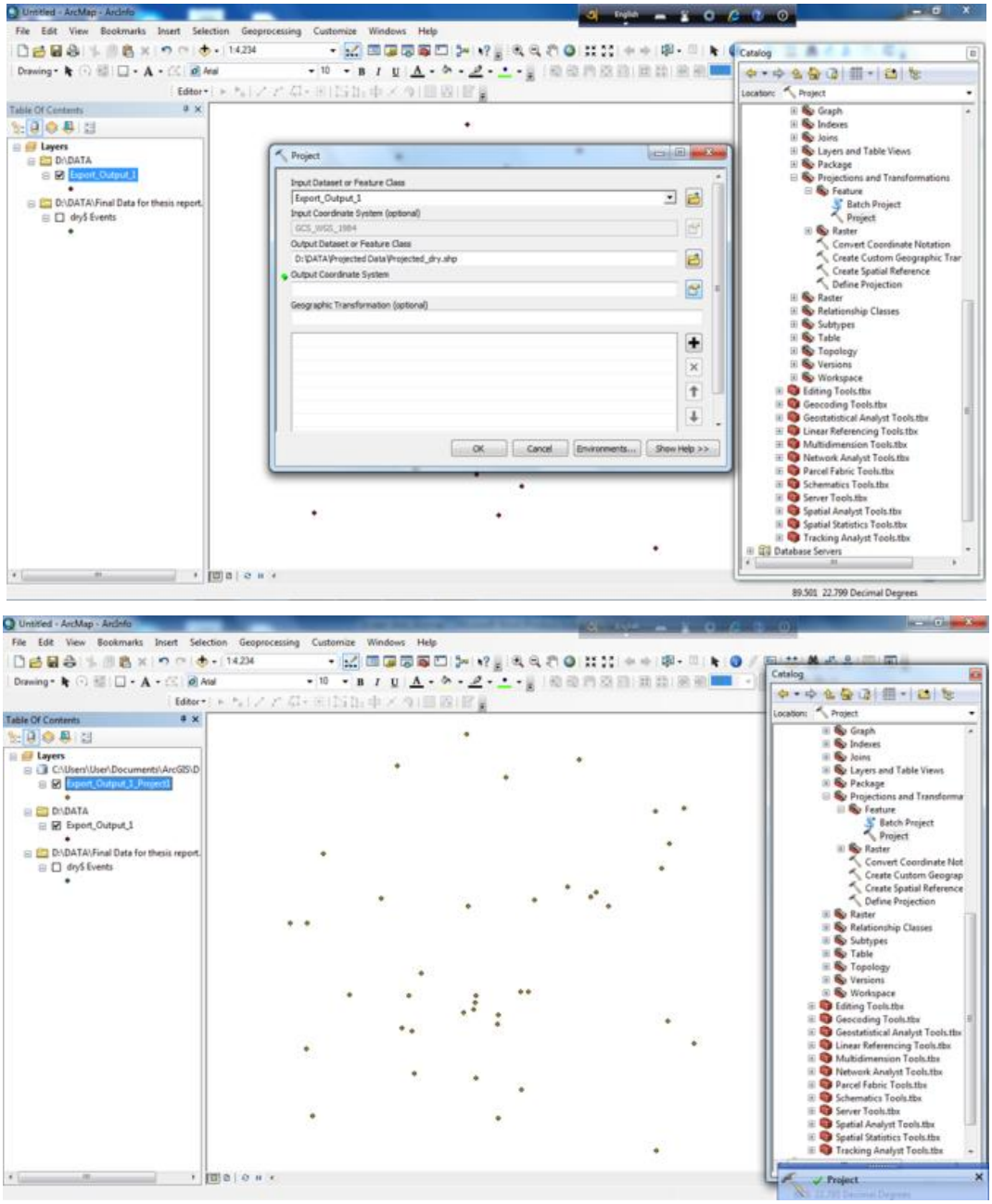
Step 3: Data exported as shape file right clicking previously created layer > “Data” > “Export data” and then a new layer created; by that step, the attribute table added to the points.





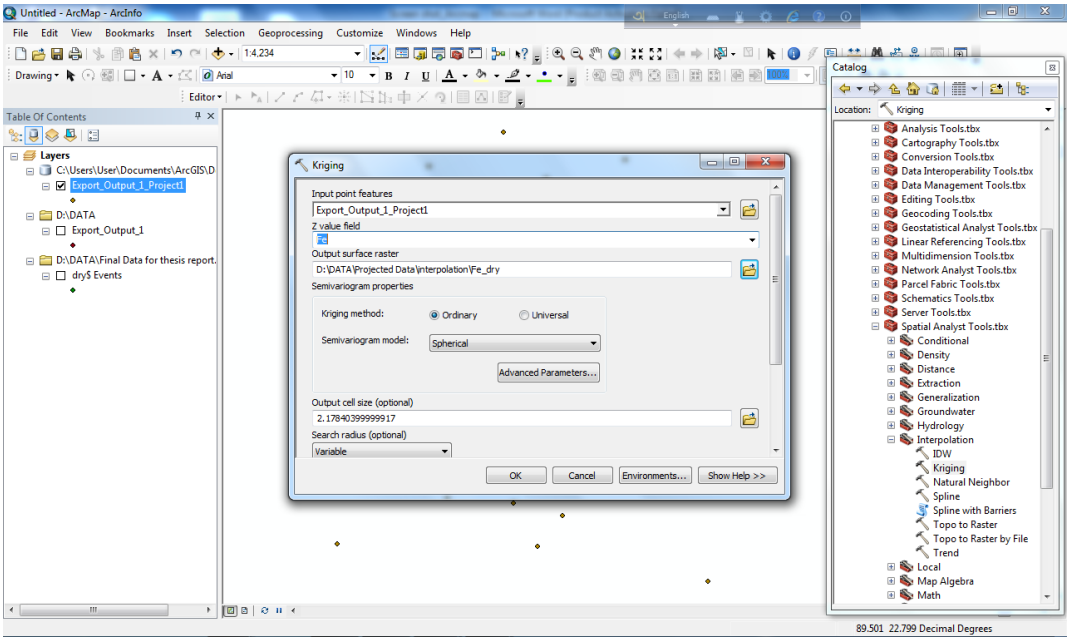
Step 4: The new layer projected through "Projected coordinated system" through clicking

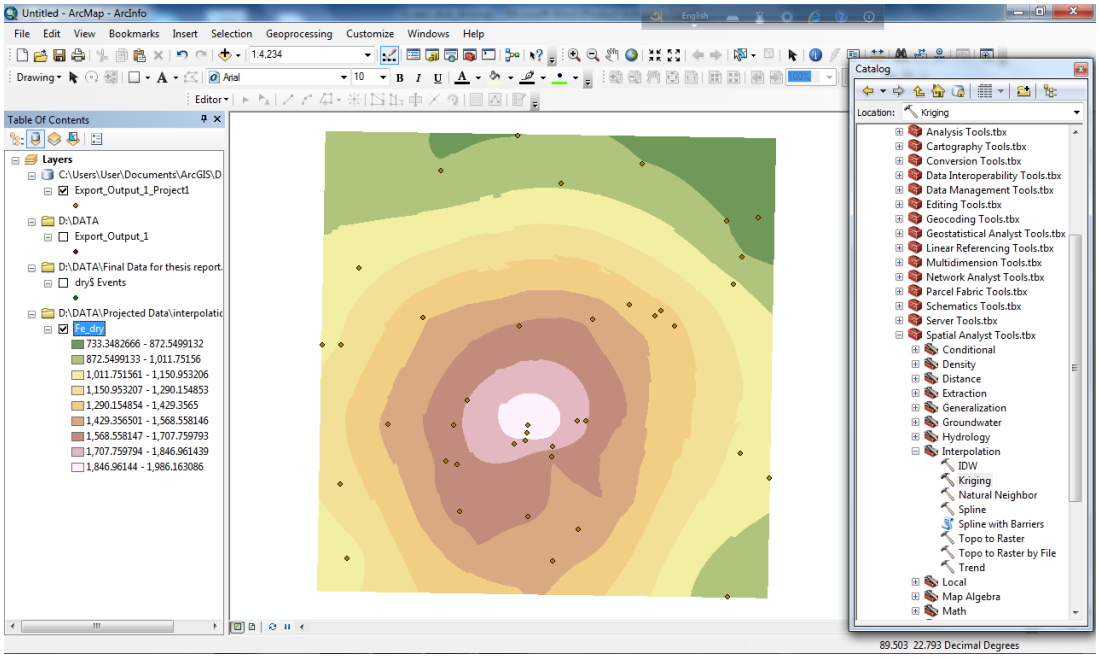
"Toolboxes"> "System Toolboxes" > "Data Management Tollboxes.tbx" > "Projection and Transformation" > "Raster" > "Project". Then the window named "Project" appeared and clicking the required field containing "Projected coordinate system" as output coordinate system. After projection a new layer added to the "Table of content" window. This whole step is essential to convert the spherical geographic data to two dimensional plain data.



Step 5: Spatial analysis done through clicking "Toolboxes"> "System Toolboxes" > "Spatial

Analyst Toll.tbx" > "Interpolation" > "Kriging" then a new window appeared named "Kriging". After providing required field including the "z value field" by the specific variable (Example: Fe concentration) and clicked "OK". As a result, spatial distribution of the specific variable appeared in the "Data View" window.





Annex-B

Results of Various Indices for Metal Elements in Soil of Waste Disposal Site

Table B.1: Contamination factor (CF) of metal elements in soil of waste disposal site during dry season

No of Bh	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
BH 1	0.035	0.032	0.060	0.246	4.528	0.725	0.107	35.150	4.872	0.887	0.481	0.004	0.022	0.008	0.011	0.340	62.744	0.928	0.144	0.617	0.287
BH 2	0.035	0.024	0.060	0.299	2.544	0.725	0.104	30.100	4.383	0.920	0.420	0.004	0.022	0.007	0.011	0.336	53.850	0.802	0.109	0.526	0.267
BH 3	0.032	0.020	0.088	0.196	2.550	0.651	0.096	29.350	4.256	0.832	0.430	0.004	0.021	0.007	0.010	0.333	48.427	0.774	0.109	0.524	0.260
BH 4	0.032	0.030	0.089	0.254	3.544	0.724	0.099	34.750	4.106	0.859	0.448	0.004	0.020	0.007	0.009	0.318	44.350	0.767	0.104	0.503	0.238
BH 5	0.032	0.024	0.098	0.234	2.533	0.698	0.095	30.650	3.861	0.722	0.429	0.004	0.019	0.006	0.009	0.310	44.350	0.765	0.101	0.488	0.237
BH 6	0.028	0.027	0.081	0.279	3.039	0.651	0.090	33.100	3.722	0.801	0.429	0.004	0.020	0.007	0.009	0.295	39.960	0.724	0.098	0.446	0.232
BH 7	0.032	0.012	0.078	0.216	2.283	0.633	0.094	24.000	3.844	0.765	0.393	0.004	0.019	0.006	0.009	0.294	39.747	0.722	0.096	0.417	0.214
BH 8	0.030	0.015	0.069	0.139	1.883	0.541	0.090	28.100	3.517	0.714	0.325	0.004	0.019	0.006	0.009	0.294	39.261	0.722	0.096	0.409	0.213
BH 9	0.030	0.016	0.070	0.123	2.038	0.501	0.090	25.150	4.056	0.614	0.356	0.004	0.018	0.006	0.009	0.293	38.850	0.671	0.095	0.377	0.207
BH 10	0.030	0.015	0.067	0.129	2.345	0.521	0.081	28.100	3.583	0.476	0.393	0.004	0.017	0.006	0.008	0.275	37.890	0.671	0.090	0.374	0.202
BH 11	0.030	0.018	0.067	0.123	1.661	0.483	0.081	29.450	3.167	0.564	0.360	0.004	0.017	0.005	0.007	0.271	35.700	0.664	0.087	0.374	0.193
BH 12	0.028	0.013	0.062	0.101	1.594	0.511	0.074	26.043	2.233	0.498	0.347	0.004	0.017	0.005	0.007	0.259	35.600	0.641	0.084	0.367	0.185
BH 13	0.028	0.011	0.055	0.110	1.645	0.498	0.074	25.415	2.711	0.498	0.340	0.004	0.018	0.005	0.007	0.256	34.400	0.631	0.082	0.363	0.185
BH 14	0.028	0.012	0.074	0.092	1.544	0.470	0.067	24.787	2.656	0.309	0.333	0.004	0.017	0.005	0.007	0.252	34.337	0.629	0.076	0.339	0.169
BH 15	0.029	0.014	0.060	0.085	1.617	0.527	0.068	24.160	2.156	0.287	0.314	0.004	0.017	0.005	0.006	0.250	34.150	0.600	0.076	0.339	0.167
BH 16	0.028	0.014	0.085	0.094	1.951	0.484	0.068	24.800	2.150	0.262	0.304	0.004	0.017	0.004	0.006	0.241	33.600	0.588	0.075	0.336	0.167
BH 17	0.028	0.016	0.077	0.110	2.033	0.494	0.068	22.904	2.042	0.303	0.298	0.004	0.016	0.004	0.006	0.234	33.304	0.571	0.073	0.309	0.155
BH 18	0.026	0.018	0.056	0.101	2.089	0.501	0.067	25.000	1.917	0.350	0.220	0.003	0.016	0.004	0.006	0.221	30.473	0.556	0.072	0.305	0.148
BH 19	0.026	0.019	0.060	0.087	1.989	0.521	0.064	21.649	1.878	0.414	0.298	0.004	0.016	0.004	0.006	0.219	30.305	0.547	0.071	0.304	0.146
BH 20	0.025	0.018	0.048	0.088	1.881	0.483	0.055	21.021	1.850	0.503	0.271	0.004	0.014	0.004	0.006	0.217	29.545	0.535	0.071	0.303	0.143
BH 21	0.024	0.018	0.060	0.074	2.039	0.511	0.062	23.600	2.167	0.562	0.279	0.003	0.015	0.004	0.006	0.213	28.066	0.526	0.071	0.302	0.142
BH 22	0.024	0.020	0.047	0.087	2.194	0.498	0.059	19.765	2.039	0.482	0.263	0.003	0.015	0.004	0.005	0.198	27.426	0.500	0.071	0.302	0.134
BH 23	0.024	0.018	0.059	0.066	1.894	0.470	0.046	23.350	1.733	0.366	0.222	0.003	0.014	0.004	0.005	0.188	26.736	0.498	0.069	0.294	0.131
BH 24	0.024	0.016	0.058	0.074	1.733	0.441	0.054	21.500	1.728	0.409	0.244	0.003	0.014	0.004	0.005	0.184	26.050	0.495	0.065	0.291	0.129
BH 25	0.021	0.014	0.058	0.063	1.633	0.412	0.041	19.500	1.717	0.377	0.239	0.003	0.014	0.004	0.005	0.179	25.450	0.490	0.063	0.287	0.111
BH 26	0.021	0.015	0.057	0.090	1.438	0.425	0.054	19.850	1.678	0.492	0.222	0.003	0.013	0.004	0.005	0.177	24.467	0.487	0.063	0.279	0.111
BH 27	0.020	0.013	0.055	0.090	1.333	0.440	0.056	16.800	1.647	0.366	0.217	0.002	0.013	0.003	0.005	0.175	24.400	0.476	0.061	0.278	0.110
BH 28	0.020	0.014	0.056	0.071	1.294	0.525	0.052	18.300	1.622	0.277	0.209	0.002	0.012	0.003	0.005	0.173	24.050	0.468	0.060	0.269	0.104
BH 29	0.019	0.013	0.054	0.069	1.339	0.507	0.052	16.650	1.606	0.209	0.213	0.002	0.013	0.003	0.005	0.171	24.050	0.459	0.059	0.264	0.103
BH 30	0.019	0.012	0.052	0.067	1.386	0.496	0.046	15.100	1.600	0.198	0.201	0.002	0.010	0.003	0.004	0.154	23.269	0.435	0.058	0.251	0.103
BH 31	0.019	0.015	0.049	0.053	1.642	0.330	0.040	20.550	1.594	0.471	0.195	0.001	0.009	0.003	0.004	0.149	20.600	0.411	0.056	0.251	0.098
BH 32	0.018	0.013	0.048	0.068	1.891	0.388	0.046	19.100	1.536	0.366	0.188	0.001	0.009	0.003	0.004	0.134	20.450	0.408	0.056	0.250	0.098
BH 33	0.018	0.018	0.048	0.083	1.178	0.397	0.064	18.800	1.478	0.392	0.186	0.001	0.007	0.003	0.004	0.132	20.407	0.399	0.055	0.247	0.097
BH 34	0.016	0.017	0.048	0.072	1.512	0.329	0.035	17.750	1.233	0.242	0.192	0.001	0.008	0.003	0.004	0.129	20.046	0.398	0.051	0.214	0.096
BH 35	0.016	0.012	0.042	0.068	1.585	0.383	0.040	15.400	1.161	0.345	0.187	0.001	0.006	0.003	0.003	0.123	18.425	0.393	0.048	0.208	0.096
BH 36	0.016	0.014	0.045	0.054	1.315	0.326	0.037	19.100	1.031	0.305	0.162	0.001	0.006	0.003	0.003	0.122	17.778	0.366	0.048	0.206	0.096
BH 37	0.016	0.012	0.046	0.054	1.214	0.381	0.048	13.950	0.989	0.339	0.156	0.001	0.006	0.003	0.003	0.119	17.631	0.360	0.045	0.176	0.096
BH 38	0.016	0.012	0.045	0.070	1.091	0.331	0.042	15.500	0.983	0.290	0.157	0.001	0.005	0.003	0.002	0.115	15.100	0.353	0.045	0.172	0.094
BH 39	0.015	0.012	0.042	0.067	1.065	0.433	0.038	12.750	0.900	0.238	0.150	0.001	0.005	0.002	0.002	0.115	15.100	0.353	0.044	0.154	0.089
BH 40	0.013	0.014	0.042	0.065	1.158	0.389	0.034	19.350	0.861	0.208	0.136	0.001	0.005	0.002	0.002	0.113	14.600	0.332	0.041	0.154	0.089

Table B.2: Contamination factor (CF) of metal elements in soil of waste disposal site during rainy season

No of Bh	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
BH 41	0.012	0.012	0.045	0.115	1.214	0.325	0.062	19.500	2.042	0.452	0.358	0.002	0.012	0.004	0.005	0.254	30.000	0.551	0.081	0.303	0.174
BH 42	0.011	0.012	0.029	0.076	1.091	0.331	0.067	15.500	1.797	0.369	0.361	0.002	0.013	0.003	0.005	0.211	30.600	0.537	0.070	0.273	0.140
BH 43	0.010	0.012	0.039	0.067	1.065	0.276	0.046	15.575	1.667	0.521	0.325	0.002	0.012	0.003	0.004	0.173	28.500	0.483	0.064	0.245	0.134
BH 44	0.010	0.014	0.055	0.065	1.158	0.284	0.048	12.750	1.536	0.233	0.275	0.002	0.010	0.003	0.004	0.164	26.650	0.459	0.060	0.225	0.134
BH 45	0.010	0.009	0.025	0.056	1.204	0.249	0.042	14.725	1.044	0.192	0.257	0.002	0.009	0.003	0.004	0.158	24.600	0.452	0.055	0.193	0.121
BH 46	0.008	0.009	0.020	0.050	0.812	0.348	0.038	10.600	1.069	0.112	0.311	0.001	0.005	0.003	0.004	0.146	22.500	0.424	0.051	0.208	0.119
BH 47	0.008	0.008	0.016	0.036	1.039	0.246	0.035	8.850	0.617	0.111	0.322	0.001	0.006	0.003	0.003	0.139	20.550	0.411	0.048	0.207	0.110
BH 48	0.010	0.007	0.017	0.052	0.794	0.270	0.033	8.250	0.589	0.145	0.305	0.001	0.006	0.003	0.003	0.134	19.400	0.408	0.049	0.189	0.099
BH 49	0.006	0.006	0.015	0.056	0.833	0.260	0.040	8.550	0.567	0.102	0.212	0.001	0.006	0.003	0.003	0.129	18.800	0.398	0.045	0.171	0.101
BH 50	0.005	0.004	0.014	0.048	0.891	0.251	0.038	9.400	0.489	0.111	0.205	0.001	0.006	0.003	0.003	0.123	18.150	0.367	0.045	0.157	0.096
BH 51	0.005	0.004	0.016	0.037	0.822	0.246	0.041	10.100	0.567	0.087	0.191	0.001	0.005	0.002	0.003	0.121	15.300	0.348	0.041	0.141	0.092
BH 52	0.004	0.003	0.017	0.046	0.760	0.236	0.037	9.400	0.617	0.088	0.122	0.001	0.004	0.002	0.002	0.111	15.000	0.348	0.040	0.135	0.089
BH 53	0.004	0.003	0.015	0.042	0.799	0.231	0.028	9.600	0.567	0.167	0.156	0.001	0.004	0.002	0.002	0.111	14.100	0.314	0.040	0.127	0.083
BH 54	0.004	0.002	0.011	0.036	0.800	0.222	0.024	9.950	0.617	0.210	0.133	0.001	0.005	0.002	0.002	0.104	12.550	0.298	0.037	0.115	0.074
BH 55	0.004	0.002	0.011	0.031	0.939	0.226	0.022	8.300	0.622	0.126	0.092	0.001	0.003	0.002	0.002	0.091	10.250	0.260	0.034	0.104	0.059
BH 56	0.004	0.001	0.010	0.042	0.786	0.224	0.016	6.150	0.572	0.099	0.115	0.000	0.003	0.002	0.002	0.087	9.900	0.248	0.034	0.099	0.054
BH 57	0.003	0.001	0.009	0.020	0.694	0.240	0.014	6.650	0.672	0.088	0.106	0.000	0.003	0.001	0.002	0.073	8.250	0.221	0.032	0.089	0.049
BH 58	0.003	0.001	0.008	0.017	0.606	0.206	0.015	7.000	0.567	0.072	0.080	0.000	0.003	0.001	0.002	0.055	6.100	0.194	0.027	0.077	0.043
BH 59	0.003	0.001	0.009	0.013	0.689	0.182	0.018	6.200	0.617	0.077	0.085	0.000	0.003	0.001	0.002	0.058	5.050	0.170	0.025	0.065	0.047
BH 60	0.003	0.001	0.008	0.024	0.544	0.169	0.023	6.000	0.483	0.077	0.079	0.000	0.003	0.001	0.001	0.043	4.900	0.137	0.024	0.051	0.044

Table B.3: Enrichment factor (EF) of metal elements in soil of waste disposal site during dry season

No of Bh	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Ti	Sb	Sc	Sr	V	Ba
BH 1	3.32	3.05	5.67	23.18	425.95	68.22	10.11	3306.93	458.38	83.45	45.23	0.40	2.07	0.72	31.98	5902.93	87.28	13.58	58.09	26.98
BH 2	3.27	2.24	5.67	28.15	239.37	68.24	9.75	2832.74	412.52	86.58	39.53	0.40	2.04	0.69	31.63	5067.87	75.48	10.23	49.51	25.08
BH 3	3.30	2.02	9.00	20.14	261.99	66.88	9.90	3016.10	437.31	85.50	44.23	0.39	2.12	0.74	34.24	4976.53	79.59	11.16	53.86	26.76
BH 4	3.40	3.19	9.39	26.90	374.97	76.64	10.48	3677.21	434.45	90.90	47.41	0.42	2.13	0.70	33.60	4693.08	81.14	10.97	53.24	25.21
BH 5	3.40	2.58	10.53	25.11	271.64	74.87	10.17	3286.94	414.07	77.43	45.98	0.45	2.08	0.68	33.22	4756.14	82.04	10.80	52.33	25.44
BH 6	3.00	2.90	8.73	29.94	326.56	69.93	9.70	3557.37	400.04	86.09	46.08	0.45	2.13	0.70	31.66	4294.65	77.82	10.52	47.94	24.97
BH 7	3.42	1.30	8.43	23.35	246.76	68.45	10.13	2594.05	415.53	82.69	42.46	0.45	2.08	0.69	31.77	4296.07	78.02	10.42	45.09	23.11
BH 8	3.38	1.72	7.66	15.49	209.42	60.22	10.03	3125.18	391.11	79.41	36.12	0.41	2.06	0.69	32.66	4366.51	80.28	10.63	45.51	23.68
BH 9	3.53	1.92	8.13	14.31	236.91	58.21	10.48	2923.59	471.44	71.38	41.38	0.44	2.04	0.67	34.01	4516.17	78.04	11.09	43.81	24.05
BH 10	3.74	1.86	8.32	16.17	293.29	65.23	10.19	3515.28	448.27	59.55	49.14	0.46	2.13	0.72	34.37	4740.05	83.93	11.23	46.84	25.24
BH 11	4.31	2.55	9.69	17.78	239.89	69.82	11.71	4254.60	457.48	81.48	51.95	0.60	2.42	0.79	39.20	5157.52	95.86	12.58	54.06	27.91
BH 12	4.21	1.97	9.18	14.91	235.52	75.51	10.94	3849.14	330.09	73.60	51.26	0.62	2.45	0.78	38.30	5261.71	94.79	12.43	54.32	27.38
BH 13	4.20	1.70	8.23	16.41	245.76	74.44	11.06	3797.00	405.04	74.40	50.86	0.62	2.69	0.75	38.31	5139.36	94.21	12.25	54.29	27.64
BH 14	4.21	1.86	11.16	13.83	231.62	70.46	10.04	3718.46	398.37	46.35	49.98	0.61	2.50	0.72	37.81	5151.04	94.40	11.45	50.85	25.35
BH 15	4.68	2.19	9.71	13.67	260.75	84.96	10.99	3897.01	347.70	46.29	50.71	0.62	2.67	0.73	40.34	5508.50	96.81	12.25	54.61	26.90
BH 16	4.52	2.28	13.75	15.21	317.01	78.62	11.07	4029.69	349.35	42.57	49.46	0.63	2.73	0.72	39.19	5459.59	95.50	12.22	54.65	27.07
BH 17	4.62	2.74	12.98	18.39	340.99	82.79	11.36	3841.70	342.45	50.82	49.98	0.61	2.70	0.74	39.17	5586.00	95.82	12.16	51.76	26.06
BH 18	4.48	3.01	9.53	17.33	358.77	86.02	11.53	4294.63	329.26	60.12	37.86	0.60	2.72	0.77	37.89	5234.76	95.54	12.38	52.46	25.48
BH 19	4.56	3.27	10.58	15.26	350.51	91.91	11.21	3816.00	331.00	72.98	52.46	0.69	2.79	0.76	38.59	5341.78	96.39	12.53	53.62	25.65
BH 20	4.48	3.16	8.50	15.74	335.09	86.09	9.71	3744.77	329.57	89.61	48.24	0.68	2.48	0.76	38.60	5263.34	95.31	12.66	53.94	25.46
BH 21	4.36	3.28	10.93	13.45	368.78	92.42	11.20	4269.36	391.96	101.67	50.51	0.57	2.71	0.73	38.49	5077.23	95.18	12.83	54.63	25.75
BH 22	4.39	3.66	8.60	15.94	403.04	91.56	10.85	3631.80	374.64	88.57	48.29	0.56	2.81	0.74	36.43	5039.34	91.79	13.02	55.44	24.59
BH 23	4.38	3.25	10.91	12.17	350.26	86.86	8.51	4318.15	320.55	67.68	41.05	0.50	2.66	0.73	34.71	4944.33	92.15	12.71	54.33	24.29
BH 24	4.40	2.90	10.87	13.88	323.54	82.33	10.07	4013.91	322.56	76.36	45.48	0.53	2.64	0.72	34.42	4863.36	92.33	12.05	54.30	24.06
BH 25	4.06	2.69	11.03	11.81	308.37	77.88	7.68	3682.28	324.17	71.19	45.09	0.56	2.60	0.72	33.80	4805.85	92.44	11.91	54.23	20.98
BH 26	4.05	2.87	11.12	17.63	282.90	83.64	10.54	3905.16	330.08	96.79	43.67	0.60	2.57	0.70	34.84	4813.51	95.83	12.41	54.96	21.82
BH 27	4.05	2.75	11.38	18.41	273.72	90.30	11.59	3450.99	338.37	75.18	44.62	0.45	2.66	0.67	35.98	5012.16	97.86	12.46	57.10	22.50
BH 28	4.09	2.84	11.52	14.64	268.52	108.97	10.79	3797.46	336.63	57.48	43.33	0.44	2.49	0.70	35.96	4990.65	97.22	12.48	55.84	21.50
BH 29	4.17	2.87	11.61	14.96	288.39	109.27	11.28	3587.41	345.93	45.03	45.85	0.40	2.79	0.69	36.86	5181.81	98.96	12.72	56.82	22.27
BH 30	4.31	2.76	11.49	15.05	309.32	110.69	10.27	3369.93	357.08	44.19	44.90	0.42	2.14	0.69	34.33	5193.04	97.16	12.86	56.07	23.04
BH 31	4.17	3.34	10.89	11.85	366.40	73.57	8.84	4586.23	355.84	105.00	43.56	0.28	1.99	0.68	33.22	4597.39	91.70	12.49	55.93	21.84
BH 32	4.37	3.14	11.49	16.12	448.92	92.10	10.89	4533.71	364.62	86.76	44.62	0.31	2.16	0.70	31.89	4854.15	96.89	13.18	59.36	23.19
BH 33	4.43	4.43	11.96	20.88	295.42	99.47	15.95	4713.69	370.52	98.29	46.64	0.36	1.83	0.73	33.06	5116.67	99.95	13.91	61.89	24.21
BH 34	4.39	4.78	13.24	19.93	419.73	91.27	9.73	4926.53	342.31	67.17	53.40	0.39	2.19	0.87	35.68	5563.88	110.52	14.29	59.38	26.72
BH 35	5.30	4.18	14.18	23.00	532.51	128.68	13.48	5173.14	390.04	115.89	62.75	0.35	2.18	1.01	41.30	6189.16	132.08	16.21	69.98	32.31
BH 36	5.56	5.00	16.04	19.35	468.55	116.07	13.21	6808.14	367.34	108.72	57.89	0.31	2.06	1.04	43.65	6336.97	130.41	17.00	73.44	34.19
BH 37	6.19	4.69	18.26	21.27	482.45	151.44	19.15	5542.68	392.91	134.69	61.82	0.36	2.24	1.05	47.18	7005.10	142.91	17.83	69.92	38.12
BH 38	6.41	5.12	18.31	28.92	448.84	136.21	17.34	6378.25	404.64	119.13	64.52	0.40	2.24	1.17	47.49	6213.65	145.33	18.47	70.82	38.50
BH 39	7.59	5.67	20.72	32.94	522.83	212.72	18.86	6260.71	441.93	116.62	73.66	0.43	2.60	1.19	56.67	7414.64	173.42	21.57	75.77	43.77
BH 40	6.77	7.34	21.78	33.73	601.83	202.02	17.74	10056.51	447.53	107.84	70.68	0.43	2.61	1.25	58.66	7587.86	172.54	21.40	80.19	46.32

Table B.4: Enrichment factor (EF) of metal elements in soil of waste disposal site during rainy season

No of Bh	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Ti	Sb	Sc	Sr	V	Ba
BH 41	2.42	2.36	8.98	22.96	242.23	64.86	12.36	3890.07	407.29	90.17	71.50	0.47	2.31	0.74	50.59	5984.73	109.90	16.19	60.41	34.73
BH 42	2.30	2.68	6.33	16.26	234.54	71.17	14.44	3332.85	386.44	79.34	77.58	0.49	2.70	0.75	45.38	6579.70	115.53	15.15	58.65	30.18
BH 43	2.36	2.60	8.84	15.12	240.00	62.15	10.37	3510.69	375.68	117.44	73.21	0.43	2.71	0.71	38.97	6424.05	108.91	14.41	55.25	30.25
BH 44	2.44	3.36	13.20	15.45	275.71	67.62	11.48	3035.63	365.73	55.47	65.43	0.42	2.28	0.69	39.02	6345.05	109.30	14.38	53.53	31.82
BH 45	2.62	2.35	6.35	13.99	302.38	62.59	10.66	3697.31	262.25	48.08	64.43	0.39	2.32	0.78	39.56	6176.83	113.45	13.91	48.54	30.26
BH 46	2.28	2.56	5.46	13.89	223.80	95.86	10.59	2923.33	294.94	30.89	85.71	0.39	1.45	0.83	40.37	6205.18	116.83	13.99	57.26	32.91
BH 47	2.32	2.37	4.48	10.41	300.39	71.16	10.14	2559.85	178.37	32.11	93.02	0.36	1.86	0.90	40.12	5944.07	118.99	13.88	59.95	31.70
BH 48	3.08	2.04	5.07	15.93	242.45	82.58	9.98	2519.20	179.82	44.28	93.20	0.35	1.83	0.89	41.01	5923.94	124.64	15.02	57.77	30.33
BH 49	2.00	1.86	4.65	18.02	267.13	83.47	12.91	2741.84	181.72	32.71	67.86	0.30	1.82	0.91	41.34	6028.83	127.54	14.57	54.82	32.45
BH 50	1.93	1.40	5.10	17.25	317.87	89.44	13.70	3353.50	174.41	39.60	73.06	0.32	1.97	0.94	43.96	6475.12	130.86	16.08	56.05	34.27
BH 51	1.82	1.61	6.13	13.84	311.27	93.21	15.70	3824.56	214.58	32.94	72.25	0.37	2.01	0.92	45.91	5793.64	131.85	15.65	53.55	34.76
BH 52	1.85	1.47	7.20	19.88	329.81	102.60	16.03	4079.20	267.61	38.19	53.12	0.38	1.88	0.94	48.15	6509.36	151.10	17.35	58.54	38.44
BH 53	1.98	1.37	7.13	19.87	374.79	108.56	13.26	4503.16	265.81	78.34	73.36	0.39	1.98	0.99	52.04	6614.02	147.33	18.54	59.76	38.71
BH 54	1.93	1.01	5.11	16.35	365.17	101.40	10.77	4541.79	281.48	95.86	60.62	0.37	2.30	0.88	47.26	5728.59	135.90	16.70	52.65	33.98
BH 55	2.02	0.97	5.37	14.92	458.53	110.28	10.81	4055.15	304.00	61.56	44.95	0.38	1.65	0.91	44.30	5007.87	127.03	16.81	50.59	28.79
BH 56	2.20	0.67	5.39	22.29	415.36	118.30	8.53	3249.94	302.39	52.32	60.67	0.25	1.76	0.88	45.96	5231.60	130.91	17.73	52.22	28.44
BH 57	1.82	0.65	4.93	11.08	384.52	132.74	7.98	3684.50	372.45	48.76	58.73	0.25	1.69	0.81	40.67	4570.99	122.40	17.46	49.25	27.42
BH 58	1.84	0.64	4.60	9.88	361.42	123.13	8.83	4178.27	338.24	42.98	47.75	0.25	2.01	0.85	32.86	3641.06	115.58	16.25	46.12	25.56
BH 59	1.84	0.83	5.55	8.47	439.25	115.93	11.31	3955.50	393.42	49.12	54.10	0.22	1.80	0.84	36.85	3221.82	108.75	15.86	41.78	30.11
BH 60	1.97	0.81	5.32	16.32	375.53	116.57	15.83	4141.92	333.65	53.15	54.67	0.25	1.82	0.74	29.54	3382.57	94.76	16.35	35.39	30.70

Table B.5: Geo-accumulation index (I_{geo}) of metal elements in soil of waste disposal site during dry season

No of Bh	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
BH 1	-5.41	-5.53	-4.64	-2.61	1.59	-1.05	-3.80	4.55	1.70	-0.76	-1.64	-8.46	-6.09	-7.61	-7.14	-2.14	5.39	-0.69	-3.38	-1.28	-2.39
BH 2	-5.43	-5.98	-4.64	-2.33	0.76	-1.05	-3.86	4.33	1.55	-0.71	-1.84	-8.48	-6.11	-7.68	-7.14	-2.16	5.17	-0.90	-3.79	-1.51	-2.49
BH 3	-5.54	-6.25	-4.10	-2.94	0.77	-1.20	-3.96	4.29	1.50	-0.85	-1.80	-8.64	-6.18	-7.70	-7.27	-2.17	5.01	-0.95	-3.79	-1.52	-2.53
BH 4	-5.54	-5.64	-4.08	-2.56	1.24	-1.05	-3.92	4.53	1.45	-0.80	-1.74	-8.58	-6.22	-7.83	-7.31	-2.24	4.89	-0.97	-3.85	-1.58	-2.65
BH 5	-5.56	-5.96	-3.93	-2.68	0.76	-1.10	-3.98	4.35	1.36	-1.05	-1.81	-8.49	-6.27	-7.89	-7.33	-2.28	4.89	-0.97	-3.90	-1.62	-2.66
BH 6	-5.75	-5.79	-4.21	-2.43	1.02	-1.20	-4.05	4.46	1.31	-0.91	-1.81	-8.49	-6.24	-7.84	-7.33	-2.35	4.74	-1.05	-3.94	-1.75	-2.69
BH 7	-5.57	-6.96	-4.27	-2.80	0.61	-1.24	-4.00	4.00	1.36	-0.97	-1.93	-8.50	-6.28	-7.87	-7.34	-2.35	4.73	-1.06	-3.96	-1.85	-2.81
BH 8	-5.63	-6.60	-4.44	-3.43	0.33	-1.47	-4.06	4.23	1.23	-1.07	-2.21	-8.65	-6.34	-7.92	-7.38	-2.35	4.71	-1.06	-3.97	-1.87	-2.82
BH 9	-5.63	-6.51	-4.42	-3.61	0.44	-1.58	-4.06	4.07	1.43	-1.29	-2.08	-8.64	-6.42	-8.01	-7.45	-2.36	4.69	-1.16	-3.98	-1.99	-2.86
BH 10	-5.65	-6.66	-4.50	-3.54	0.64	-1.52	-4.20	4.23	1.26	-1.66	-1.93	-8.66	-6.46	-8.03	-7.55	-2.45	4.66	-1.16	-4.06	-2.00	-2.89
BH 11	-5.65	-6.41	-4.48	-3.61	0.15	-1.63	-4.21	4.30	1.08	-1.41	-2.06	-8.49	-6.48	-8.10	-7.76	-2.47	4.57	-1.18	-4.11	-2.00	-2.96
BH 12	-5.72	-6.82	-4.59	-3.89	0.09	-1.55	-4.34	4.12	0.57	-1.59	-2.11	-8.49	-6.50	-8.16	-7.79	-2.53	4.57	-1.23	-4.16	-2.03	-3.02
BH 13	-5.74	-7.04	-4.77	-3.77	0.13	-1.59	-4.34	4.08	0.85	-1.59	-2.14	-8.50	-6.38	-8.22	-7.81	-2.55	4.52	-1.25	-4.19	-2.05	-3.02
BH 14	-5.74	-6.92	-4.33	-4.02	0.04	-1.68	-4.49	4.05	0.82	-2.28	-2.17	-8.52	-6.49	-8.30	-7.81	-2.57	4.52	-1.25	-4.30	-2.15	-3.15
BH 15	-5.69	-6.79	-4.64	-4.15	0.11	-1.51	-4.46	4.01	0.52	-2.39	-2.25	-8.61	-6.50	-8.37	-7.92	-2.58	4.51	-1.32	-4.30	-2.15	-3.17
BH 16	-5.75	-6.74	-4.15	-4.00	0.38	-1.63	-4.46	4.05	0.52	-2.52	-2.30	-8.59	-6.48	-8.40	-7.93	-2.64	4.49	-1.35	-4.32	-2.16	-3.17
BH 17	-5.77	-6.52	-4.28	-3.77	0.44	-1.60	-4.47	3.93	0.44	-2.31	-2.33	-8.69	-6.54	-8.41	-7.97	-2.68	4.47	-1.39	-4.37	-2.28	-3.27
BH 18	-5.85	-6.42	-4.76	-3.89	0.48	-1.58	-4.48	4.06	0.35	-2.10	-2.77	-8.76	-6.57	-8.39	-8.01	-2.77	4.34	-1.43	-4.38	-2.30	-3.34
BH 19	-5.86	-6.34	-4.64	-4.12	0.41	-1.52	-4.56	3.85	0.32	-1.86	-2.33	-8.58	-6.57	-8.44	-8.05	-2.78	4.34	-1.46	-4.40	-2.30	-3.37
BH 20	-5.90	-6.40	-4.97	-4.09	0.33	-1.63	-4.78	3.81	0.30	-1.58	-2.47	-8.62	-6.75	-8.45	-8.06	-2.79	4.30	-1.49	-4.40	-2.31	-3.39
BH 21	-5.96	-6.37	-4.63	-4.33	0.44	-1.55	-4.60	3.98	0.53	-1.42	-2.43	-8.90	-6.65	-8.53	-8.08	-2.82	4.23	-1.51	-4.40	-2.31	-3.40
BH 22	-5.97	-6.23	-5.00	-4.11	0.55	-1.59	-4.67	3.72	0.44	-1.64	-2.51	-8.94	-6.61	-8.54	-8.11	-2.92	4.19	-1.59	-4.40	-2.31	-3.49
BH 23	-5.99	-6.41	-4.67	-4.51	0.34	-1.68	-5.03	3.96	0.21	-2.04	-2.76	-9.10	-6.70	-8.58	-8.12	-3.00	4.16	-1.59	-4.45	-2.35	-3.51
BH 24	-5.99	-6.59	-4.69	-4.33	0.21	-1.77	-4.80	3.84	0.20	-1.87	-2.62	-9.05	-6.73	-8.60	-8.13	-3.02	4.12	-1.60	-4.54	-2.37	-3.54
BH 25	-6.13	-6.72	-4.68	-4.58	0.12	-1.86	-5.20	3.70	0.19	-1.99	-2.65	-8.98	-6.77	-8.63	-8.15	-3.07	4.08	-1.62	-4.57	-2.38	-3.75
BH 26	-6.19	-6.68	-4.73	-4.06	-0.06	-1.82	-4.81	3.73	0.16	-1.61	-2.76	-8.94	-6.84	-8.72	-8.21	-3.08	4.03	-1.62	-4.57	-2.42	-3.76
BH 27	-6.25	-6.81	-4.76	-4.06	-0.17	-1.77	-4.73	3.49	0.14	-2.04	-2.79	-9.43	-6.85	-8.85	-8.27	-3.10	4.02	-1.65	-4.63	-2.43	-3.78
BH 28	-6.25	-6.77	-4.76	-4.41	-0.21	-1.51	-4.85	3.61	0.11	-2.44	-2.84	-9.45	-6.97	-8.80	-8.28	-3.11	4.00	-1.68	-4.64	-2.48	-3.86
BH 29	-6.28	-6.81	-4.80	-4.43	-0.16	-1.56	-4.84	3.47	0.10	-2.84	-2.82	-9.68	-6.85	-8.88	-8.34	-3.13	4.00	-1.71	-4.67	-2.51	-3.86
BH 30	-6.28	-6.92	-4.86	-4.47	-0.11	-1.60	-5.03	3.33	0.09	-2.92	-2.90	-9.63	-7.29	-8.92	-8.39	-3.29	3.96	-1.78	-4.70	-2.58	-3.86
BH 31	-6.33	-6.65	-4.94	-4.82	0.13	-2.19	-5.24	3.78	0.09	-1.67	-2.94	-10.23	-7.40	-8.95	-8.39	-3.33	3.78	-1.87	-4.74	-2.58	-3.94
BH 32	-6.35	-6.83	-4.95	-4.47	0.33	-1.95	-5.03	3.67	0.03	-2.04	-3.00	-10.17	-7.37	-8.98	-8.48	-3.48	3.77	-1.88	-4.76	-2.58	-3.94
BH 33	-6.41	-6.41	-4.97	-4.17	-0.35	-1.92	-4.56	3.65	-0.02	-1.94	-3.01	-10.04	-7.69	-9.01	-8.55	-3.51	3.77	-1.91	-4.76	-2.60	-3.96
BH 34	-6.57	-6.44	-4.97	-4.38	0.01	-2.19	-5.42	3.56	-0.28	-2.63	-2.96	-10.07	-7.57	-8.91	-8.70	-3.54	3.74	-1.91	-4.86	-2.81	-3.96
BH 35	-6.57	-6.91	-5.15	-4.45	0.08	-1.97	-5.22	3.36	-0.37	-2.12	-3.01	-10.48	-7.86	-8.96	-8.98	-3.61	3.62	-1.93	-4.96	-2.85	-3.96
BH 36	-6.59	-6.74	-5.06	-4.79	-0.19	-2.20	-5.34	3.67	-0.54	-2.30	-3.21	-10.73	-8.02	-9.01	-9.06	-3.61	3.57	-2.04	-4.98	-2.86	-3.97
BH 37	-6.59	-6.99	-5.03	-4.81	-0.30	-1.98	-4.96	3.22	-0.60	-2.15	-3.27	-10.69	-8.06	-9.15	-9.22	-3.66	3.56	-2.06	-5.06	-3.09	-3.97
BH 38	-6.59	-6.91	-5.08	-4.42	-0.46	-2.18	-5.15	3.37	-0.61	-2.37	-3.26	-10.60	-8.11	-9.05	-9.27	-3.70	3.33	-2.09	-5.06	-3.12	-4.00
BH 39	-6.60	-7.02	-5.15	-4.48	-0.49	-1.79	-5.29	3.09	-0.74	-2.66	-3.32	-10.73	-8.15	-9.27	-9.52	-3.70	3.33	-2.09	-5.09	-3.28	-4.07
BH 40	-6.85	-6.73	-5.16	-4.53	-0.37	-1.95	-5.46	3.69	-0.80	-2.85	-3.46	-10.83	-8.22	-9.28	-9.61	-3.73	3.28	-2.18	-5.19	-3.28	-4.07

Table B.6: Geo-accumulation index (I_{geo}) of metal elements in soil of waste disposal site during rainy season

No of Bh	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co	Na	K	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
BH 41	-6.95	-6.99	-5.06	-3.70	-0.30	-2.21	-4.60	3.70	0.44	-1.73	-2.07	-9.31	-7.02	-8.67	-8.23	-2.56	4.32	-1.45	-4.21	-2.31	-3.11
BH 42	-7.13	-6.91	-5.67	-4.31	-0.46	-2.18	-4.48	3.37	0.26	-2.02	-2.06	-9.38	-6.90	-8.76	-8.33	-2.83	4.35	-1.48	-4.41	-2.46	-3.42
BH 43	-7.16	-7.02	-5.26	-4.48	-0.49	-2.44	-5.03	3.38	0.15	-1.53	-2.21	-9.63	-6.96	-8.89	-8.40	-3.12	4.25	-1.63	-4.55	-2.61	-3.48
BH 44	-7.19	-6.73	-4.76	-4.53	-0.37	-2.40	-4.96	3.09	0.03	-2.69	-2.45	-9.73	-7.29	-9.02	-8.48	-3.19	4.15	-1.71	-4.63	-2.74	-3.49
BH 45	-7.17	-7.32	-5.89	-4.75	-0.32	-2.59	-5.14	3.30	-0.52	-2.97	-2.55	-9.91	-7.34	-8.91	-8.56	-3.25	4.04	-1.73	-4.76	-2.96	-3.64
BH 46	-7.50	-7.33	-6.24	-4.90	-0.89	-2.11	-5.29	2.82	-0.49	-3.74	-2.27	-10.04	-8.15	-8.96	-8.69	-3.36	3.91	-1.82	-4.89	-2.85	-3.65
BH 47	-7.55	-7.52	-6.60	-5.38	-0.53	-2.61	-5.42	2.56	-1.28	-3.76	-2.22	-10.23	-7.86	-8.91	-8.76	-3.43	3.78	-1.87	-4.97	-2.86	-3.77
BH 48	-7.22	-7.81	-6.50	-4.85	-0.92	-2.47	-5.52	2.46	-1.35	-3.37	-2.30	-10.36	-7.96	-9.01	-8.84	-3.48	3.69	-1.88	-4.93	-2.99	-3.92
BH 49	-7.91	-8.01	-6.69	-4.74	-0.85	-2.53	-5.22	2.51	-1.40	-3.88	-2.83	-10.66	-8.04	-9.05	-8.91	-3.54	3.65	-1.92	-5.04	-3.13	-3.89
BH 50	-8.11	-8.58	-6.71	-4.95	-0.75	-2.58	-5.29	2.65	-1.62	-3.76	-2.87	-10.69	-8.09	-9.15	-9.06	-3.61	3.60	-2.03	-5.06	-3.26	-3.97
BH 51	-8.29	-8.47	-6.53	-5.36	-0.87	-2.61	-5.18	2.75	-1.40	-4.11	-2.97	-10.60	-8.14	-9.27	-9.15	-3.63	3.35	-2.11	-5.18	-3.41	-4.03
BH 52	-8.46	-8.79	-6.50	-5.03	-0.98	-2.67	-5.34	2.65	-1.28	-4.09	-3.62	-10.73	-8.44	-9.43	-9.35	-3.76	3.32	-2.11	-5.23	-3.48	-4.08
BH 53	-8.47	-9.01	-6.62	-5.15	-0.91	-2.70	-5.73	2.68	-1.40	-3.17	-3.26	-10.82	-8.47	-9.47	-9.46	-3.76	3.23	-2.26	-5.25	-3.56	-4.18
BH 54	-8.47	-9.41	-7.07	-5.39	-0.91	-2.76	-5.99	2.73	-1.28	-2.84	-3.50	-10.85	-8.22	-9.60	-9.42	-3.86	3.06	-2.33	-5.36	-3.70	-4.33
BH 55	-8.50	-9.57	-7.09	-5.62	-0.68	-2.73	-6.08	2.47	-1.27	-3.57	-4.03	-10.92	-8.79	-9.66	-9.52	-4.05	2.77	-2.53	-5.45	-3.86	-4.67
BH 56	-8.50	-10.20	-7.20	-5.15	-0.93	-2.74	-6.54	2.04	-1.39	-3.92	-3.71	-11.62	-8.81	-9.81	-9.63	-4.11	2.72	-2.60	-5.48	-3.92	-4.80
BH 57	-8.84	-10.33	-7.40	-6.23	-1.11	-2.65	-6.70	2.15	-1.16	-4.09	-3.82	-11.68	-8.94	-10.01	-9.70	-4.35	2.46	-2.76	-5.57	-4.08	-4.92
BH 58	-8.93	-10.45	-7.61	-6.50	-1.31	-2.86	-6.66	2.22	-1.40	-4.38	-4.23	-11.80	-8.80	-10.05	-9.81	-4.77	2.02	-2.95	-5.78	-4.28	-5.13
BH 59	-9.02	-10.18	-7.43	-6.82	-1.12	-3.05	-6.40	2.05	-1.28	-4.28	-4.14	-12.07	-9.06	-10.16	-9.90	-4.70	1.75	-3.14	-5.92	-4.52	-4.99
BH 60	-9.04	-10.33	-7.61	-5.99	-1.46	-3.15	-6.03	2.00	-1.63	-4.28	-4.24	-12.02	-9.15	-10.46	-10.02	-5.13	1.71	-3.45	-5.99	-4.87	-5.08

Annex-C

Spatial and Seasonal Variation of the Concentrations of Metal Elements in soil of Waste Disposal Site

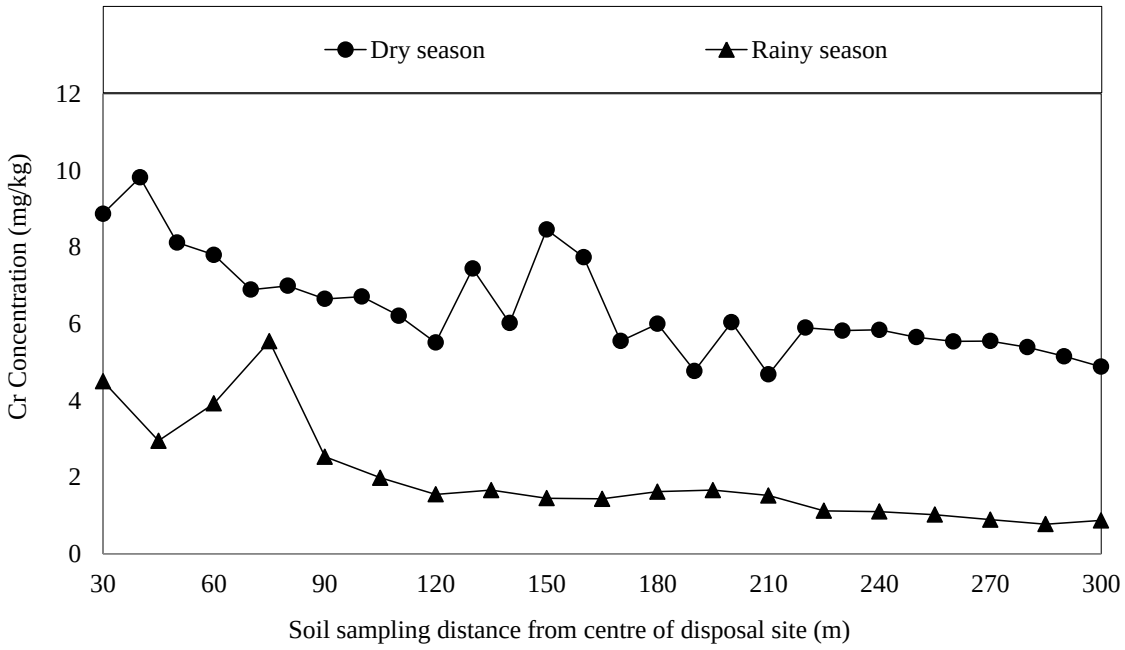


Figure C.1: Spatial and seasonal variation of Cr concentration in soil.

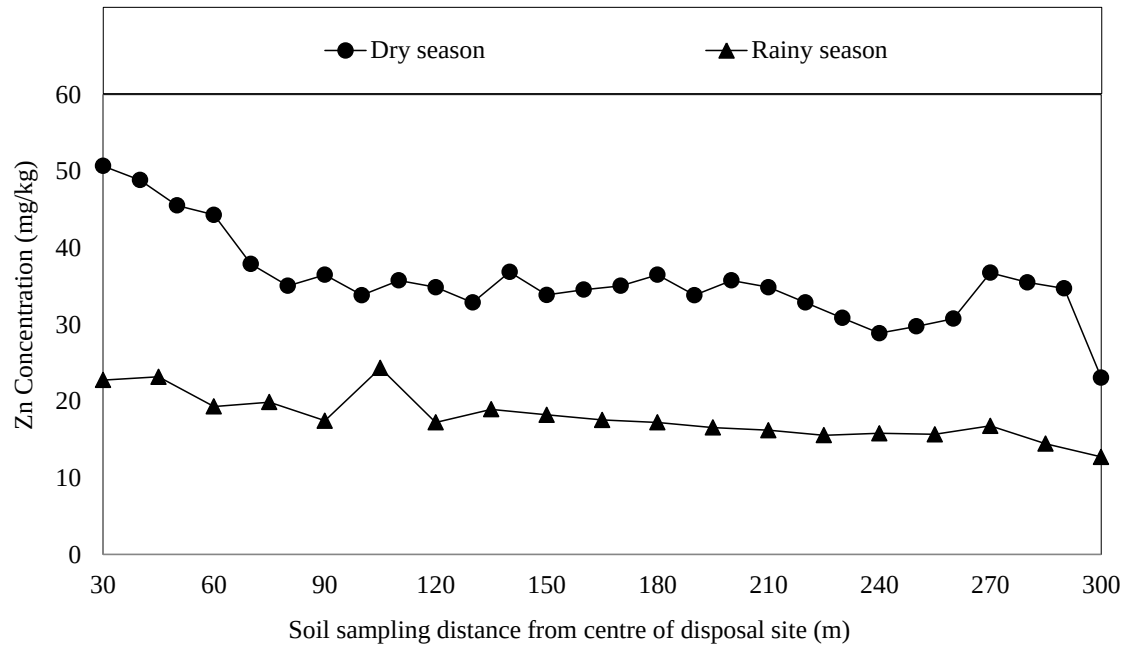


Figure C.2: Spatial and seasonal variation of Zn concentration in soil.

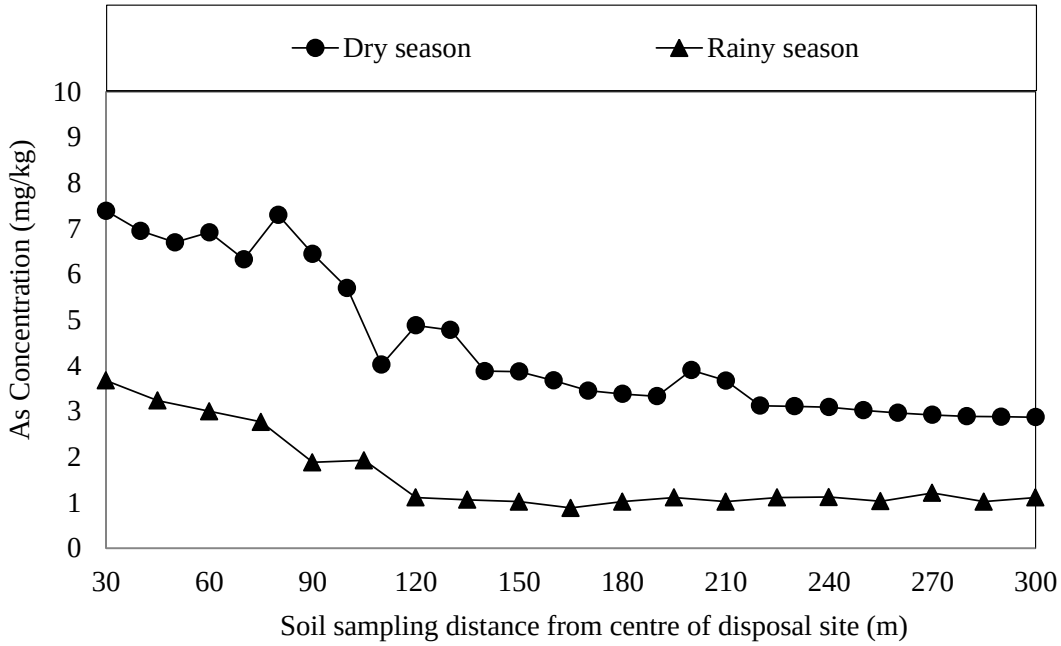


Figure C.3: Spatial and seasonal variation of As concentration in soil.

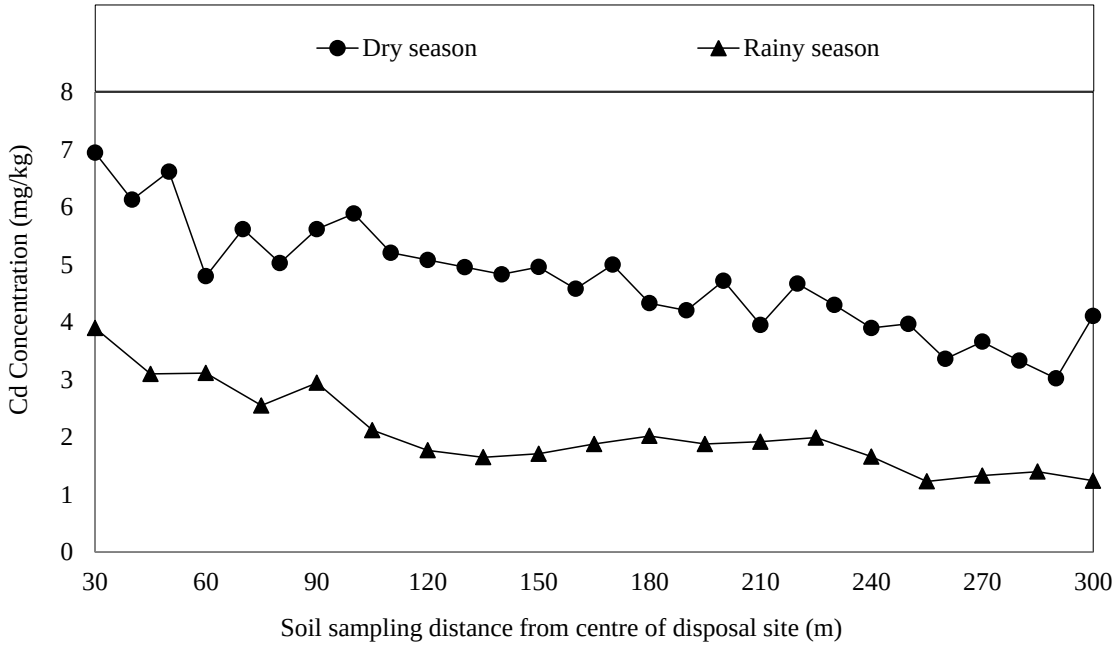


Figure C.4: Spatial and seasonal variation of Cd concentration in soil.

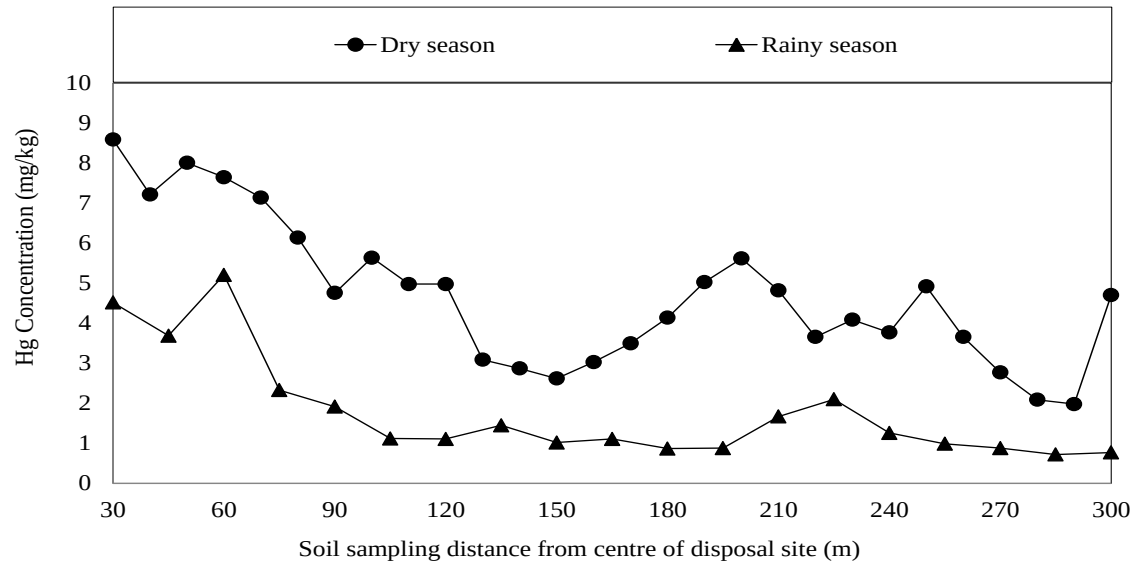


Figure C.5: Spatial and seasonal variation of Hg concentration in soil.

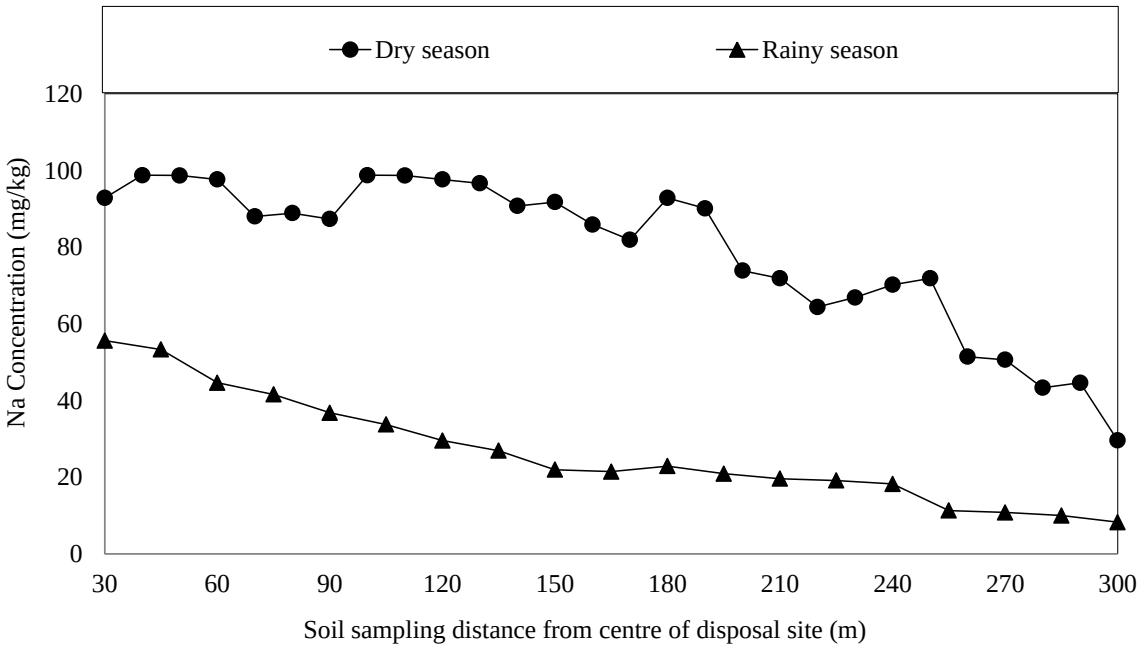


Figure C.6: Spatial and seasonal variation of Na concentration in soil.

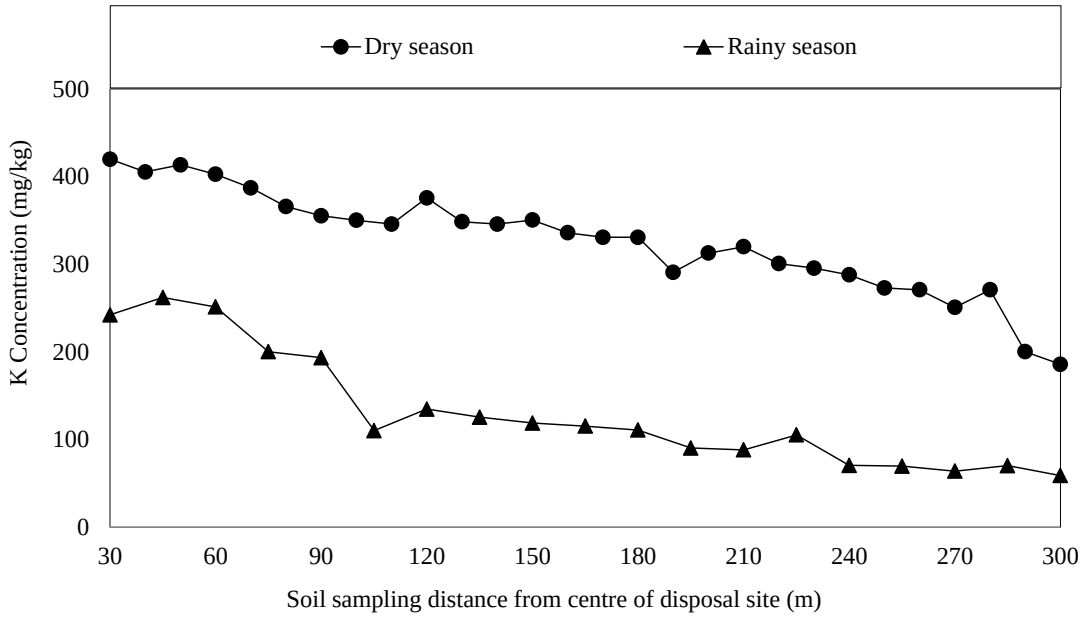


Figure C.7: Spatial and seasonal variation of K concentration in soil.

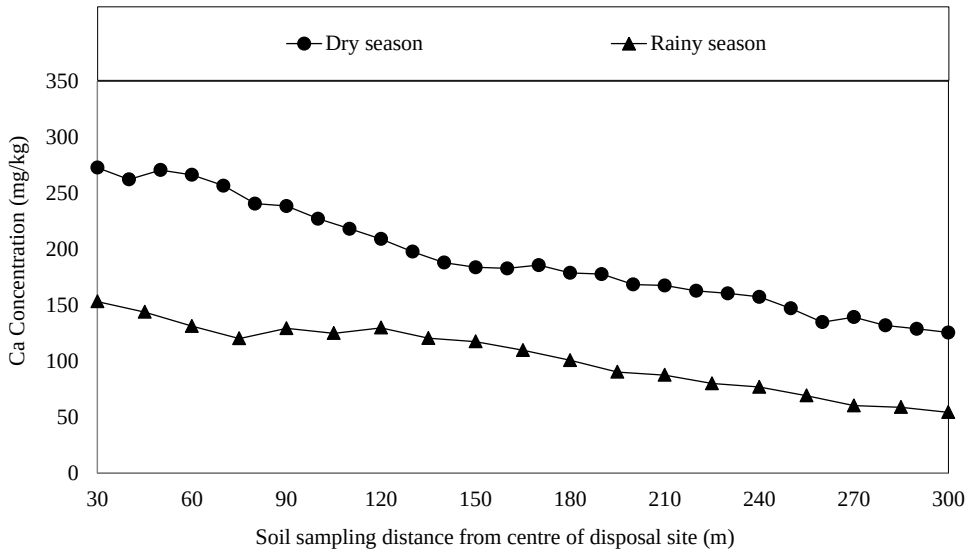


Figure C.8: Spatial and seasonal variation of Ca concentration in soil.

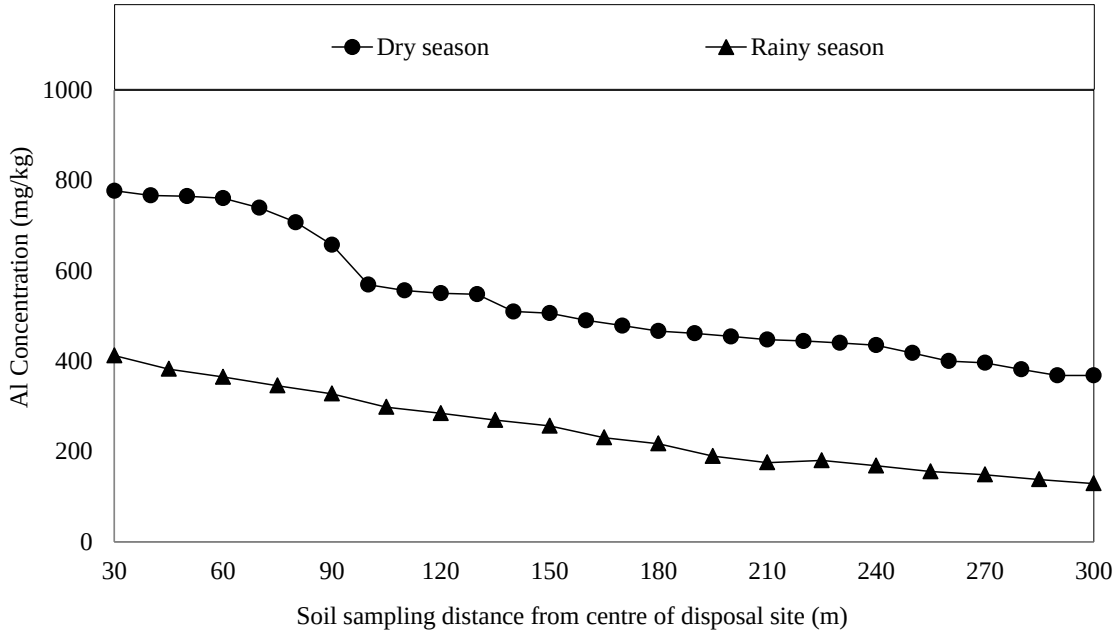


Figure C.9: Spatial and seasonal variation of Al concentration in soil.

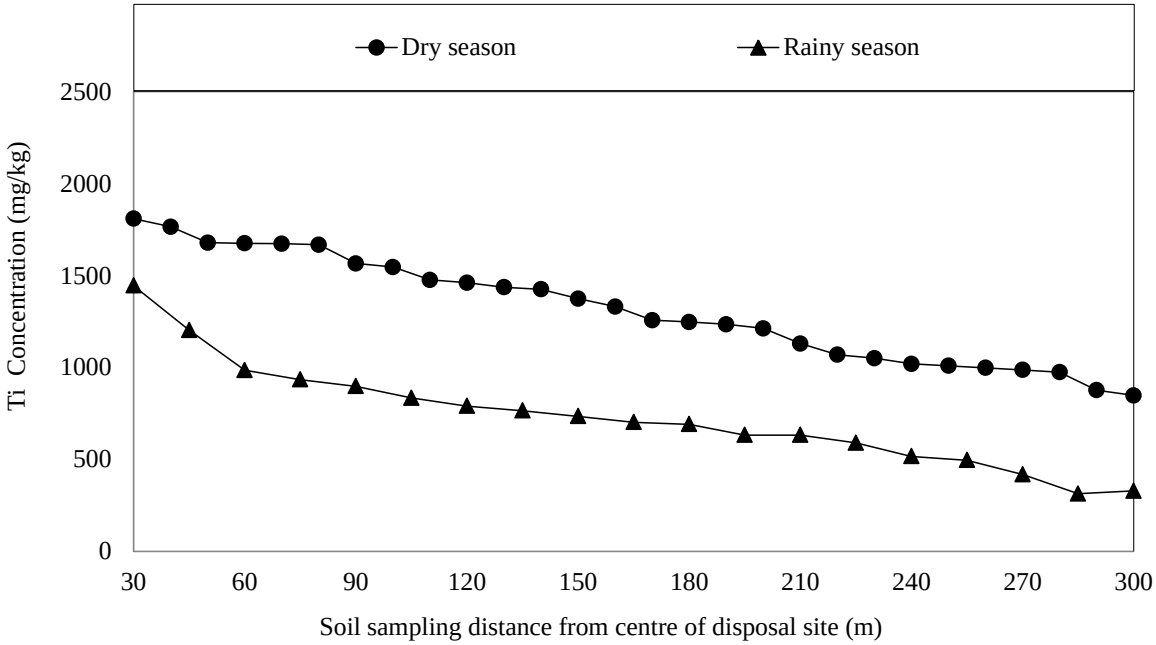


Figure C.10: Spatial and seasonal variation of Ti concentration in soil.

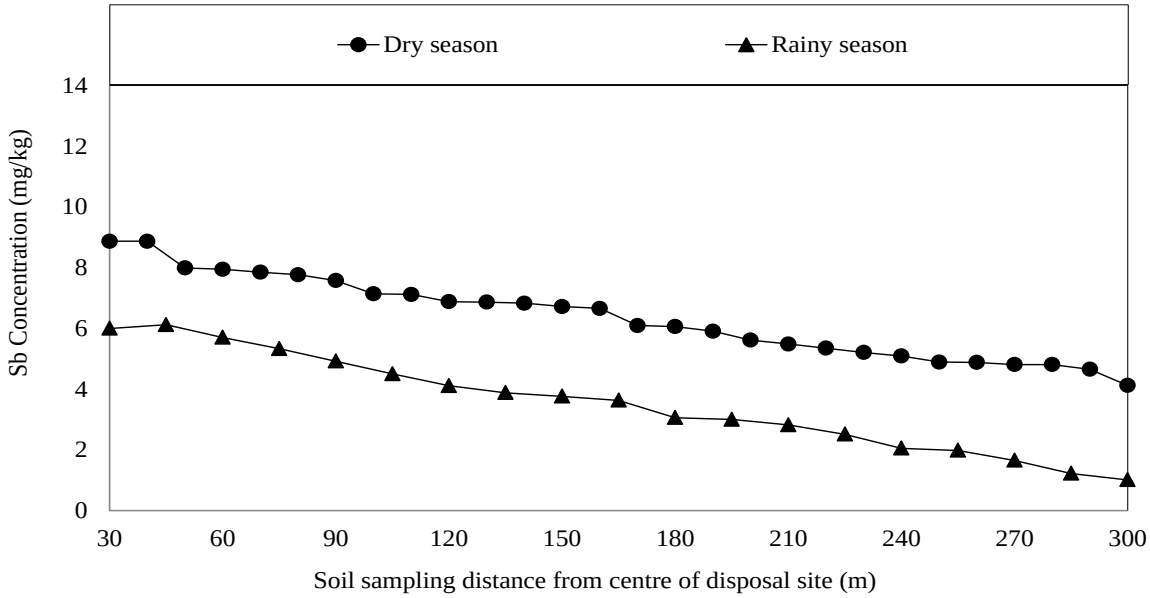


Figure C.11: Spatial and seasonal variation of Sb concentration in soil.

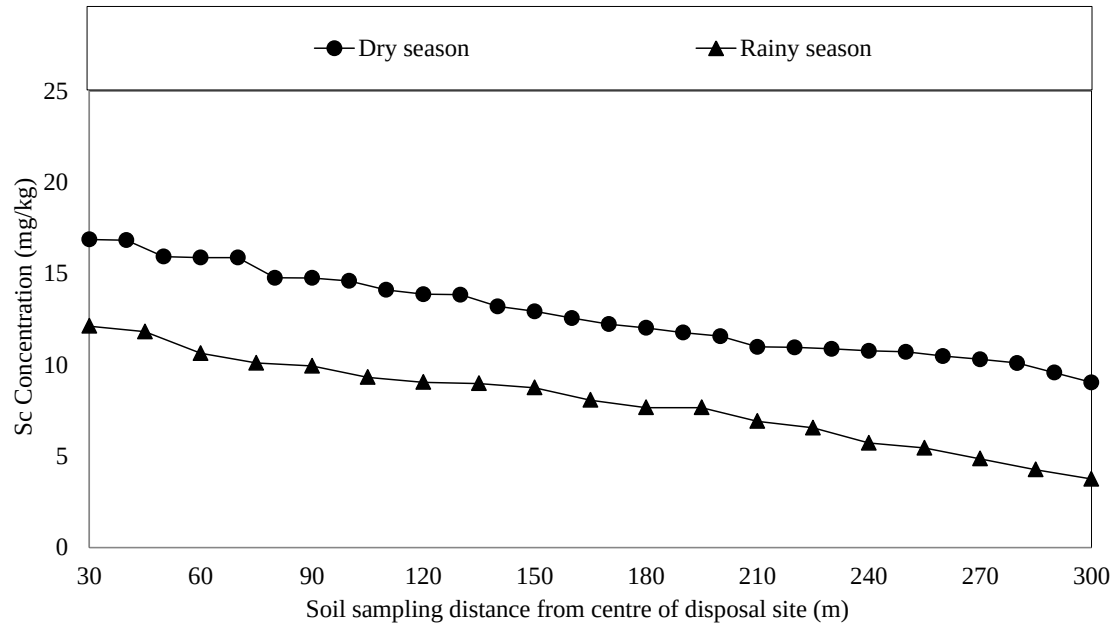


Figure C.12: Spatial and seasonal variation of Sc concentration in soil.

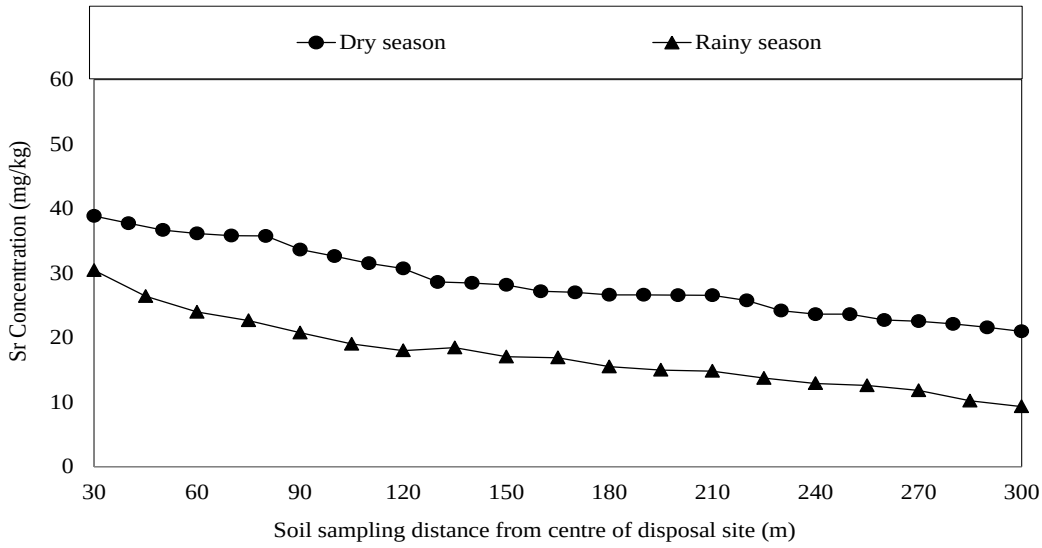


Figure C.13: Spatial and seasonal variation of Sr concentration in soil.

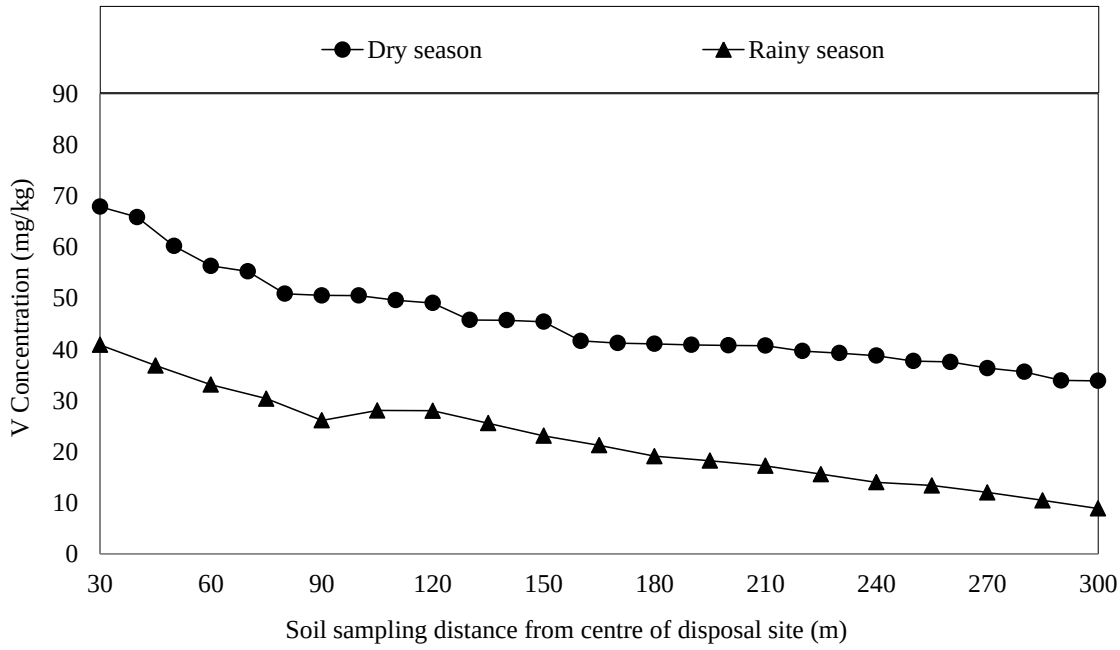


Figure C.14: Spatial and seasonal variation of V concentration in soil.

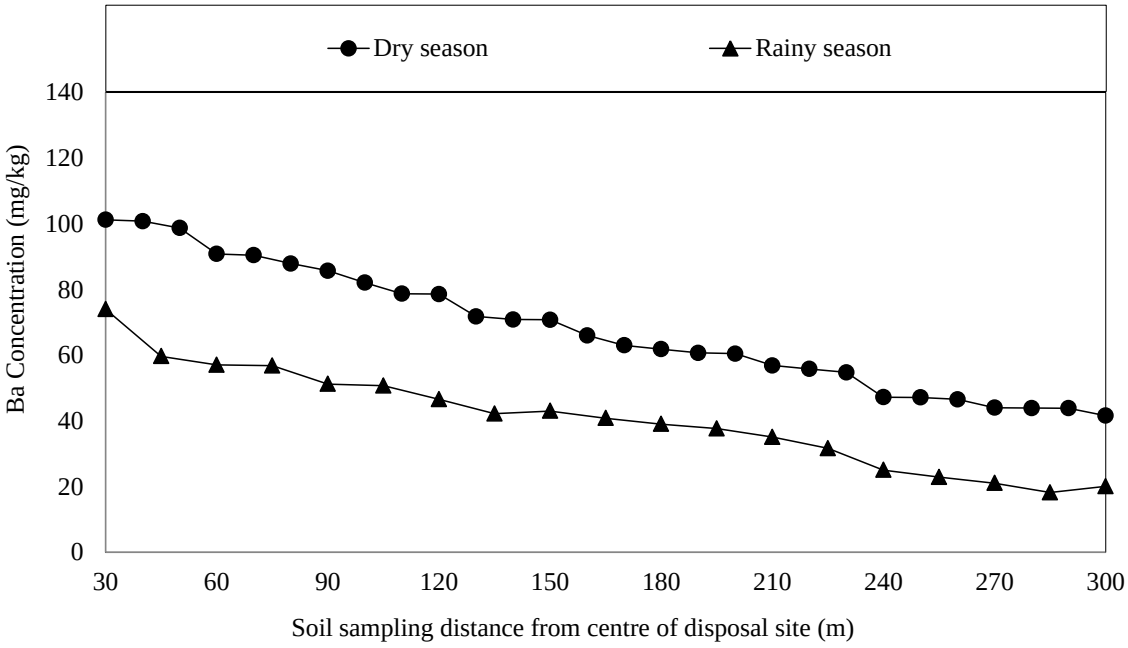


Figure C.15: Spatial and seasonal variation of Ba concentration in soil.

Annex-D

Spatial Distribution of Concentration for Different Metal Elements in Soil of Waste Disposal Site

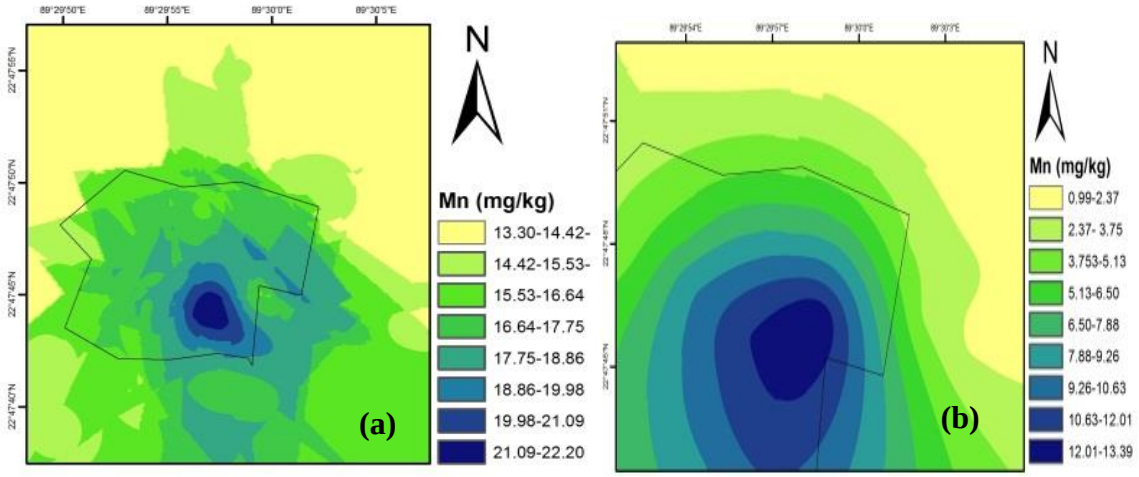


Figure D.1: Spatial distribution of Mn concentration in soil for (a) dry and (b) rainy season.

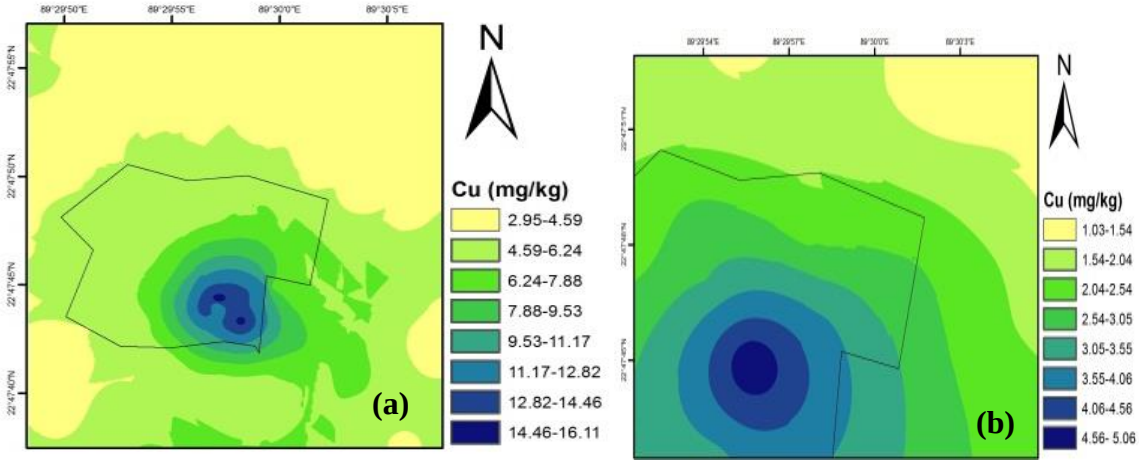


Figure D.2: Spatial distribution of Cu concentration in soil for (a) dry and (b) rainy season.

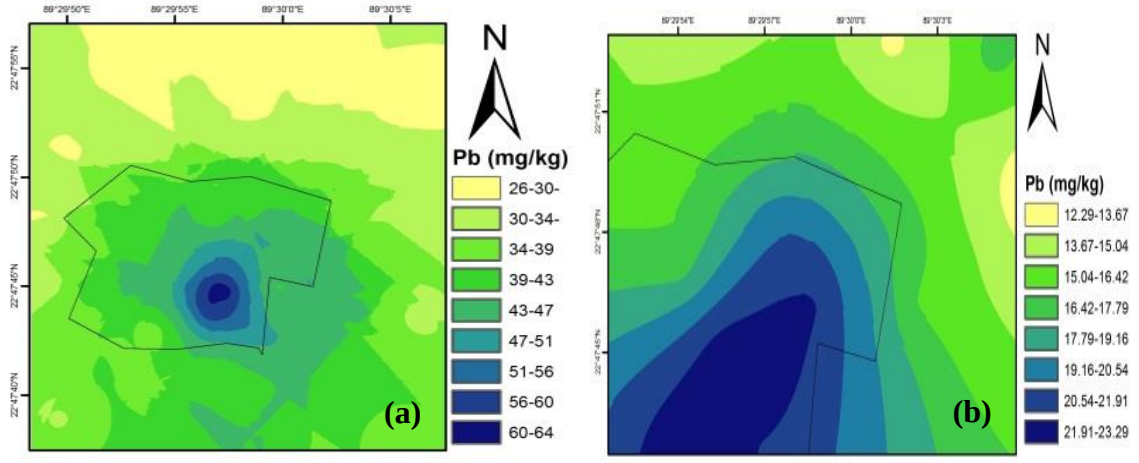


Figure D.3: Spatial distribution of Pb concentration in soil for (a) dry and (b) rainy season.

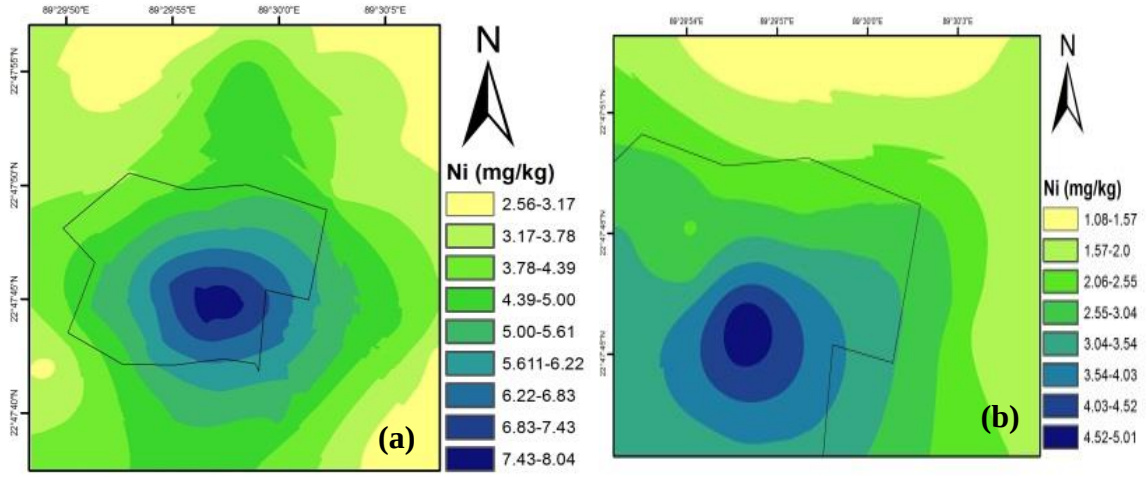


Figure D.4: Spatial distribution of Ni concentration in soil for (a) dry and (b) rainy season.

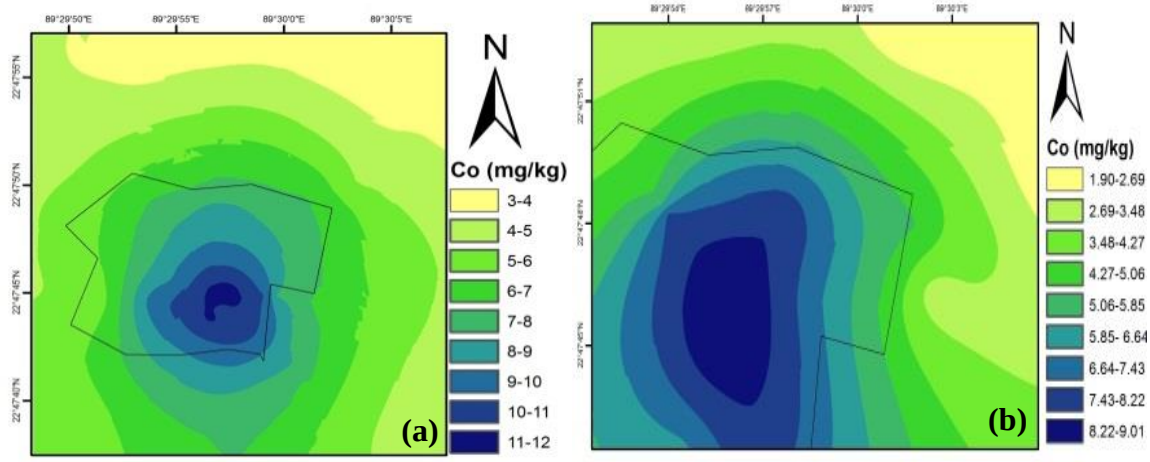


Figure D.5: Spatial distribution of Co concentration in soil for (a) dry and (b) rainy season.

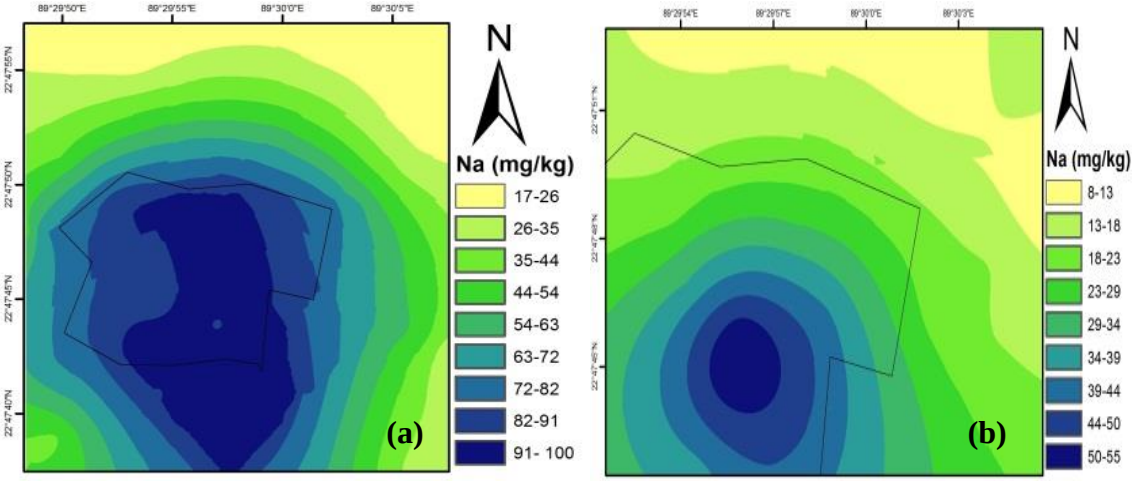


Figure D.6: Spatial distribution of Na concentration in soil for (a) dry and (b) rainy season.

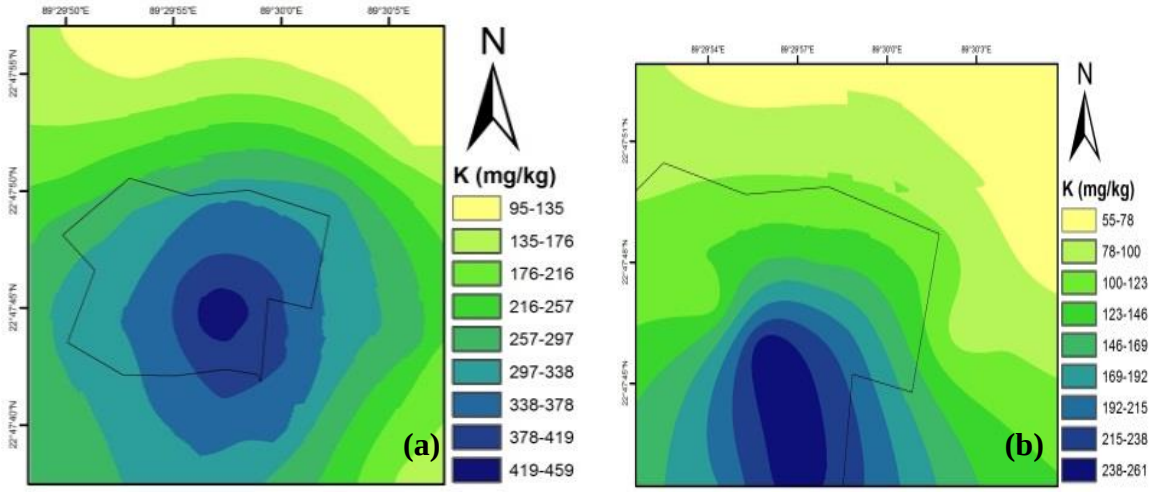


Figure D.7: Spatial distribution of K concentration in soil for (a) dry and (b) rainy season.

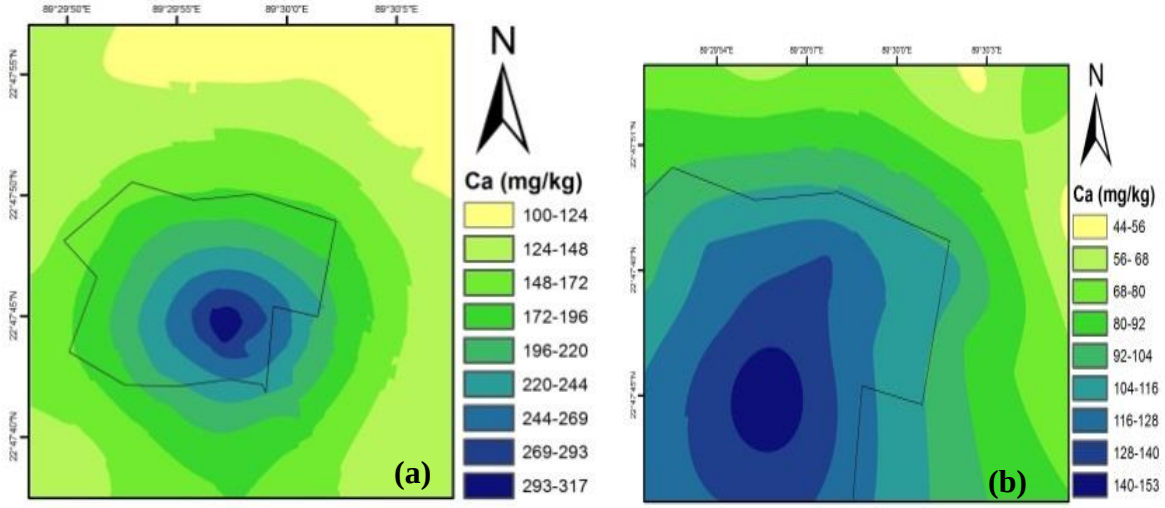


Figure D.8: Spatial distribution of Ca concentration in soil for (a) dry and (b) rainy season.

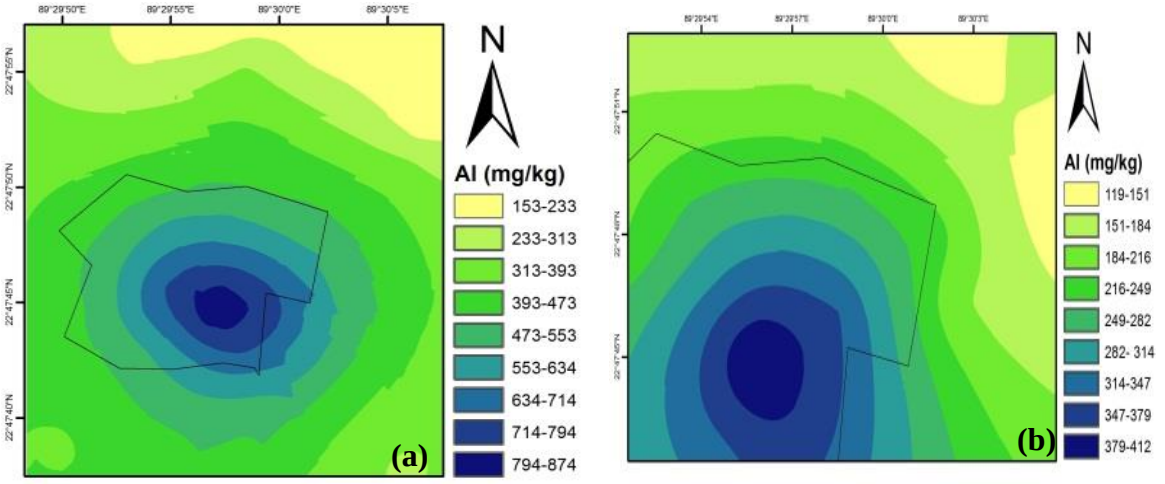


Figure D.9: Spatial distribution of Al concentration in soil for (a) dry and (b) rainy season.

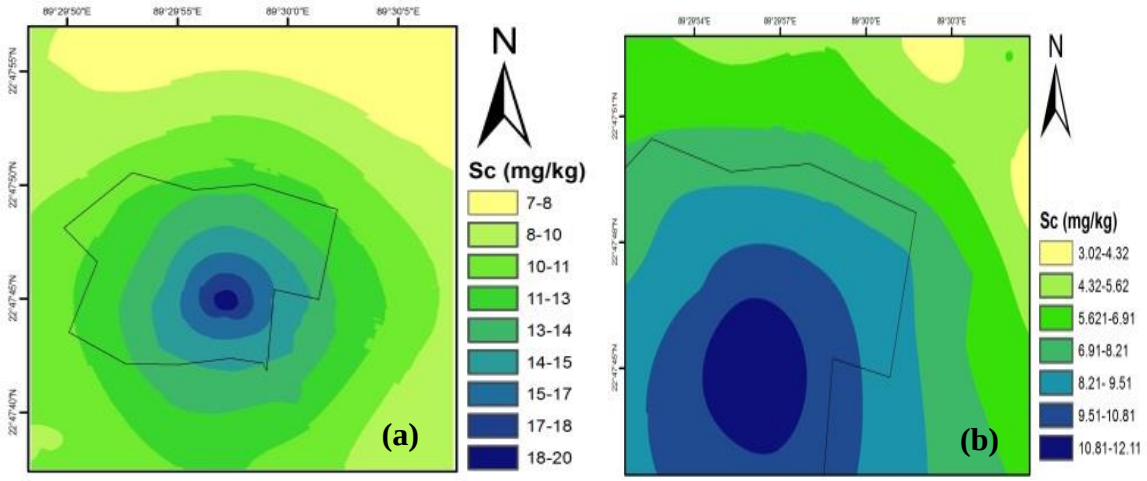


Figure D.10: Spatial distribution of Sc concentration in soil for (a) dry and (b) rainy season.

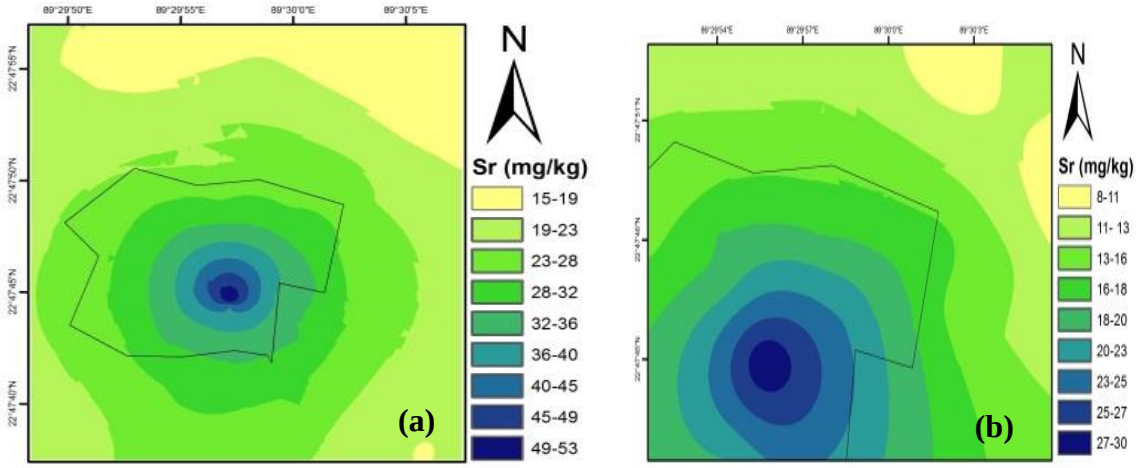


Figure D.11: Spatial distribution of Sr concentration in soil for (a) dry and (b) rainy season.

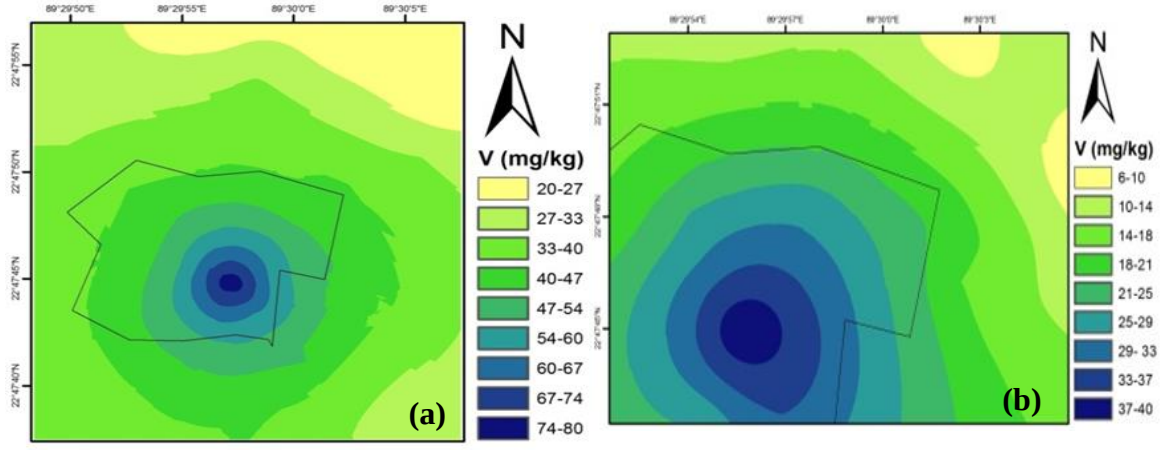


Figure D.12: Spatial distribution of V concentration in soil for (a) dry and (b) rainy season.

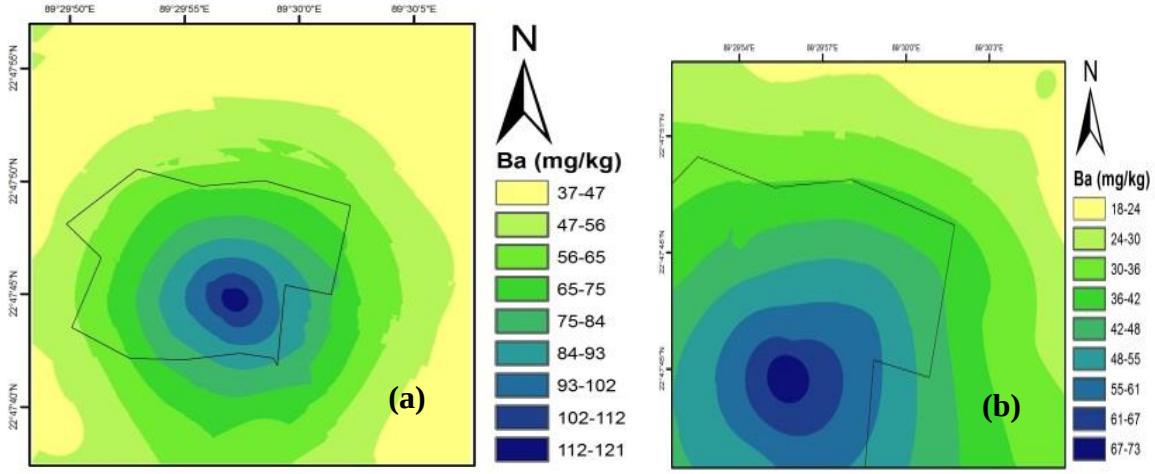


Figure D.13: Spatial distribution of Ba concentration in soil for (a) dry and (b) rainy season.

Annex-E

Spatial Distribution of Contamination Factor (CF) for Metal Elements in Soil

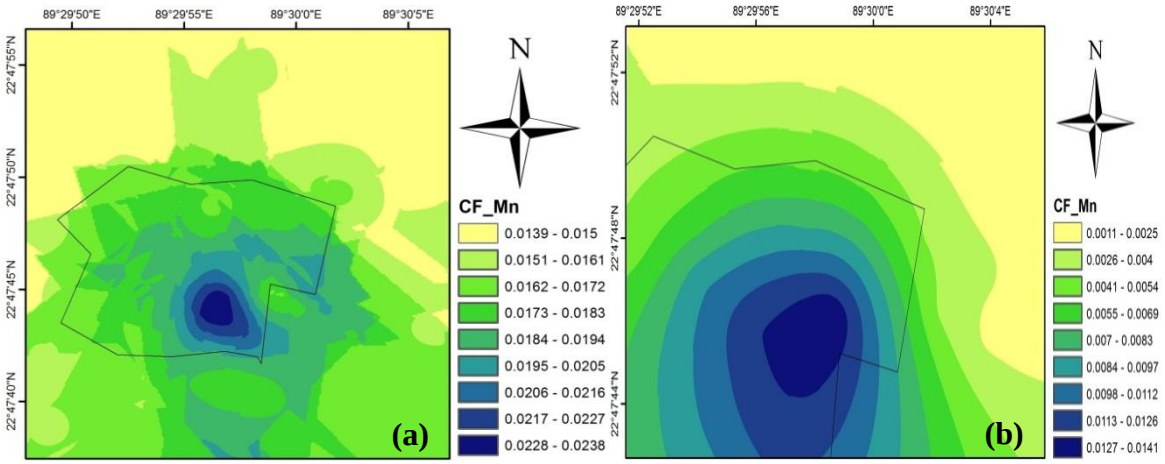


Figure E.1: Spatial distribution of CF of Mn in (a) dry season and (b) rainy season

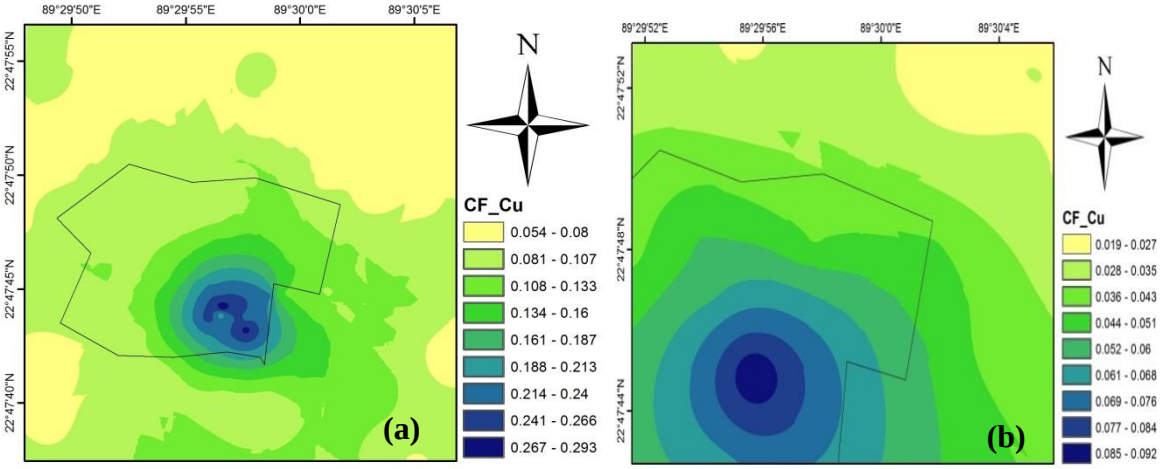


Figure E.2: Spatial distribution of CF of Cu in (a) dry season and (b) rainy season

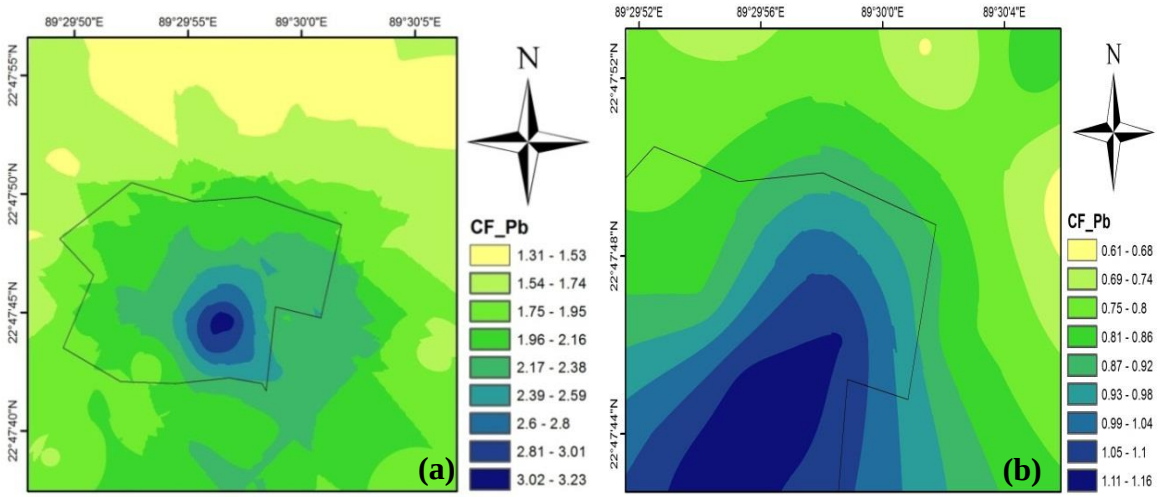


Figure E.3: Spatial distribution of CF of Pb in (a) dry season and (b) rainy season

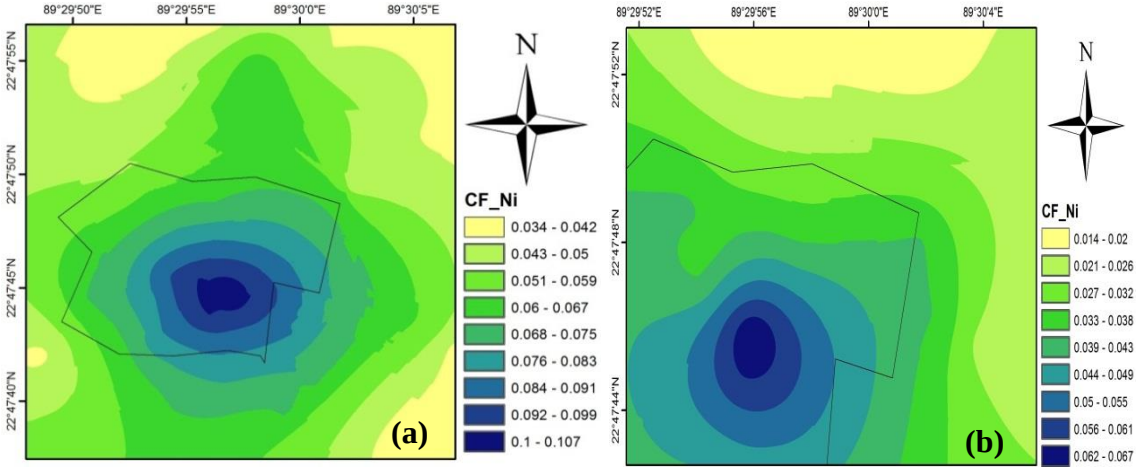


Figure E.4: Spatial distribution of CF of Ni in (a) dry season and (b) rainy season

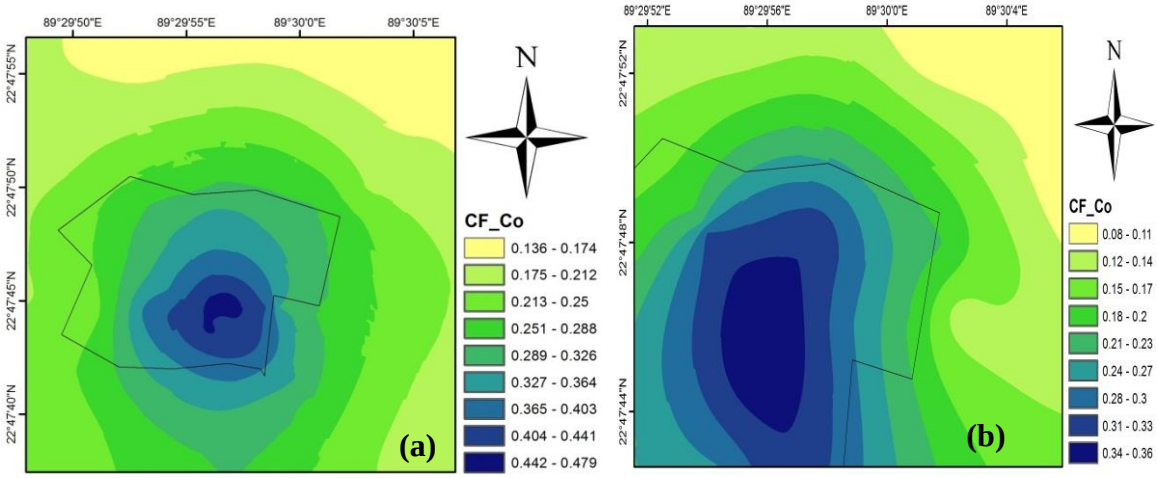


Figure E.5: Spatial distribution of CF of Co in (a) dry season and (b) rainy season

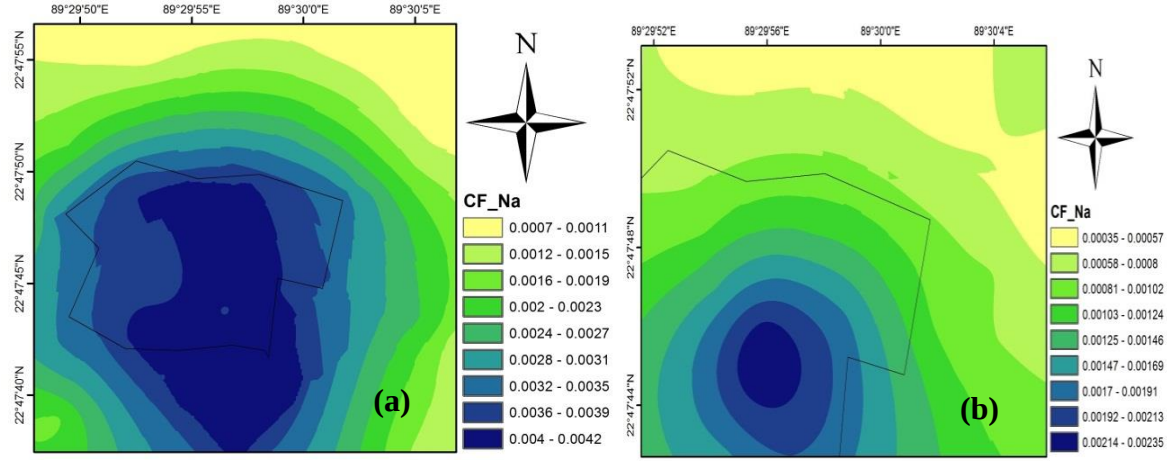


Figure E.6: Spatial distribution of CF of Na in (a) dry season and (b) rainy season

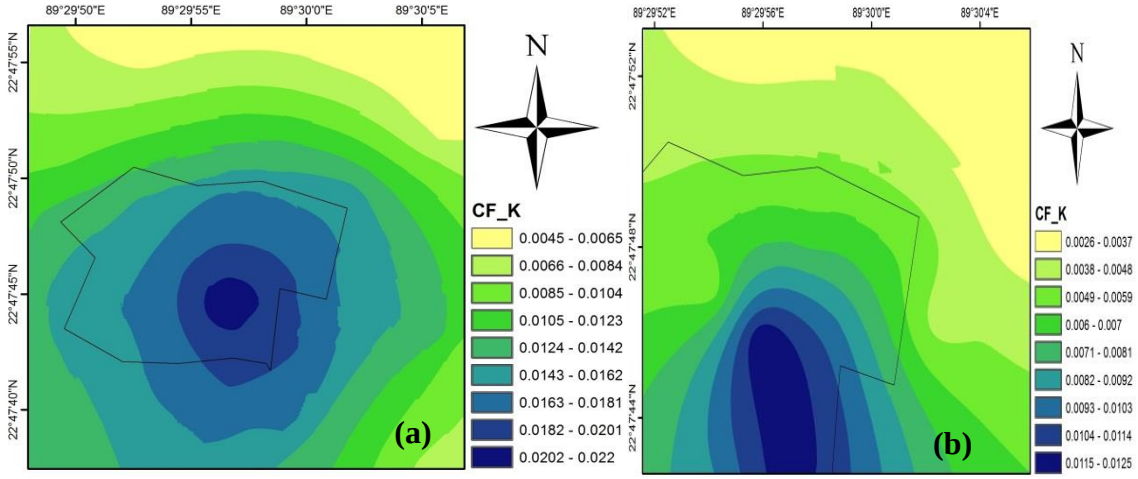


Figure E.7: Spatial distribution of CF of K in (a) dry season and (b) rainy season

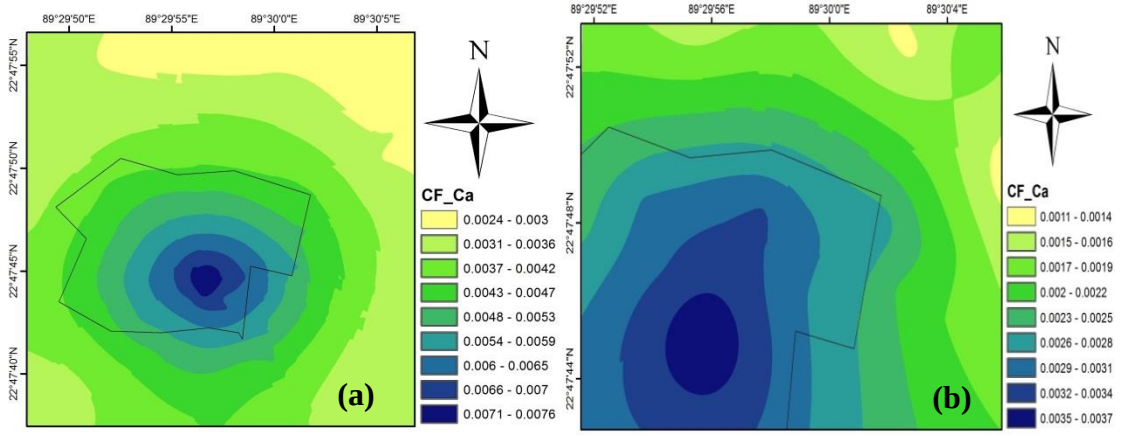


Figure E.8: Spatial distribution of CF of Ca in (a) dry season and (b) rainy season

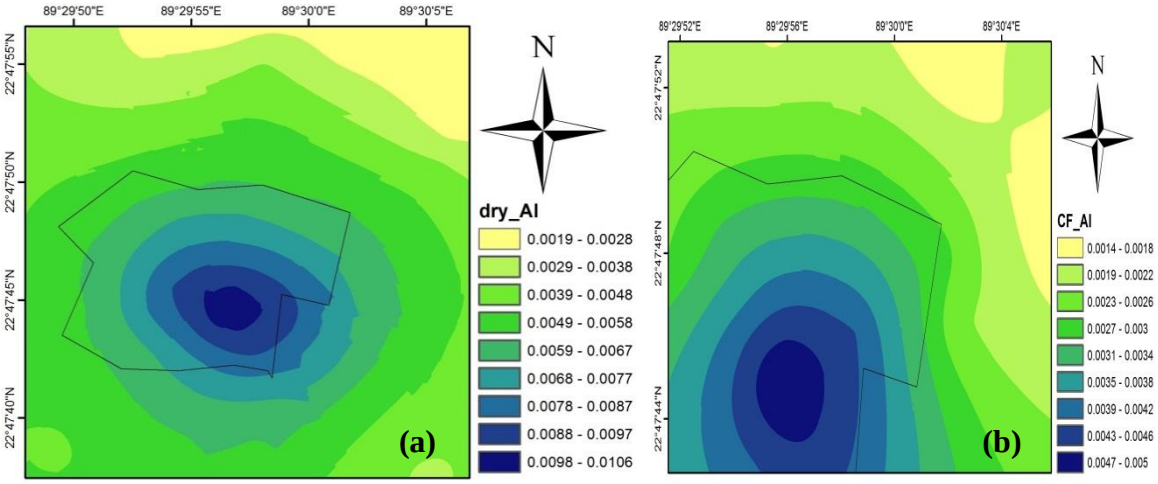


Figure E.9: Spatial distribution of CF of Al in (a) dry season and (b) rainy season

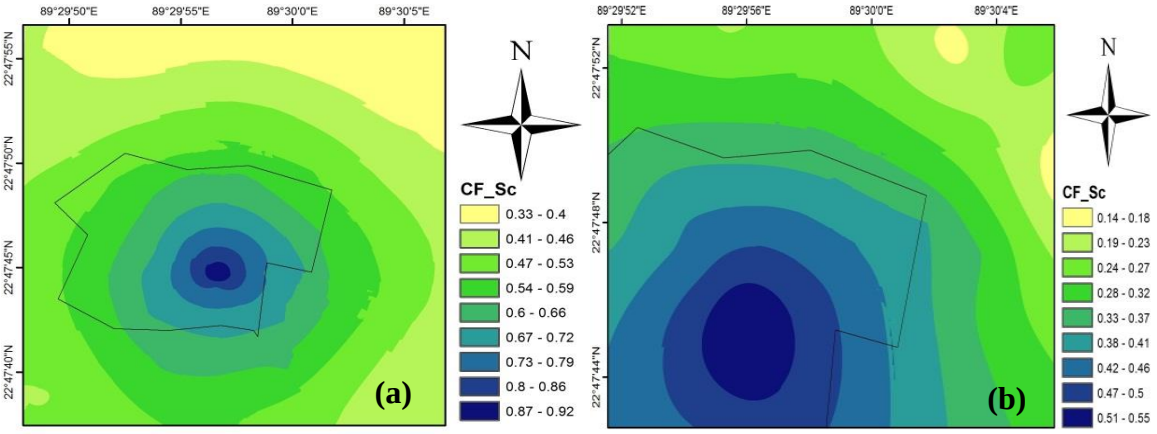


Figure E.10: Spatial distribution of CF of Sc in (a) dry season and (b) rainy season

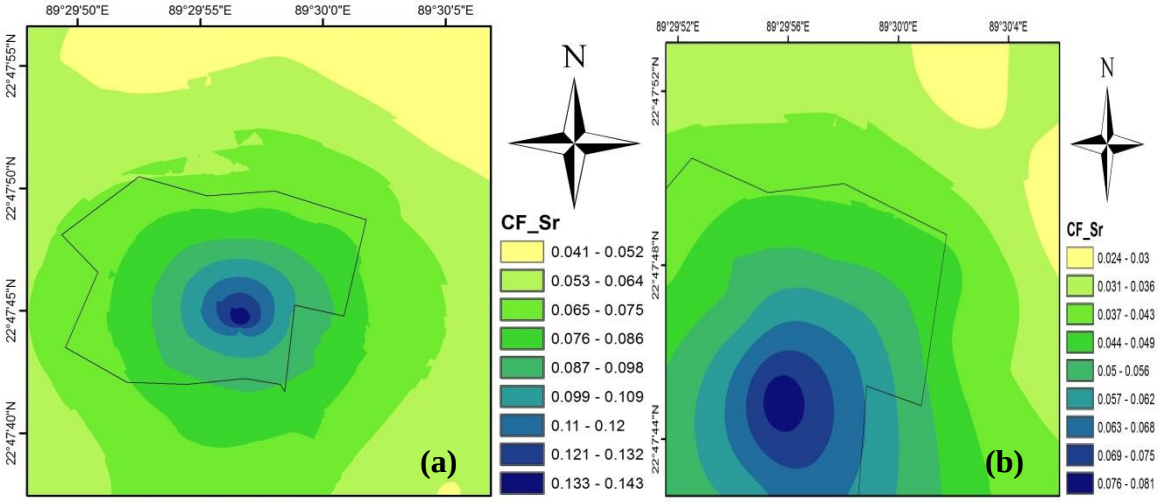


Figure E.11: Spatial distribution of CF of Sr in (a) dry season and (b) rainy season

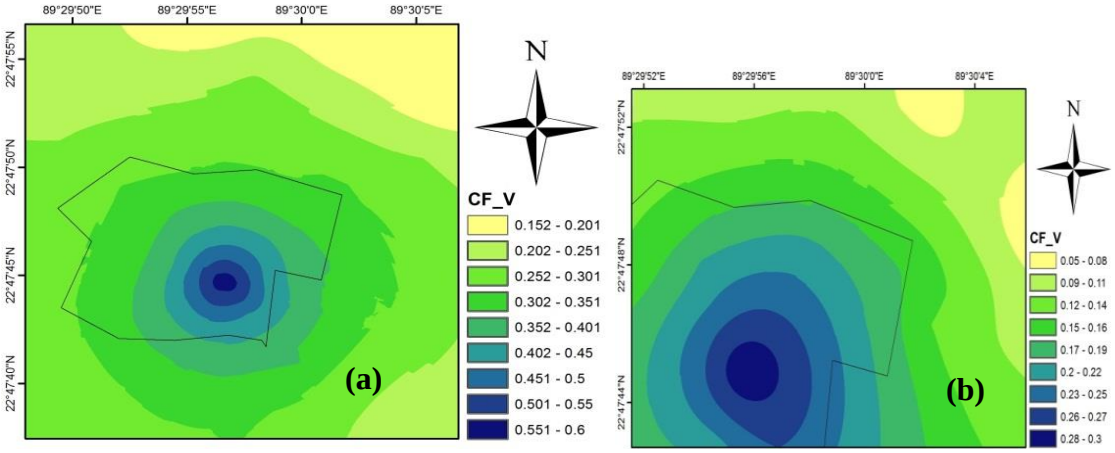


Figure E.12: Spatial distribution of CF of V in (a) dry season and (b) rainy season

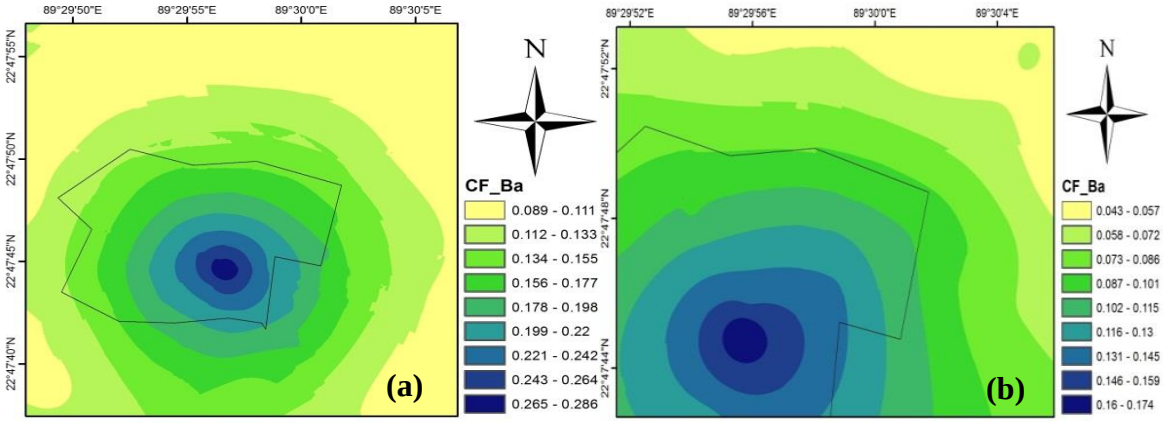


Figure E.13: Spatial distribution of CF of Ba in (a) dry season and (b) rainy season

Annex-F

Spatial Distribution of Enrichment Factor (EF) for Metal Elements in Soil

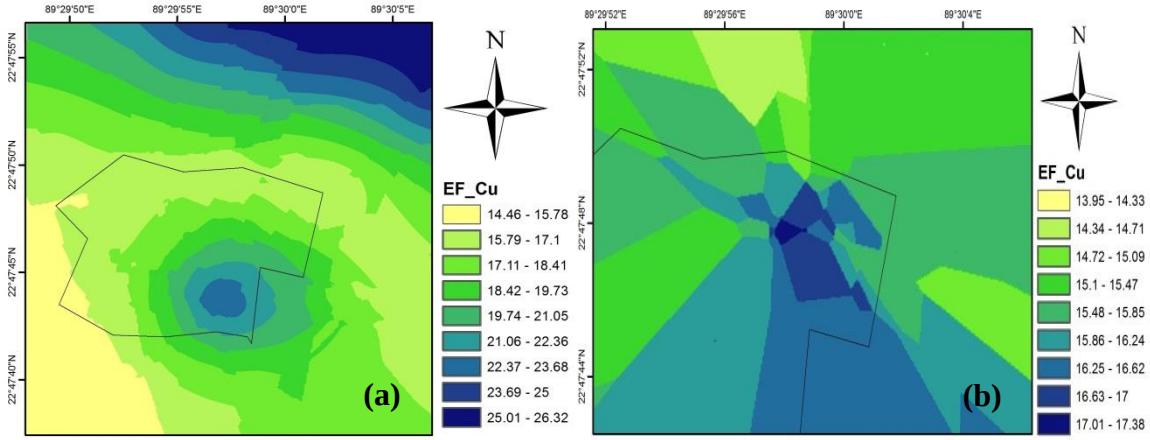


Figure F.1: Spatial distribution of EF for Cu during (a) dry season and (b) rainy season

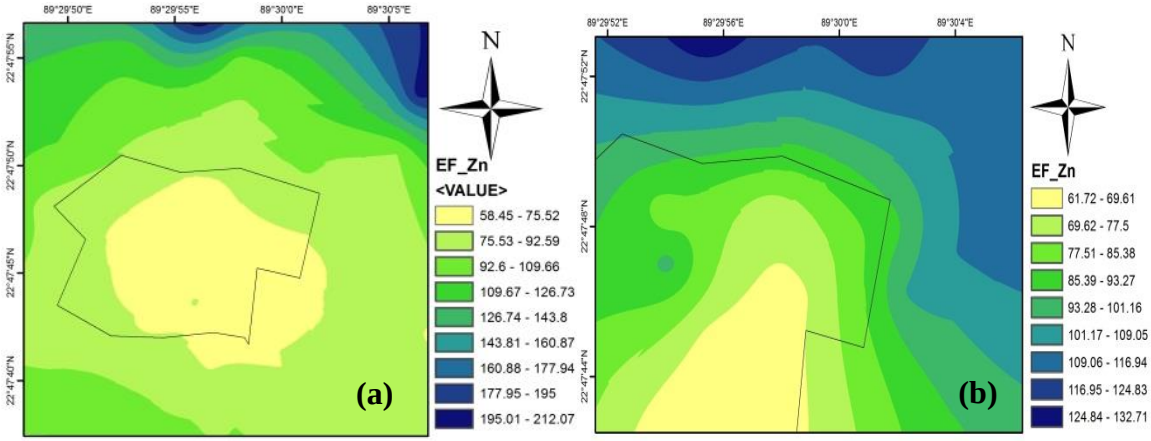


Figure F.2: Spatial distribution of EF for Zn during (a) dry season and (b) rainy season

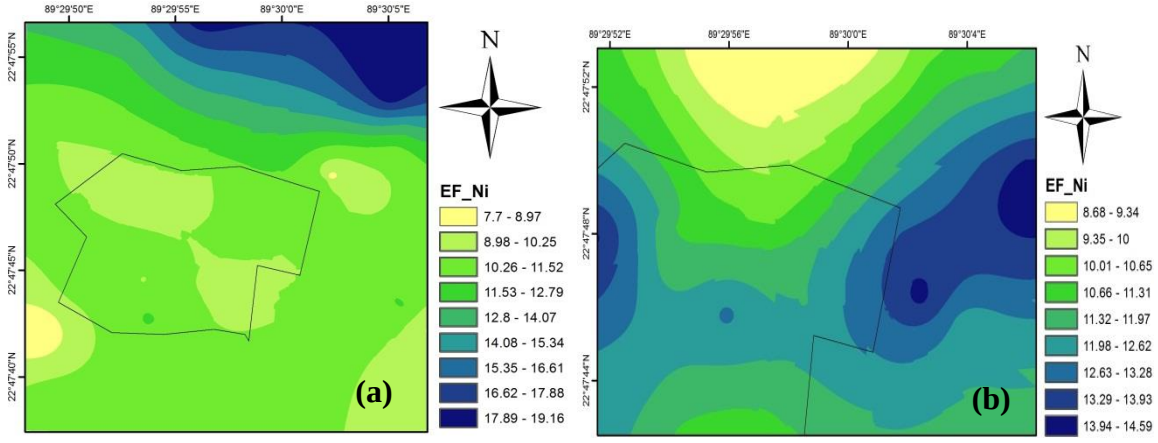


Figure F.3: Spatial distribution of EF for Ni during (a) dry season and (b) rainy season

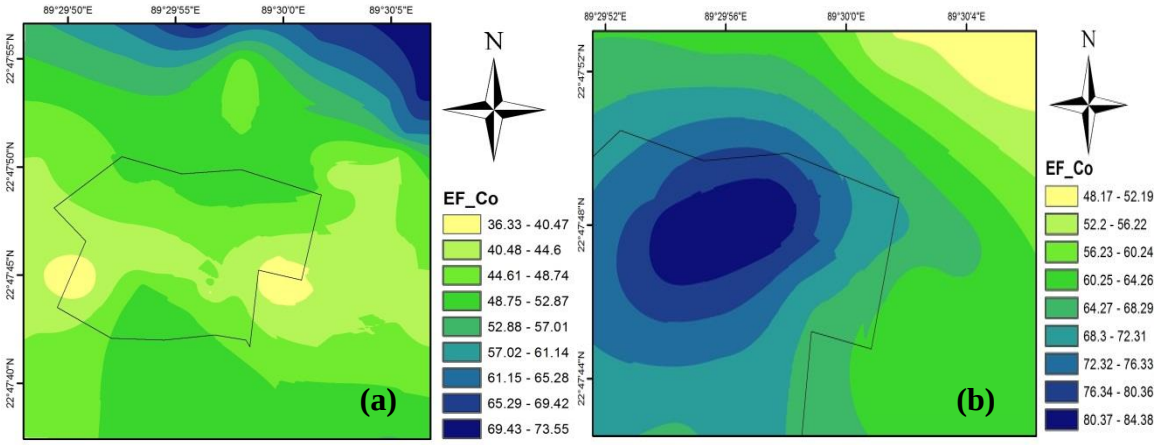


Figure F.4: Spatial distribution of EF for Co during (a) dry season and (b) rainy season

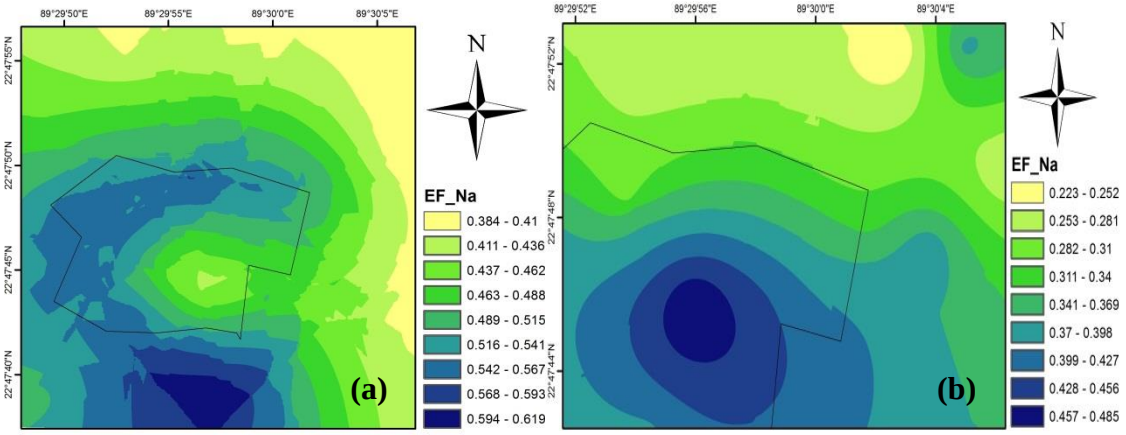


Figure F.5: Spatial distribution of EF for Na during (a) dry season and (b) rainy season

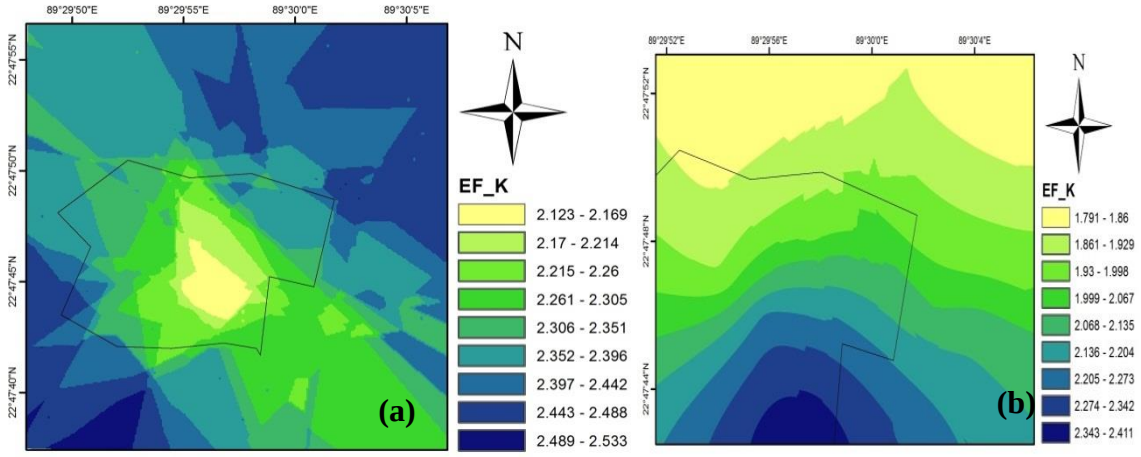


Figure F.6: Spatial distribution of EF for K during (a) dry season and (b) rainy season

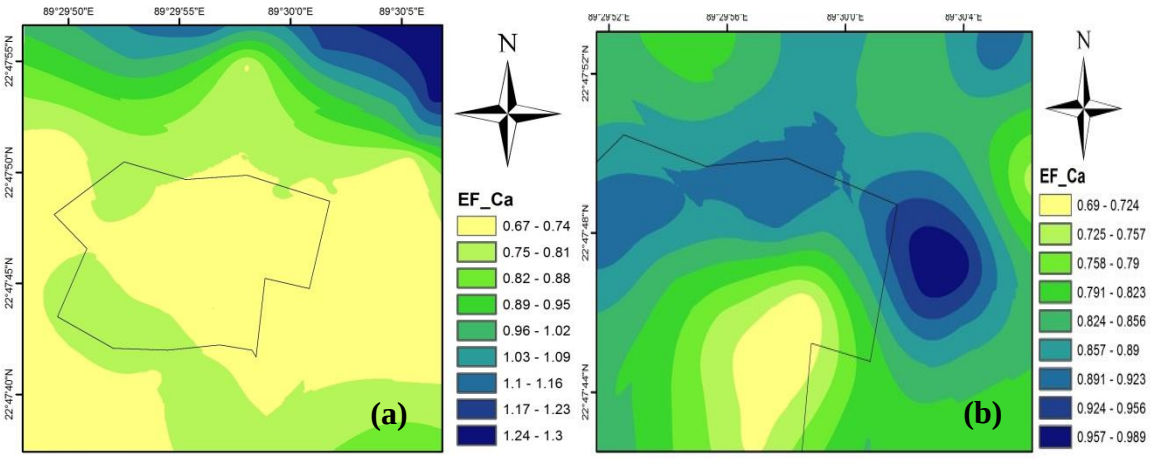


Figure F.7: Spatial distribution of EF for Ca during (a) dry season and (b) rainy season

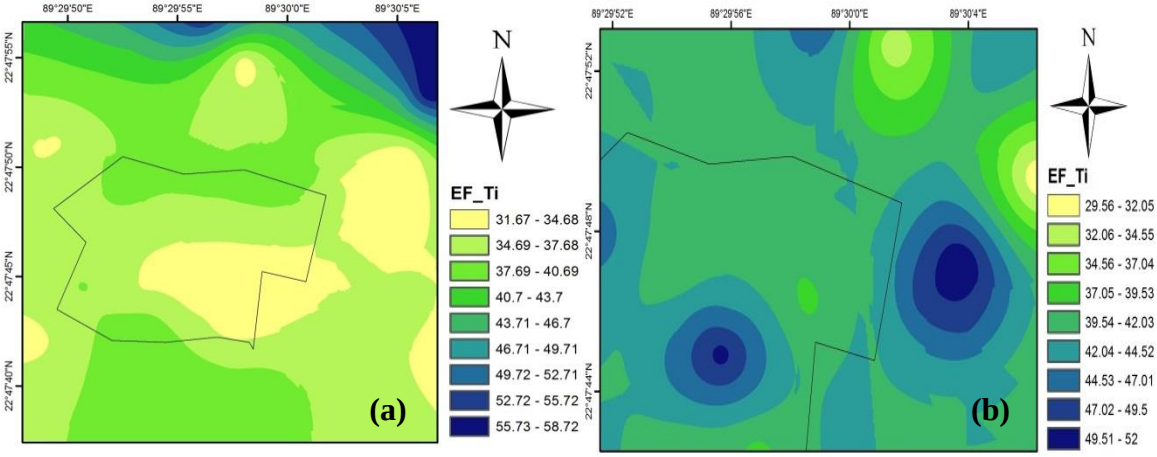


Figure F.8: Spatial distribution of EF for Ti during (a) dry season and (b) rainy season

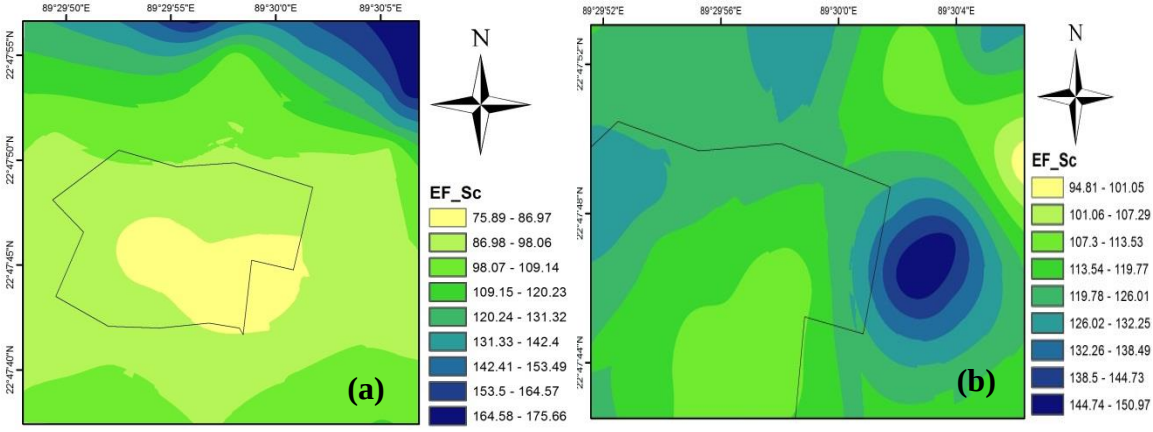


Figure F.9: Spatial distribution of EF for Sc during (a) dry season and (b) rainy season

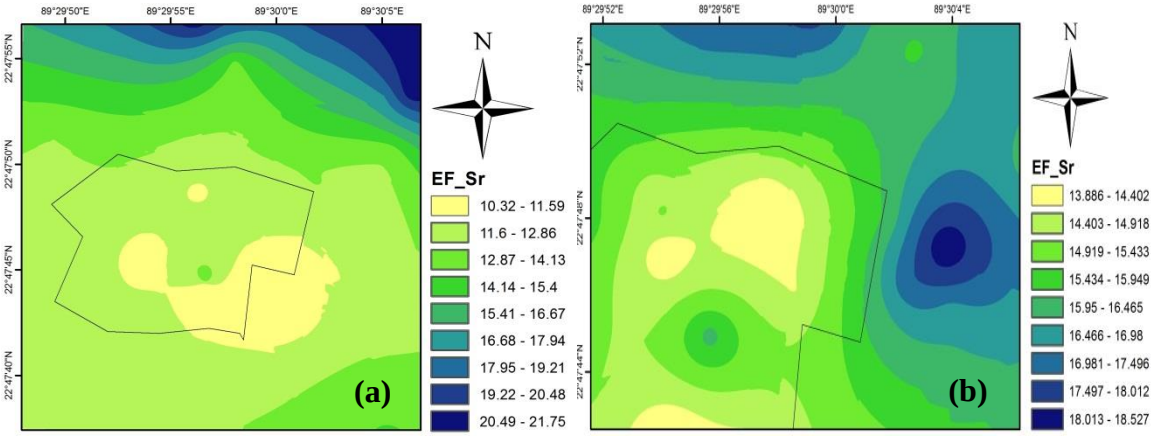


Figure F.10: Spatial distribution of EF for Sr during (a) dry season and (b) rainy season

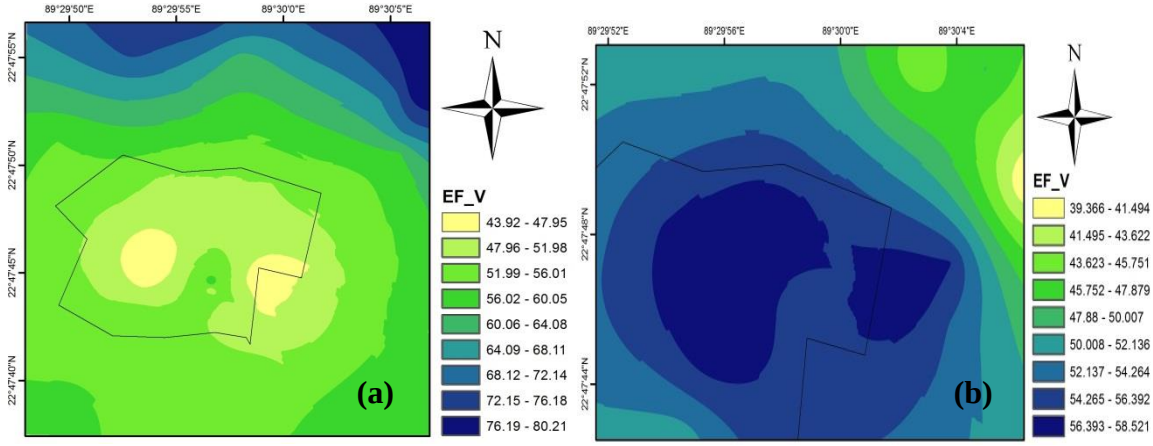


Figure F.11: Spatial distribution of EF for V during (a) dry season and (b) rainy season

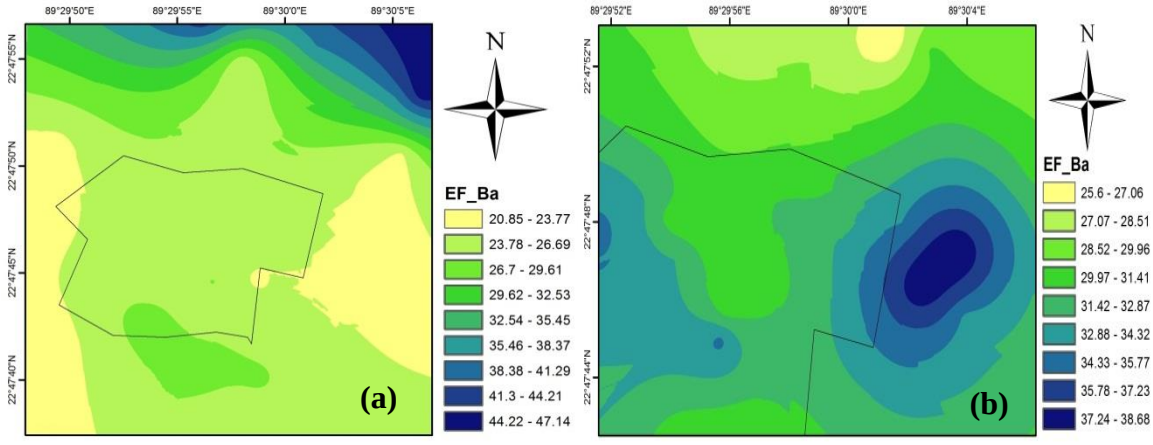


Figure F.12: Spatial distribution of EF for Ba during (a) dry season and (b) rainy season

Annex-G

Results of principal component analysis for Metal Elements in soil for Rainy Season

Table G.1: Eigenvalue of PCA analysis for metal variables in rainy season

PCs	Eigenvalue	Variability (%)	Cumulative %
F1	18.533	88.251	88.251
F2	0.906	4.317	92.568
F3	0.399	1.898	94.466
F4	0.334	1.592	96.058
F5	0.263	1.251	97.309
F6	0.180	0.859	98.168
F7	0.151	0.719	98.887
F8	0.080	0.383	99.269
F9	0.054	0.260	99.529
F10	0.043	0.207	99.736
F11	0.016	0.077	99.812
F12	0.015	0.074	99.886
F13	0.009	0.045	99.931
F14	0.007	0.032	99.963
F15	0.003	0.017	99.980
F16	0.003	0.012	99.992
F17	0.001	0.005	99.996
F18	0.001	0.003	99.999
F19	0.000	0.001	100.000

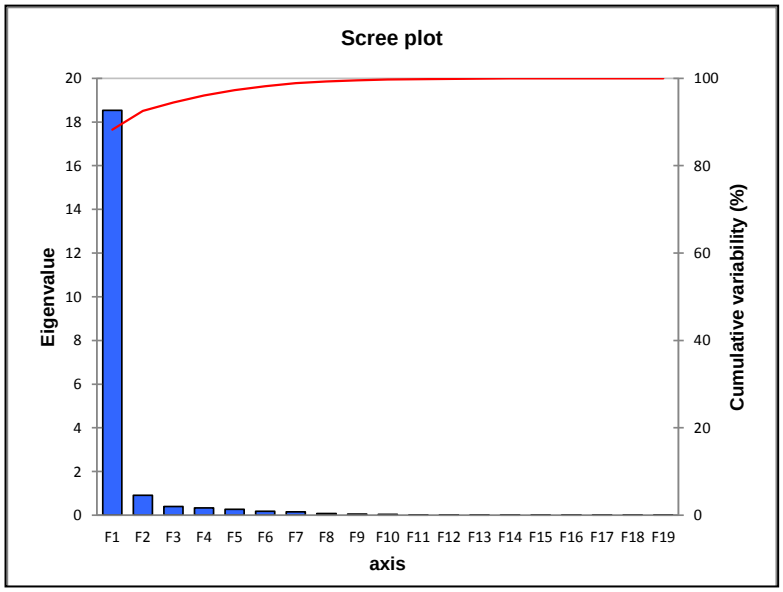


Figure G.1: Scree plot of the PCA analysis for metal variables in rainy season.

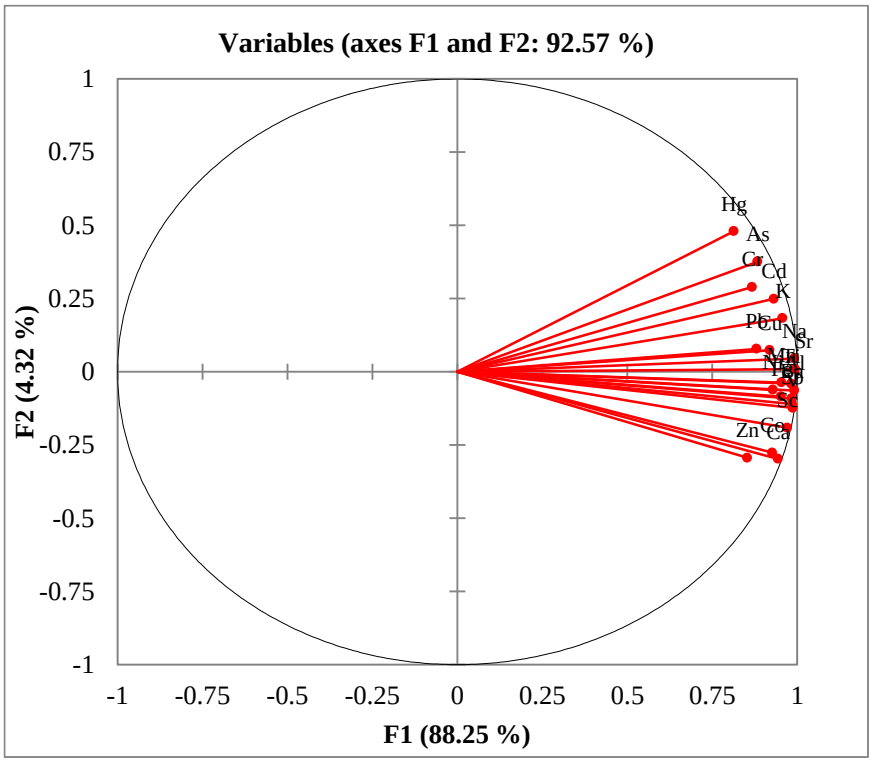


Figure G.2: correlation circle (axis F1-F2 plan) for different sampling points in rainy season.

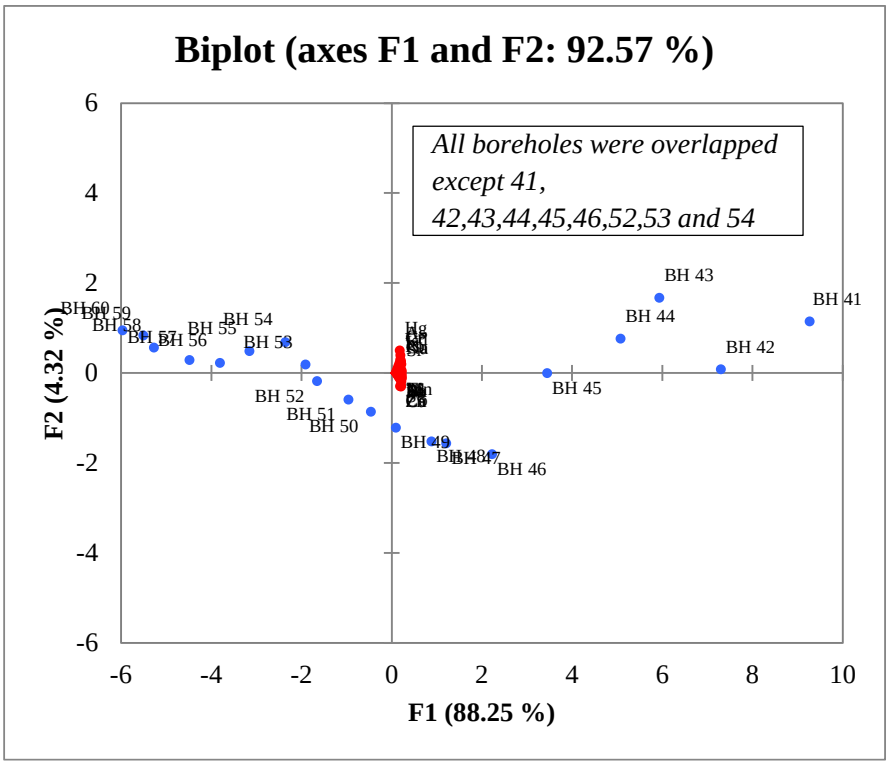


Figure G.3: Biplots of sampling points on the factorial plane in rainy season.