CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Environmental pollution and management problems are among the major challenges facing many developing countries of the world. These problems often emanate from both natural and anthropogenic sources. Natural sources may result from the host rocks (depending on the geology of the area), volcanic activities, and chemical evolution of hydrochemical facies, while anthropogenic sources often emanate from the challenges of waste disposal linked to human activities, including urbanization, industrialization, mining, municipal and domestic activities, among others (Nnabo *et al*., 2011; Obasi and Akudinobi, 2015). Lead – zinc mineralization and mining in Abakaliki area increases the potential for environmental pollution. Ebonyi River, which drains the entire area transverses the lead – zinc fields, thus increasing the ease of pollutant and contaminant transport in the aqueous medium. This river, with its numerous tributaries, constitutes a major source of water supply for rural dwellers.

The study area consists of Enyigba, Mkpuma Akpatakpa, Ameka, Amorie, Amanchara, Agbaja and Alibaruhu where active and abandoned mines are located. These areas are rural communities endowed with lead- zinc mineralization which occurs as lodes and veins traversing the area. This mineralization has led to indiscriminate and illegal mining which has resulted in random citing of excavations and waste dumps, and unplanned disposal of mine wastes. All these affect the hydrogeochemistry of the area. Ezeh and Nnabo, (2006); Ezeh *et al*., (2009); Nnabo *et al*., (2009); Nnabo *et al*., (2011); Obarezi and Nwosu, (2013); Okogbue and Ukpai, (2013); Oti and Nwabue, (2013); Obasi *et al*., (2015); Obasi and Akudinobi,

(2015) and Obiorah *et al*., (2016) have done some work in some parts of the study area. These works point to the fact that the mining activities have an effect on the soils, water resources and arable crops of the area. The inhabitants being villagers do not consider the dangers which these mining activities poses to their health and the environment as most of them fetch their water for drinking and other domestic uses directly from the mine ponds (Plates 1.3, 1.5 and 1.6). This is because most of these communities do not have access to portable water supply. In few places where boreholes have been drilled, the minerals dissolve and migrate into groundwater. This can cause pollution of groundwater. Moreover, these areas have geologically been associated with the uplift, faulting, fracturing, magmatism and Pb – Zn mineralization of the Santonian orogeny (Kogbe, 1976). Groundwater flow and contaminant transport are controlled by fractures and faults genetically linked to the Santonian Tectonism (Todd, 1980).

The purpose of this work is to establish the spatial distribution of Pb, Zn, Cu, Cd, Hg, Cr, Ag and As in the soils/ sediments of the area and evaluate the pollution status using the concepts of Effect Range Median (ERM) and Effece Range Low (ERL), pollution index (€), geoaccumullation Index (Igeo), Pollution Load Index (PLI), contamination factor (C_f) and contamination degree. Assessment of the water resources (surface and groundwater), active and abandoned mine ponds (which serve as domestic source of water for the inhabitants) and hydrologic studies will be carried out to determine the flow direction of these hydrochemical attributes. Kamau, (2001), Asaah *et al*., (2006), Ezeh *et al*., (2007); Dikinya and Areola, (2010); Harikumar and Jisha, (2010); Nnabo *et al*., (2011), and Obiorah *et al*., (2016) have used these methods to evaluate pollution status of soils and sediments in mining areas.

1.2 Statement of the Problem

The study area comprises predominantly rural populations of farmers who have little or no knowledge of the harm which mining activities causes to their environment. Since the discovery and mining of mineral deposits in the Abakaliki area in the early 1990s, a comprehensive data has not been assembled on the hydrogeochemical attributes of mining activities in all the mining areas. Heavy metal effluents from the weathering of the mineral deposits may have adverse consequences on soil and water quality due to soil – water interaction. Apart from the challenges to sustainable water quality, pollutants and contaminants from mining sources constitute a major threat to human health, aquatic lives, land use and agriculture and other aspects of ecosystem imbalance. Soil/ land degradation problem is obvious. Mine wastes and tailings are directly discharged into farmlands, streams and river channels (Plate 1.1 to 1.4), lithostratigraphic sections of wells (boreholes) show mineralization in wells (EB-RUWASSA, 2010), and rural dwellers in various communities commonly depend on water from the abandoned mines and drainage channels for their domestic activities (Plates1.5 to 1.7, 1.9 to 1.11). Numerous health challenges such as miscarriages, selenoises in infant, decline in fertility, physiological and mental inbalance are commonly encountered in various communities (Obasi *et al.*, 2015). They often attribute these health cases to evil forces and evil men and probably as penal measures for inadequate sacrifices to their gods.

Although, several authors including Ezeh and Nnabo, (2006); Ezeh *et al.*, (2009); Nnabo *et al.*, (2009); Nnabo *et al.*, (2011); Okagbue and Ukpai, (2011); Obarezi and Nwosu, (2013); Oti and Nwabue, (2013); Obasi and Akudinobi, (2015); Obasi *et al.*, (2015) and Obiora *et al.*, (2015) have done some work in parts of the study area, with minimal emphasis on soil – water interaction at a particular time or season, which is necessary for the study of seasonal variation. There have not been any wholistic assessments across the mining fields at a particular time or season. Also, there is need to carry out geohydrological studies to determine the principal flow direction of the hydrochemical attribute.

It is against this background that a systematic assessment of the quality of the environment (especially in the area of water safety and agricultural soils) in the mineralized and mining affected areas of Abakaliki, Ebonyi State, Nigeria should be carried out. The water / soil interaction shall be investigated, since the affected communities are predominantly farmers. Emphasis shall be placed on qualitative assessment of the various water sources and soils in the area, various input sources of hydrochemical significance shall be assessed. Hence, providing valuable information in this regard may likely alleviate the numerous health problems in the area and constitute a vital planning tool to healthcare providers, agro allied agencies and industries, environmental management and regulatory authorities and rural water supply agencies. The aquifer system(s) shall be studied to understand the availability of potable water sources in the area. There is need to investigate the movement of groundwater in the area, since the possible contaminants in the host rocks can migrate and be carried along in solution from one point to another. This will assist in the establishment of safe and unsafe areas with respect to contaminant transportation and waste management, and will also be used to determine recharge and discharge areas, which constitutes a vital tool in groundwater prospecting and management. All these, when carried out shall provide the basic hydrogeological and geochemical information of the area, thus, providing a link between the problems associated with mining activities and their remedies in the mining areas of Abakaliki.

Plate1.1: Abondoned lead zinc mine at Mkpuma Akpatakpa.

Plate1.2: Farm land affected by effluent discharge from mines at Alibaruhu.

Plate 1.3: Children swiming in a stream affected by effluent from mines at Enyigba.

Plate 1.4: Farm lands affected by effluent discharge at Ameka.

Plate 1.5: A villager fetching water for domestic use from Mkpuma Akpatakpa abandoned mine.

Plate 1.6: Stream affected by mine (effluent) wastes serving as a source of domestic water supply.

Plate 1.7: Abandoned mine pit at Mkpuma Ekwaoku serving as ephemeral water

Plate 1.8: Environmental degradation caused byArtisinal mining at Enyigba.

Plate 1.9: Abandoned mine (with impounded water) at Mkpuma Akpatakpa.

Plate1. 10: Active mine impounded by water at Amachara village.

Plate 1.11: Active mine (with impounded water) at Mkpuma Akpatakpa.

Plate 1.12: Environmental degradation caused by Artsinal minning at Ameka.

1.3 Aim and Objectives

The aim of this work is to carry out hydrogeological and geochemical assessment of the lead – zinc mining areas of Abakaliki, Ebonyi State, Southeastern Nigeria.

The objectives include to;

i. Identify the major rock types and their characteristics through geologic field mapping.
ii. Produce an inventory of the active and abandoned mines in the area.
iii. Identify the aquifer unit(s) in the study area.
iv. Assess the quality of the available water sources in the area.
v. Produce a phreatic surface map of the area, and hence determine the principal groundwater flow direction(s).
vi. Evaluate the pollution status of available soils (and hence their suitability for agriculture) in the area using various geochemical pollution indices.

1.4 Scope of the study

The scope of this study involves intensive geologic field mapping to study the rock types and their structural trends, locate the various mines in the mining areas of Abakaliki, collect samples for hydrochemical and geochemical analysis. The area lies between longitudes 8°00'E and 8°12'E and latitudes 6° 05'N and 6° 34' N covering a total area of about 794.2 km^2. It extends from Amanchara in the north to Ameka in the south and Izzi and Ngbo communities in the east and west respectively. The study constitutes the investigation of the chemical constituent of soils, stream sediments and water sources (surface and groundwater) of the mining areas of Abakaliki. The study also applies six (6) geochemical methods to assess the pollution status of soils / stream sediments in the area. It also uses water elevation of wells to determine the principal flow direction of groundwater. This is to determine recharge and discharge areas as it affects water resources development and waste management.

1.5 Significance of the Study

i. The research shall provide a data bank on the hydrogeochemical characterics of soils, stream sediments and water sources of the areas. Such data constitute the basic planning tool for economic development, especially in the areas of urban planning, water resources development, mineral resources development and waste management.

ii. This study will provide geological information on the economic mineral potential of the area as well as the adverse consequences of the mineralization and mining activities in the study area.

iii. This study will provide information on the aquifer types and groundwater conditions. This is necessary for harnessing groundwater for water supply purposes.

iv. This work will provide relevant information required to ascertain the principal direction(s) of flow of groundwater, and hence distinguish between recharge and discharge areas.

v. The above is very important as will be used to determine the safe areas with respect to water resources development, waste management and contaminant transport.

vi. iv and v above will be intergrated and used to categorize the study area with respect to risk potential in socio – economic development efforts, such as location of industries, waste disposal sites, markets, schools, etc.

vii. It is hoped that the fore-going would be useful in future exploration works for water and solid mineral resources in these areas.

1.6 Location, Accessibility and Settlement.

The study area lies between longitudes 8°00'E and 8°12'E and latitudes 6° 05'N and 6° 34' N (Fig 1.1). It extends from Amanchara in the north to Ameka in the south and Izzi and Ngbo communities in the east and west respectively covering a total area of about 794.2 km^2. The only major town within the area is Abakaliki, others being rural communities where mining activities have been going on. These communities include Mkpuma Akpatakpa and Amanchara (in Izzi Local Government Area), and Ameka, Amorie and Enyigba (in Ezza South Local Government Area), all in the Abakaliki area of Ebonyi State, Southeastern Nigeria.

The area is accessible through a network of well developed roads from Enugu, Afikpo and Ogoja axis (of Cross River State). Major roads include the Enugu - Abakaliki road, Abakaliki - Ogoja road and Abakaliki – Afikpo road. These roads are major express roads that lead to the area at various points. Minor roads in the area include: Abakaliki – Iboko - Izzi road, Abakaliki – Onueke – Ikwo road and Abakaliki – Ogbaga - Nwofe road. Footpaths were also available to access some villages, thereby accelerating the transverse of the area (Fig. 1.2).

The settlement pattern of the study area is both linear and nucleated. Along the major roads the settlement pattern is linear, while in the villages it is nucleated. This is due to prevalence of Unitarianism form of government, where brotherhood and neighborhood are given priority attention. The general language spoken in the area is Igbo with predominence of the Abakaliki dialect (Izzi and Ikwo). Cultural practices were observed to vary from one place to another. A greater number of the inhabitants belong to the Christian religion while others practice the African Traditional Religion.

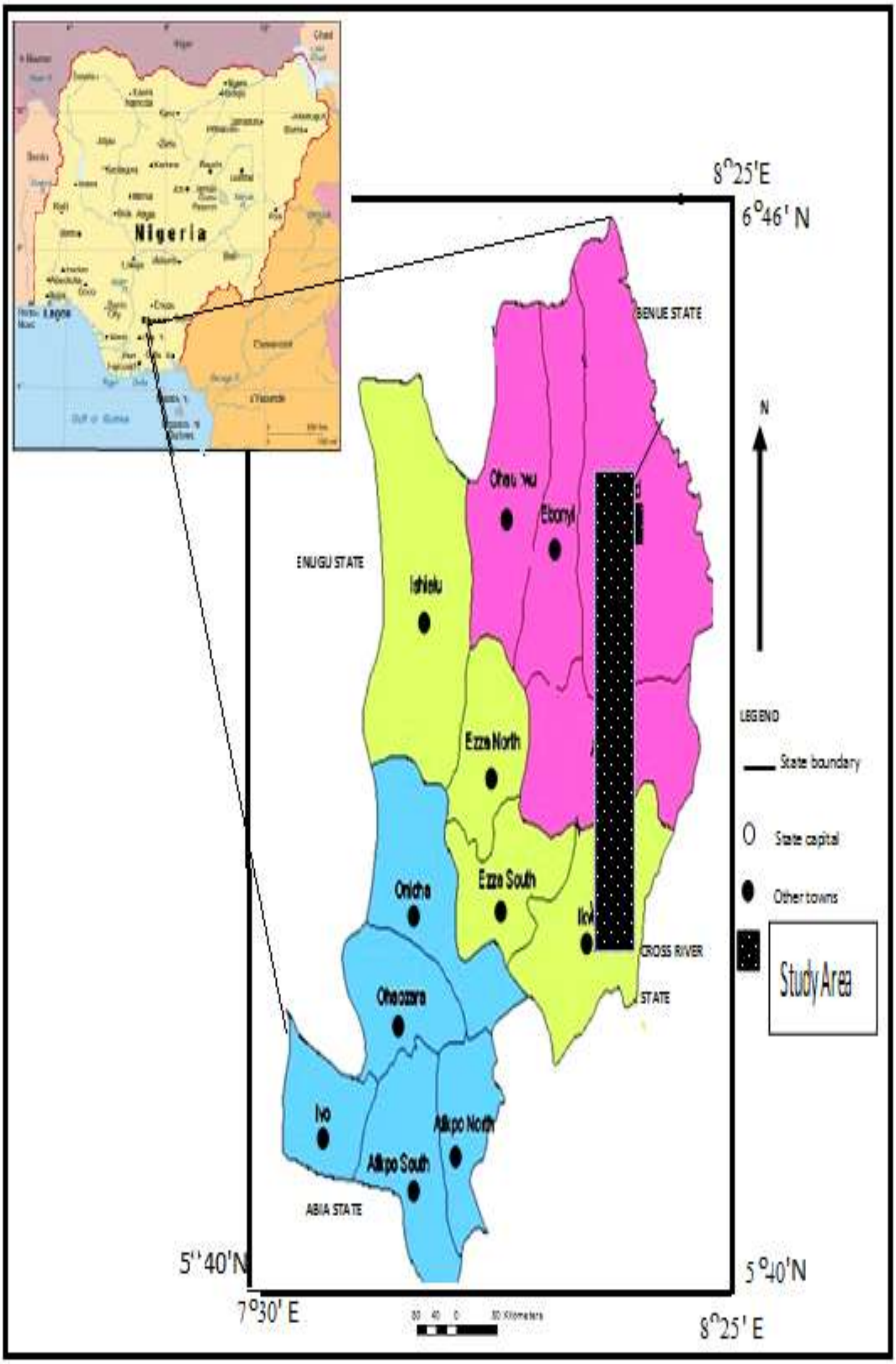


Fig. 1.1: Map of Ebonyi State showing the study area.

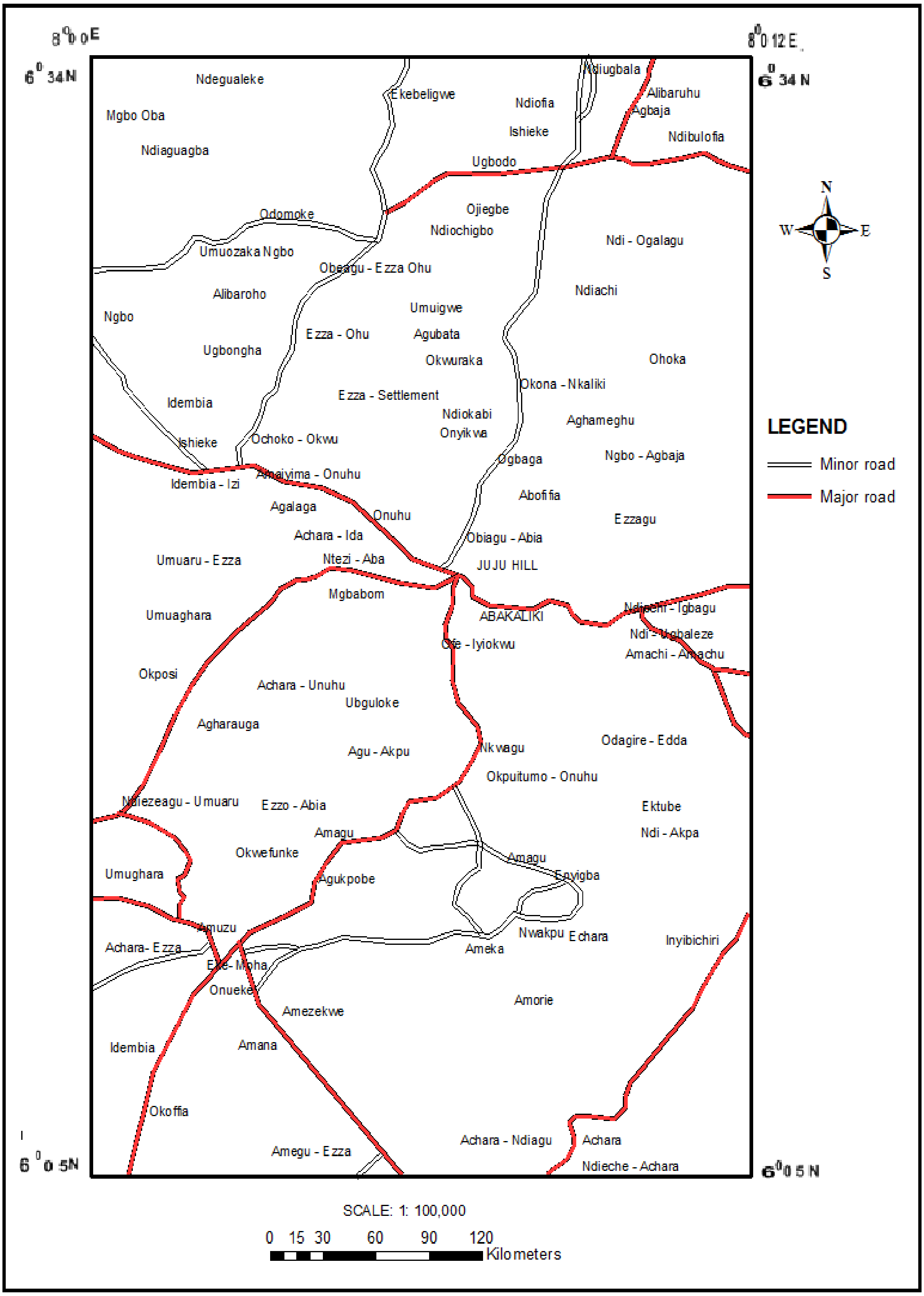


Fig. 1.2: Accessibility Map of the Study Area

1.7 Climate and Vegetation

The study area is part of the tropical hinterland climate (Iloeje, 1979). The average monthly rainfall is about 222mm, with mean annual temperature of about 29^0C (FARM Unit, EBSU, 2009). It has a relatively longer rainy season (March-October) and a shorter dry season (November to February). These two climatic regimes are caused by two prevailing air masses that blow across Nigeria at different periods of the year. The tropical maritime air mass originates from the Southern high-pressure belt, which crosses the equator, and picks up moisture from the Atlantic Ocean and enters Nigeria from the south. This air mass (wet) is responsible for the wet season. The tropical continental air mass (essentially dry) originates from Eurasia-Arabia high-pressure belt (Ajayi, 2003). Its effect predominates in Nigeria from October to February, resulting in dry periods. The dry season is also characterized by the northeasterly wind (the hamattan wind) which causes extreme dryness. Climatological analysis of rainfall and temperature of the study area shows that between 1999 and 2008, May and June received the highest amount of rainfall, while January and February have the least. February has the highest mean annual temperature, with August as the lowest, (Obasi, 2009). The result of this analysis is supported by Inyang, (1975) who reported that the area falls within the fourth climatic region with four dry months. The driest month has annual rainfall less than 2.9mm, with the mean annual rainfall ranging from 2000-2500mm.

The study area is part of the rain forest region of southeastern Nigeria. It has a humid climate and evergreen vegetation. The vegetation cover is composed of very dense trees and undergrowth of creepers. These trees are mostly tall, with buttress roots. However, consistent farming in the area has left some parts of the land bare, cultivated or fallowed. The vegetation is controlled by many factors, including the drainage, topography, lithology and rainfall. The area has been described as part of the lowland rainforest region (Nnabo *et al*., 2011). The forest is rich in loamy and humus soils, which support the farming activities of the inhabitants of the area.

1.8 Soil Type

Regionally, the study area falls within the Rainforest soil zone (Ajayi, 2003). This zone is characterized by the major features of the tropical rainforest such as moderate temperature; high rainfall and heavy cloud cover. The forest vegetation supplies humus to the soil through fallen and decayed leaves, which as well protects it from erosion. Locally, the soil variety is composed of loamy soils and clayed-loams. These soils develop in areas underlain by bedrocks consisting of intercalations of sandstones and shales. They have less developed profiles, more in nutrient content and higher in biological activities and humus. The clayed-loams are highly weathered red soils of the humid tropics. This type of soil is a by-product of weathering of rainwater - saturated shales and mudstones. They also have high water and nutrient retention capacity. The colour variation in places (from reddish-brownish-yellow) is due to the variable oxidation state of iron forming iron oxide cement. Soils are the main repositories of wastes, nutrients and all forms of inputs in the ecological system. In the study area, mine waste, gangue and dumps deteriorate and weather into fine particles to form soil. Oti and Nwabue, (2013) have shown high risk assessment for agricultural products from Enyigba areas. Chibuike and Obiorah, (2014) noted that such polluted soils have negative effects on plants while studies of arable soils in the Enyigba area by (Obiora *et al*.,2015) also indicated high risks for food crops.

1.9 Geomorphology and Drainage

The geomorphology of the study area is controlled by the prevalent structural, lithologic and physico-chemical factors. The topography could be described as comprising irregular ridges and gentle sloping hills. The elevation of the highlands range from 45m to 65m above mean sea level, while the lowlands rise to an average of about 30m (Aghamelu, 2011). The area is characterized by a uniform sloping drainage slightly tilted eastwards. This is due to the Basement complex rocks of the oban massif, Obudu hills and Mamfe Embayment, which bound the area to the east (Chukwu and Obiora, 2014). These topographic features are controlled by the bedrock geology. The Abakaliki area is underlain by sedimentary rocks with pronounced intrusions of pyroclastic rocks in many places. The lithology consists mainly of well-indurated shales, argillaceous sandstones, siltstones and mudstones. The well indurated sandstones and siltstones are exposed at the hills and ridges while the shales and mudstones occupy the lowlands.

Surface drainage in the study area is controlled by the Ebonyi River (Fig. 1.3). This river traverses the entire study area with its eminent tributaries and distributories transporting its hydrochemical attributes from one point to another. It flows predominantly north - south. Other major rivers in the area include Rivers Abe, Iyiokwu, Ololo, Achi and Atang while some minor ones include River Akpara, Ohamini, Ewe, Ogbogbo, Awumini and Oyirigbo. These rivers and streams vary in sizes, colour, taste, flowpath and chemistry. Some are seasonal and therefore, dry up during the dry season and increase in volume during the rainy season. The origin of most of these rivers and streams has been linked to the fractured shale and impervious contact between the shale and sandstone lenses, which characterize the lithology of the area (Okagbue and Ukpai, 2013). Due to the poor economic situation in these areas, these surface water resources have not been developed optimally.

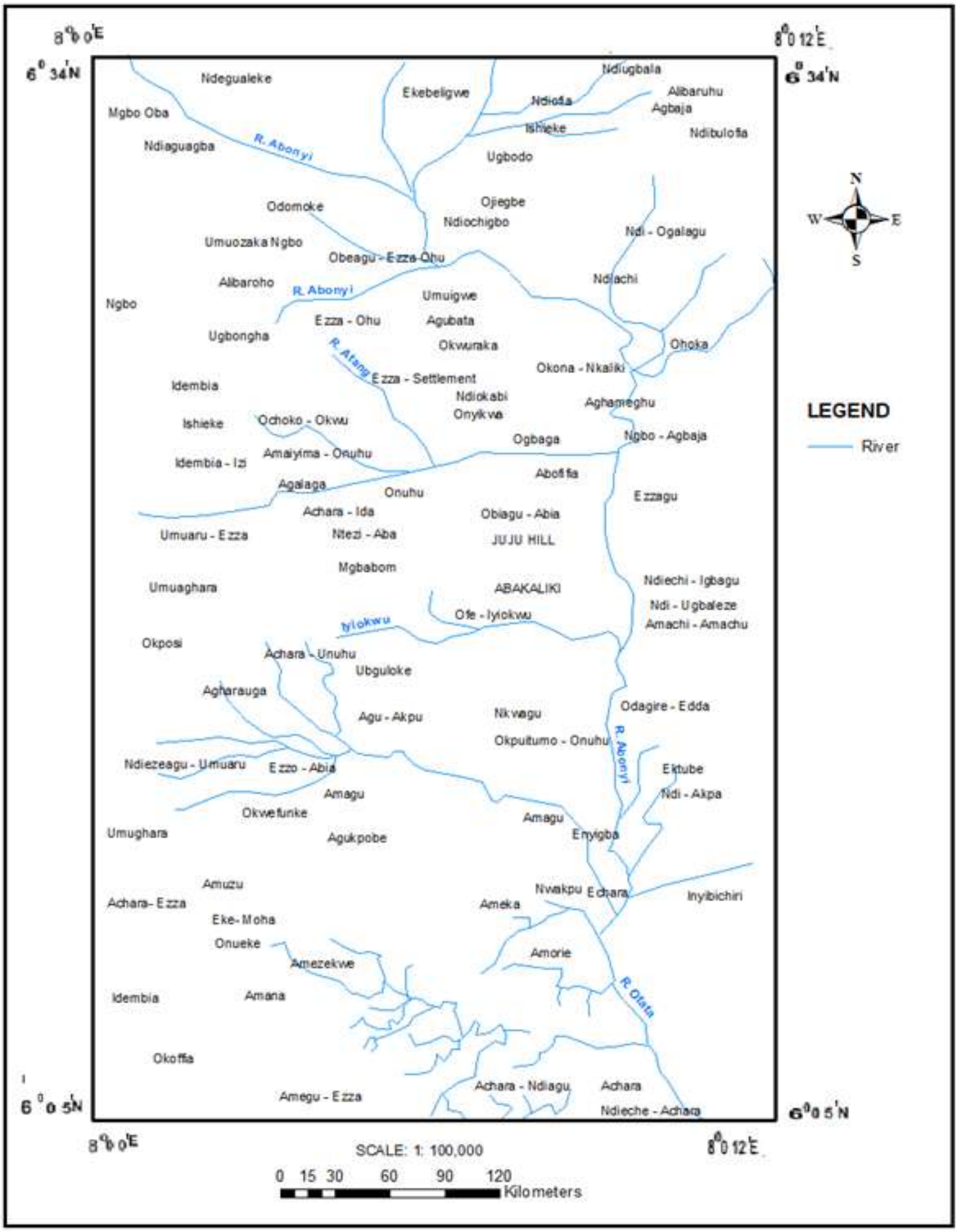


Fig. 1.3: Drainage Map of the Study Area

CHAPTER TWO

LITERATURE REVIEW

2.1 Geology of Southeastern Nigeria

Most research work in the study area has been incorporated into regional investigation. Ealier investigation in the area include those by Tattam, (1944); Simpson, (1954); Reyment, (1965); Orajaka, (1965); Burke *et al.*, (1972); Murat, (1972); Nwachukwu, (1972); Uzuakpunwa, (1974); Kogbe,(1976); Olade, (1976); Peters, (1978); Offodile, (1980) and Benkhelil, (1989). However, the stratigraphy of Nigeria has been subdivided into the pre-Cretaceous, Cretaceous, Tertiary and the Quaternary (Murat, 1972). The Southern sedimentary basin of Nigeria belongs to the Benue Trough. The Trough was formed by the break-up of the South- American and African continents in the Early Cretaceous (Murat, 1972; Burke, 1976). Various cases of geomorphologic, structural, stratigraphic and Paleontologic evidence have been presented to support a rift model (King, 1950; Bullard *et al.*, 1965; Reyment, 1969; Benkhelil, 1989; Guiraud and Bellion, 1995).

Three sedimentary phases/cycles have been described in the regional stratigraphic history of southeastern Nigeria (Short and Stauble, 1967; Murat, 1972; Obi, 2000). These three phases include the Abakaliki-Benue phase/the first sedimentary cycle (Aptian-Santonian); the Anambra-Benin phases/second sedimentary cycle (Campanian – Mid Eocene); and the Niger Delta phase/third sedimentary cycle (late Eocene-Pliocene) (Oboh-Ikuenobe *et al*., 2005). Each of these sedimentary phases is bounded by sequence boundaries with unconformity surfaces. Table 2.1 shows the regional stratigraphic sequence of southeastern Nigeria.

The first cycle was initiated by the Mid-Albian transgression. The product of this transgression is the Asu River Group. The first regressive phase deposited the Odukpani Formation (Cenomanian). This was followed by the Turonian global transgression that deposited the Ezeaku Group and then, a regression that followed deposited the Coniacian Awgu Shale (Petters, 1978). This sedimentary cycle was terminated by the Santonian tectonic episode, which resulted in the folding of the earlier deposited sediments (Hoque and Nwajide, 1985; Murat, 1972).

The second sedimentary phase resulted from the Santonian folding and uplift of the Abakaliki region and dislocation of the depocenter into the Anambra Platform and Afikpo Region (Oboh-Ikuenobe *et al*., 2005). The third marine transgression occurred in this sedimentary phase and deposited the Nkporo Group unconformably over the folded pre-Santonian sediments (Murat, 1972; Obi, 2000). Regressive phases which occurred during the Campanian to early Maastrichtian deposited the Mamu Formation, Ajali Sandstone and Nsukka Formation respectively (Oboh-Ikuenobe *et al*., 2005).

The third sedimentary phase, linked to the formation of the proliferous Niger Delta (Fig. 2.2), commenced in the late Eocene as a result of a major earth movement that structurally inverted the Abakaliki region and displaced the depositional axis further to the south of the Anambra Basin (Hoque, 1977; Obi *et al*., 2001). The wide spread marine transgression that began in the Paleocene led to the deposition of sediments that developed the proto Niger Delta. (Short and Stauble, 1967; Murat, 1972; Kogbe, 1976; 1986)

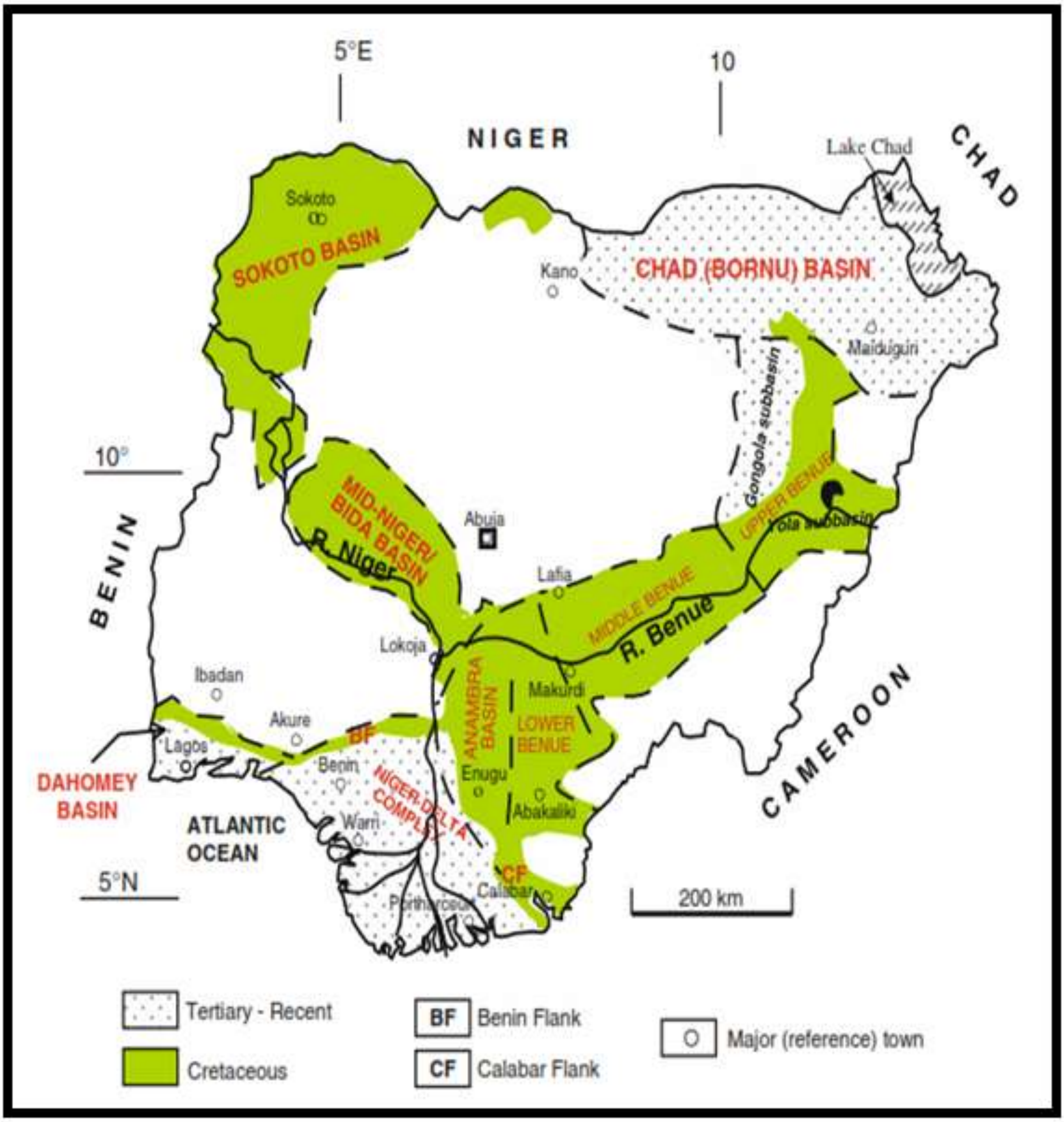


Fig 2.1: Map of Nigeria showing the extent of the Lower Benue Trough in relation to other basins. (After Obaje, 2009)

2.2 Tectonic Setting

Tectonism in Southern Nigeria started in the Early Cretaceous with the separation of Africa from South America and the opening of the Atlantic (Burke *et al.*, 1972; Murat 1972, Nwachukwu, 1972). Regionally, the study area lies within the lower Benue Trough. The Benue Trough is an elongate intracontinental Cretaceous basin (about 1000km in length), stretching in a NE-SW direction and resting uncomformably upon the Precambrian Basement rocks (Burke *et al.*, 1972; Nwachukwu, 1975) (Fig 2.1 and 2.2). It extends from the Gulf of Guinea to the Chad basin, and is thought to have been formed by the “Y”-Shaped triple - R Junction ridge system that initiated the breaking up and separation of the Afro-Brazilian plates in the Early Cretaceous (Burke *et al.*, 1972). Uzuakpunwa, (1974) suggested that the Benue Trough resulted from the pre-Albian rifting of the African shield prior to the opening of the South Atlantic (South-Eastern Nigeria).

Nwajide and Reijers, (2001) emphasized that the two arms of the South Atlantic and the Benue Trough represent the third failed arm and is associated with the event, which rose to the Aulacogen. Benkhelil, (1989) proposed that the Benue Trough originated in the Albian in relation to occurrence of North-South Oceanic transform fault, which probably initiated as a result of old lines of weaknesses found within the mobile belt.

Hoque and Nwajide, (1985) proposed four tectono-sedimentologic stages in the evolution of the Benue Trough. These are the Rifting stage, Deformation stage, Platform and Trough stage. The rifting stage in which depression was formed, allowed rifting with a large lip, adjourning the Western margin of the Southern edge (Afikpo Syncline). The basin experienced a deposition of a coarse feldsparthic detritus (the Ogoja Sandstone) from the adjacent basement complex, the Albian Asu River Group, the Cenomanian Odukpani Formation and the Turonian Ezeaku Group.

The rifting was followed by the deformation stage which led to the accumulation of thick sediments in the trough and led to the evolution of instability of the base of the faulted crustal blocks which accumulated in large scale folding with fold axes parallel to the trends of the trough (Fig 2.3). The lip of the Trough began to sag from the Anambra Basin and Afikpo Syncline. Broad scale alkalic volcanism took place at this stage, which resulted in the formation of sills and dykes. The platform stage gave rise to the deformed and uplift trough and later became the positive element (Abakaliki Anticlinorum) to shed the detritus into the new depocentre, the Anambra and Afikpo Syncline (Fig 2.3).

2.3 Stratigraphic Setting

The stratigrahic history of the region started with the deposition of marine shales, with subordinate sandstones and limestones ranging in age from middle – upper Albian. These rocks consist of non-fossiliferous, arkosic, poorly sorted, commonly cross-bedded sandstones and grey to dark fossiliferous shales.

The rocks are exposed around Ogoja and Abakaliki areas (Reyment, 1965). Uzuakpunwa, (1974) however dated the Ogoja sandstone as Aptian. Nwabufo-Ene, (1976) noted that the Abakaliki Shales of the Asu River Group is middle Albian, while the sediments at Ishiagu and Ndeaboh are early Albian. However, the Albian stage is the first transgressive phase of the Benue Trough. The regressive phase to this transgression occurred in the Cenomanian and deposited the Odukpani Formation in the Calabar Flank. These rocks consist of alternations of sandstones, shale, sandy shale and fossiliferous limestone.

In the Turonian, a further global transgression occurred and deposited the Ezeaku Group. It consists of grey shales, limestone lenses, siltstones and sandstones with shallow marine fauna such as ammonites, gastropods, pelacypods and foraminiferas (Fayose and

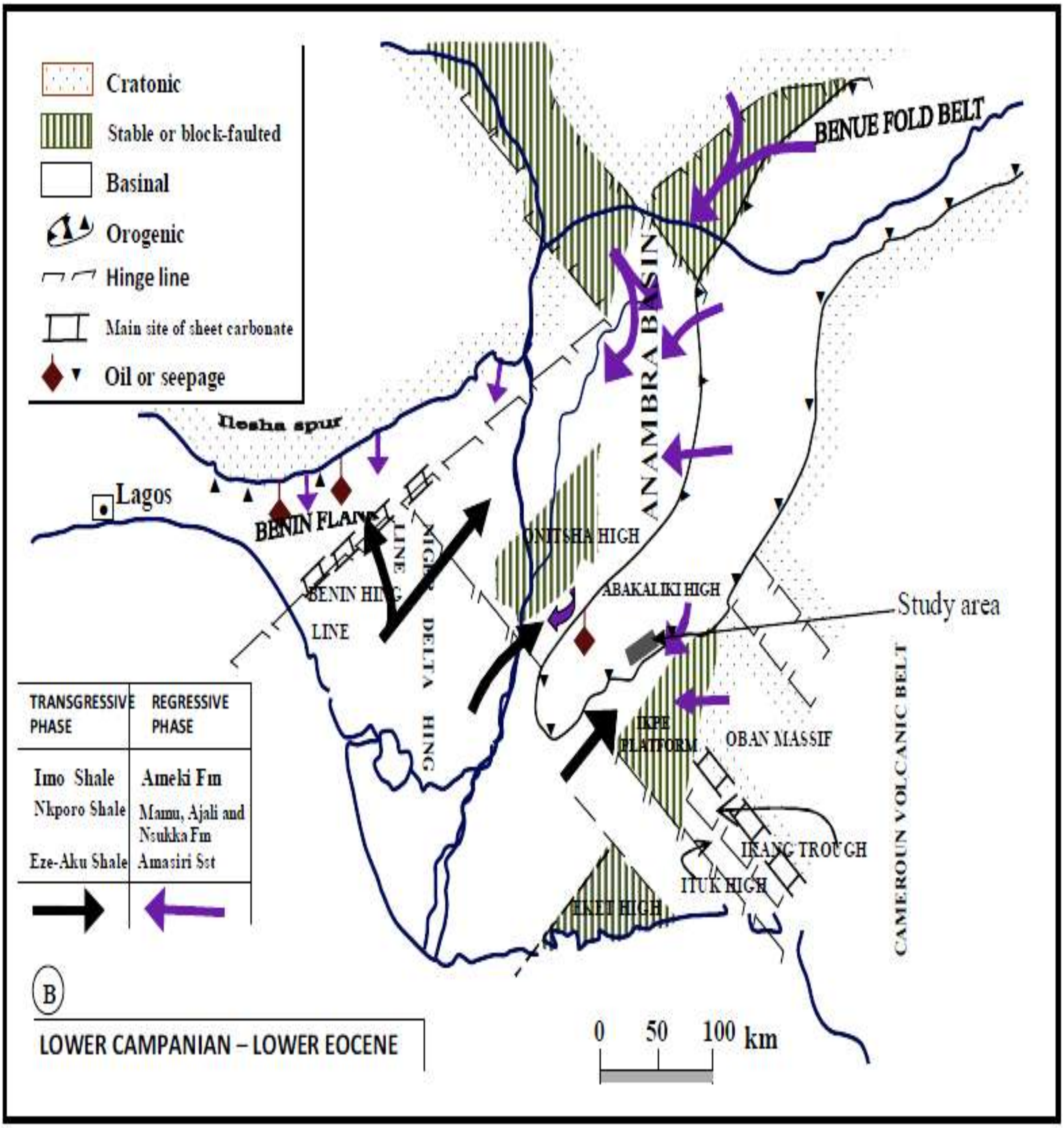


Fig 2.2: Tectonic map of Southeastern Nigeria from Albian to Eocene (Murat, 1972)

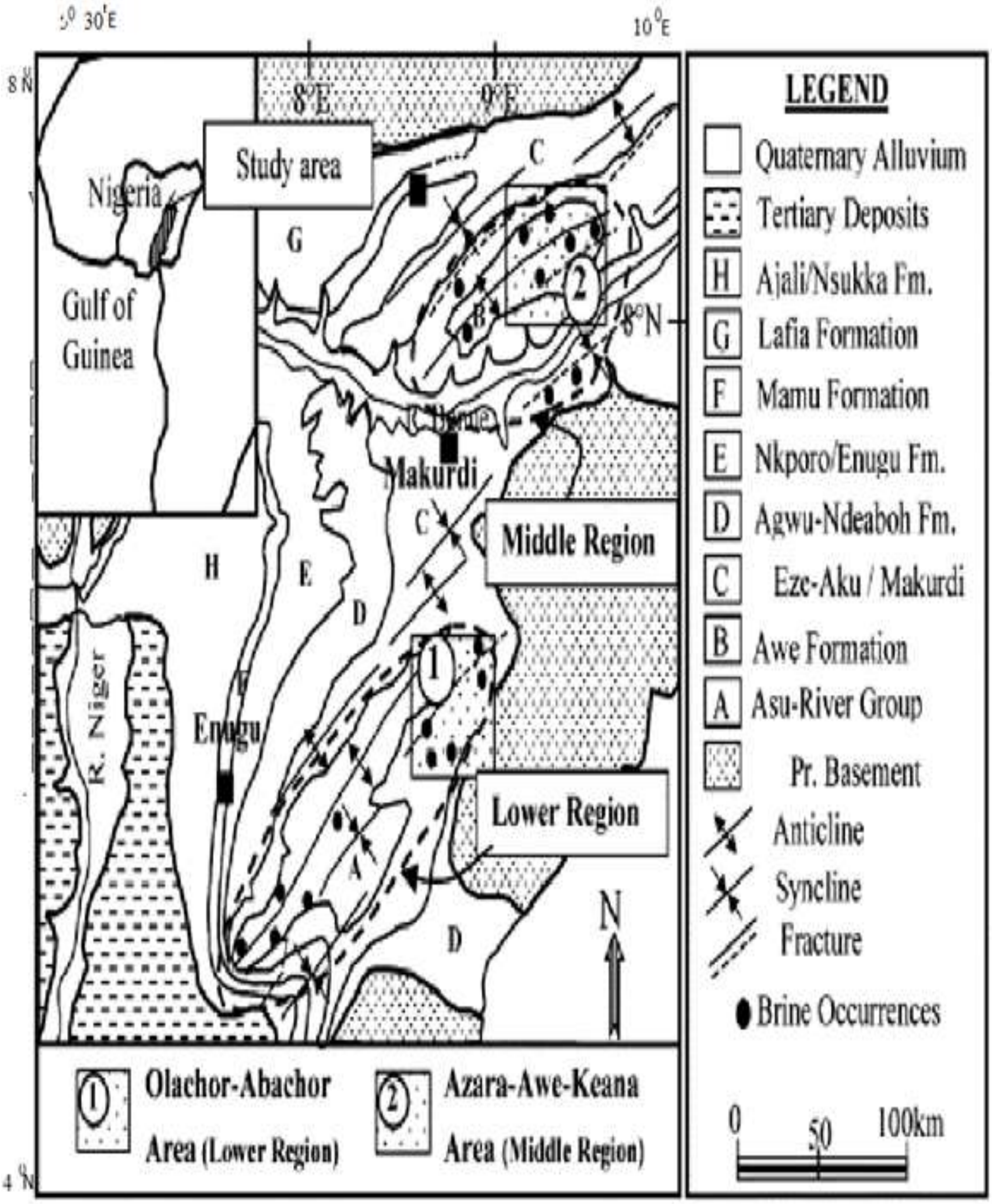


Figure 2.3: General geology of southern portion of the Benue Trough (After Olade, 1976).

Klast, 1976). The formation grades laterally into the Amasiri Sandstone and Awgu Shale. The regressive phase deposited the Coniacian Awgu Shales (Reyment, 1965).

The Santonian is a period of non-deposition (Oboh-Ikuenobe *et al*., 2005). It resulted in the uplift, folding and widespread erosion of the pre-Santonian sediments (Short and Stauble, 1967). The Santonian events signified the end of the Aptian-Santonian sedimentary phase and also led to the uplifting of the Abakaliki Anticlinorium (Kogbe, 1976).

Subsidence occurring after the folding initiated renewed marine transgression and hence the deposition of the Nkporo Shales and its lateral equivalent, the Enugu Shale and Oweili Sandstone (Kogbe, 1976; Short and Stauble, 1967). Minor regressions within this transgression deposited the Mamu Formation, Ajali Sandstone and Nsukka Formation comformably over the Nkporo Shales. The Nkporo is Campanian while others are Maastrichtian in age (Kogbe, 1976).

Marine transgression was widespread in the Tertiary period. A major transgression in the Paleocene deposited the Imo Shale. At the end of the Paleocene, renewed regression initiated the period of deposition of the Tertiary Niger Delta. This regression deposited the Ameki Formation. The ages of this formation have been considered to range from Early to Middle Eocene (Reyment, 1965; Adegoke, 1969; Adegoke *et al*., 1980). This consideration is due to the ostracod and foraminiferal assemblages of this formation.

The Eocene progradation continued into the Oligocene and deposited the Ogwashi-Asaba Formation (Kogbe, 1976). Reyment, (1965) suggested an Oligocene-Miocene age for the Formation. This stratigraphic unit is represented by the Benin Formation (Kogbe,1989; Oboh-Ikuenobe *et al*., 2005). (Fig. 2.4)

The Abakaliki area is also associated with the occurrence of intrusions known as the Abakaliki pyroclastics. The Abakaliki pyroclastics have altered mafic agglomerates, interstratified lava flows and tuffs as their lithofacies (Olade, 1979). The crystalline vitric tuffs are grayish-green, basaltic and vitro-clastic in texture, while the lava flows are relatively less abundant in distribution. It is mostly dominated by patches of dark layers observed to be xenoliths of shales, which might be an important evidence to support the fact that the pyroclastics are post Albian. Abakaliki pyroclastics are generally light grey in colour. They consist of a compact chaotic mixture of unsorted angular lithic fragments (shales, mudstone, siltstone and limestone), amygdaloidal scoria and pumice set in a highly altered basaltic groundmass (Agumanu, 1989). The primary mineralogy comprises pyroxene (suspected to be augite) that has been replaced by chlorite and calcic-plagioclase that has been recrystallized and altered to albite, carbonate and epidote (Ofoegbu and Amajor, 1987). The accessory minerals include iron, apartite and titanium oxide (Olade, 1979). The matrix is made up of altered devitrified glass, plagioclase and secondary carbonates (Igwe, *et al*., 2013). They are known as the Abakaliki Pyroclastics. The rocks comprises angular to sub-angular fragments (1.0cm thick, average size) with a medium to coarse texture.

2.4 Hydrogeochemical Evaluation of Mining Areas

The discovery of lead – zinc in the Abakaliki area has attracted more interest in the detailed geological study of the area. Many workers including Ezeh and Nnabo, (2006); Ezeh *et al*.,(2007); Nnabo *et al*.,(2009); Nnabo *et al*.,(2011); Ukpai and Okagbue, (2013); Obarezi and Nwosu, (2013); Oti and Nwabue, (2013); Obasi and Akudinobi, (2015); Obasi *et al*.,(2015); Obiora *et al*., (2015) have done some work in parts of the study area.

Detailed geological work in the Abakaliki area was first carried out by the field surveyors of the British Government of the ministry of overseas (Directorate of over-seas surveys), under the special Commonwealth African Assistance Plan, (Federal surveys of Nigeria, 1966). Orajaka, (1965); Offodile, (1980) and Nwachukwu, (1975) studied the origin of the Benue

Trough and established that the study area lies within the Southeastern limb of an asymmetrical axis whose axis trend NE-SW. Orajaka, (1972) investigated and established the economic importance of the brine deposits in the Cretaceous sediments of Southeastern Nigeria. Recent workers, including Ezeh and Nnabo, (2006), enumerated the areas which are endowed with lead – zinc deposits in Ebonyi state. Ezeh *et al*., (2009); Nnabo *et al*., (2009); Nnabo *et al*., (2011) carried out preliminary investigations on the assessment and distribution of heavy metals in soils and stream sediments of Enyigba areas. Ezeh *et al*., (2009) established high concentration of cadmium, lead and arsenic, while Nnabo *et al*., (2009 and 2011) reported moderate pollution status for soils and stream sediments of the Eka Awoke and Enyigba areas respectively. Okagbue and Ukpai, (2013) investigated the concentrations of hydrochemical attributes of water resources of Abakaliki and observed high concentrations of nitrate, sulphates and some heavy metals. Obarezi and Nwosu, (2013) studied the structural controls of mineralization in the Enyigba and Ameka area and showed NW-SE and N-S directions and dips of SW-NE direction. Obasi and Akudinobi, (2015) studied the geochemical assessment and pollution status of soils of Ameka and observed moderate and extreme contamination for arsenic and cadmium respectively. Obasi *et al*., (2015) carried out hydrogeochemical investigation of water resources of Mkpuma Ekwaoku and environs and reported high concentration of heavy metals like cadmium, zinc, chromium and arsenic. Obiora *et al*., (2015) carried out an assessment of heavy metals in soils of the Enyigba areas and observed high risk for arable crop products. Oti and Nwabue, (2013) investigated the concentration of heavy elements in some vegetable species, and observed high concentrations in the area. In all cases, none of these workers have assessed the soil – water interaction at a particular time or season which is necessary for the study of seasonal variation. Also, these researches have not assessed the entire mining fields in other to compare the concentration and degree of pollution or comtamination of the hydrogeochemical attributes in the various mining fields, and the flow direction of these hydrochemical attributes have not been established.

According to Reyment, (1965) the Santonian tectonic phase resulted in a lot of fracturing and folding in the Abakaliki area, giving rise to series of anticlines known as the "Abakaliki Anticlinorium". The sediments of Asu River Group have been established to be between 1900m and 3000m thick (Kogbe, 1976; Peters and Ekweozor, 1982; Agumanu, 1989). The Asu River Group Sediments are also associated with saline seepages, Lead-Zinc mineralization, basic intrusions and pyroclastic (Agumanu, 1989). It rests uncomformably on the Basement Complex (Reyment, 1965). This group consists of fossiliferous shales, siltstone, limestone and minor fine to coarse grained sandstone (Agumanu, 1989). It has been described as the lower shale (Simpson, 1954) and Cross River-Benue shale. Simpson, (1954) called it the Asu River Group Series, while Offodile, (1976) designated it the Asu River Formation. The multiplicity of names existed because detailed stratigraphy and petrologic features of the group have not been described (Agumanu, 1989). According to Farrington, (1952) the major directions of the folds are in the NW/NNW-SE/SSE.

The study area is however underlain by the Asu River Group, which is the product of the earliest documented marine transgression in Nigeria (Nwajide, 2013). This marine transgression occurred during the middle Albian and was limited to the Benue valley and south-eastern Nigeria where the Asu River Group sediments as well as the Abakaliki Shales were deposited in moderately deep marine waters (Kogbe, 1976). The Asu River Group consists largely of olive-brown sandy shales, fine grained micaceous sandstones and micaceous mudstones. Bluish-grey or olive-brown shales, which weather to a rusty brown colour, are also present. The sequence is poorly fossiliferous, though there are occasional outcrops of thin shelly limestone. The beds are exposed in the Ivo River, about two and a half km south of Ishiagu, and in its left bank tributary, the Ike-Ebi (Simpson, 1954). Paleontologically, the Albian is mainly characterized by species of *Mortoniceras* and *Eloiceras*. It is also rich in ammonites as well as foraminifera, radiolaria and pollens (Reyment, 1965). Structurally, the sediments are folded, particularly in the southern area of Abakaliki; the fold axes stretch NE-SW (Nwajide, 2013).

2.5 Hydrogeology

Despite the high amount of rainfall in the area, groundwater resources are relatively scarce. This is because the shale, which predominantly underlay the study area, is rarely aquiferous. They are predominantly hard, massive and impermeable. Three major types of aquifers have been observed in the area by Egboka *et al*., (1993). These include the fractured zone aquifer of the shales, the minor aquiferous sandstone and the alluvial deposit aquifers. They opined that these aquifer types have high values of transmissivity and hydraulic conductivity, and hence, preferred for groundwater supply. They also estimated borehole depth of about 70m to 150m to obtain water of good quality in the areas.

2.5.1 Groundwater Hydrology

Geology, stratigraphy, topography and structural features control groundwater hydrology. All these have been affected appreciably by the Santonian tectonic episode, which affected the study area (Orajaka, 1972), resulting in considerable variation in depth to water table at various places. Egboka and Uma (1985) noted that the depth to water table ranges from 0.3m to 12.6m. They also stated that pumping tests were not performed but the yield of the boreholes is estimated to be about $0.28ls^{-1}$ ($1000\ lh^{-1}$). Sandstones of the type described in the study area have hydraulic conductivities ranging between $10^{-7}ms^{-1}$ and $10^{-5}ms^{-1}$ (Egboka and Uma, 1985).

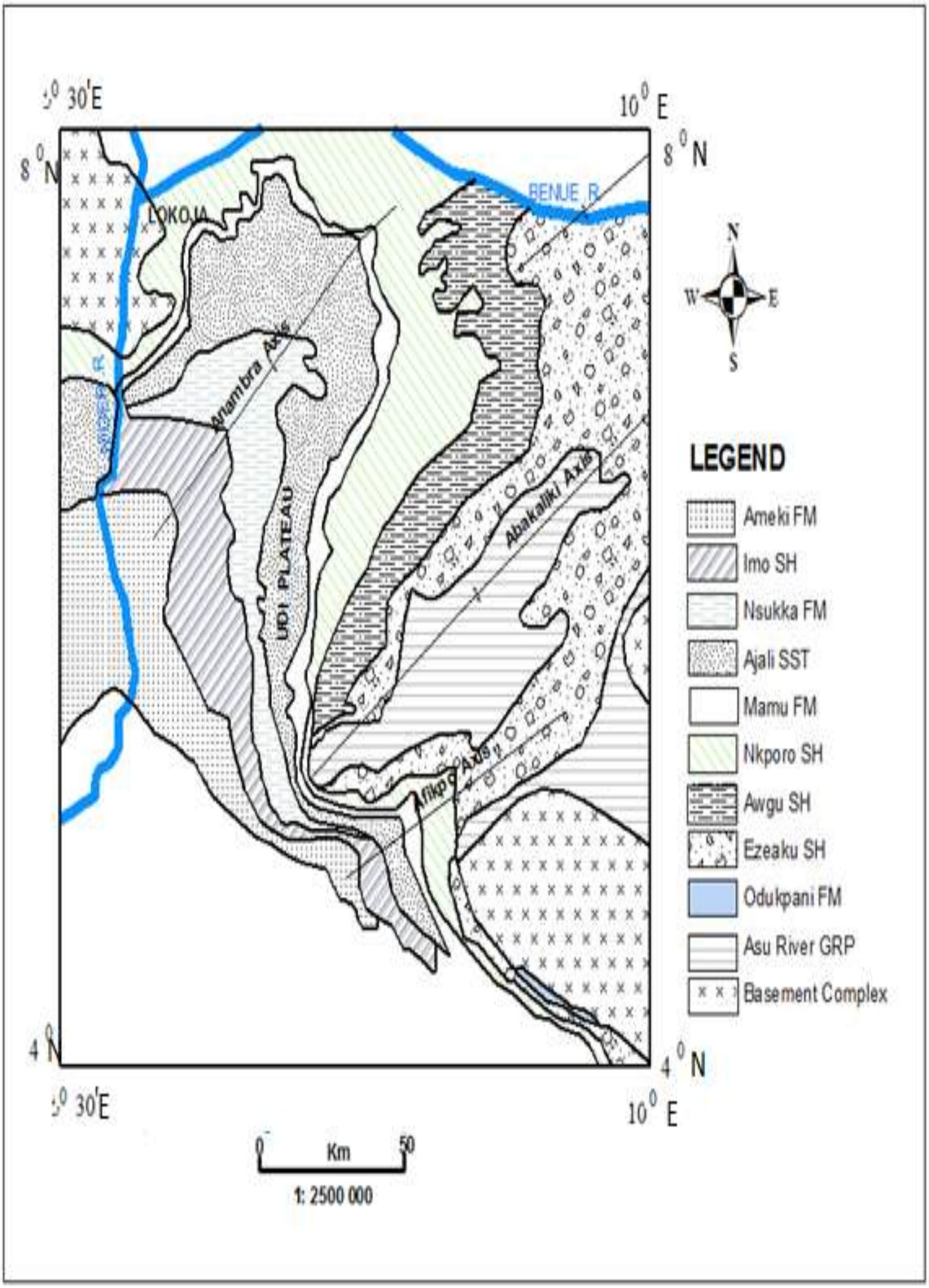


Fig 2.4: **Geological map of Southeastern Nigeria (modified from Nwajide, 2001)**

Table 2.1: Regional Stratigraphic Sequence of Southeastern Nigeria.

PERIOD	AGE	FORMATION	SEDIMENTARY PHASE/BASIN
QUATENARY	**PLEISTOCENE**	BENIN	
	PLIOCENE		
	MIOCENE		
		OGWASHI-ASABA	
	OLIGOCENE		3^{RD} SEDIMENTARY CYCLE/PHASE
TERTIARY			
	EOCENE	AMEKI	NIGER DELTA. (DEVELOPED DURING THE UPPER EOCENE)
	PALEOCENE	IMO SHALE	
UPPER CRETACEOUS			
		NSUKKA	
	MAASTRICHTIAN	AJALI SANDSTONE	
			2^{ND} SEDIMENTARY CYCLE/PHASE
		MAMU	
			ANAMBRA BASIN/
	CAMPANIAN	NKPORO SHALE	AFIKPO BASIN
	SANTONIAN	DIASTEM (UNCOMFOMITY)	1^{ST} SEDIMENTARY
	CONIACIAN	AWGU SHALE	CYCLE/PHASE
	TURONIAN	EZEAKU GROUP	THE ABAKALIKI –
	CENOMANIAN	ODUKPANI	BENUE BASIN
	ALBIAN	ASU RIVER GROUP	
LOWER CRETACEOUS			
APTIAN	**UNNAMED UNITS**		
BARREMIAN			
	PRECAMBRIAN BASEMENT COMPLEX		
HAUTERIVIAN			

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Geologic Fieldwork Materials.

Simple field geologic materials and equipments including brunton compass, Global Positioning System (GPS), water level indicator, the geologic hammer, hand lens, measuring tapes, water sample bottles, soil sediment bags, pencil, field notebooks and camera were used.

3.1.2 Laboratory Materials

The following materials and instruments were used: Hydrochloricacid (HCl), Hydrogentrioxonitrateacid (HNO_3), Heater, Agate mortar with pestle, Nose mask, Burette and pipette, Measuring Cylinder, Syringe (10ml), spatulas and dropers, polyethylene sieve, Electronic weighing balance, automatic sieve shaker, De-ionised water, sterilized specimen bottle, filter paper, conical flasks, Aliquot, mercury- in- glass thermometer, electrical conductivity meter (DDS 307 model), pH meter (Hanna model H1991300) and Varian AA240 Atomic Absorption Spectrophotometer, .

3.1.2.1Working Principle of Varian AA240 Atomic Absorption Spectrophotometer

The principle of Varian AA240 Atomic Absorption Spectrophotometer is based on the sample being aspirated into the flame and atomized when the AAS’s light beam is directed through the flame into monochromator, and onto the detector that measures the amount of light absorbed by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences.

The amount of energy of the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample. The principle of varian Atomic Absorption Spectrophotometer is based on the ability of an excited atom of an element to absorb energy from wavelength of light of the same frequency (Hz). Elements have their series of specific characteristics for sensitivity, noise and linearity.

When electric current is applied into the lamp, the fill gas atoms are ionized positively. These collisions then cause dislodgement of the radiations. The atom then becomes excited to a certain level and emits radiations.The amount of the radiation absorbed is a measure of the numbers of atoms of that element present in the sample. This is then displayed on the read-out screen system as digital signals.Atomization is followed, whereby each sample is spread into the spray chamber of AAS and is passed in the form of fine aerosol into the flame. This brings the dissociation of the sample. The sample then melts, evaporates and volatiles to gaseous molecules that then undergoes thermal dissociation into atoms. A light of defined wavelength for a particular element is then passed through the flame.

The Instrument of Atomic Absorption Spectrophotometer

The instrument of AAS is made up of four basic sections, which include:

The Light Source (Hollow Cathode Lamp): This is also known as resonance line source. It consists of an emitting cathode made of element being studied in the flame. Ions are produced from noble gas and accelerated to the cathode, and on collision, excite the cathode element to emission.

An Atomizer Section: This converts the test solution to gaseous atom (flame atomization). An absorption measurement is made by comparing the intensities of radiation from blank solution reaching the detector (Alloway, 1995).

Monochromatic Section: This selects the analysis wavelength of the target element and isolates it from other lines, and occasionally from the molecular band emissions. The monochromator isolates the resonance of the radiation.

Detector Sector: This section converts the light into electrical signal. The output from the detector is processed and fed into a suitable read-out system.

3.2 Methods

3.2.1 Geologic Fieldwork.

The present work commenced with a reconnaissance survey of the area to note the accessibility and general geology of the area to enable efficient working plan. Detailed geologic mapping was done on a scale of 1:100,000. Simple traversing and compass method was used in carrying out the geological mapping. The investigation involved the identification of the lead – zinc mine fields (both active and abandoned sites) (Table 3.1), rock types (lithofacies) which host the mineralized veins and lodes, and collection of samples (rocks, stream sediments, soils and water) at various points of interest. These rock samples were used to infer geologic boundaries in the study area.

3.2.2 Sample Collection

Water and soil samples were collected at points of interest for hydrochemical and geochemical analysis respectively.

3.2.2.1Water Sample Collection/Preservation

Water samples were collected from groundwater and surface water sources for hydrochemical analysis.Surface water sources considered include active and abandoned mine pits, rivers, streams and lakes, while groundwater sources include shallow wells (hand dug wells and hand pump wells). A total of one hundred and sixteen (116) water samples were collected systematically from different locations comprising fourty- seven (47) from groundwater sources and sixty – nine (69) from surface sources (Fig 3.1). These samples were collected in two seasons.

Table 3.1: Locations of mines in the study area.

S/N	Name Of Mine	Coordinates	Location	Remarks
1	Mgbuchi Mine	N 06^{0}09.314’ E 008^{0} 06.685’	Ohankwo Ikwo	Abandoned Mine
2	Ehotu Onuegbu Mine	N O6^{0} 09.580’ E 008^{0} 06.642’	Ezza Ame	Active Mine
3	Mbara-Eke	N06^{0} 09.934’ E 008^{0} 06.622’	Amaeka Ezza	Active Mine
4	Enyi Chukwu Mine	N06^{0} 10.198’ E008^{0} 07.331’	Ikwo/Ezza Boundary	Active Mine
5	Tobias Mine	N06^{0} 10.590’ E008^{0} 07.413	Ikwo, Enyimchukwu	Active Mine
6	Ogodo-Agu Mine	N06^{0} 10.259’ E008^{0} 08.315	Ikwo, Alike	Abandoned Mine
7	Nwamgbam Ishiagu Mine	N06^{0} 11.196 E008^{0} 08.263	Enyigba	Abandoned Mine
8	Ameri Mine	N06^{0} 10 850 E008^{0} 08.252	Enyigba/Ikwo Boundary	Active Mine
9	Okpugwu-Adit Mine	N06^{0} 11.780 E008^{0} 08.286	Ishiagu-Enyigba	Active
10	Nwode Joe Mine	N06^{0}0 11.508’	Ishiagu Enyigba	Active
11	Friday Oketa Mine	N06^{0}11.478 E008^{0} 08.359	Ishiagu Enyigba	Active
12	Mbareke Enyigba Mine	N06 11.607’ E008^{0} 08.373	Enyigba	Active
13	Nwambam-Ukpabi Mine	No6^{0} 11.260 E008^{0} 08.390	Enyigba	Active
14	Alibaruhu	N06^{0} 11.102 E008^{0} 08.532	Alibaruhu Enyigba	Active
15	Mkpuma mine	N06^{0} 10. 02 E008^{0} 08.05	Mkpuma Akpatakpa	Active
16	Amanchara mine	N06^{0} 12.102 E008^{0} 07.52	Opu, Amanchara	Active

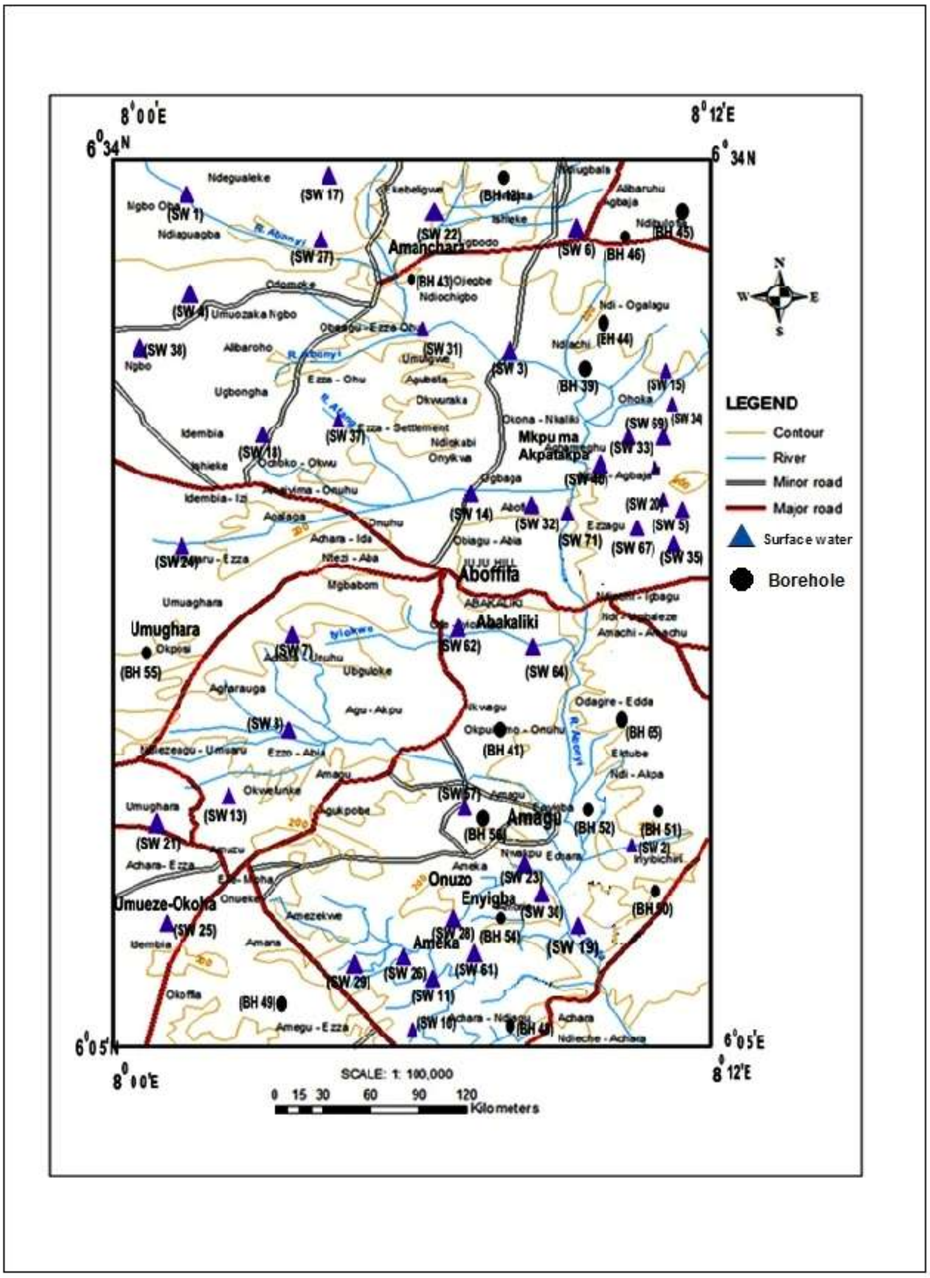


Fig 3.1: Map of Study area showing Water sample locations

At each location, observations on the physical aspects of water quality such as colour, taste, odour, pH and electrical conductivity were done. Two samples were collected at each location. One set was for cation and the other was for anion analysis. Samples for cation test were filtered and stabilized with two (2) to three (3) drops of dilute hydrochloric acid at the point of collection. This treatment was necessary prior to transport to the laboratory to suppress hydrolysis, sorption and other processes that influence concentration, and hence accuracy of results. Filtration was necessary to prevent dissolution or desorption of trace metals from the particular phase to the dissolved phase within the samples. Samples for anions tests were also collected at the same point. Both samples were stored in ethylene – free plastic bottles with fitted lids, and preserved in an ice – packed coolers below 4^0C prior to laboratory analysis.

3.2.2.2 Soil Sample Collection

Samples were collected from stream sediments at various locations from the major tributaries and distributories of Ebonyi River (which controls the drainage of the area), mine sites, and agricultural (crop) lands to assess the distribution of ionic species in the ecosystem. A total of one hundred and sixteen (116) soil samples were collected in two seasons, fifty – eight (58) from each season, (Fig 3.2). Pre – test systematic sample preparation was done for each soil sample analysed, including drying, screening, and digestion. At thee point of collection, the soil was dug about 10 cm to avoid undue concentration from top soil.

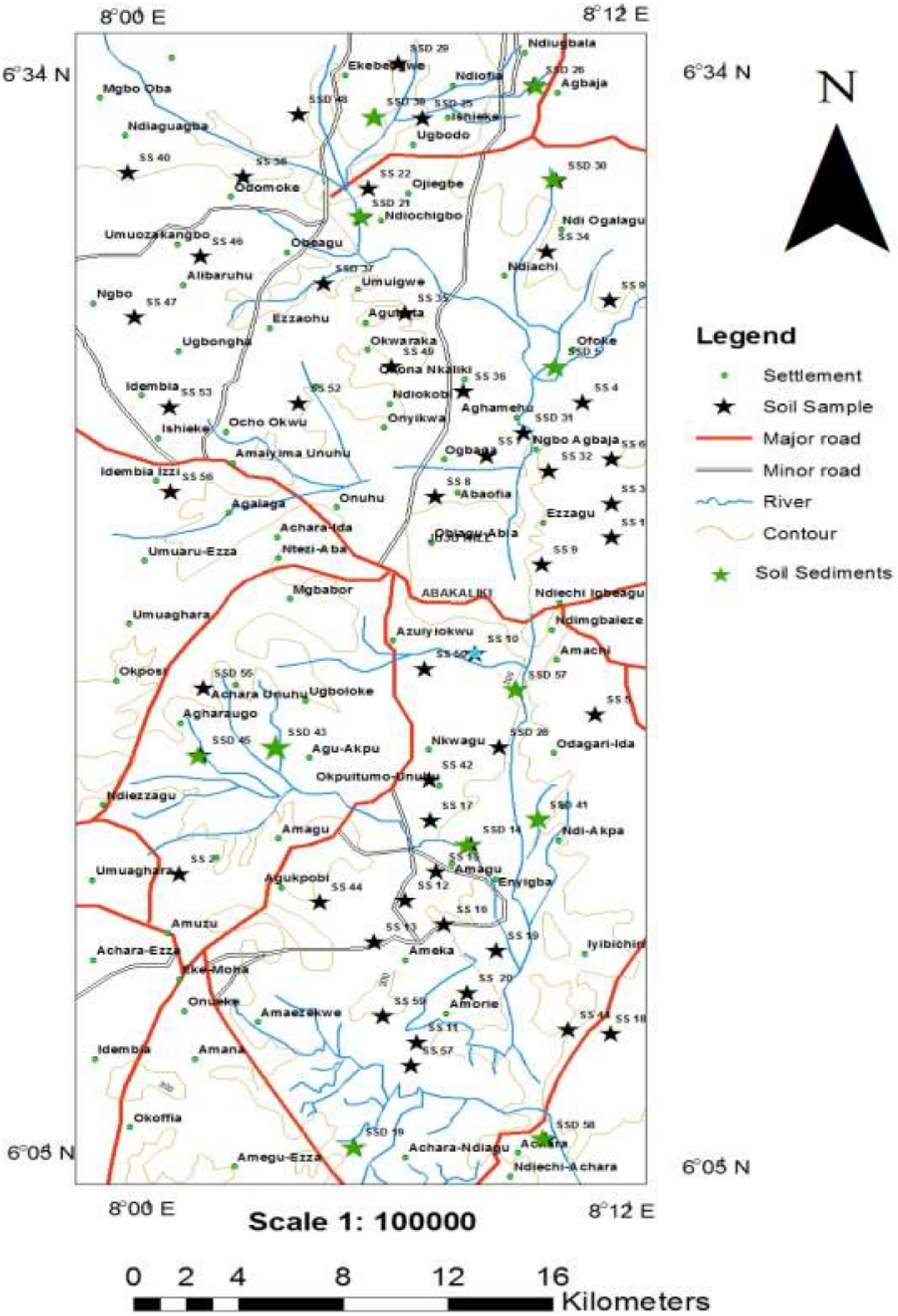


Fig 3.2: Map of the study area showing stream sediments/soil sample location

3.2.3 Drying and Screening of Soil Samples

Since the sediments were damp, they were firstly dried and disaggregated prior to sieving. The samples were laid out in pre-numbered evaporating dishes and sun-dried for three days.Each sample was disaggregated and homogenized by the use of agate pestle and mortar. Ukpong, (1991) noted that for sediments from Benue Trough, the optimum grain size to achieve best geochemical contrast is the 120mesh. That level of geochemical contrast is needed for exploration for mineral deposits. In environmental research with the purpose of assessment of total elements concentration, it is necessary to use broader screen value (Mendham *et al.*, 2000; Okoronkwo *et al.*, 2005). It was therefore decided to pass the homogenized samples through 100 micron sieve mesh. This helped to extract metals from 400mesh fractions which is considered the highly adsorptive fraction. The nylon screen was used to avoid contamination. After screening, 2.0g of each sample was weighed for digestion.

3.2.4 Soil Sample Digestion

The samples were digested by using aqua regia, which was prepared by the mixture of HNO_3 and HCl in the ratio 1:3. The advantage of this mixture is that it can be kept at higher temperature than other acids. The decomposition is also faster than most other techniques. 2g of the dried samples were weighed into a digestion flask and 20ml of the acid mixture (650ml conc. HNO_3; 80ml per hydrochloric acid; 20ml conc.H_2SO_4) was added. 10ml of aqua regia was added with syringe and stirred. The resulting mixture was heated on a Bunsen burner to a volume of 2.5ml, then 10ml of de-ionized water was added and again heated gently to a volume of 5ml, it is then removed and allowed to cool. After this, it was filtered into measuring cylinder with the help of filter paper and de-ionized water was added to an appreciable level of about 25ml. This is called aliquot. This aliquot was put in a container with a tight lid and used for analysis of Zn, Cu, Pb, Cd, Cr, Hg and Ag. The heavy metal analysis was conducted using Varian AA240 Atomic Absorption Spectrophotometer in line with American Public Health Association (APHA), (1998) specification. This analysis was done at Springboard Analytical Research Laboratory, Awka, Anambra State. The result of the analysis was reported in mg/l and was converted to concentration of metal in mg/kg of dry sediment.

3.2.5 Water Laboratory Analysis

Water quality (especially groundwater) is just as important as its quantity. Hence the emphasis in groundwater investigation has shifted from problems of supply to considerations of quality. All groundwater contains salts in solution that are derived from the location and past movement of the water (Todd, 1980). To establish quality criteria, measures of chemical, physical, biological and radiological constituents need to be specified, as well as standard methods for reporting and comparing results of water analysis.

The analysis was carried out within forty-eight (48) hours of collection. The samples were analyzed at Springboard Analytical Laboratory, Awka, Anambra State. Temperature, electrical conductivity and pH were measured in-situ at the points of collection usingmercury- in- glass thermometer, electrical conductivity meter (DDS 307 model), and pH meter (Hanna model H1991300) respectively. Laboratory analysis for the concentration of major cations comprising Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, K^{+}, was done using Varian Fast Sequential (FS) 240 Atomic Absorption Spectrophotometre (AAS), while anions comprising SO_4^{2-}, NO_3^-, HCO_3^- and $CO_3^{2-}$was done using Ultra Violet/ Visible (UV /VIS) Spectroscopy (PV 300 Opel). Cl^- and hardness were done using titrimetric method. Trace constituents including As, Cr^{3+}, Zn^{2+}, Ni^{2+}, Mo^{2+},Al^{3+}, Mo^{2+}, Pb^{2+},Cu^{2+},Hg^{2+}, Cr^{2+}, Ni^{2+}, Cd^{2+}, Ag^{+} and Mn^{2+}were analysed using Fast Sequential (FS) (Varian 240 AA) Atomic Absorbtion Spectrophotometer.

The results were discussed and compared with the World Health Organization (WHO) standards for water quality.

3.2.6 Preparation of Standard Solution for AAS

In order to ensure effective calibration of the instrument, standardized concentrated solutions are prepared and used as working standard. Standard solution of known metal concentration in water with a matrix similar to the sample was first prepared.

Noting that 100mg/l (100ppm) = 1g of test sample dissolved in 1 litre of water. Or

$$100\text{mg/l } (100\text{ppm}) = \frac{\text{Molar mass of compound containing the test element}}{\text{Atomic mass of element}}$$

$$\text{For example, 100mg/l of Pb} = \frac{\text{Molar mass of Pb }(NO_3)_2}{\text{Atomic mass of Pb}}$$

$$= \frac{331}{207} = 1.6\text{g}$$

Therefore, 1.6g of lead nitrate dissolved in 1 litre will produced 100ppm (100mg/l).

Working Standard: eg 10mls of 100ppm stock solution of Pb was pipetted and diluted to 100mls with distilled water, thus giving 100ppm of Pb. From 100ppm of Pb pipetted 2ml, 4ml, 8ml, and 10ml, were pipetted, each diluted with distilled water. This will give 2ppm, 4ppm, 8ppm and 10ppm respectively which thenbecome a known concentrated working standard solution.

The operation was repeated to prepare standard solution for other seven elements (Zn, As, Cu, Cr, Hg, Cd, and Ag). The samples are thoroughly mixed by shaking. 100ml of thoroughly mixed sample is transferred into a glass beaker of 250ml volume, to which 5ml of concentrated nitric acid is added and heated to boil till the volume is reduced to about 15-20ml, by adding concentrated nitric acid in increments of 5ml till all the residue is completely dissolved. The mixture is cooled, transferred and made up to 100ml using metal free distilled water. The sample is aspirated into the oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is observed (Adriano, 1986)

3.2.7 Determination of Groundwater Flow Direction

The most direct and accurate method of determining the direction of groundwater movement is by measuring the elevation of groundwater at multiple locations over the aerial extent of an aquifer (Buddermeier and Schlooss, 2000). Three major stages of procedures were used in this research: data collection, processing and interpretation.

With the aid of a water level indicator, the static water level in the hand dug wells were measured and recorded. The Global positioning system (GPS) was used to measure the longitude, latitude and the surface elevations with respect to the mean sea level to the lowest surface within the earth. The surface elevation at different point, varied. This uniform water level coincided with static water level in the case of an unconfined aquifer while it was the piezometric surface if the aquifer was confined (Buddermier and Schlooss, 2000)

Let DHDW = the depth from the surface of the earth to the water level in the hand-dug well (Direct Bore hole logging)

E = the surface elevation with respect to the mean sea level

Swl = The true or uniform water level otherwise known as the static water level in the case of an unconfined aquifer then

$$\text{Swl} = E - \text{DHDW} \qquad \text{Eqn (3.1)}$$

The values of the static water levels were contoured on the map of Abakaliki and its environ. These lines represented the water table contours. According to Buddermeier and Schlooss (2000), groundwater would flow from the highest values of contour lines to the lowest values in a direction perpendicular to the contour lines.

3.2.8 Pollution Assessment of Soils

Geochemical studies of soils were carried out using various methods to determine the pollution/ contamination status of soils. This includes:

3.2.8.1 Effect Range Low (ERL) and Effect Range Median (ERM)

The metal concentration of stream sediments/ soils was compared with the Effect Range Low (ERL) and Effect Range Median (ERM) values used by United State Environmental protection Agency (USEPA), Mid Atlantic Integrated Assessment (MAIA) for estuaries (1997-98 summary report). This was in line with the sediment quality guideline established by Levinson, (1974). ERL is the lowest concentration of metals in stream sediments that produced adverse effects in 10% of organisms reviewed in MAIA project. The ERM shows the 50% of the organism's studies reported harmful effects. Based on ERL and ERM values, metal concentrations below the ERL values are not expected to pose any adverse effects, while levels above the ERM values are likely to be very toxic.

3.2.8.2 Pollution Index (€)

Pollution index (€) as proposed by Powell (1992) is the ratio of individual metal concentration in soils to the ERM value for that particular metal. It expresses how many times the concentration of the individual metal is higher than the ERM for that metal in soil samples.

Mathematically; pollution index (€) = C/ERM Eqn (3.2)

Where C is the concentration of the individual metal in bed sediments (in mg/kg), ERM is the effect Range Median (in mg/kg).

3.2.8.3 Geoaccumulation Index (Igeo)

Geoaccumulation index (Igeo) according to Muller, (1979) is defined by the formula

$$\text{Igeo} = \frac{log2Cn}{1.5Bn} \qquad \text{Eqn (3.3)}$$

Where Cn is the measured concentration of metals in politic sediment fraction and Bn is the geochemical background value for shale

3.2.8.4 Contamination Factor

Determination of pollution status of heavy metals in the stream bed sediment/ soils was also assessed using the contamination factor.

Mathematically, contamination factor is expressed as:

$$C_f = \frac{C_{n-1}^F}{C_n^F} \qquad \text{Eqn (3.4)}$$

WhereC_{n-1}^F is the mean content of the metal from sampling locations. $C_n^F$is the concentration of the heavy metals in the Earth's crust as a reference value**.**

3.2.8.5 Pollution Load Index (PLI)

The Pollution Load Index (PLI) is obtainedas concentration Factors (C_f). This CF is the quotient obtained by dividing the concentration of each metal. The PLI of the place arecalculated by obtaining the n-root from the n-CFs that was obtained for all the metals.

Generally pollution load index (PLI) as developed by Tomilson *et al.*, (1980), which is as follows:

$PLI = n\sqrt{(C_{f1} x C_{f2} x C_{f3} x \ldots x C_{fn})}$ Eqn (3.5)

Where,

C_f = C metal / C background value

C_f = contamination factor, n = number ofmetals

C metal = metal concentration in pollutedsediments

C Background value = background value ofthat metal.

3.2.8.6 Contamination Degree

Abrahim and Parker (2008) presented a modified and generalized form of the Hakanson (1980) equation for the calculation of the overall degree of contamination as below.

$$mCd = \sum_{i=1}^{i=n} Cf \quad \text{Eqn (3.6)}$$

Where, n = no of analysed elements,

I= ith element

C_f= Contamination factor

Investigation for Contamination degree is very important because it shows at a glance the degree of contamination of the sample areas for all the metals analysed (Casper *et al.*, 2004). It can be used to generally classify the soil with respect to the level of contamination.

3.3 Data Interpretation

Bargraphs, linegraphs and trilinear diagram were used for classifications of dominant anions and cations of hydrochemical facies and geochemical attributes. Softwares used for accurate interpretation includes suffer 11 for contoring, ARCGIS for drawing of maps and microsft Excel was used to plot graphs and create tables.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Lithologic Description of Stratigraphic Units of the Study Area

The study area is underlain by the Asu River Group (Fig 4.1). The Asu River Group is the oldest sedimentary rock in southeastern Nigeria (Kogbe, 1976). It is exposed variously in the Abakaliki area where they are often referred to as the Abakaliki Shale.

The study area is predominantly underlain by shale lithology (Table 4.1). These shales differ in their physical characteristics. Some are fissile while other are indurated. Hence, the designation into three different units: A, B and C. Igneous intrusions were also encountered in the area at Ndiechi, Abakaliki and Ezzagu. Lead- zinc mineralizations (veins and lodes) were observed in some locations, which include Mkpuma Akpatakpa, Ameka, Enyigba, Amorie, Ekweburu Village and Agbaja (Fig 4.1).

Table 4.1: LithostratigraphicSuccession of Rocks in the Study area

AGE	GROUP	FORMATION	LITHOSTRATIGRAPHIC UNIT	LITHOFACIES
Middle Albian	Asu River	ABAKALIKI Shales	Unit A: Light – Grey Fissile Shale	Shale and mudstone
			Unit B: Dark Grey Shale	Very hard and massive shale and mudstone
			Unit C: Olive Brown Fissile Shale	Brownish shales and mudstone

4.1.1 Unit A: Light Grey Fissile Shales

These shales are highly fissile and have light grey colour (Plates 4.1 and 4.2). Fissility in rocks refers to the property of rocks to split along planes of weakness into thin sheets. This is commonly observed in shales and slates and phylites (which are foliated metamorphic rocks). However, the fissility in these rocks is caused by the preferred alignment of platy phyllosilicate grains due to compaction, deformation or new mineral growth. Fissile shales were encountered at various locations: Ogbogbo River, about 1.5km away from Ekebeligwe, along the road leading from Ekebeligwe to Ndiefi; River Abe, Ekerigwe; Ngele Okoro Ebonie; Ndiugbala, the entire Amanchara village, Amuzu Igbeagu and Ewe River, Igbuhuotum. The upper layers of the shales are fissile whereas the lower layers (the base) are indurated, as illustrated in the lithostratigraphic section in Fig. 4.2.

The Shales in this unit are silty, with carbonaceous stains, which are mostly superficial. It is extensively weathered in some locations, resulting in reddish brown colouration in places. It is highly fractured which led to series of joints observed in the area. The major trend of the beds is in the NE –SW direction with southeastward dips. The shale occupies the synclinal part of the study area. Fractures observed trend mainly in the NW – SE direction. Outcrops in Okaria Nkaliki and 4 Bridge, Ndiabor Ishiagu Village of Mkpuma Akpatakpa were logged and described in Fig 4.2 and 4.3 respectively.

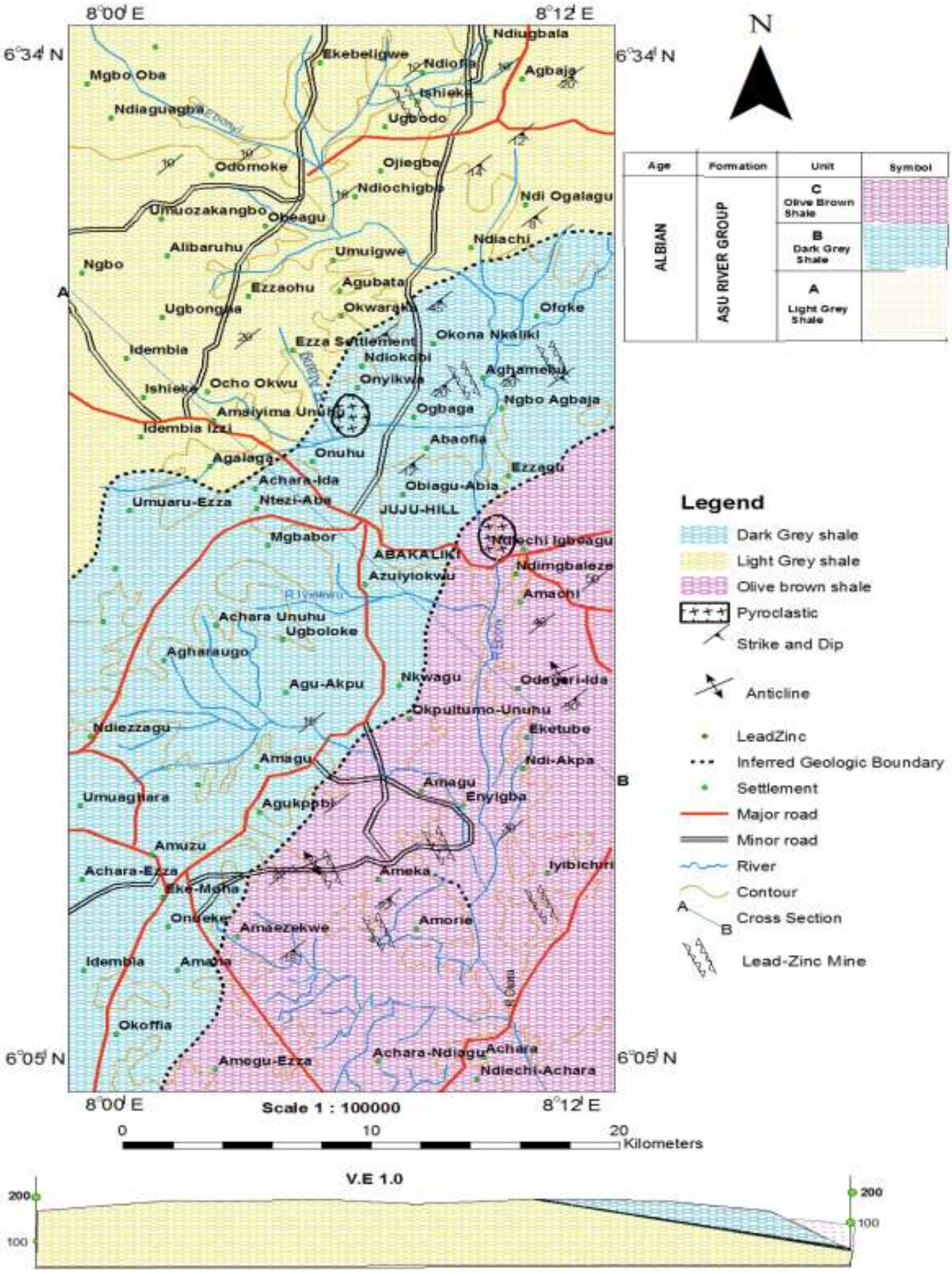


Fig 4.1: Geological Map of the Study Area.

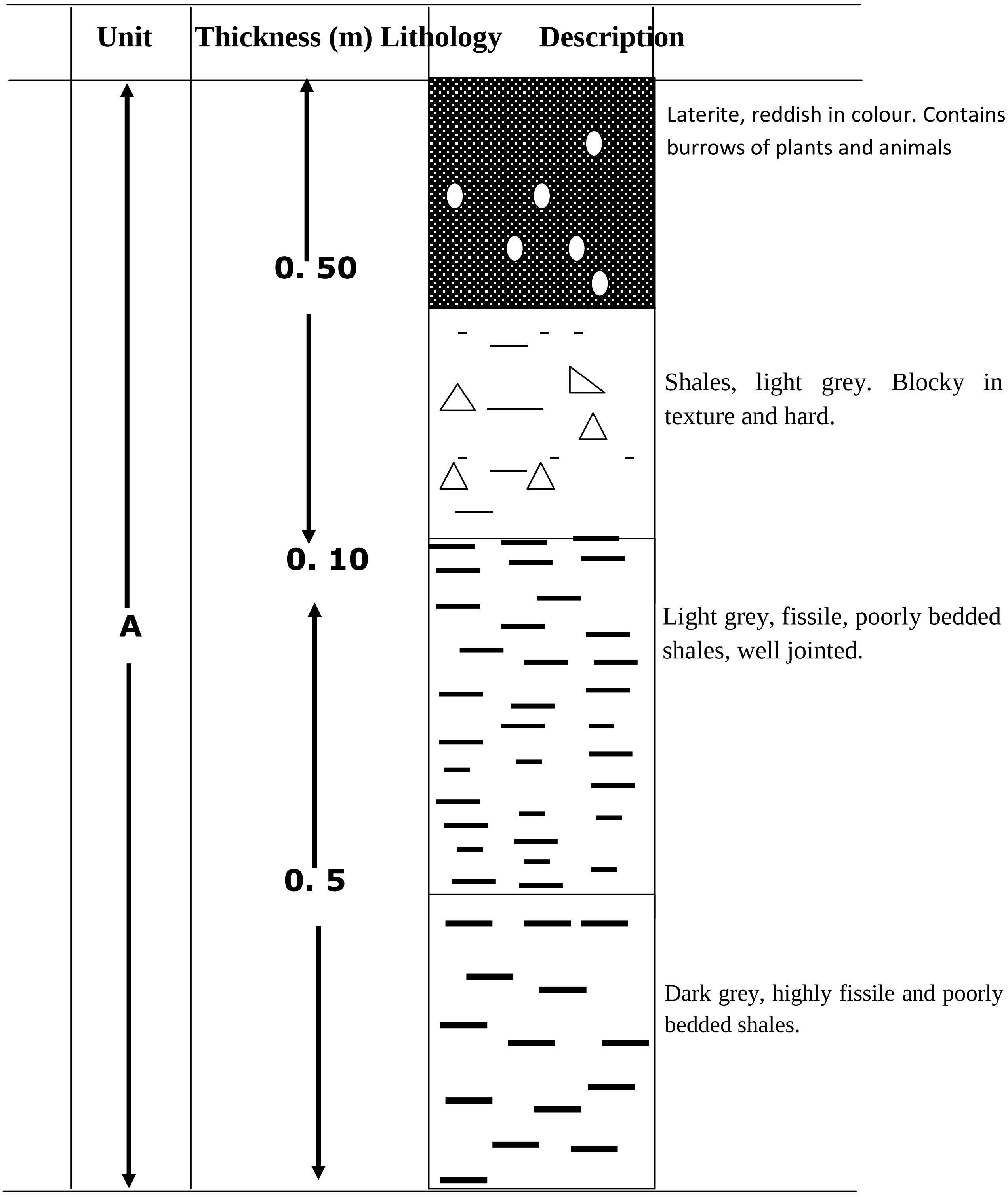
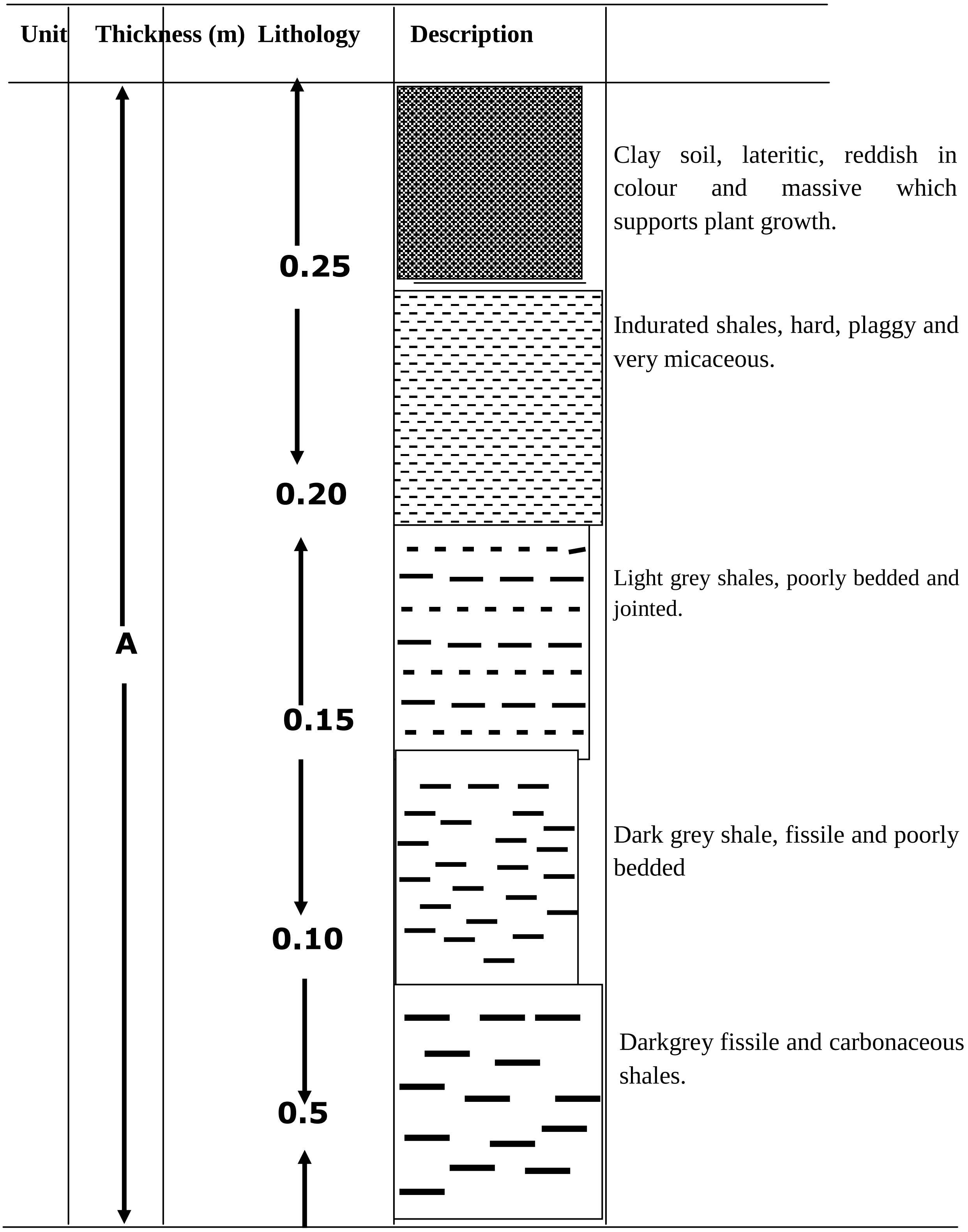


Figure 4.2: Lithostratigraphic log of shale outcrop at (4 bridge) along Ishiagu – Iboko road.



Clay soil, lateritic, reddish in colour and massive which supports plant growth.

Indurated shales, hard, plaggy and very micaceous.

Light grey shales, poorly bedded and jointed.

Dark grey shale, fissile and poorly bedded

Darkgrey fissile and carbonaceous shales.

Figure 4.3: Lithostratigraphic log of shale outcrop at Mpuma Akpatakpa.

Plate 4.1: Fissile shale, about 100m away from Nwofe Junction. X10

Plate 4.2: Outcrop of Light grey shales observed at Ololo River. X10

4.1.2 Unit B: Dark Grey Indurated Shale

This unit is composed of highly indurated shales, with dark grey colour (Plates 4.3 and 4.4). They are very hard and massive. The dark grey and black Shale occupies the core of the Abakaliki Anticlinorium which cut across the study area. The hardness of these rocks may be as a result of the magmatic activity that has affected them in the Santonian event. Induration in rocks refers to the hardening of rocks by heat or baking; it also refers to the hardening of sediments through cementation or compaction or both, without the introduction of heat. The features observed (such as hardness and lack of fissility) show that this unit was affected by the Santonian Orogeny. These shales are very hard and are used for engineering constructions within and outside the Abakaliki area. The indurated shales occur as massive and highly consolidated beds. The rocks strike in NE-SW direction, with dip amount ranging from 10°- 45° in the SE direction. They occur narrowly following a NE – SW axis and are well exposed in the Abakaliki urban where they are quarried. These shales were observed in various locations including Ebonyi River, Odomoke, Ishieke; along the Omunihu – Ekebeligwe road; Onyirigbo River, Ishieke; Okposi Umuoghara quarry site where they are beautifully exposed. Others are Ebonyi River, at Agbaja Unuhu, Ezzagu/Ikenyi River, Agbaenyim Village, Ebonyi River at Ngbo Agbaja, Mkpuma-Akpatakpa in Agbaja Village, Ololo River in Agbaja Village, Ndiabor River, in Ishiagu Village, Onuebonyi River and Egwudinagu River, about 100m to Egwudinagu Village.

Plate 4.3: Dark Grey shales observed at Ebonyi River, Odomoke, Ishieke

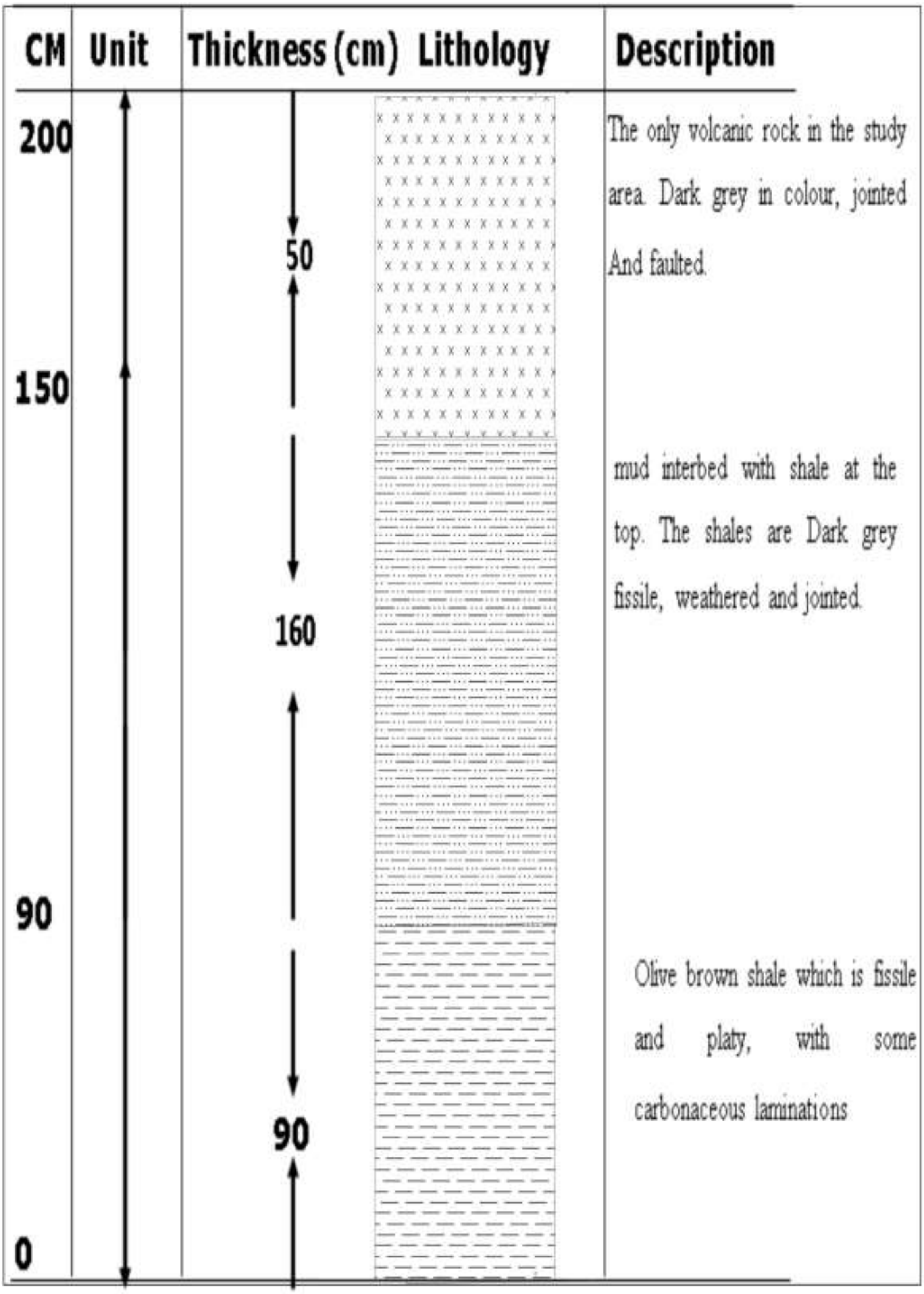
Plate 4.4: Dark Grey Shales observed in lead-zinc mine site in Ndiachi village.

4.1.3 Unit C: Olive (reddish) Brown Shale

This unit is made up of olive brown shale and was encountered at the base of juju hill, Agbaja community, 500m East of Hausa quaters junction, Ugboloke abandoned lead-zinc mine, besides rice mill and very prominently around Nwakpu areas of Ikwo LGA near Ndiufu Aleke Federal University. It is less-dominant in the lithostratigraphy of the study area. It is mostly exposed at road cuts. The shale is silty and shows carbonaceous streaks (Plate 4.5 and Fig 4.4). The carbonaceous (dark) patches appear mostly superficial. The shale is mostly flaky and intensely weathered in some places. It is also profusely jointed (Plate 4.5), with a general joint azimuth of NW-SE. The fractures vary from NE/SW to NW/SE direction. The beds generally strike in the NE-SW with an average dip of 20^0 in the South-East direction. The shale is composed of clay minerals, micaceous minerals as well as pyrite. However, only the shiny micaceous minerals (muscovite), pyrite as well as carbonaceous streaks are obvious in outcrops and hand specimen. These shales are olive (reddish) brown in colour withdark patches as seen in plates 4.5 and 4.6.

Plate 4.5: Fissile Olive brown shale, observed at the base of juju hill.

Plate 4.6: Fractures in Outcrop of the Olive Brown shale observed at Hausa quarters



The only volcanic rock in the study area. Dark grey in colour, jointed And faulted.

mud interbed with shale at the top. The shales are Dark grey fissile, weathered and jointed.

Olive brown shale which is fissile and platy, with some carbonaceous laminations

Fig 4.4: Lithostratigraphiclog of the outcrops observed at the base of Juju hill.

4.1.4 Igneous Intrusion

The Abakaliki area is characterized by the occurrence of baked shales and pyroclastic rocks. This has been linked to the Santonian epirogeny which affected the area. They were observed as intrusions on the shales and in some places, the baked shales show gradational contact, indicating actions of metamorphism.Igneous intrusions are predominant in high relief areas in the study area as observed at Juju hill of Abakaliki, Ezzagu pyroclastic quarry site, Ndiechi Hill, and Umuaghara where it is being quarried. In Egwudinagu and Ekebiligwe areas, they occur prominently as boulders, with medium- coarse grain sizes and grey in colour (Plate 4.8).

Plate 4.7: Pyroclastics outcrop (showing Zenolith) observed at Ministry of Works Quarry Abakaliki

Plate 4.8: Igneous intrusion observed at Ogboro River, Ekebeligwe, under the bridge.

4.2 Hyrogeology

The hydrogeology of an area is influenced by geology, structure, topography and physico-chemical composition of the rocks that underlain the area (Freeze and Cherry, 1979; Todd, 1980). The water resources of the study area consist of surface water and groundwater.

4.2.1 Groundwater Resources / Aquifer Characteristics

The geology of the area is mainly composed of shales and mudstones, although minor occurrences of sandstone, siltstone, sandy-shale and limestone were observed during the field work. The fractured shales form the main aquifer system, while the sandstone and limestone are complementary area. These fractures resulted due to the Santonian Orogeny which uplifted, folded and faulted the sediments, thus creating secondary porosity structures which houses groundwater. Fracturing has improved the water bearing potential of the shale. Within Abakaliki metropolis, these fractures trends majorly in the NW- SE (Fig 4.5) and are connected, their openings are upto 10cm on the surface, this can yield economic quantity of water. On the out skirt of Abakaliki, fracture system analysis also shows major trends of NW- SE with few in the NE- SW direction. These fractures are not prominent, and their openinings do not transmit sufficient amount of groundwater. This can be attributed to the high dip amount (38° - 52º) of the beds. This is accountable for the high number of aborted and very low yield wells observed around Iboko, Mkpuma Akpatakpa, Idembia, Isieke and Odomoke areas. Minor occurrences of the sandstones aquifers were also observed in some parts of Abakaliki metropolis. The sandstones, fractured shale and weathered shale/silt are potential aquifers, while the baked shales, mudstone and siltstone constitute aquitards. The sandstone of the Asu River Group and the Alluvial Deposits of the Ebonyi River forms the water table aquifers while the fractured shalesin the Abakaliki area form the semi-confined aquifer.

4.2.2 Rose Plots for joints and Fractures

Azimuths of joints and fractures were measured at various outcrops in the area. They include Onu- Ebonyi, Azoto – Amachi, Enyigba, River Ewe, Ebonyi River and Juju hill. These azimuths were used to plot rose diagrams for analysis of the major joint/ fracture trends (Appendix 1 to 7 and Fig 4.6 to 4.11). Rose plots show a major direction of NW – SE and a minor direction of NE - SW for the joint and fracures of the area. The mineralized lodes and veins were observed to follow the same trend. This can be linked to the tectonic activities in the area.

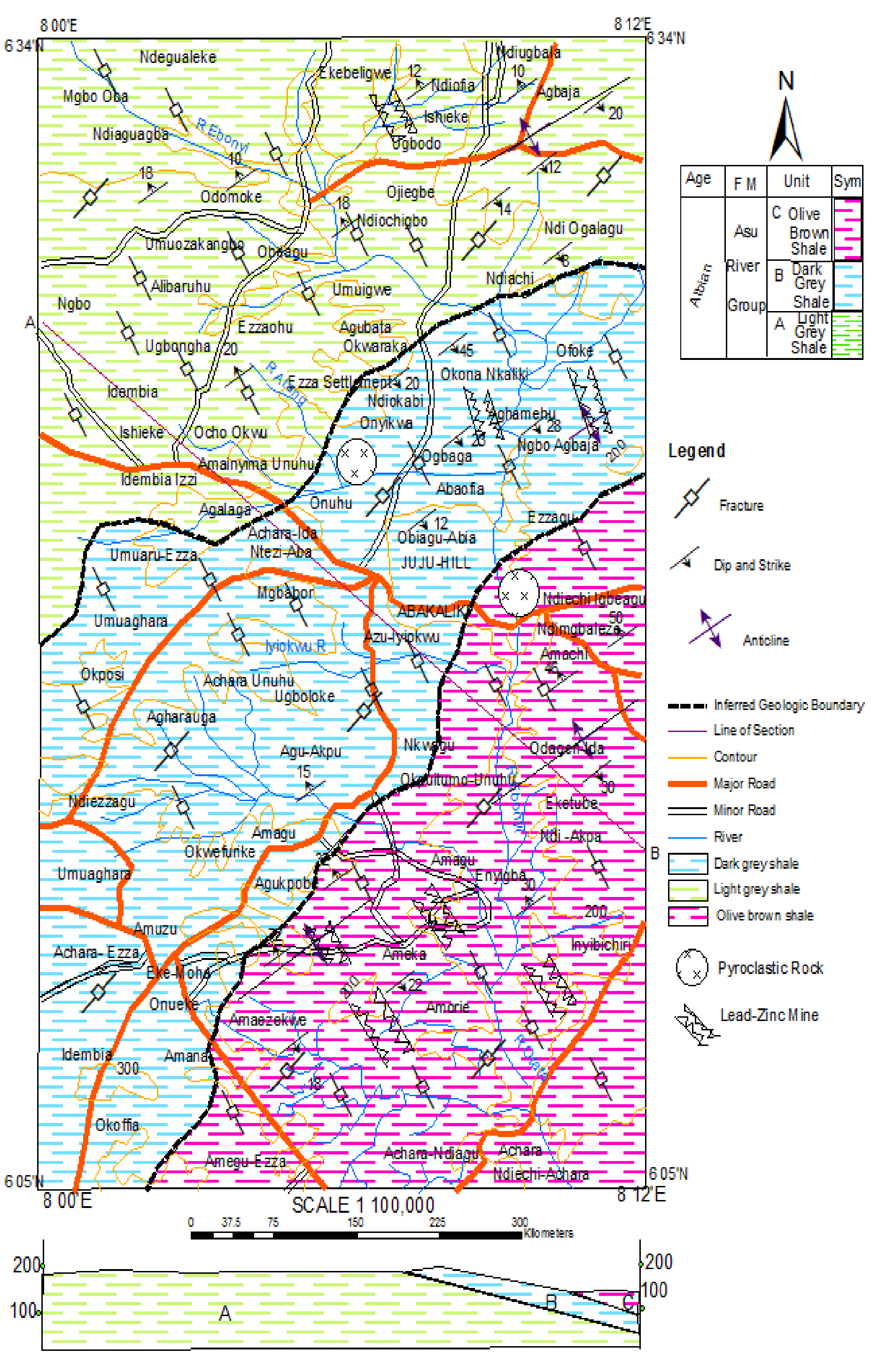


Fig 4.5: Fracture system of rocks of the study area.

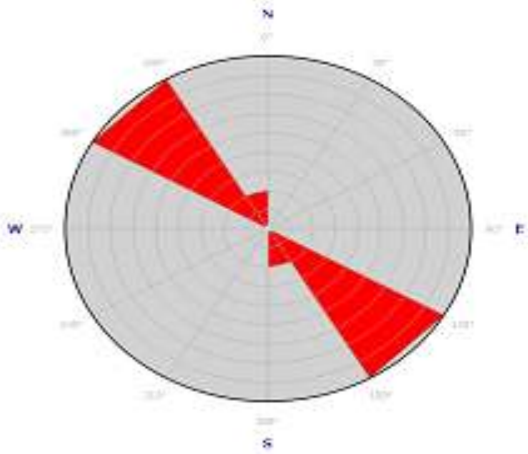


Fig 4.6: Rose plots of joint/ fractures observed at River Ebonyi at Onu Ebonyi.

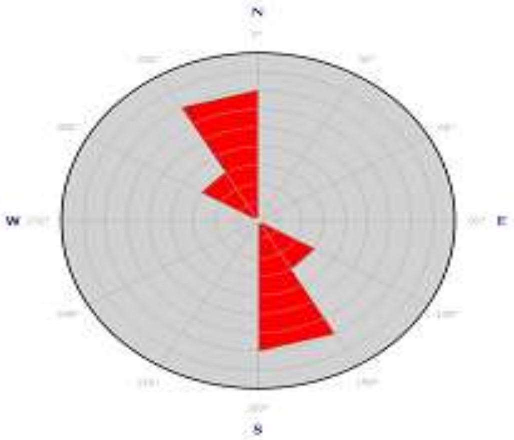


Fig 4.7: Rose plots of joints/ fractures observed at Juju hill.

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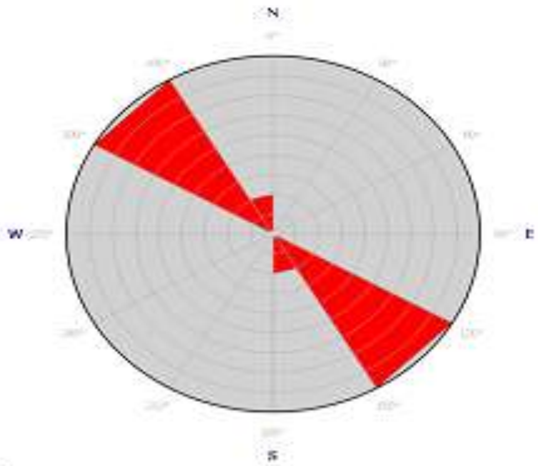

Fig 4.8: Rose plot of joints / fractures observed at Azuoto Amachi

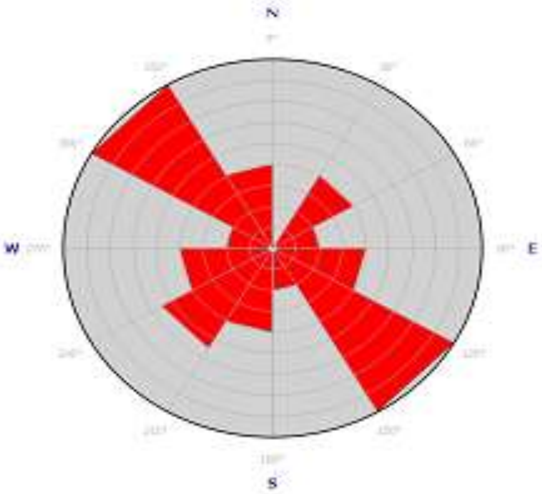

Fig 4.9: Rose plot of joints/ fractures observed at Enyigba.

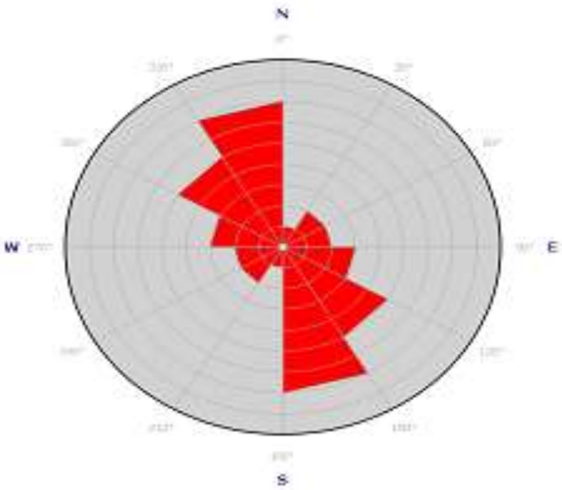

Fig 4.10: Rose plot of joints/ fractures observed at River Ewe, Mkpuma Akpatakpa

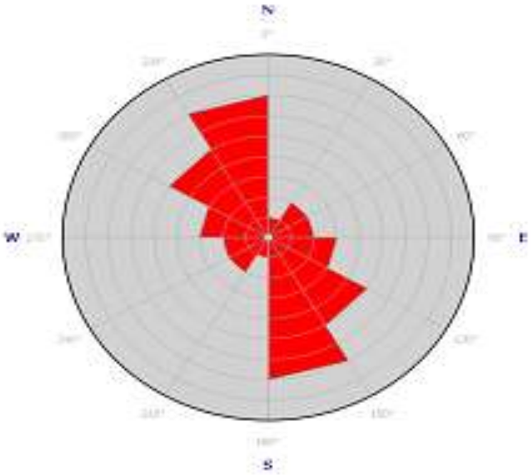

Fig 4.11: Rose plots of joints / fractures observed Onu-Ebonyi River, Mkpuma Akpatakpa.

4.2.3 Groundwater Flow Direction

Groundwater flow map shows the direction of flow of groundwater. It is very useful in the study of contaminant transport in hydrogeochemistry. It helps for proper management of groundwater resources with respect to waste disposal, plume migration, and effluent/ leachate movement. Recharge and discharge zones can be determined using groundwater flow studies. One hundred and ten (110) hand dug wells were observed for measurement of water level and depth of wells (Appendix 8).

The water table map (Fig 4.5), shows that there is no principal direction of groundwater for the area. This is due to the fracture system of the shales which make up the semi- confined aquifers. Fracture map (Fig 4.5), and rose plots of joints and fracture shows a NW- SE and NE – SW system (Fig 4.6 to 4.11). It also revealed that the fractures are not connected in all places. Two watershed flow patterns were observed in the area. These are the Isieke – Abakaliki- Amanchara and the Ezza-obia – Amagu – Ameka – Enyigba watershed pattern. Analysis of the flow direction shows that waters from the northwestern area flows radially away from the Isieke and Idembia areas (which makes up the highlands) to Ndiagu, Amanchara, Mpkuma Akpatakpa, Ezzagu, Umuaghara, and Achara – Unuhu areas (which makes up the the lowland areas) (Fig 4.13). The other watershed flow pattern shows that the water flows radially from the Achara- Ezza, Ezza- obia, Onueke, Amagu, Achara and Ndiakpa into the Ameka areas (Fig 4.12 and 4.13). However, because of the high elevation of Abakaliki, Idembia, Isieke and Enyibga areas, a regional radial flow pattern can be ascribed for the entire area. This implies that groundwater flows away from Isieke, Idembia, Enyigba and Abakaliki to other lowland areas. The implication of this to contaminant transport is that the rich carbonate composition of the Abakaliki Shale can flow in groundwater to other areas but the hydrochemical constituents of the Ameka, Enyigba, Amorie and Enyigba mining areas do not flow towards the Abakaliki area. This is also the same for the Mkpuma Akpatakpa and Amanchara mining areas. The flow direction indicates a westerly movement of groundwater from the Mkpuma Akpatakpa and Amanchara areas to the Ndiobulofia and Ezzagu areas. This also shows that the recharge zones are along the fractured shales and sandstone ridges/ hills of the Idembia, Isieke Enyigba, and Abakaliki areas, while the discharge zones are along the bases of the slopes forming the lowlands. Evidences for the discharge zones are the existence of seepages at the valley slopes. The continuity patterns of the flow system are demonstrated by the distribution of groundwater heads in the area.

The implication of this is very important in waste disposal and management. Groundwater recharge areas are not adequate sites for waste disposal, this is because they can easily pollute and contaminate groundwater sources. In Abakaliki metropolis, the waste management agency is currently using the abandoned quarry pits at Umuaghara as the central waste dumping sites. This is grossly inaprioppriate as this area is part of the recharge areas, and any waste input will flow to pollute or contaminate other areas. Moreover, the shales and pyroclastics which these quarry pits are composed of, have high frequency of joints and fractures which provides secondary porosity structures where these groundwater pollutant can be transmitted from one point to another.

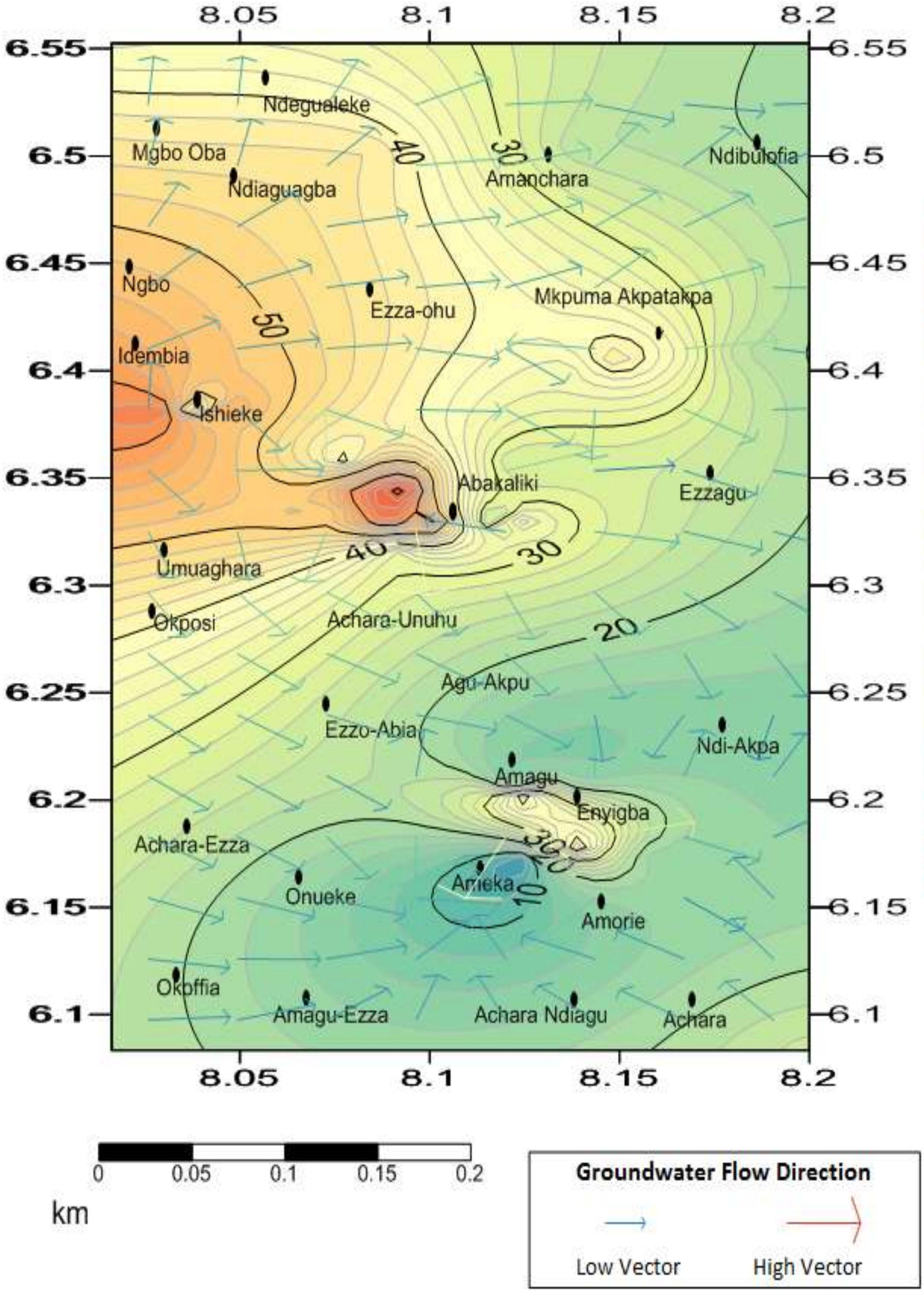

Fig 4.12: Contoured Groundwater Flow Map of the area.

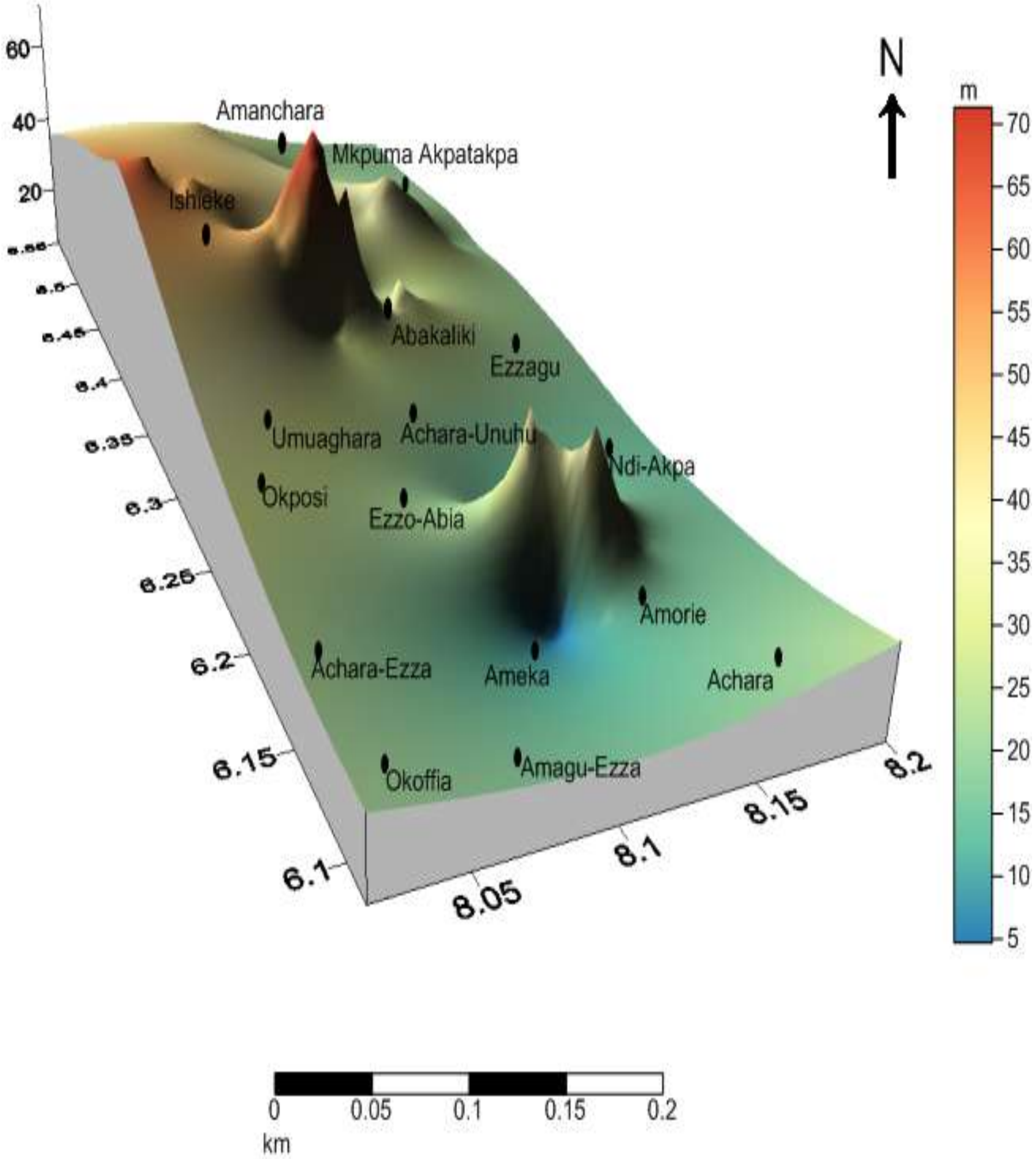

Fig 4.13: 3D Elevation map of the study area.

4.3 Results of Hydrochemical Analysis

The results of hydrochemical analysis are shown (Appendix 9 to 14). Appendix 9 to11 shows concentration of dry season samples while appendix 12 to 14 shows concentrations of rainy season samples.

4.3.1 Physical Parameters

Physical parameters include pH (H^+ concentration), turbidity; electrical conductivity, temperature, and total dissolved solids (TDS).

A. pH

The pH of water samples of dry season in the study area ranges from 0.96 – 9.53, while samples of rainy season ranged from 4.65 – 10.68. Dry season samples show that the surface waters are more acidic than groundwater. The pH of samples from mine sites, especially the active mines, ranged from 0.96 – 4.56. This indicates that the water is highly acidic, especially in areas like Enyigba, Amorie, Ameka and Mkpuma Akpatakpa, where active mining is on going.The pH of water samples analyzed shows that water sources (especially streams and rivers) in the Enyigba areas are more acidic than other mining areas of the Abakaliki area. Generally, the pH of water resources in the mining areas is not in line with the WHO guideline for drinking water, especially in rivers and streams closer to the mines. This acidity in the active mining areas can be attributed to the active chemical activities taking place in the area. This high acidity was observed in dry season samples, it is very worrisome because this is the time when the villagers suffer shortage of water, and they are left with no option apart from using this acidic water for domestic purposes.Villages affected by this high acidity include Enyigba, Okpuitumo, Amanchara, Oganga, Ezza- Obia, Ameka, Mkpuma Akpatakpa, Onuzu and Okaria Agbaja (Figs 4.14 and 4.15).

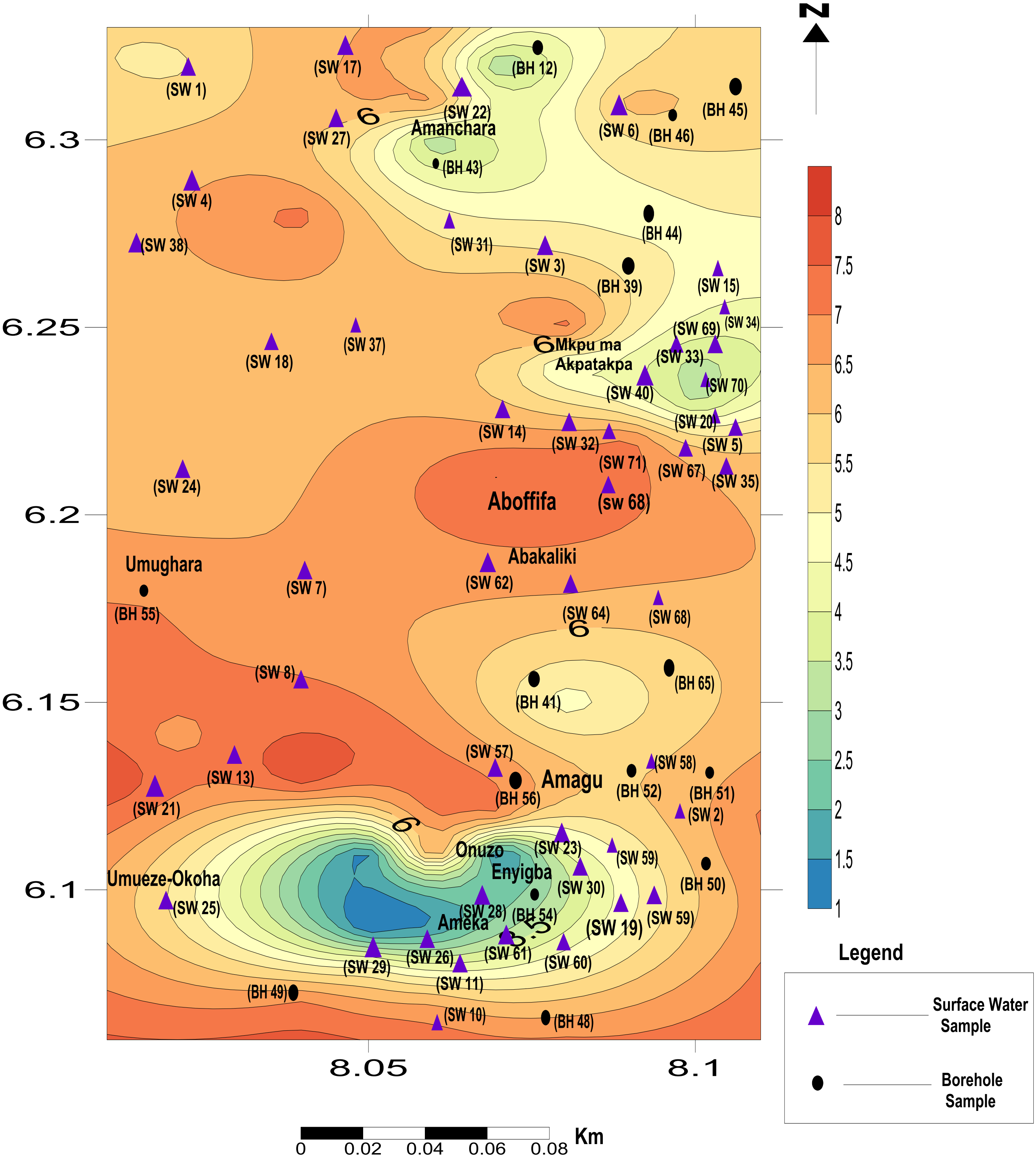

Fig 4.14: Contoured Distribution of pH in dry season Water Samples Analysed.

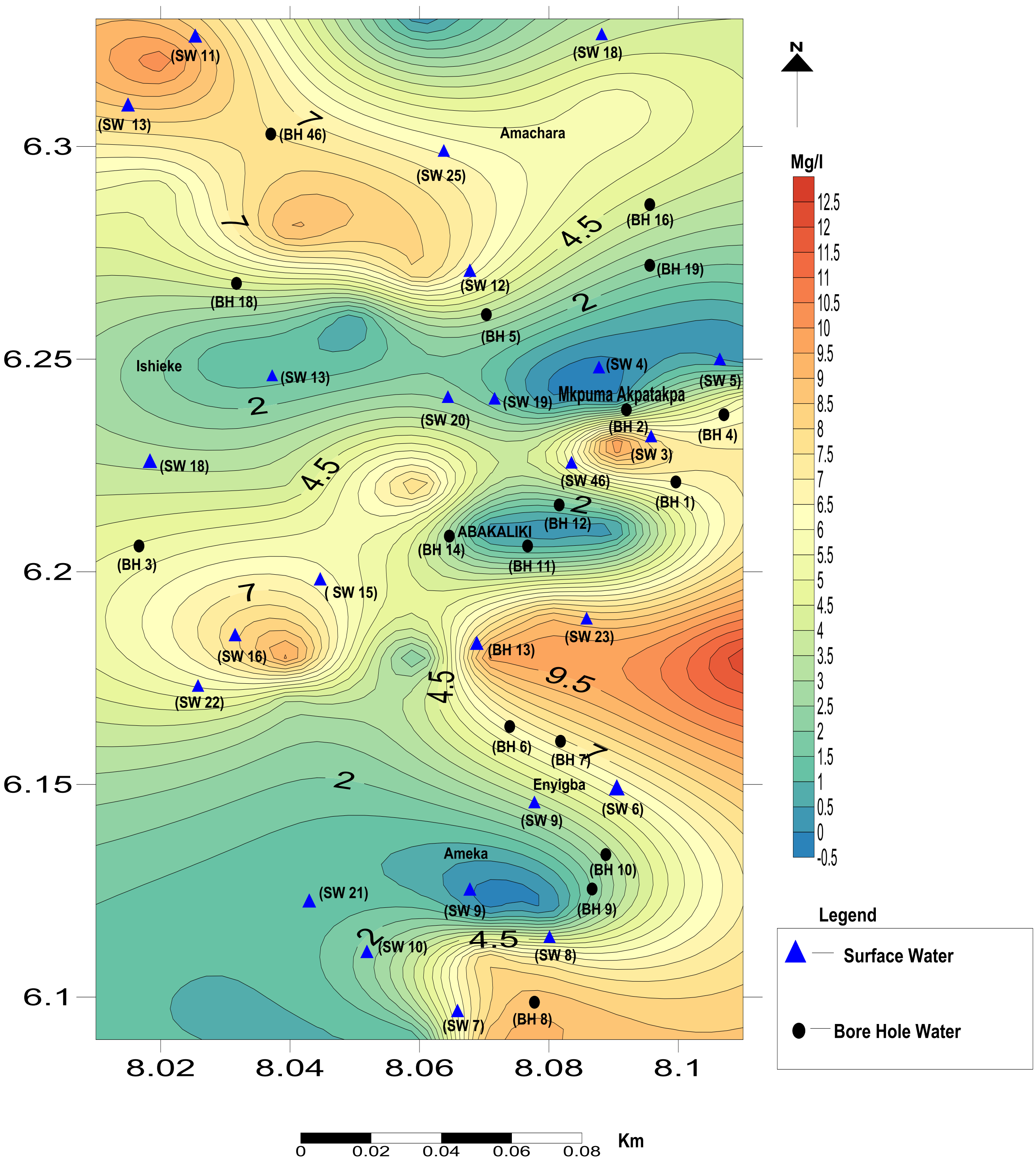

Fig 4.15: Contoured distribution of pH in rainy season water samples analysed

B.Turbidity

The turbidity of the water samples analysed in the dry season ranges from 8 - 940 NTU, while that of rainy season ranges from 0.01 -38.2 NTU (Figs 4.16 to 4.17). Although there is a wide range of values, this result shows that surface water sources are more turbid than groundwater, especially for the dry season samples. However, it was observed that the tributories and distributories of the Ebonyi River around Enyigba and Mkpuma Akpatakpa have high turbidity. Considering WHO, 2011 standard for drinking water, turbidity exceeding 1NTU is not good for domestic use. Therefore, the available water sources in the area are considered turbid.

C. Electrical Conductivity

The electrical conductivity of dry season water samples ranges from 0.17 - 918μScm^{-1}, while that of rainy season ranges from 9.8 – 28.26μScm^{-1}. However, high values of electrical conductivity were recorded in the areas close to the mines (Figs 4.18 and 4.19). The mine waters show very high conductivity values, especially in the dry season samples. Such high values were recorded in sample 20 (Mkpuma Akpatakpa mine, 918μS cm^{-1}; sample 26 (Enyigba mine, 404μS cm^{-1}); sample 28 (Onuzu mine, 406μS cm^{-1}) and sample 70 (Mkpuma Akpatakpa mine, 850μS cm^{-1}). This can be attributed to the high content of charged ions due to oxidational processes going on in the mines. This conductivity does not exceed the WHO, 2011 limit of 1000μS cm^{-1}. It is worthy of note that conductivity is lower in surface water sources than in groundwater. High values were observed at the water sources closer to the mines. From figs 4.18 and 4.19, a southeasterly trend can be ascribed for electrical conductivity of the area. This indicates the high conductivity areas, while the northwestern parts show low electrical conductivity for water sources.

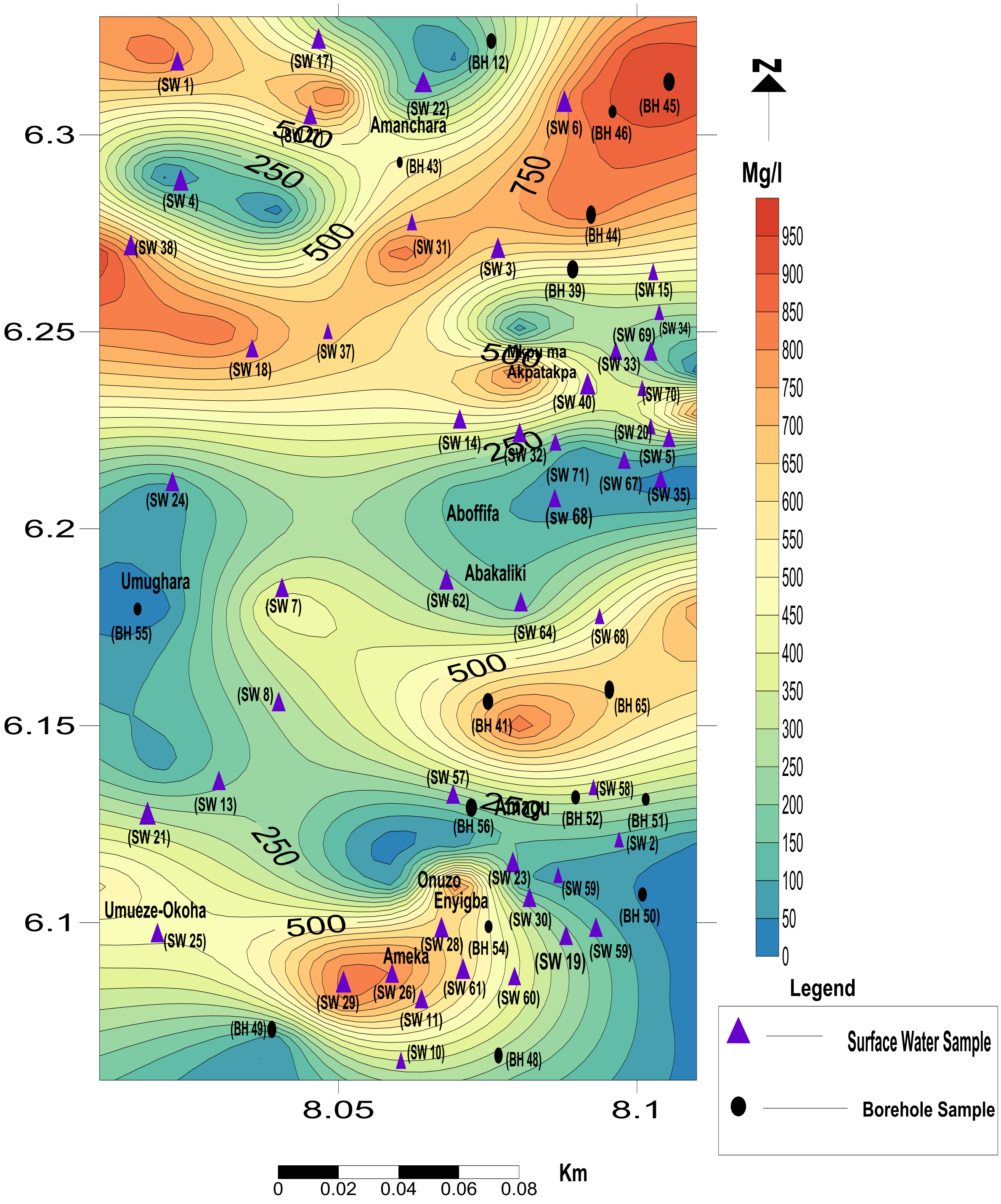

Fig 4.16: Contoured distribution of Turbidity in dry season water samples analysed

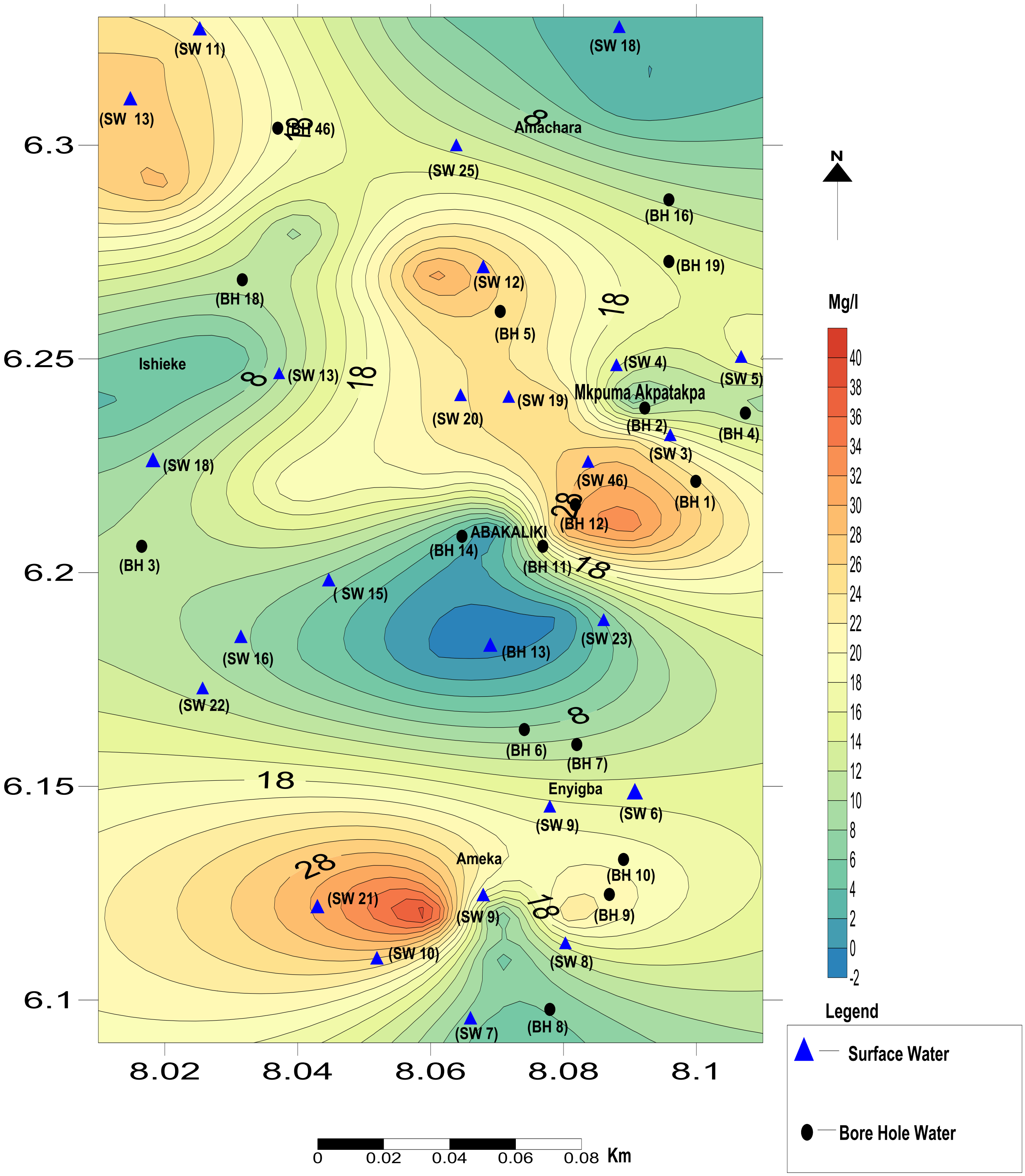

Fig 4.17: Contoured distribution of turbidity of rainy season water samples analysed

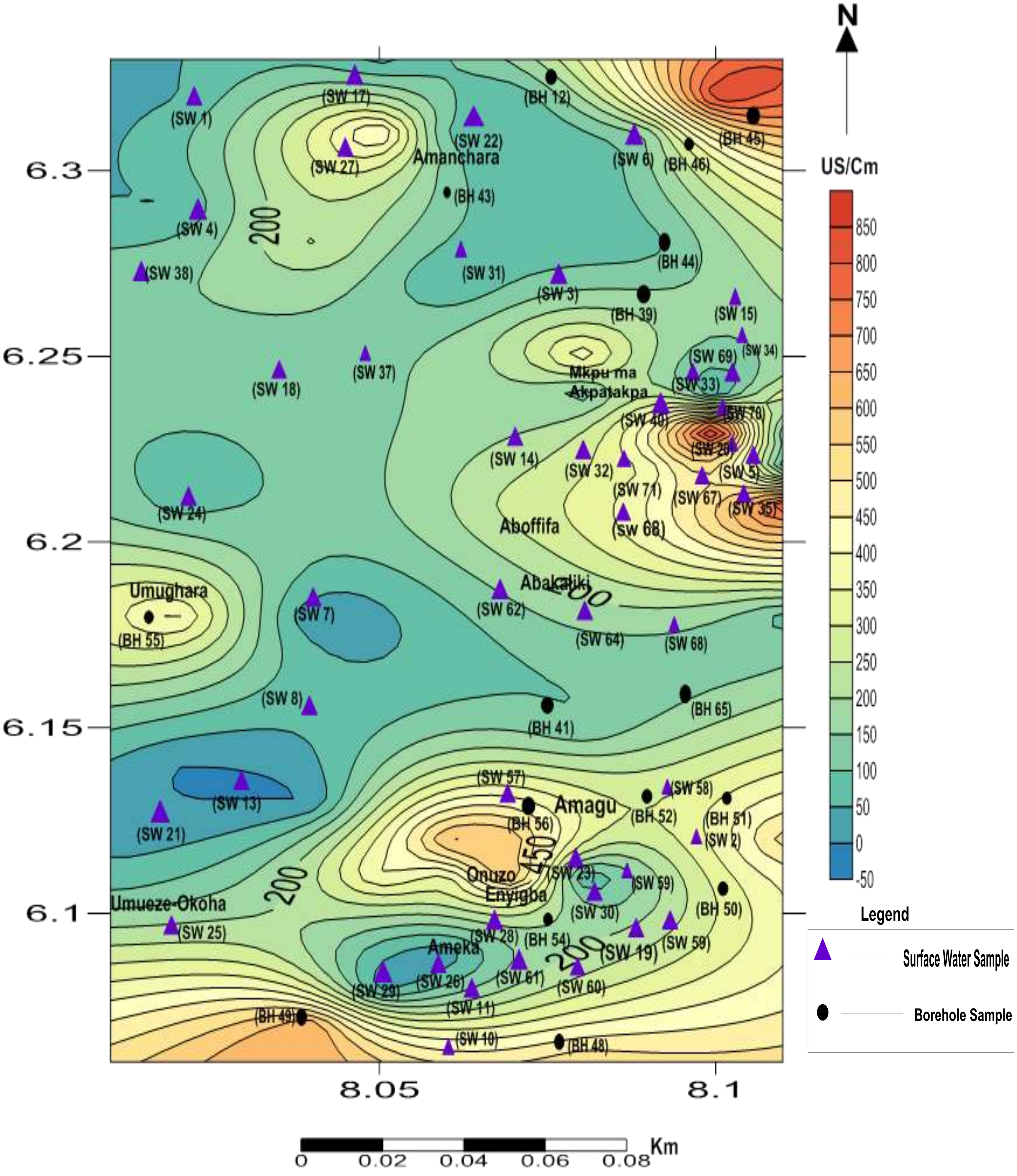

Fig 4.18: Contoured Distribution of Electrical Conductivity in dry seasonwater samples analysed.

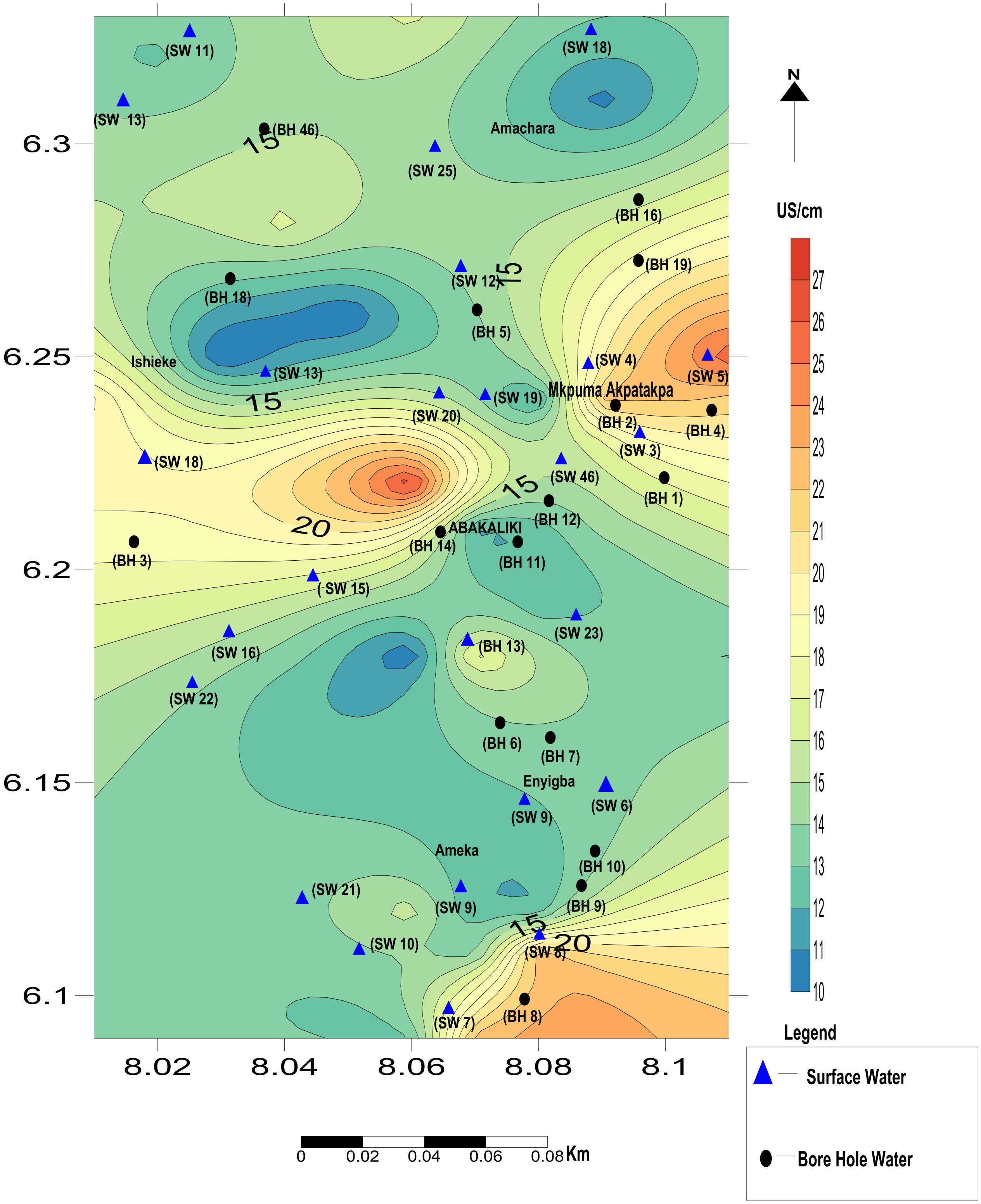

Fig 4.19:Contoured distribution of electrical conductivity of rainy season water samples analysed

D. Total Dissolved Solid (TDS)

In the first edition of the WHO Guidelines for Drinking-water Quality, (published in 1984), a guideline value of 1000 mg/litre was established for TDS, based on taste considerations. However, the presence of high levels of TDS in drinking-water (greater than1200 mg/litre) may be objectionable to consumers (WHO, 2011). Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste.From the analysis, the TDS of dry season water samples analysed ranges from 1.01 – 281 mg/L for both surface water and groundwater, while TDS values for rainy season samples ranged from 0.361 – 33.74 mg/L (Figs 4.20 and 4.21). This value is below the WHO limit of 1000 mg/L for drinking water. No specific trend was shown in the contoured diagram, but the result show that water sources from the mining sites have higher TDS.

E. TEMPERATURE.

Temperature is the measure of the degree of hotness or coldness of a body. The temperature of water sources of the area ranges from 17^0 C to 27^0C for both dry and rainy season samples. This shows that water sources in the area are not of magmatic or volcanic origin, which would have induced high temperature. Dry season samples show higher temperatures than rainy season samples, due to natural variations in atmospheric temperatures. Cool water is generally more palatable than warm water, and temperature will impacton the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth ofmicroorganisms and may increase taste, odour, colour and corrosion problems (WHO, 2011). However, contoured distribution of the temperatures of water samples analysed shows that water sources from the mining areas have higher temperatures than other areas (Fig 4.22). The result also shows a NE – SW trend of the higher temperature water.

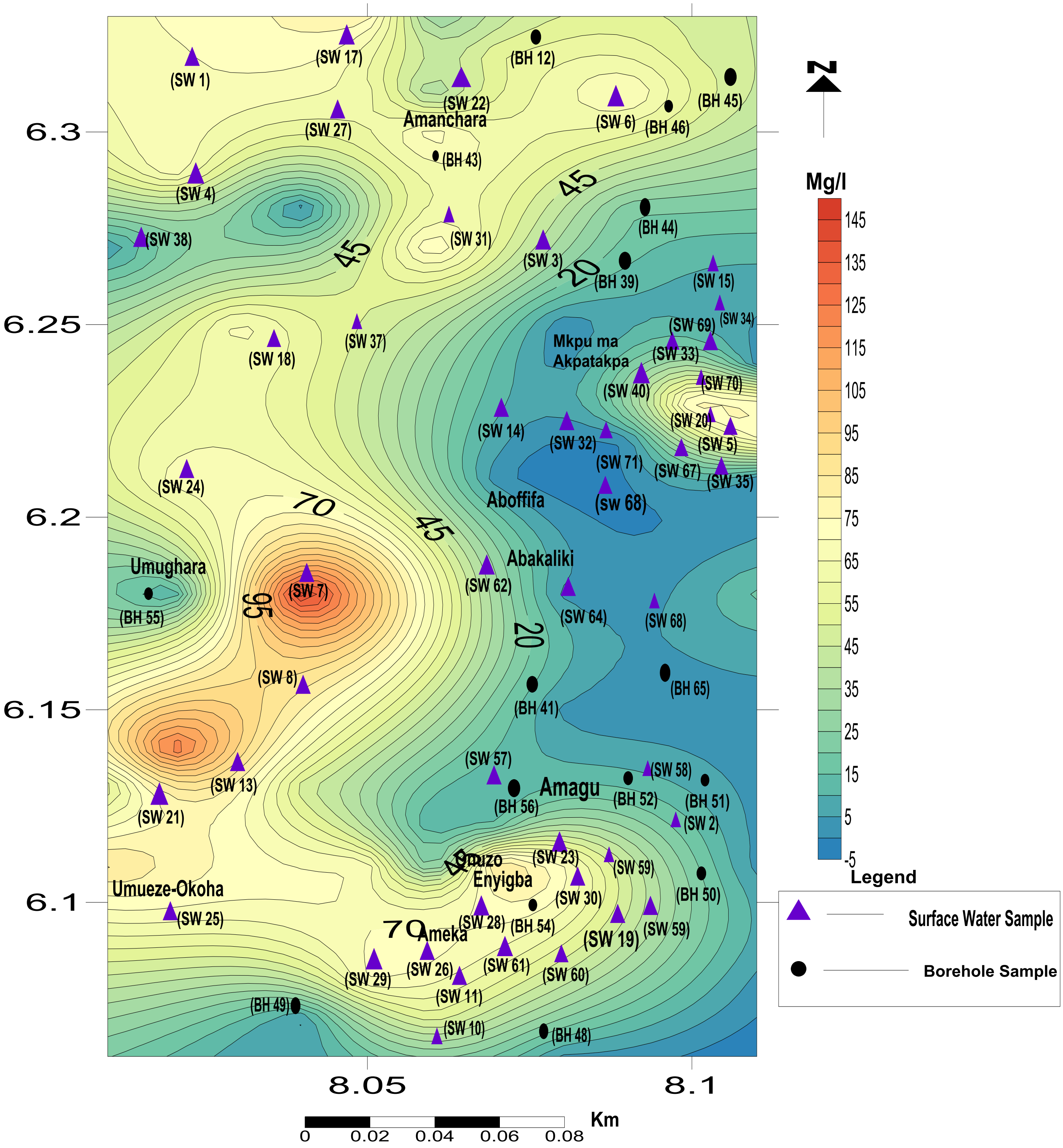

Fig 4.20: Contoured distribution of TDS in dry season water samples analysed

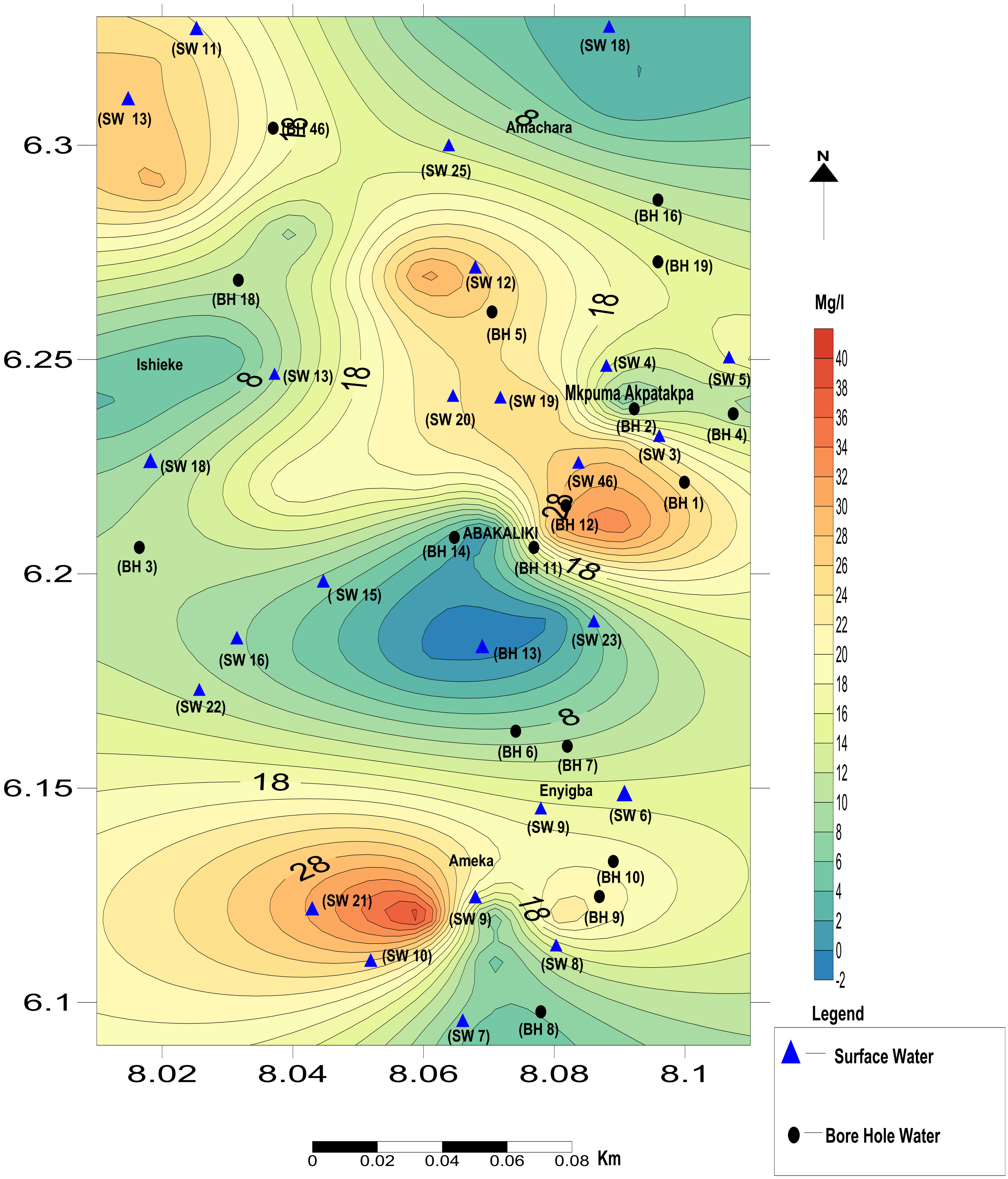

Fig 4.21: Contoured Distribution of TDS in rainy Water Samples Analysed

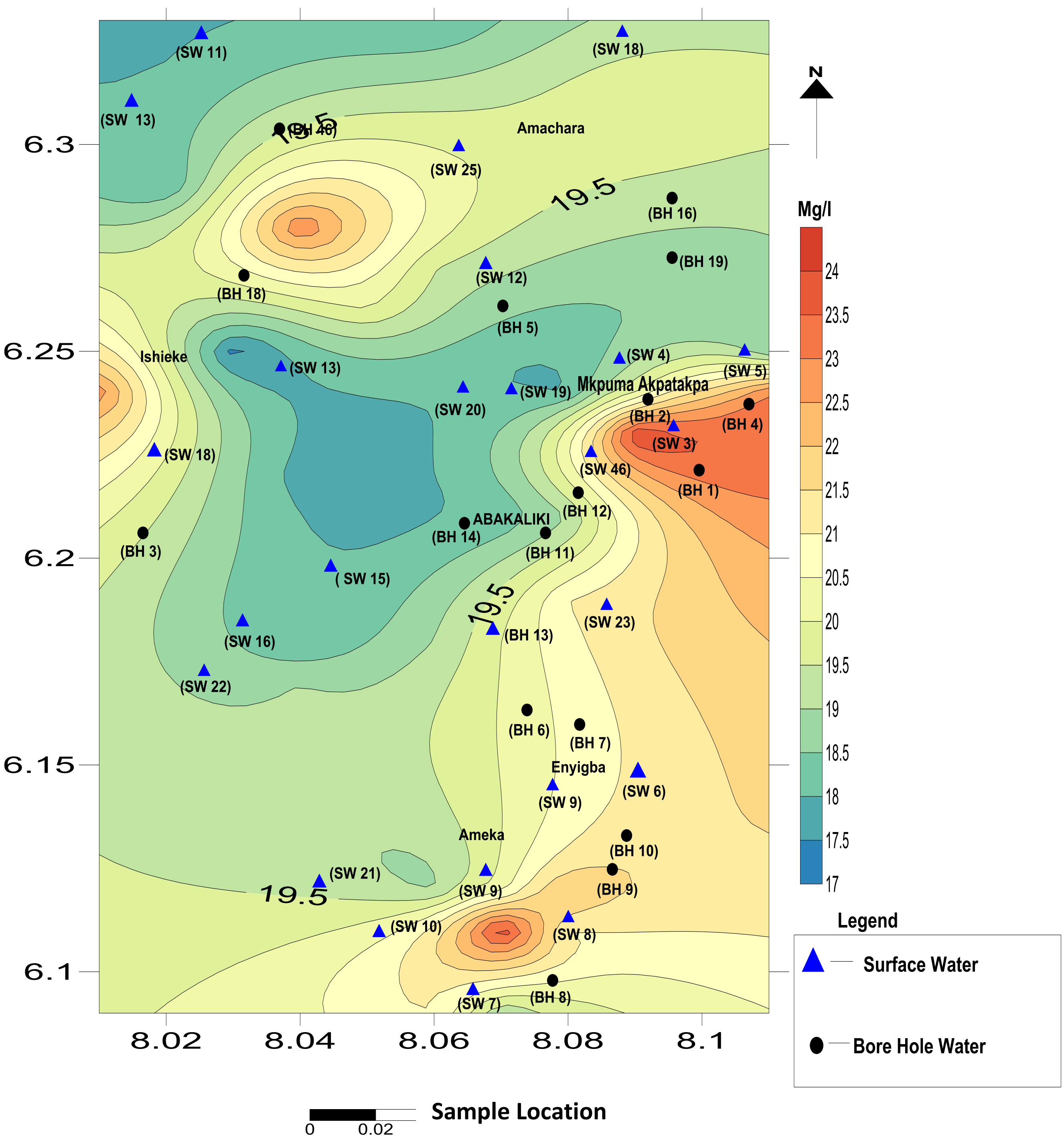

Fig 4.22: Contoured Distribution of Temperature in dry season Water Samples Analysis

4.3.2 Chemical Parameters

The chemical parameters include the concentration of dissolved chemical constituents in water. Some might be of organic or inorganic origin. For easy discussion of this analysis, the chemical parameters have been grouped into major cations and major anions, and minor/trace constituents.

4.3.2.1 Major Cations

A. Calcium Ion (Ca^{2+}).

Calcium ion (Ca^{2+}) is commonly present in natural waters, often resulting from the dissolution of calcium-rich rocks. It may occur as carbonates and sulphates of calcium, as in limestone, dolomite, chert, flint and gypsum. The salts of calcium, together with those of magnesium, are responsible for the hardness of water (IPCS, 1994). Ca^{2+} values of water samples (dry season samples) in the study area ranges from 0 mg/L- 191mg/L while those of rainy season ranged from 3.41mg/L – 51.281mg/L. This result shows that groundwater sources are higher in calcium than surface water. This is as a result of the dissolution of calcium in the rocks of the area. Shales are composed of high amount of calcium. Water samples from areas around Mkpuma Akpatakpa, Ameka and Abakaliki have high concentrations of calcium especially in the dry season (Fig 4.23). This is attributable to the carbonaceous content of the dark grey shales and the baked (black) shales which underlie the areas. Although, the WHO 2011 guideline for drinking water does not state a permissible limit, it stated that concentrations in excess of 75 mg/Lin water can be unpalatable. This indicates that water sources around Aboffia, Onuzu and Enyigba are not potable, especially in the dry season. Contoured distribution of calcium for both seasons (Figs 4.23 and 4.24) shows that the dark grey and baked shales have an influence on the hydrochemistry of the area. They also show that the mining areas have higher concentrations of calcium, these concentrations reduces away from the mining areas.

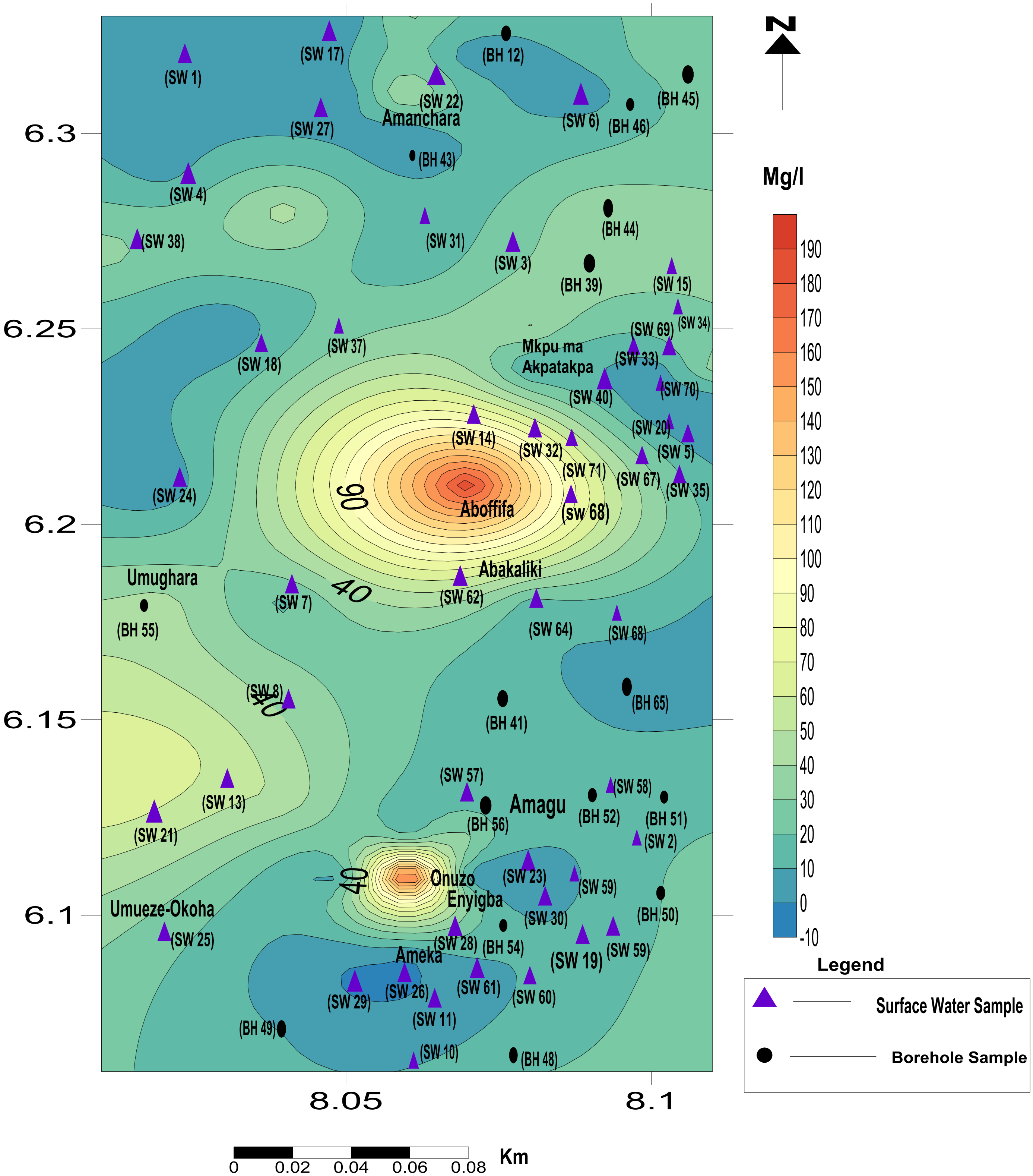

Fig 4.23: Contoured Distribution of Calcium in dry season water samples analysed

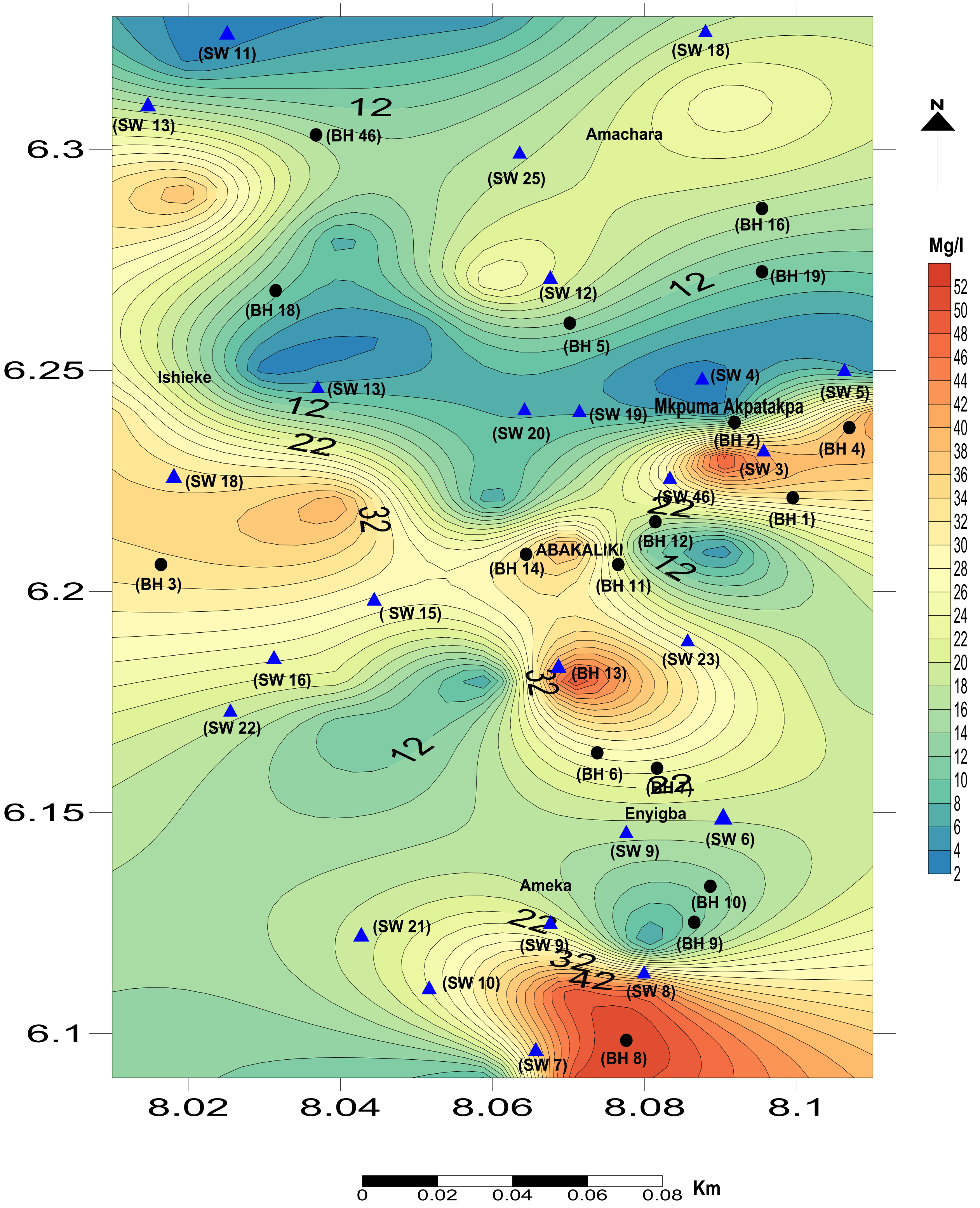

Fig 4.24: Contoured distribution of Calcium in rainy season water samples analyse

B. Iron Ion (Fe^{2+})

Iron is present in surface water and groundwater but its concentration is very minor and variable (WHO, 2011). It mostly occurs in the form of ferrous bicarbonates ($Fe(HC0_3)_2$), ferrous sulphate ($FeS0_4$), or ferrous chloride ($FeCl_2$), especially when it occurs in acidic surface water (WHO, 1993). The values of iron (Fe^{2+}) in the dry season water samples of the study area ranges between 0 to 58.2 mg/L, while rainy season samples ranges between 0 mg/L – 31.58 mg/L. This shows very high concentration of iron. This result also indicates that groundwater has lower concentrations of iron in the study area, with higher values in the dry season. WHO (2011) guideline for drinking water does not state any limit for iron, but indicated that value of Fe^{2+} exceeding 0.3mg/l can pose some risk on the usability of the water. The result indicates localized contamination of iron in the mining areas. High contamination was observed around Mkpuma Akpatakpa, Enyigba and Alibaruhu, (Figs 4.25 to 4.26) and in mine water. The localization can be attributed to the non connectivity of the fractures of the area. This result also shows that the pyrite and siderite contents of the chalcopyrite mineral play a significant role in the hydrochemistry of the area. The high concentration of iron in the water sources indicates the high rate of dissolution / oxidation of iron in the area. "Chalybeate" or "ferruginous" have been used to describe water of high Fe^{2+} content (Ogunji *et al.*, 2004). Chalybeate is used if the water has got iron taste, while ferruginous implies that the water has rusty (iron) colour. Pipkin, (1994) associated the bitter sweet astringent taste in drinking water and the staining of clothes and porcelain to high concentration of Fe^{2+}(values between 1 mg/L to 2 mg/L). Iron also promotes the growth of "iron bacteria," which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. At levels above 0.3 mg/L, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/L, although turbidity and colour may develop (WHO, 2011).

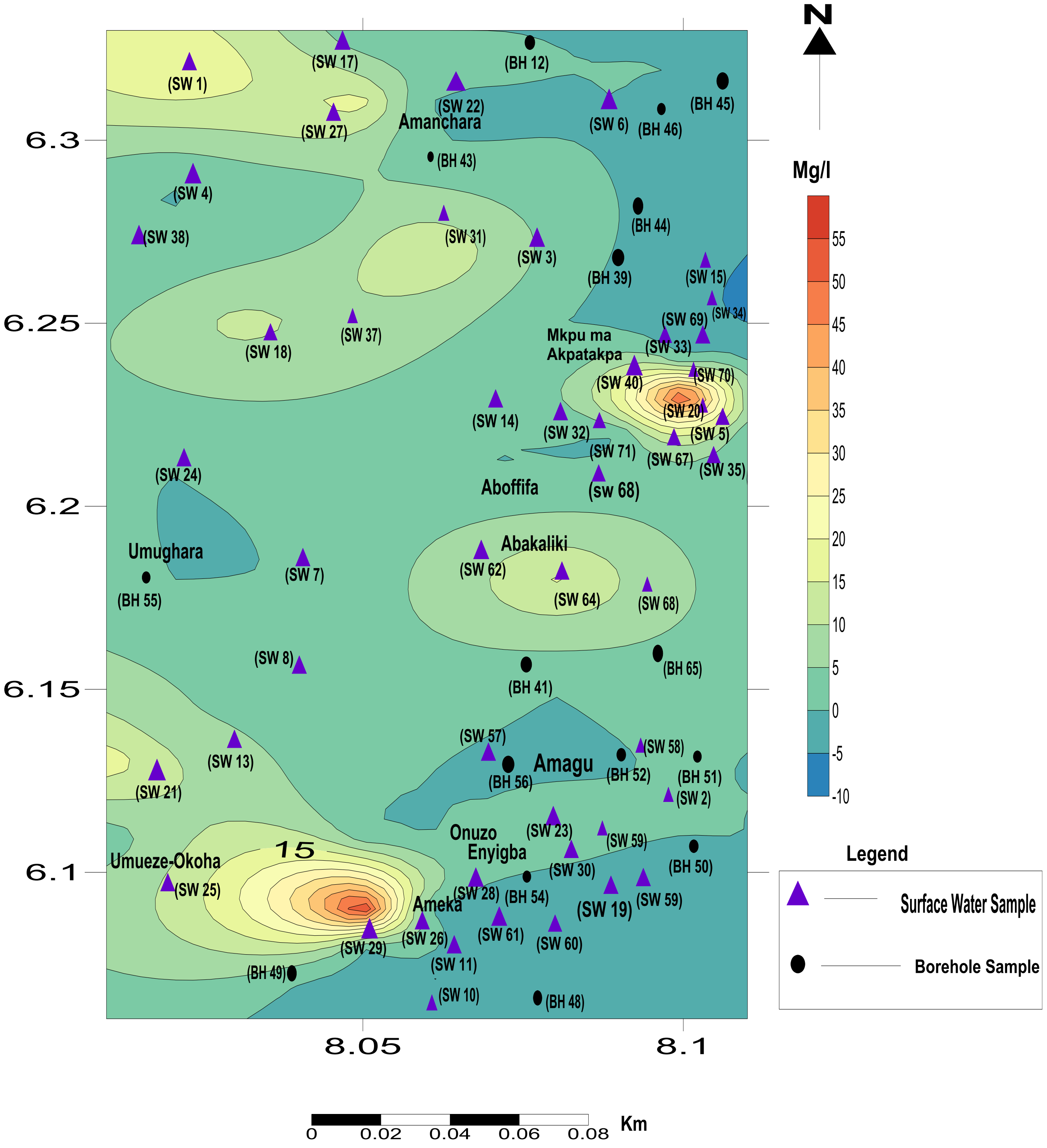

Fig 4.25: Contoured Distribution of Iron in dry season water samples analysed.

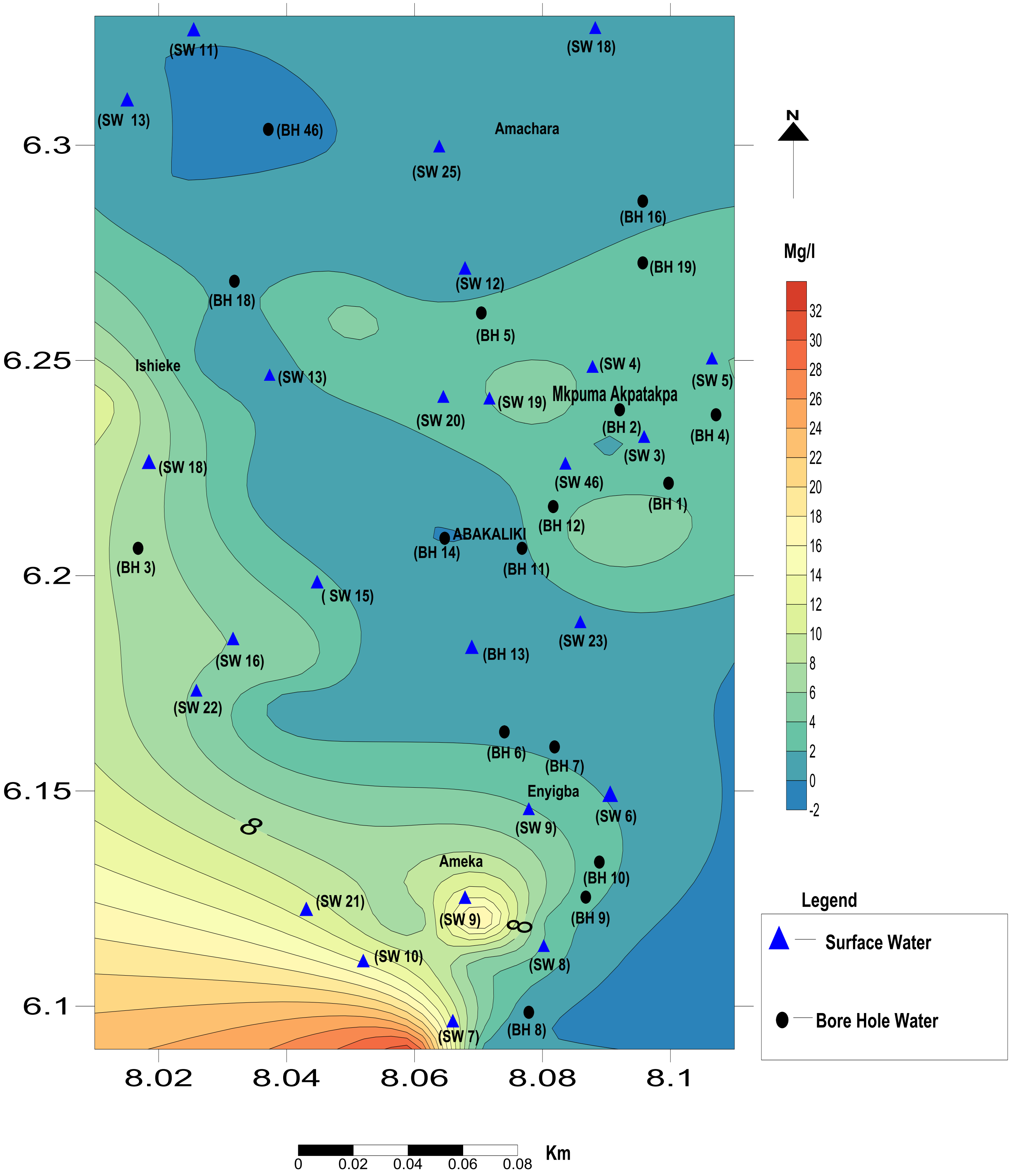

Fig 4.26: Contoured distribution of iron in rainy season water samples analysed

C. Magnesium Ion (Mg^{2+})

Magnesium ion (Mg^{2+}) is very common in natural waters. It has always been associated with water hardness. In natural water it occurs in the form of Mg^{2+}, magnesium carbonate ($MgCO_3$), magnesium sulphate ($MgSO_4$) or in some organo-metallic compounds and organic matters. Its sources in natural water include amphiboles, olivine, pyroxene, dolomite, magnesite and other clay minerals (Tijani *et al*., 1996). Apart from its effects of hardness in association with calcium ion (Ca^{2+}) to cause clogging in pipes, furring in kettles and boilers, and soap wastage to form suds, high concentrations of magnesium has a laxative effect, especially on new users of the supply (Todd, 1980).

The analysis revealed that the magnesium ion concentration in dry season water samples in the area ranges between 0 mg/L –178.89 mg/L while rainy season samples ranged from 0mg/L – 10.59 mg/L. High values were observed in water samples at Ezza – Abia (178.89 mg/L) (Figs 4.27 to 4.28). WHO, (2011) standards indicate that the permissible limit for magnessium is 50 mg/L. This implies that apart from the Ngele Ocha (Sample 13), surface water and groundwater sources in the area have low concentrations of Mg^{2+}. However, water sources in these areas have been reported to show excessive hardness in laundry and furring in kettles. Okagbue and Ukpai, 2013 opined that this is due to high content of magnesium in the water sources. In the study area magnesium is sourced from weathering of rocks containing ferromagnesian minerals and from carbonate rocks. A comparison of the two seasons shows higher dissolution in the rainy season, than dry season. No particular trend was established for magnesium.

D. Potassium Ion (K^+) and Sodium Ion (Na^+):

Potassium (K^+) and sodium (Na^+) are present in natural waters in low concentrations. They occur in plant and animal matters, and may be introduced to the environment as sewages, industrial effluents, agricultural fertilizers and other farm inputs. All these are leached into natural waters, contributing to concentrations in natural waters (WHO, 2011). Sodium salts (e.g., sodium chloride) are found in virtually all food (the main source of daily exposure) and drinking-water. WHO (2011), also stated that although concentration of sodium in potable water is typically less than 20 mg/L, they can greatly exceed this in some countries. It should be noted that some water softeners can add significantly to the sodium content of drinking-water. WHO, (2011), clearly noted that no firm conclusions can be drawn concerning the possible association between sodium in drinking-water and the occurrence of hypertension. Therefore, no health based guideline value is proposed. However, concentrations in excess of 200 mg/Lmay give rise to unacceptable taste (WHO, 2008).The concentration of Na^+ and K^+ in natural water is generally less than 200 mg/L and 50mg/l respectively. More than 50 mg/L of potassium in the presence of suspended matter causes foaming, which accelerates scale formation and corrosion in boilers. Sodium and potassium carbonate in recirculating cooling water can cause deterioration of wood in cooling towers. Higher concentrations can cause problems in ice manufacture (Todd, 1980).

The concentrations of Na^+ and K^+ in the study area is relatively high especially in the dry season. Concentrations of dry season samples for Na^+ ranged from 0 mg/L – 120.89 mg/L while rainy season samples ranged from 1.178mg/L -11.902mg/L. Concentrations of K^+ in dry season water samples ranged from 0mg/L – 33.85 mg/L, while rainy season samples ranged from 0 - 21.48 mg/L. High values of sodium were recorded at Amanchara, Ndiabor Ishiagu and the Enyigba areas, especially in groundwater samples. Values of Potassium were moderately high in groundwater samples analysed (Figs 4.30 and 4.32). Water sources (especially groundwater) have always caused scales in boilers and foaming during boiling. The sources of this high concentration are groundwater which migrates from the Enyigba salt lake and weathering of volcanic rocks in the area which intruded the Asu River shales (Igwe *et al.*, 2013; Igwe *et al.*, 2014).

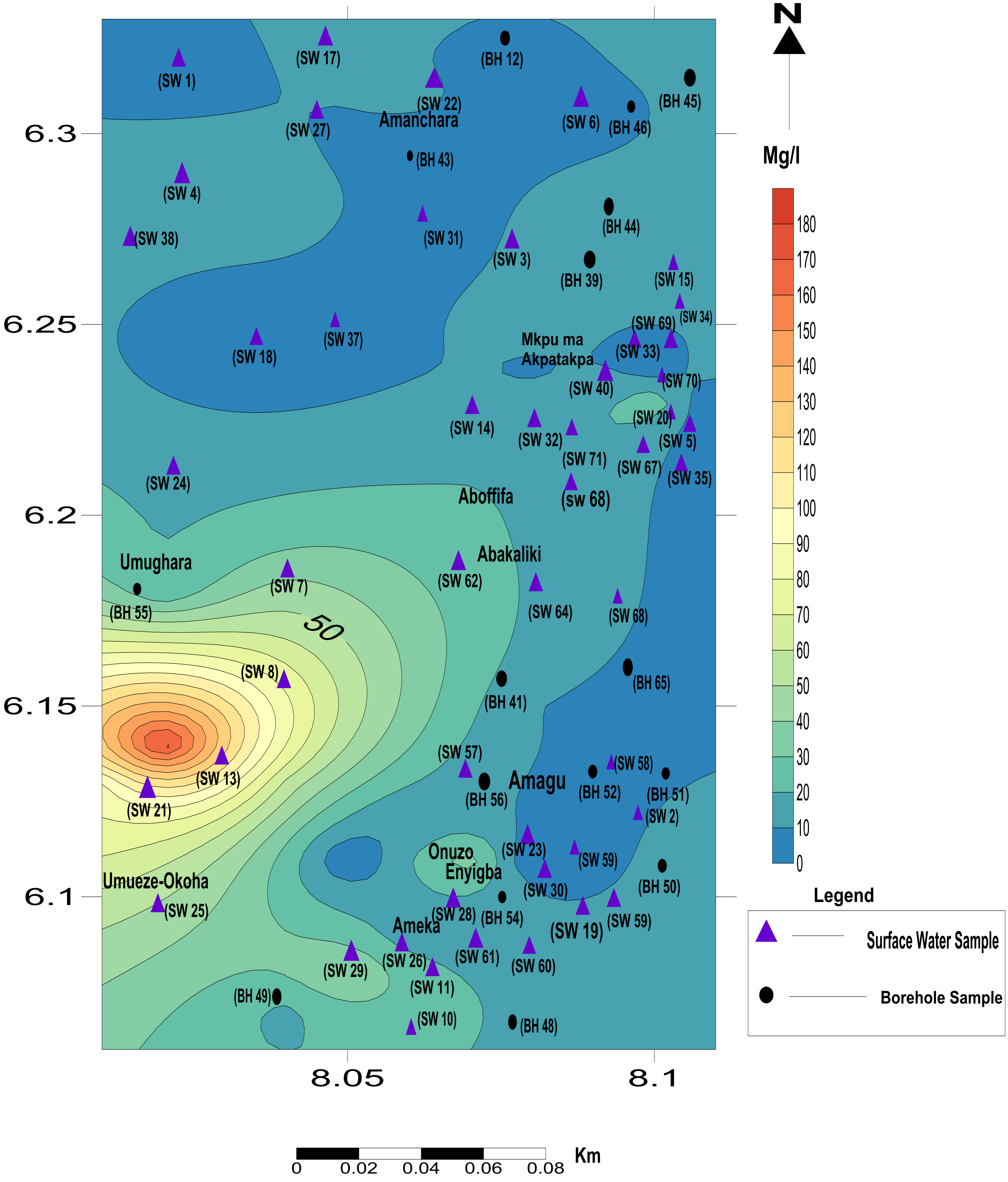

Fig 4.27: Contoured Distribution of Magnesium in dry season water samples analysed

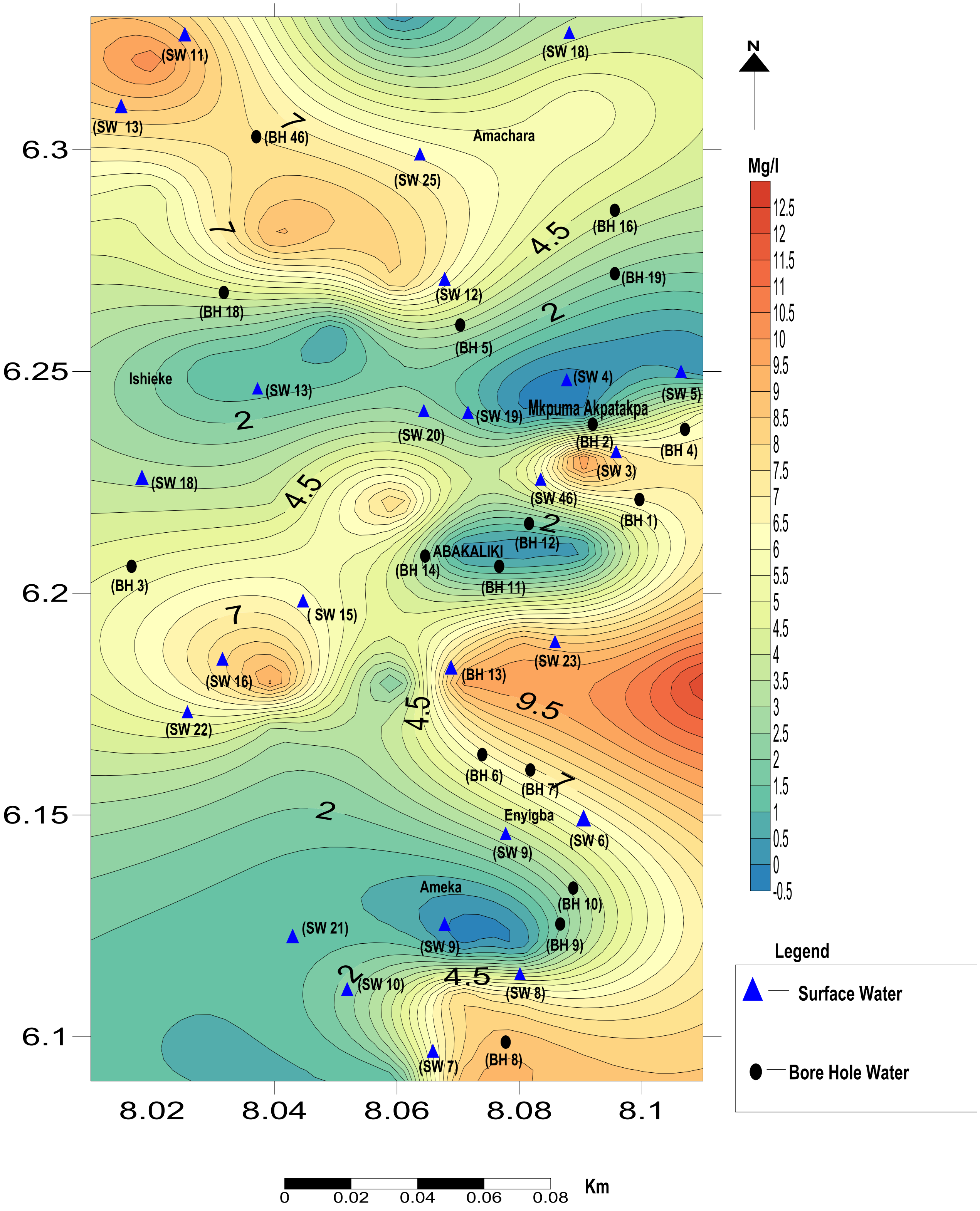

Fig 4.28: Contoured Distribution of Magnesium in Rainy Season Water Samples analysed

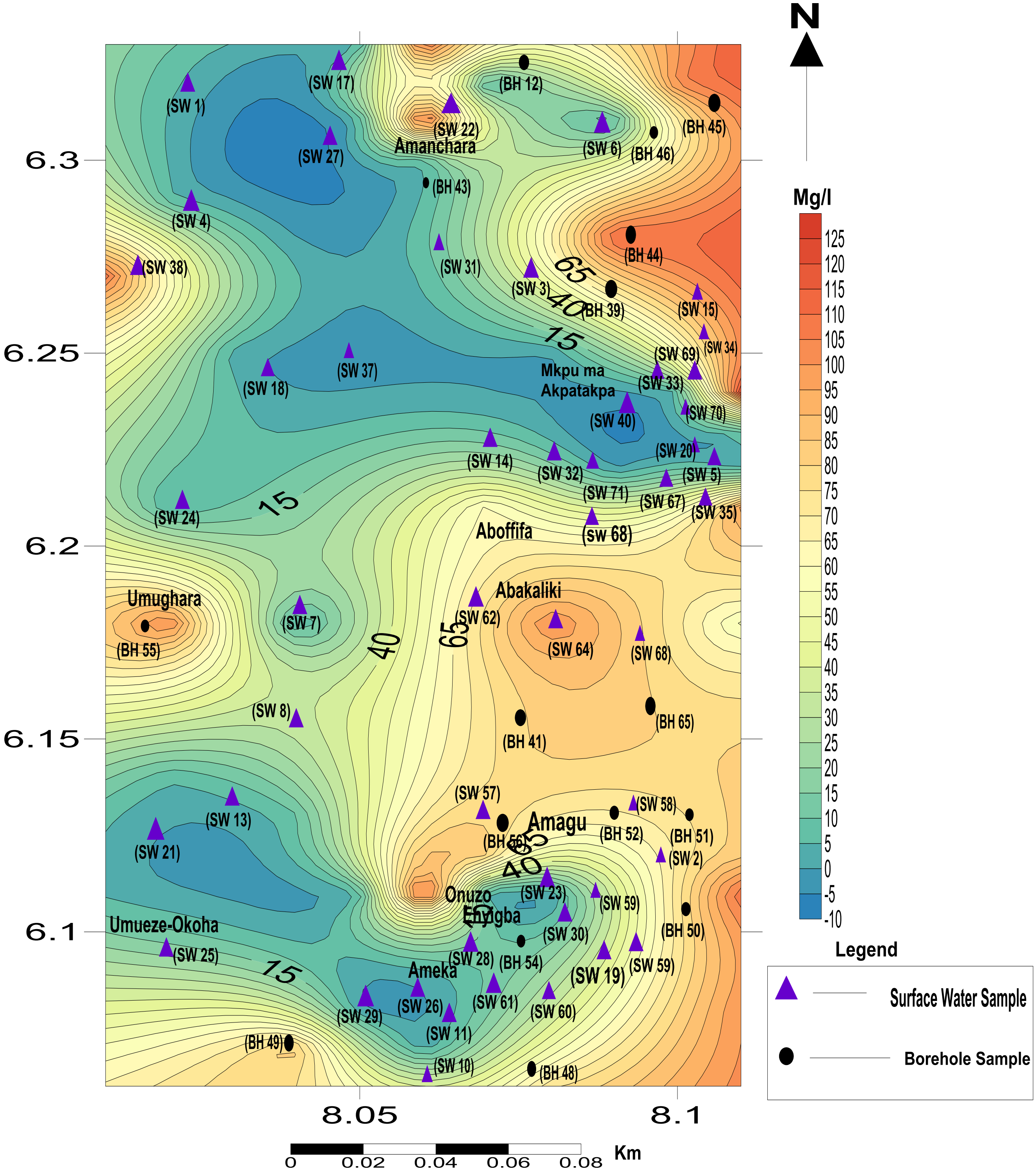

Fig 4.29: Contoured Distribution of Sodium in dry season water samples analysed

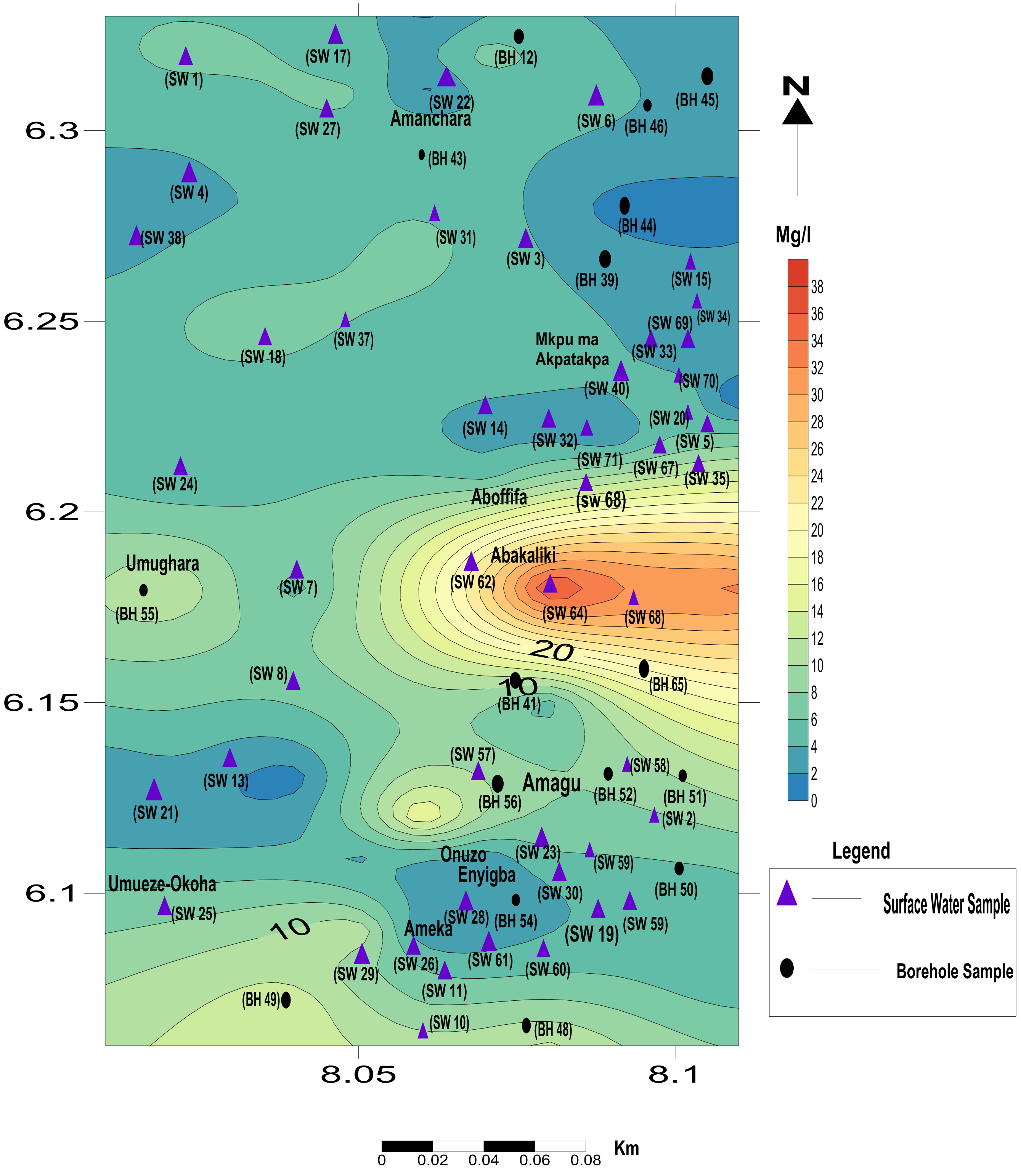

Fig 4.30: Contoured Distribution of Potassium in dry season water samples analysed

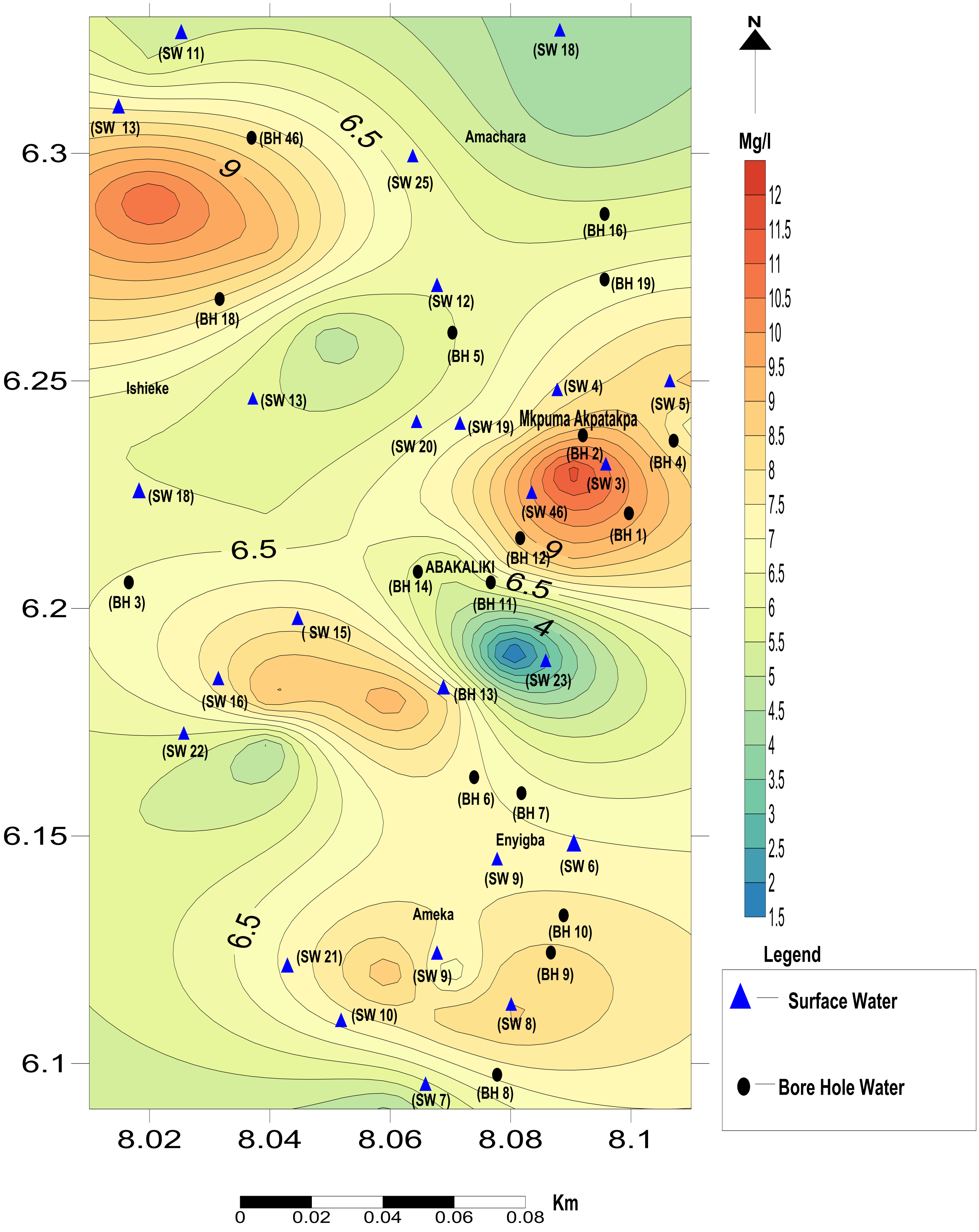

Fig 4.31: Contoured distribution of sodium in rainy season samples analysed

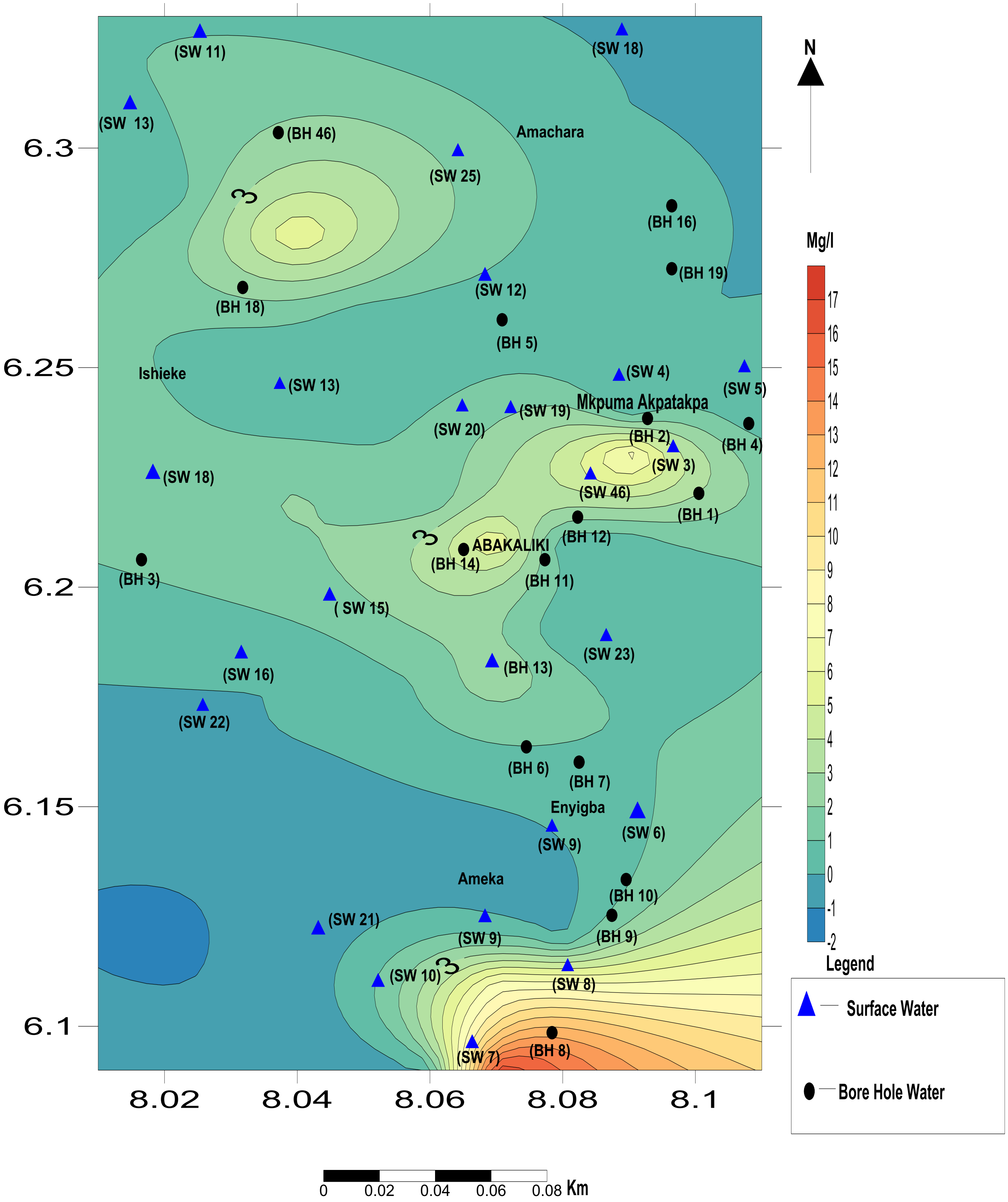

Fig 4.32: Contoured Distribution of Potassium in Rainy Season Water Samples Analysed

4.3.2.2 Major Anions

Major anions of appreciable concentration in water samples analyzed include carbonate ion (CO_3^{2-}), sulphate ion (SO_4^{2-}), chloride ion (Cl^-) and nitrate (NO_3^-).

A. Carbonate Ion (CO_3^{2-})

Carbonate ions (CO_3^{2-}) are present in natural waters and have been associated with the alkalinity and hardness of water (Hems, 1989). Carbonate is commonly less than 10 mg/L in groundwater. Water high in sodium may contain as much as 50 mg/L of carbonate. The concentration of carbonate ions in dry season water samples analysed ranges between 0.04 mg/L – 517.9 mg/L, while rainy season samples ranged from 50mg/L –442 mg/L. This result shows high concentration of carbonate in water sources (especially for surface water samples) of the study area. The main tributaries of Ebonyi River and the mine water around Enyigba and Mkuma Akpatakpa recorded high concentration. This is attributed to the dissolution of the carbonaceous shales which underlay these areas. Contoured distribution of carbonates (Figs 4.33 and 4.34) shows a uniform trend of increase from the SW to the NE direction for both seasons. WHO (2011) recommends a concentration of 200mg/l for drinking water supply. Possible sources of this high concentration in the study area include weathering of the dark grey and black shales (which are rich in carbonate), and inorganic carbon component (CO_2) which arises from the atmosphere and soils. Mining excavations also exposes these rocks to the atmosphere where the can be attacked by climatic forces.

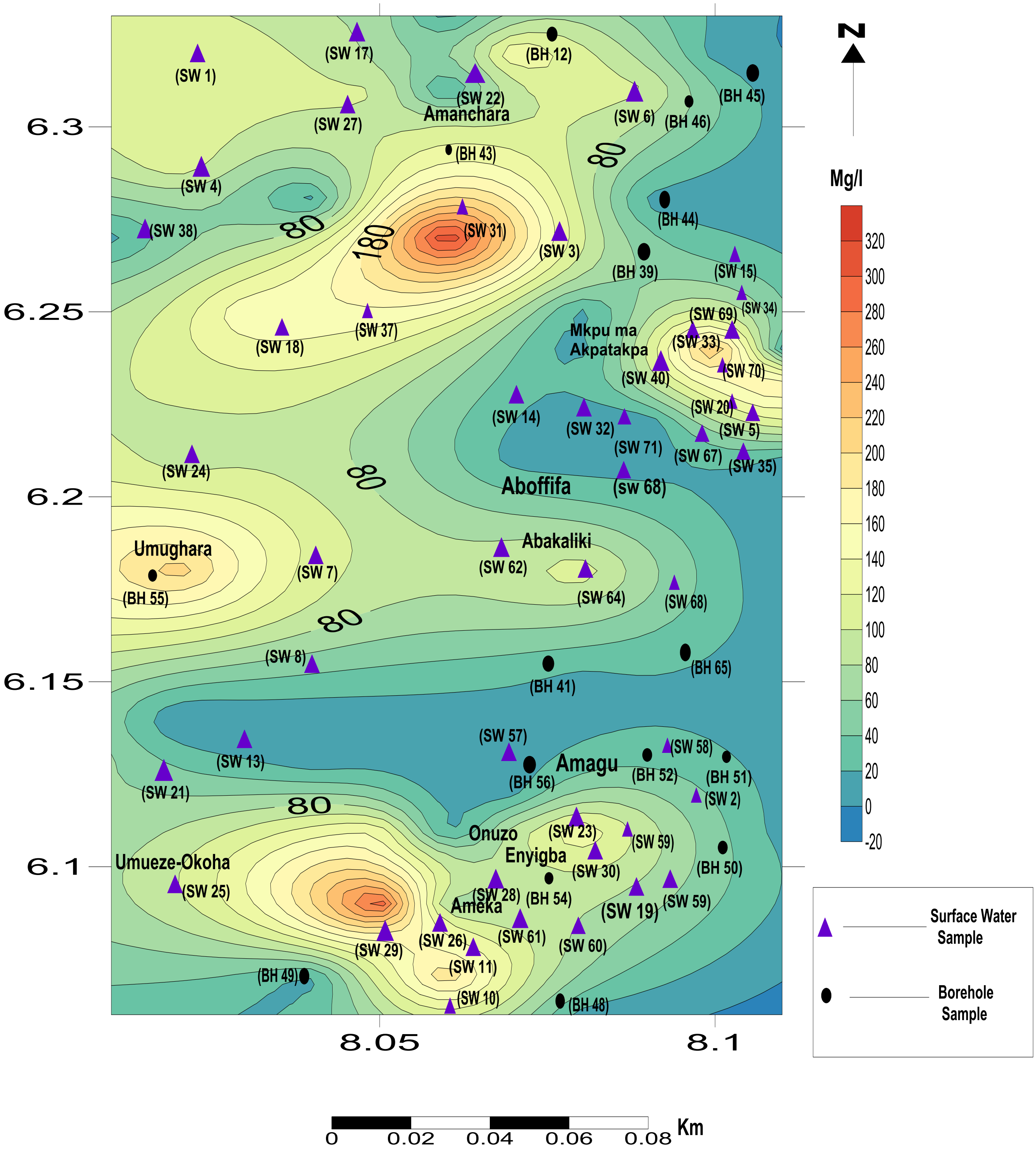

Fig 4.33: Contoured distribution of Carbonates in dry season water samples analysed

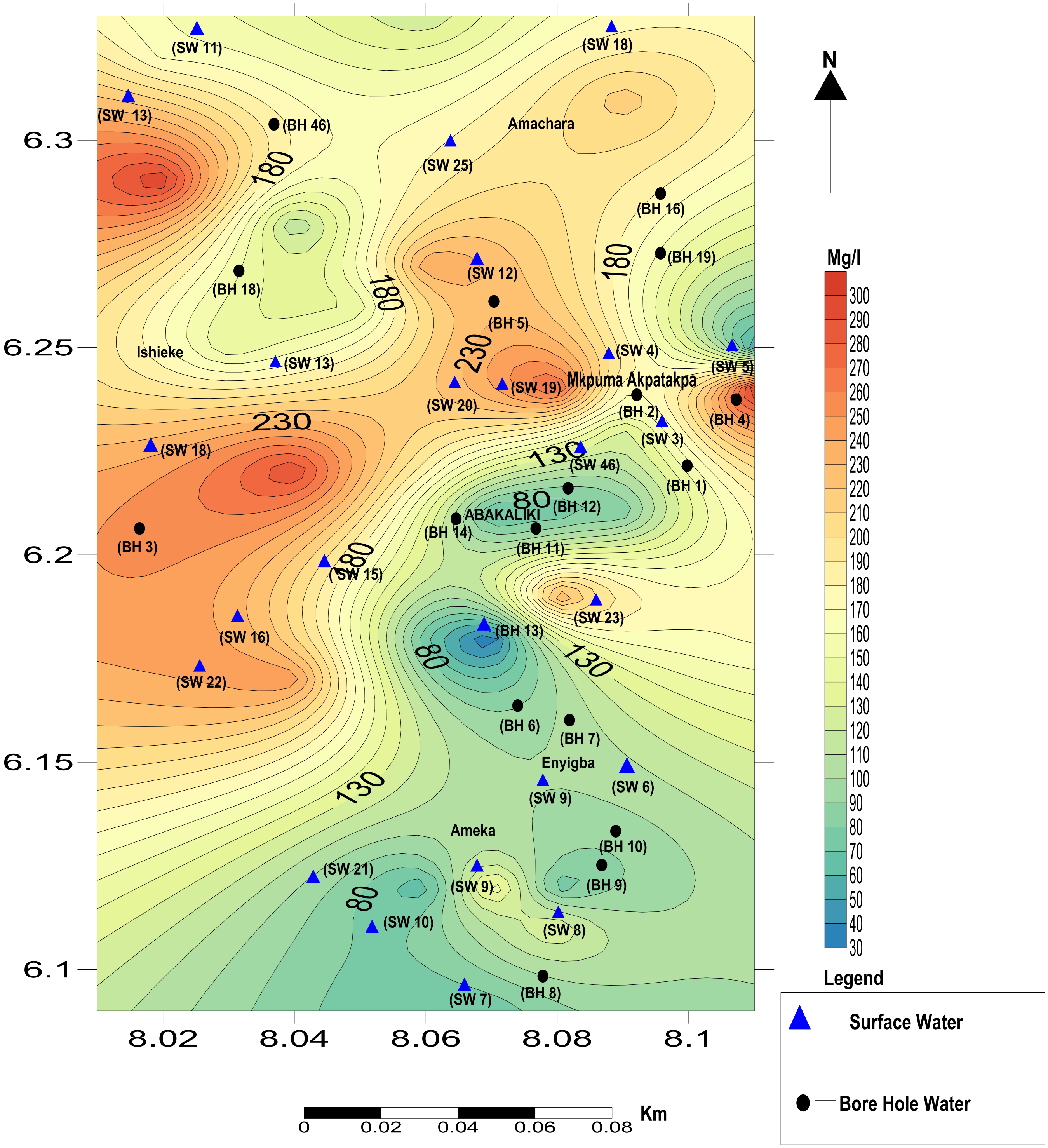

Fig 4.34: Contoured Distribution of Carbonate in rainy season water samples analysed

B. Sulphate Ions (SO_4^{2+})

Sulphate ions are present in natural waters. They mostly occur as a result of the oxidation of sulphide ores, gypsum and anhydrite (Obasi *et al.*, 2015). They can also occur as leachates from their ores and other pyrite minerals. Sometimes they originate from the atmospheric deposition of oceanic aerosols. Sulphate ion is commonly less than 300mg/l in natural waters except in wells influenced by acid mines (Todd, 1980). Sulphate combines with calcium to form an adherent, heating retarding scale. Sulphate concentration greater than 400mg/l makes drinking water unpleasant (Pipkin, 1994), while concentration above 500 mg/L imparts bitter taste in water (Todd, 1980). Sulphate could constitute an oxygen source for bacteria, which chemosynthetically converts it to hydrogen sulphide (H_2S) in anaerobic conditions (WHO, 2008). This process causes odour in water.

The concentration of sulphate in dry season water samples ofthe study area ranges between 0.1 m/L to about 930 mg/L, while rainy season samples ranged from 1.71mg/L – 174.5 mg/L (Figs 4.35 and 4.36). The WHO, (2011) guidelines for drinking water does not stipulate any standard for sulphate, but stated that concentrations above 250 mg/L can cause health effects. High values were recorded in the mining sites especially at the Ameka, Allibaruhu, Amanchara, Enyigba and Mkpuma Akpatakpa areas. Contoured distribution shows a specific trend of increase towards the eastern parts of the area with peaks in the mining areas. This imply that the mineralization of the area have serious effects on the water sources of the area. These ores (siderite, chalcopyrite, pyrite and galena), are rich in sulphate, and as they get exposed to water, processes of weathering (oxidation) causes them to deteriorate, and they subsequently migrate into water sources. This is evidenced as the result also shows that groundwater samples have higher concentration than surface water sources.

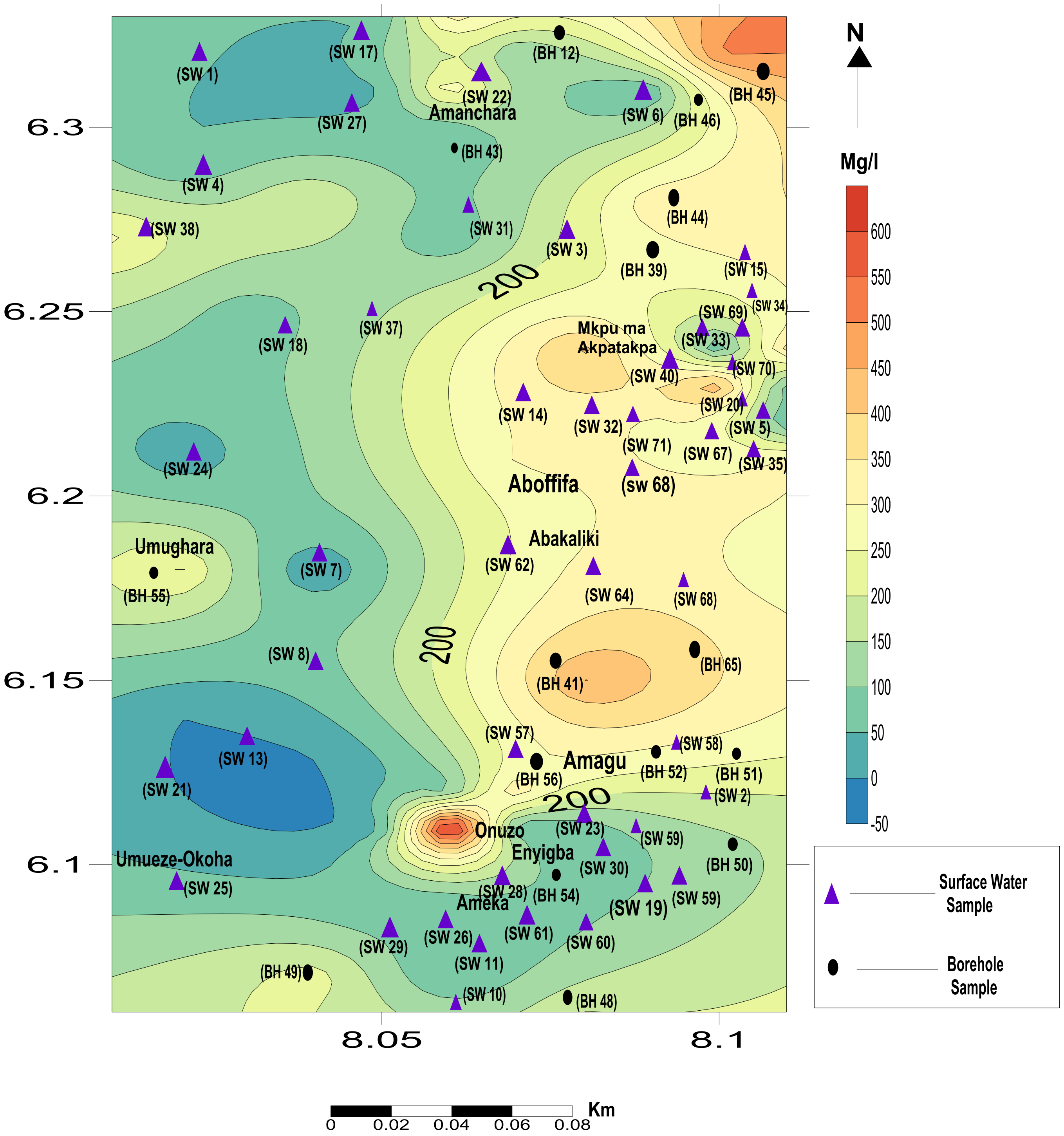

Fig 4.35: Contoured Distribution of sulphate in dry season water samples analysed.

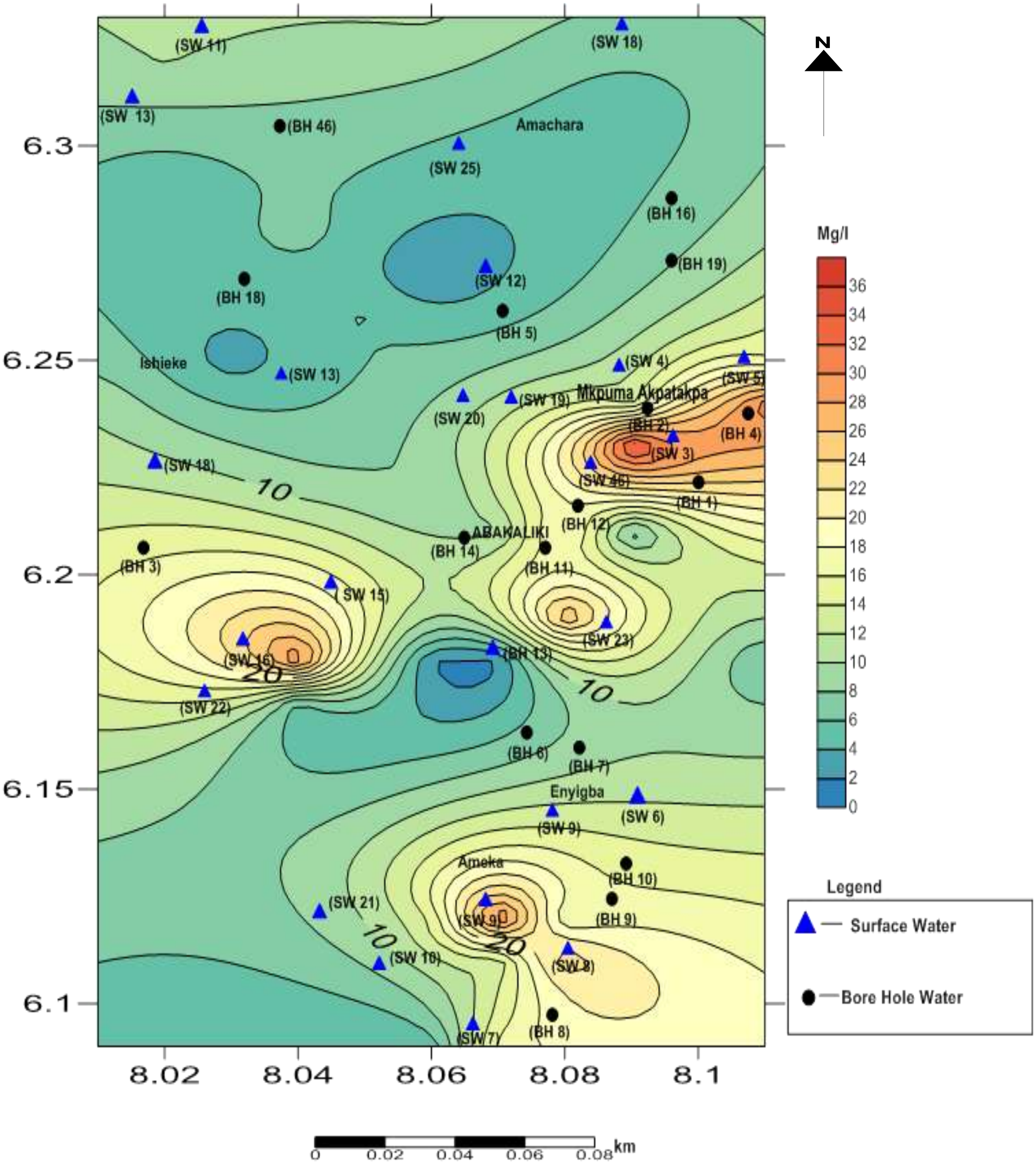

Fig 4.36: Contoured distribution of sulphate in rainy season water samples analysed

C. Chloride Ions (Cl^-)

The concentration of Cl^- in dry season water samples of the study area ranges from 0.67 mg/L to 4050 mg/L, while rainy season samples ranged from 17.3 mg/L – 444 mg/L. This shows excessively high values for some places. This includes the Alibaruhu active mine (4050 mg/L), Ameka active mine (1950 mg/L), Oganga (2250 mg/L), Ameri salt lake (2500 mg/L), Mkpuma Akpatakpa active mine (900 mg/L), infact all the active mines have very high values (Figs 4.58 to 4.61). Although, the WHO, 2011 guideline for drinking water does not stipulate any health based limit, it stated that concentration above 250 mg/L can have effects on the useability of the water. This result shows that the effects of the mineralized lodes and veins on the water sources cannot be over emphasized. Obiorah *et al*., 2015 and Oti and Nwabue, (2013) noted that the high concentration of chloride in food crops is due to in-takes from soil, which emanates from the composition of the ores. Geologically, these ores (galena, chalcophyrite, pyrite, siderite) have high composition of chloride, as they interact with the environment, weathering processes causes the deposition of chloride in the water sources. It was also observed from the result that surfaces water sources recorded higher concentration than groundwater sources. Apart from the occurrence of the Enyigba salt lake, high concentration in surface water sources can be attributed to the deteroriaton of gangues which are dumped indiscriminately around the mining areas, and are carried by runoff into surface water souces.Contoured distribution (Fig 4.37 and 4.38) shows no particular trend, but pockets of high concentrations in the mining areas of Amanchara, Ameka, Enyigba and Mkpuma Akpatakpa. The major sources of chloride ion (Cl^-) in natural water are dissolution of sedimentary rocks especially the evaporites (rock salts) like gypsum and halite; agricultural inputs, sewages and industrial wastes (WHO, 2011). Chloride Concentration is commonly less than 10mg/l in humid regions, but up to 1000 mg/L in more arid regions (WHO, 2011). Chloride in excess of 100 mg/L imparts a salty taste, and concentrations in excess of 100 mg/L may cause physiological damage (Todd, 1980). Concentration above 25 mg/L is corrosive to pipes (Hems, 1989).

D. Nitrate (NO_3^-)

Nitrate is an important natural constituent in water. High concentrations may indicate sources of past or present pollution (IPCS, 2009). The major sources of nitrate in water include organic matter from man-made nitrate pollutants such as agricultural fertilizers, urban effluents, solid waste disposal, livestock sewage, legumes, plant debris and atmospheric aerosols (WHO, 2011). In some circumstances, nitrate has been shown to present a health hazard to infants, and possibly to older children, if they are present in drinking water at concentrations greater than 300mg/l, (Tables 4.9 and 4.10). In excess (above 100mg/l) nitrate imparts bitter taste and may cause physiological distress (Freeze and Cherry, 1979). Todd (1980) emphasized that concentrations above 45 mg/L in shallow well can cause methemoglobinemia. The WHO, 2011 health based guidelines for drinking water stipulates a permissible limit of 50 mg/L. Higher concentration has been known to cause cyanosis and Asphyxia in infants under three months old (WHO, 2008).

The concentration of NO_3^- in dry season water samples anlysed ranges from 0.01mg/l to 13.2 mg/L, while rainy season water samples ranged from 2.006 mg/L – 81 mg/L. This shows a slightly high distribution (Figs 4.39 and 4.40), (especially in rainy season samples). Areas of high concentration are within Abakaliki. Theyinclude Isieke, Idembia, Umuaghara, Okposi, Agharaugha, Okoffia and Ndiezzagu- Umuaru. Since the major input source of nitrate in water is anthropogenic (WHO, 2011; Howard and Batram, 2003), this high concentration can be attributed to the dumping of refuse in the Umuaghara quarry site, which is serving as the waste receptacle point for all waste in Abakaliki metropolis.These wastes decompose and migrate through fractures into water sources.

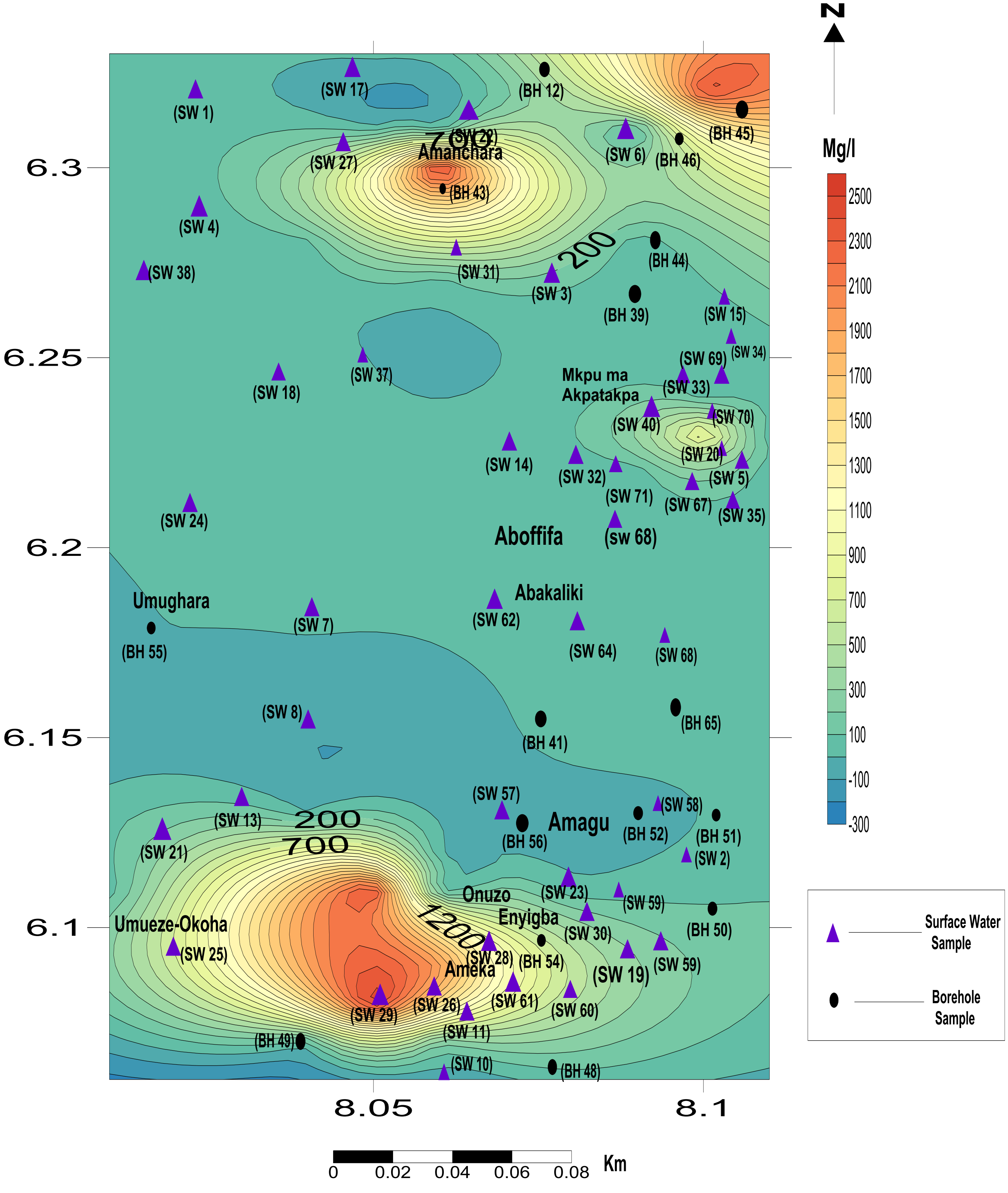

Fig 4.37: Contoured Distribution of Chloride in dry season water samples analysed

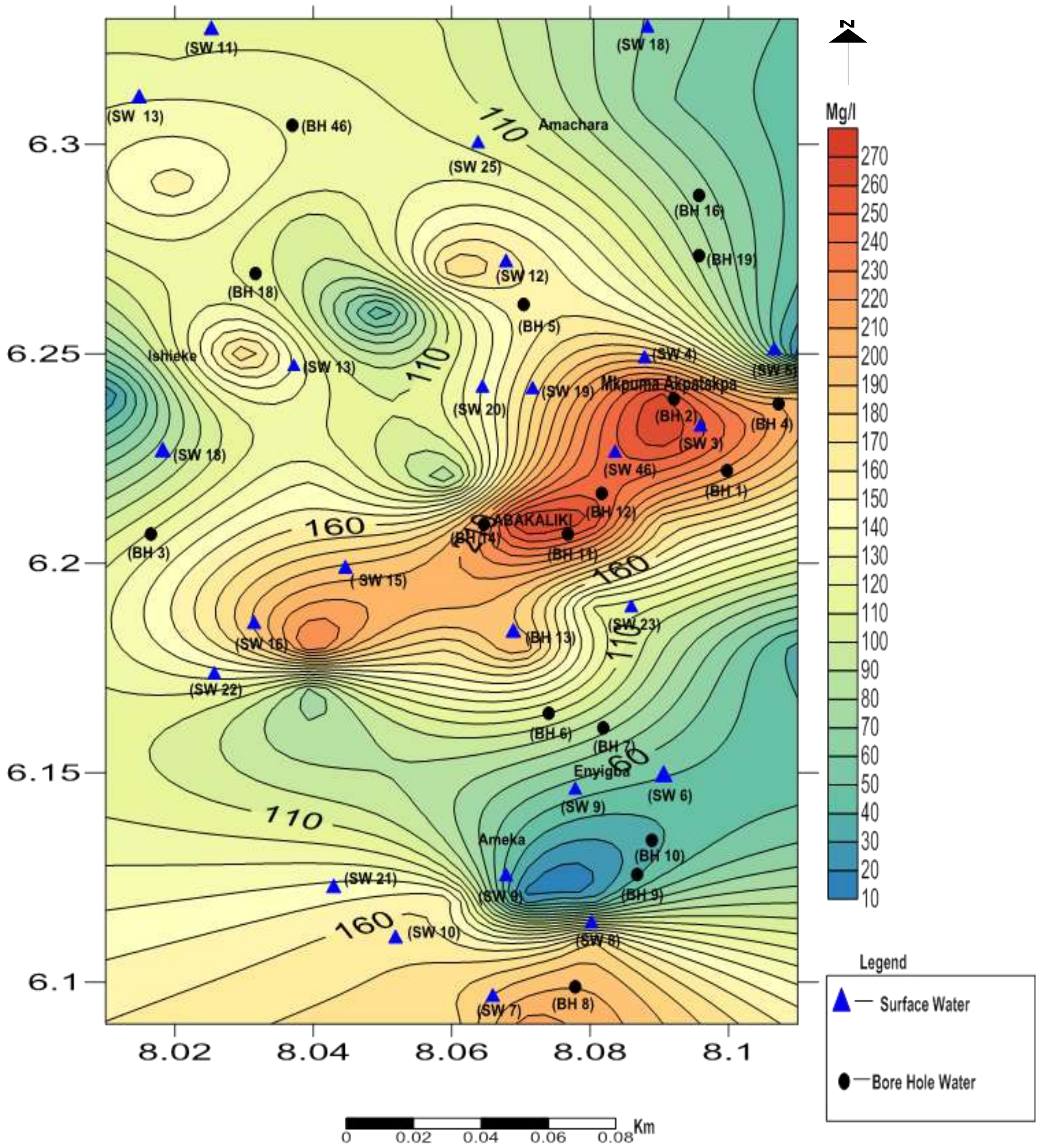

Fig 4.38: Contoured distribution of chloride in rainy season water samples analysed

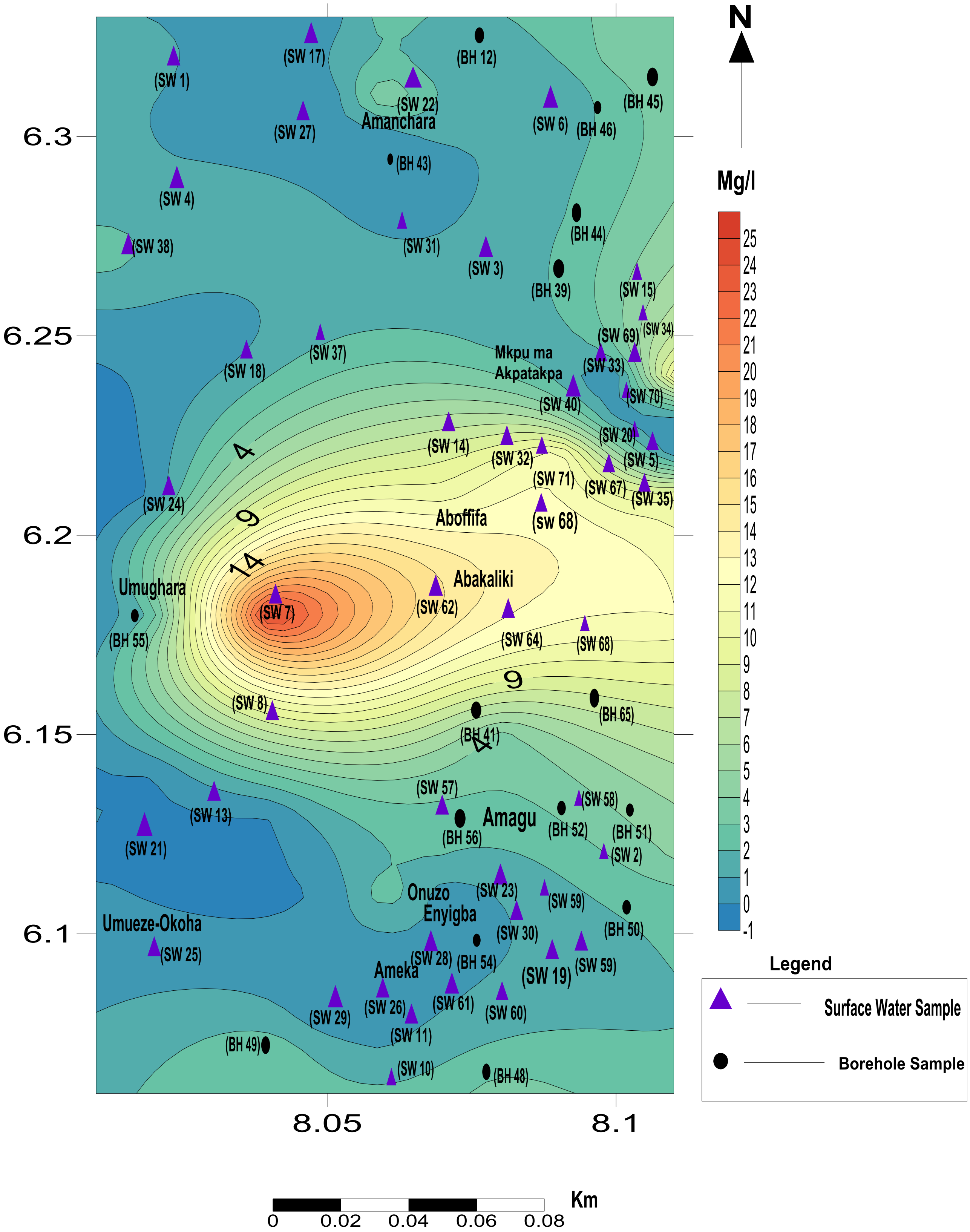

Fig 4.39: Contoured distribution on Nitrate in dry season water samples analysed

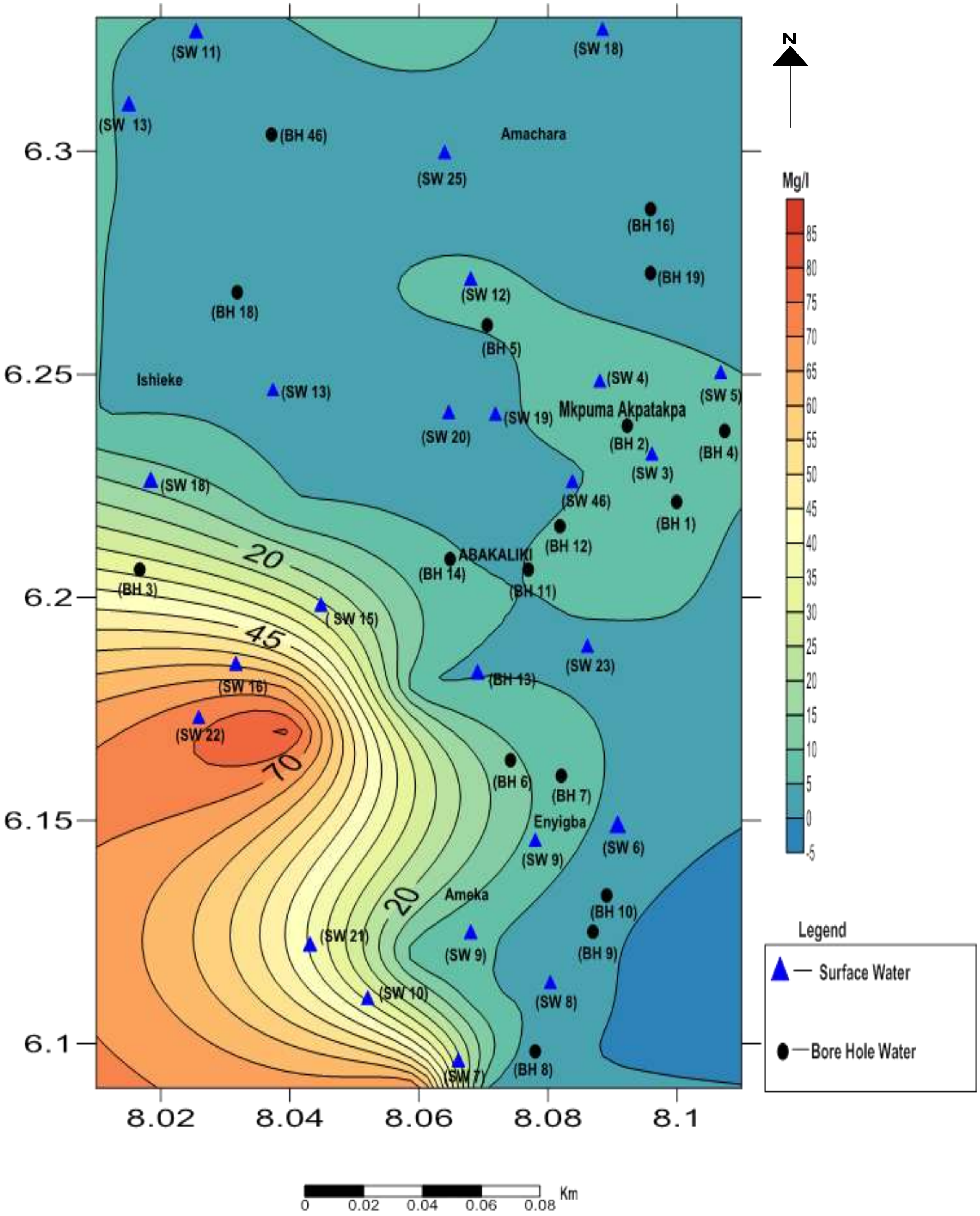

Fig 4.40: Contoured distribution of nitrate in rainy season water samples analysed

4.3.2.3Trace/Minor Constituents

LEAD

From the analysis, lead concentrations of dry season water samples ranges between 0 mg/L (only in very few places) to 11.4 mg/L, while rainy season sample ranges fron 0 mg/L – 4.01mg/L. This shows very high pollution (about 85%) for the water samples especially in the active mining areas. This result clearly indicates that the gangues and mine wastes of the lead ores (galena) significantly affect the quality of water sources of the area. Apart from the composition of these waste and gangues in the area, the low pH, the salinity and presence of CO_2 in the water sources causes faster dissolution of lead in water (ATSDR, 2007). WHO, (1984) proposed a health guideline value of 0.05 mg/L and in 1993 reviewed it to 0.01mg/L. This review was necessary on the basis that lead is a cummulative poison and that there should be no accumulation of body burden of lead. Davies *et al*., 2005 opined that the high concentration of lead in water of mining sites can be attributed to the high immobility of lead. Contoured distribution of lead (Figs 4.41 and 4.42) for the samples shows a NE – SW trend with notable increase from the mining sites to other areas. The rainy season contoured distribution show higher concentration at the Mkpuma Akpatakpa than other areas. This is due to higher exposure of the the ores in Mkpuma Akpatakpa than other mining areas. Lead occurrence concentrations in drinking-water is generally below 5 mg/L, although much higher concentrations (above 100 mg/L) have been measured where lead fittings are present (Howard and Batram, 2003). The amount of lead dissolved from the plumbing system depends on several factors, including pH, temperature, water hardness and standing time of the water, with soft, acidic water being the most plumbosolvent (WHO, 2008). Owing to the decreasing use of lead- containing additives in petrol and of lead-containing solder in the food processing industry, concentrations in air and food are declining, and intake from drinking-waterconstitutes a greater proportion of total intake of lead (Sawyer, *et al*., 1998).

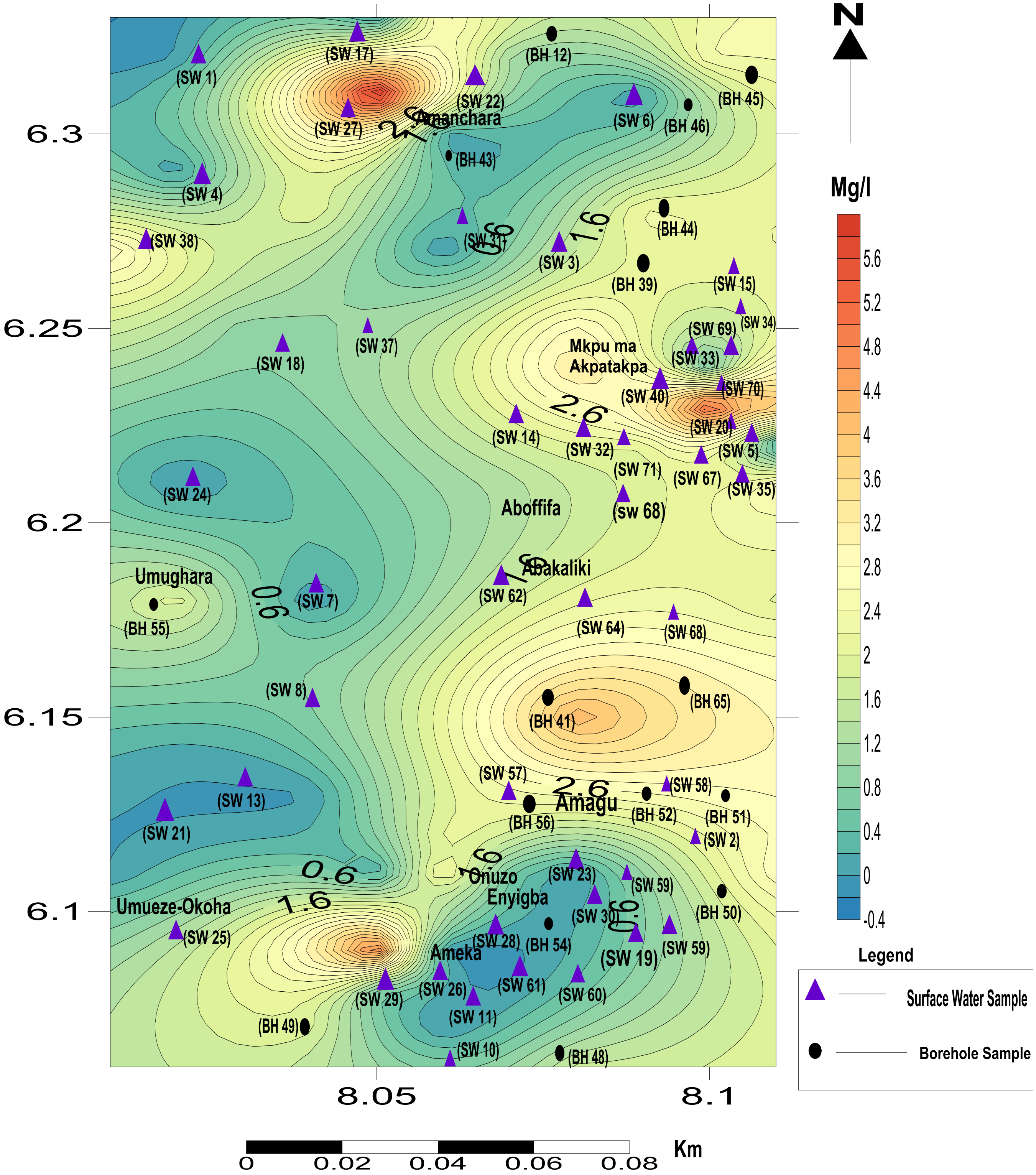

Fig 4.41: Contoured Distribution of lead in dry seasonwater samples analysed

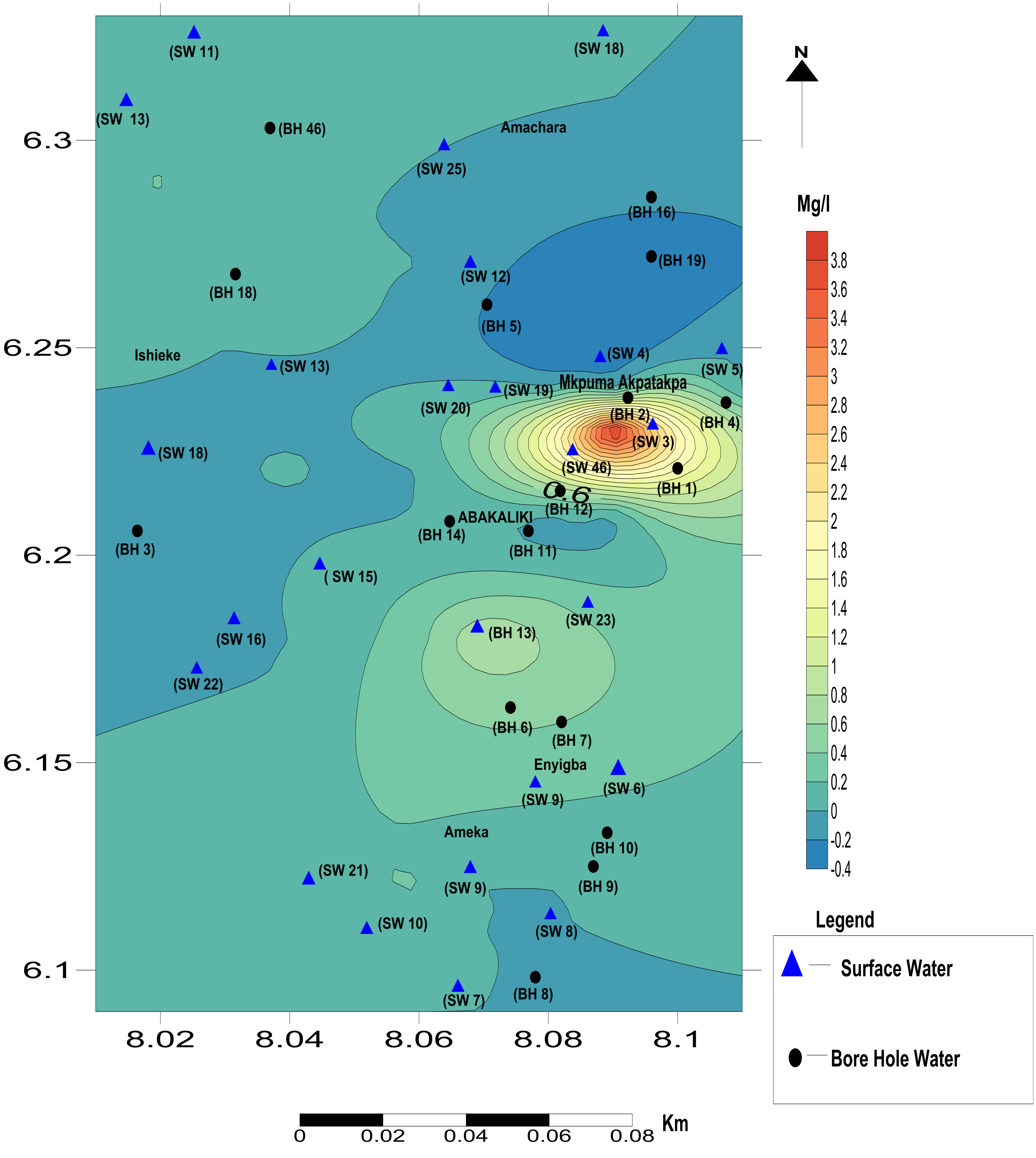

Fig 4.42: Contoured distribution of lead in rainy season water samples analysed

COPPER

Copper is both an essential nutrient and a drinking-water contaminant. Food and water are the primary sources of copper exposure in developed countries. Ores of copper are Chalcopyrite ($CuFeS_2$), Chalcocite (Cu_2S), Covellite (CuS), Cuprite (Cu_2O) and Malachite ($CuCO_3$. $Cu(OH)_2$) (ATSDR, 2007). Copper concentrations in treated water often increase during distribution, especially in systems with low pH, or high-carbonate waters with high pH (Todd, 1980). Staining of laundry and sanitary wares occurs at copper concentrations above 1 mg/L. Gallagher *et al.*, (2001) stated that at levels above 2.5 mg/L copper imparts an undesirable bitter taste to water; at higher levels, the colour of water is also impacted. The WHO, 2011guidelines derived a provisional health-based guideline value of 2mg/L for copper.

From the analysis, copper values of dry and rainy season samples ranged from 0mg/L – 0.341 mg/L. Significant values were recorded at the active mines at Ameka, Mkpuma Akpatakpa, Amanchara and surface water sources around Onuzu (Figs 4.43 and 4.44). The result indicates that the concentration ofcopper in the study area isbelow the WHO, (2011) guideline for drinking water. Brikke, (2000) noted that chalcopyrite (which is endowed in the area), breaks down into copper and pyrite but copper has low mobility and reacts slowly with water. This can be attributed to the low concentration of copper in the area. Nriagu and Pacyna, (1988), also stated that copper, on exposure to air and water forms a thin protective metallic shield which reduces the surface area for reactivity. Contoured distribution of copper for the two seasons does not show a particular trend but, indicates notable increase from the mines of Mkpuma Akpatakpa, Ameka and Amanchara.

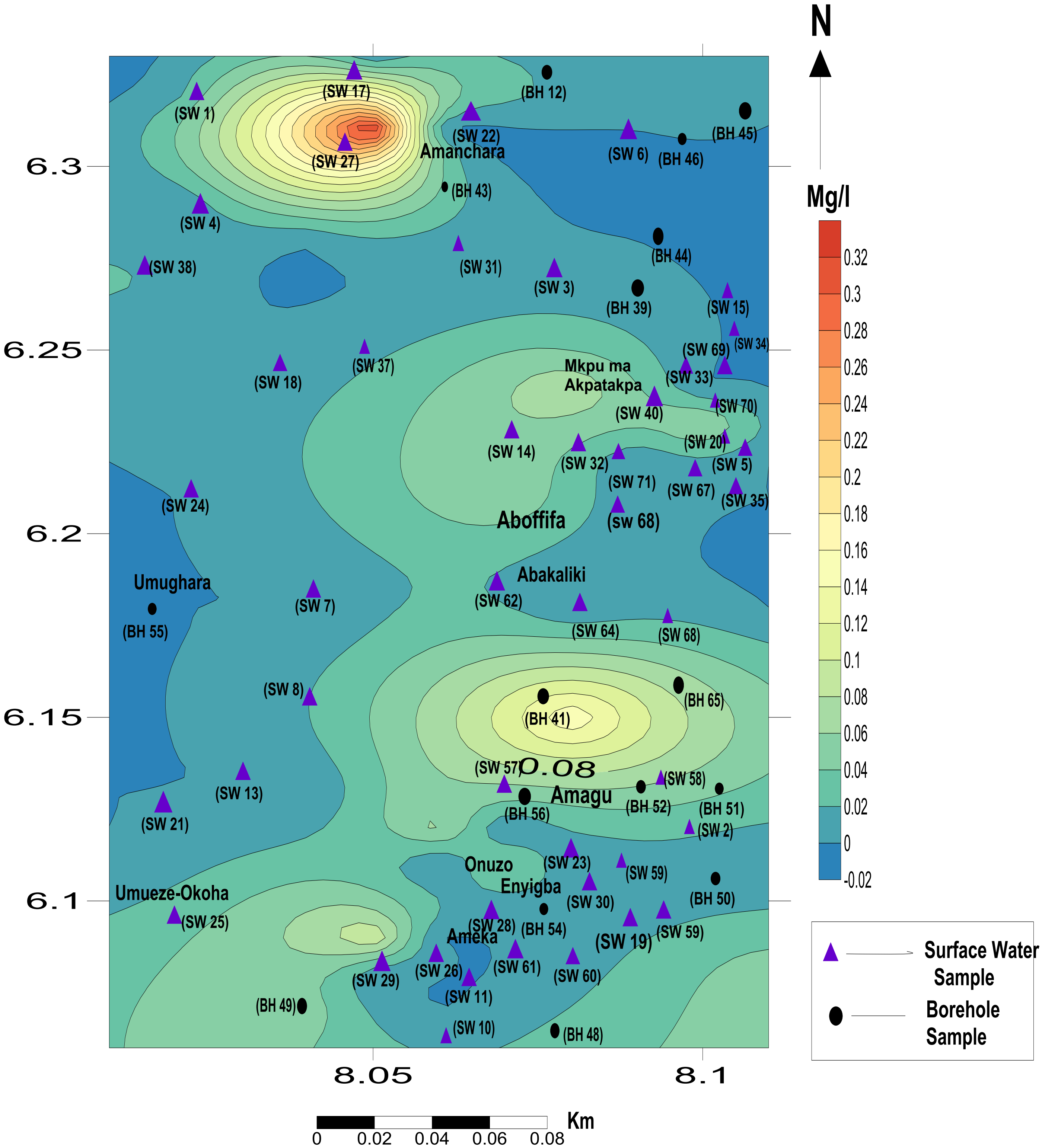

Fig 4.43: Contoured Distribution of Copper in dry season water samples analysed

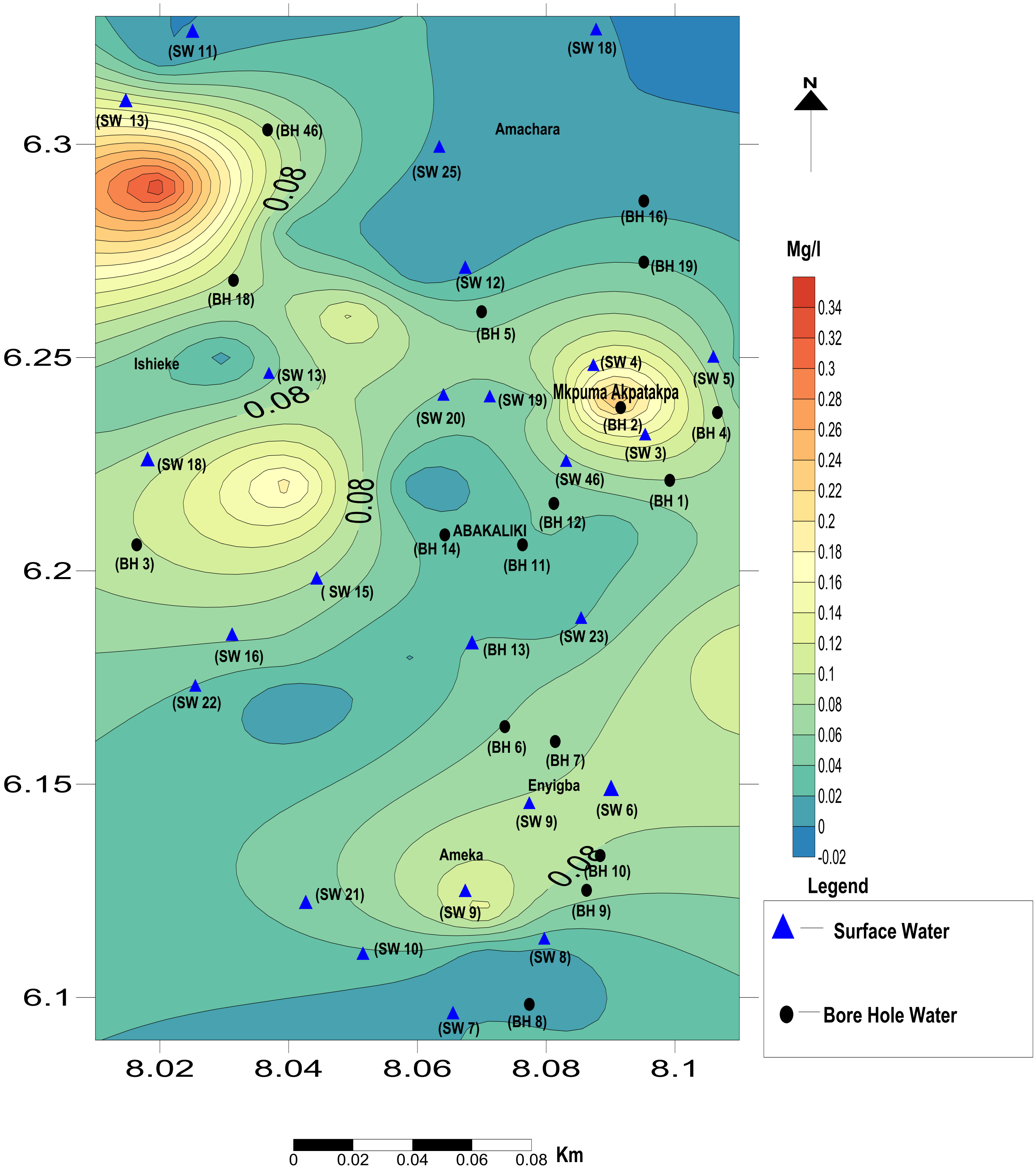

Fig 4.44: Contoured distribution of copper in rainy season water samples analysed

CHROMIUM

Chromium is widely distributed in the Earth's crust. It can exist in valences of +2 to +6. In general, food appears to be the major source of intake (Jardine *et al.*, 1999; Robson 2003). Chromium is highly carcinogenic, therefore, minimal intake has been advocated (WHO, 2011).

The analysis shows that concentrations of Chromium in dry season samples ranges between 0 mg/L – 14.6 mg/L, while rainy season samples ranges from 0 mg/L – 0.818 mg/L. About 80% of the samples show no content for chromium while the mines and the sorrounding rivers around them shows values above the WHO guideline of 0.05 mg/L especially at the Enyigba mine where it rose to 14.6 mg/L (Figs 4.45 to 4.46).

Sources of chromium in the area include the rocks and soils of the area. The reduction of chromium (VI) to chromium (III) and the oxidation of chromium (III) to chromium (VI) in water has been investigated extensively. Reduction of chromium (VI) to chromium (III) can occur under suitable conditions in the aqueous environment. The most common reducing agents present in aqueous systems include: organic matter; hydrogen sulfide; sulfur, iron sulfide; ammonium; and nitrate (Kimbrough *et al.*, 1999). The reduction of chromium (VI) by S^{-2} or Fe^{+2} ions under anaerobic conditions occurs rapidly, with the reduction half-life ranging from instantaneous to a few days (Seigneur and Constantinous, 1995). However, the reduction of chromium (VI) by organic sediments and soils is much slower and depends on the type and amount of organic material and on the redox condition of the water. The reduction half-life of chromium (VI) in water with soil and sediment ranged from 4 to 140 days, with the reaction typically occurring faster under anaerobic rather than aerobic conditions (Saleh *et al.*, 1989). Generally, the reduction of chromium (VI) to chromium (III) is also favored under acidic conditions (Kimbrough *et al.*, 1999). This is true as water sources recorded low pH in the area.

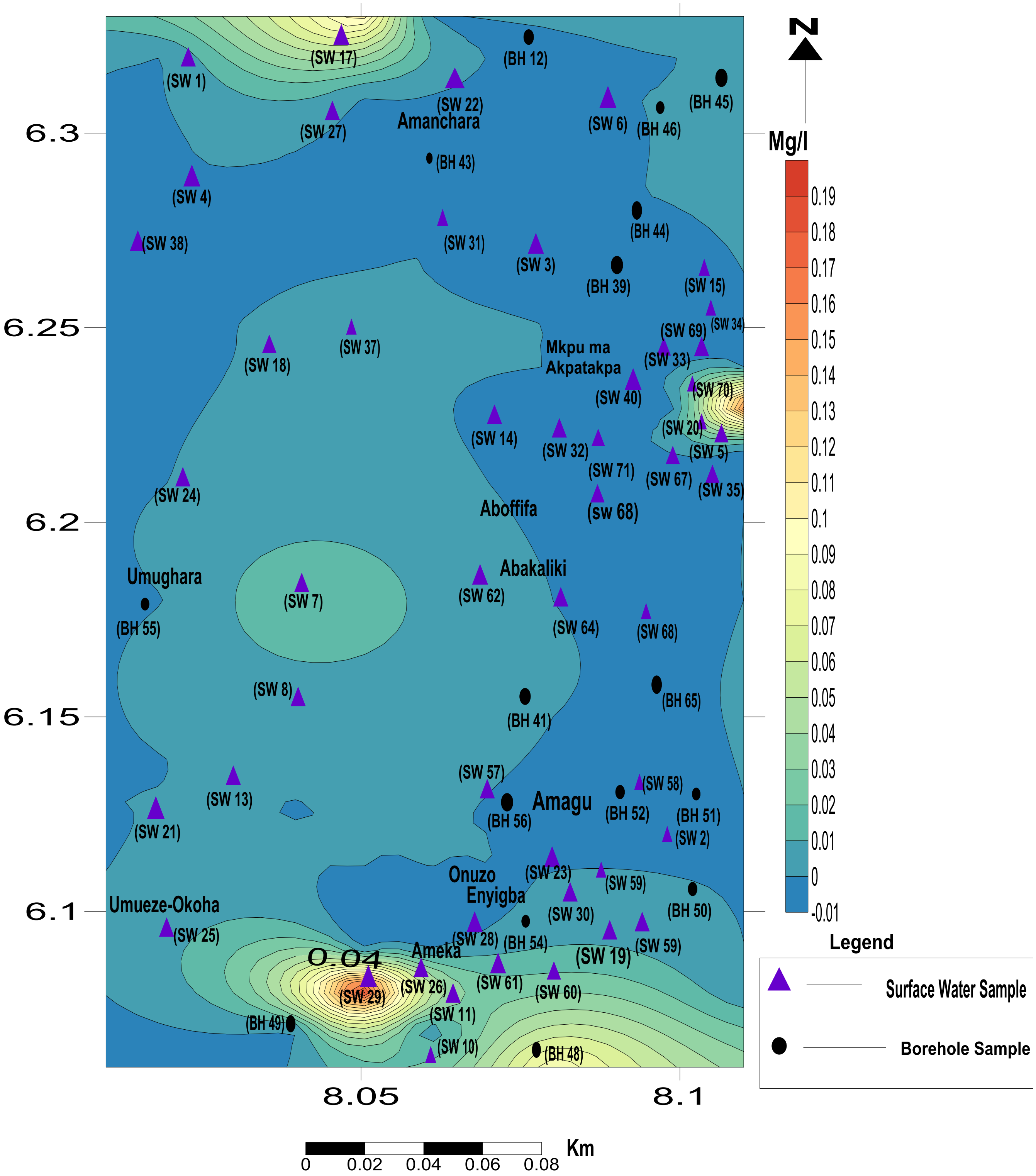

Fig 4.45: Contoured Distribution of Chromium in dry season water samples analysed

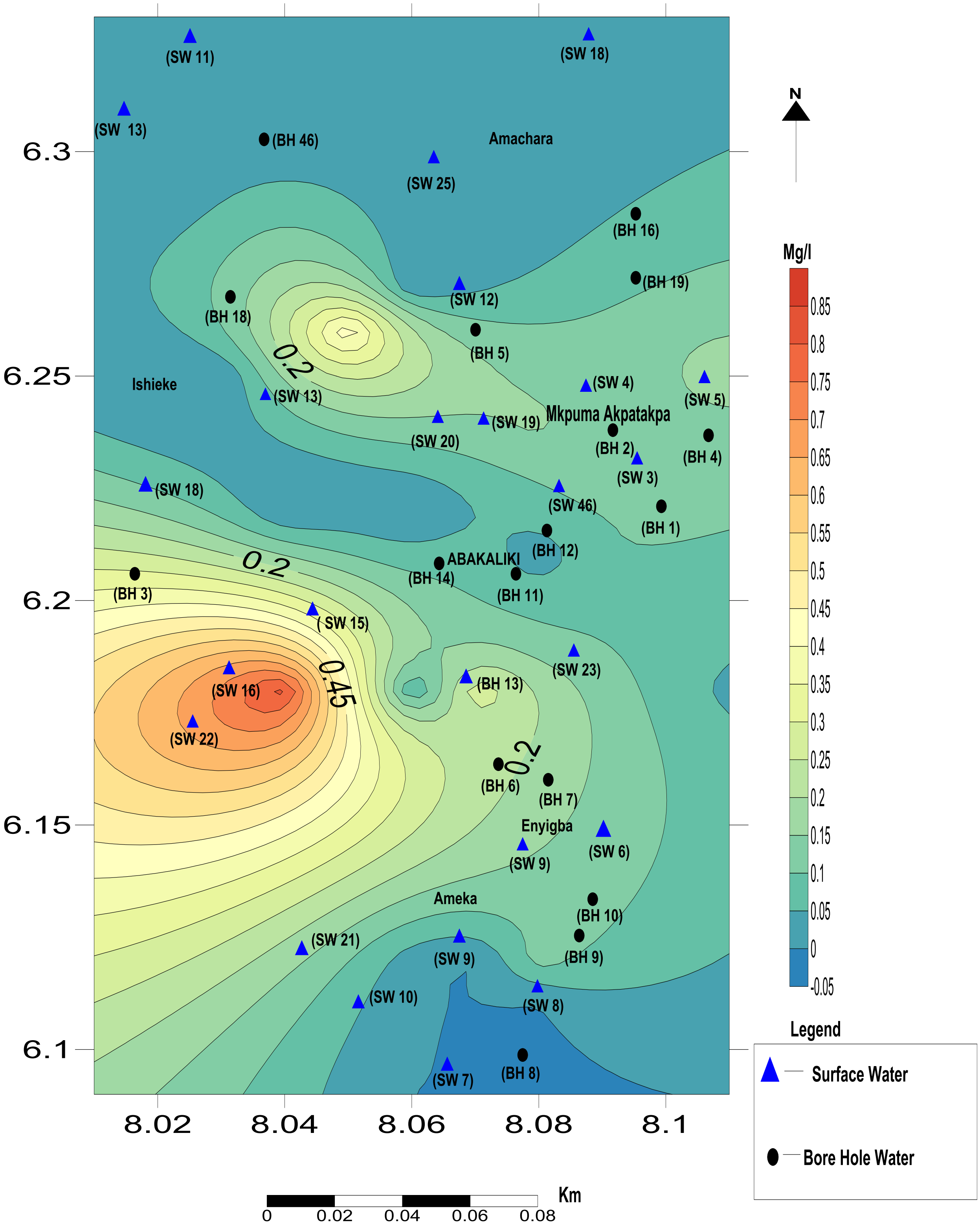

Fig 4.46: Contoured distribution of Chromium in rainy season water samples analysed

NICKEL

Nickel occurs naturally in water. The concentration in drinking-water is normally less than 0.02 mg/L, although nickel released from taps and fittings may contribute up to 1 mg/L (WHO, 2011). It also noted that, in special cases of release from natural orindustrial nickel deposits in the ground, the nickel concentrations indrinking-water may be higher. Food is thedominant source of nickel exposure in the non-smoking, non-occupationally exposed population, while water is generally a minor contributor to the total daily oral intake (Aremu *et al.*, 2002).

The analysis shows concentrations of water samples in dry season samples ranged from 0 mg/L to 1.26 mg/L, while rainy season samples ranges from 0 mg/L – 0.186 mg/L. Only the distributaries of Ebonyi River show significant concentrations, especially around the mines of Enyigba (Figs 4.47 and 4.48). But water samples within the mining areas are above the WHO, 2011 guideline value of 0.07 mg/L. This reflects high concentration for nickel. ATSDR, (2005), stated that effluent water generated from mining and smelting operations, runoff from tailing piles, or from utility water used for mine operations can lead to higher concentrations of nickel in mining areas. Barcan, (2002) showed that these discharges consist mostly of less-soluble silicates and sulfides that readily settle out. Tailing effluents from sulfidic ores are acidic due to the bacterial generation of sulfuric acid from the sulfidic minerals in the tailings, and very high concentrations of soluble nickel sulfate may be released (Mann *et al.*, 1989). Also the presence of iron-(di) sulfides in wetland sediments has been associated with increased mobilization of nickel into groundwater during periods of drought (Lucassen *et al.*, 2002). Clemens and Landolph, 2003, suggested that dessication of sediments leads to oxidation of iron (di) sulfides and subsequent acidification of the sediments which increases mobilization of heavy metals like nickel, leading to groundwater concentrations of nickel.

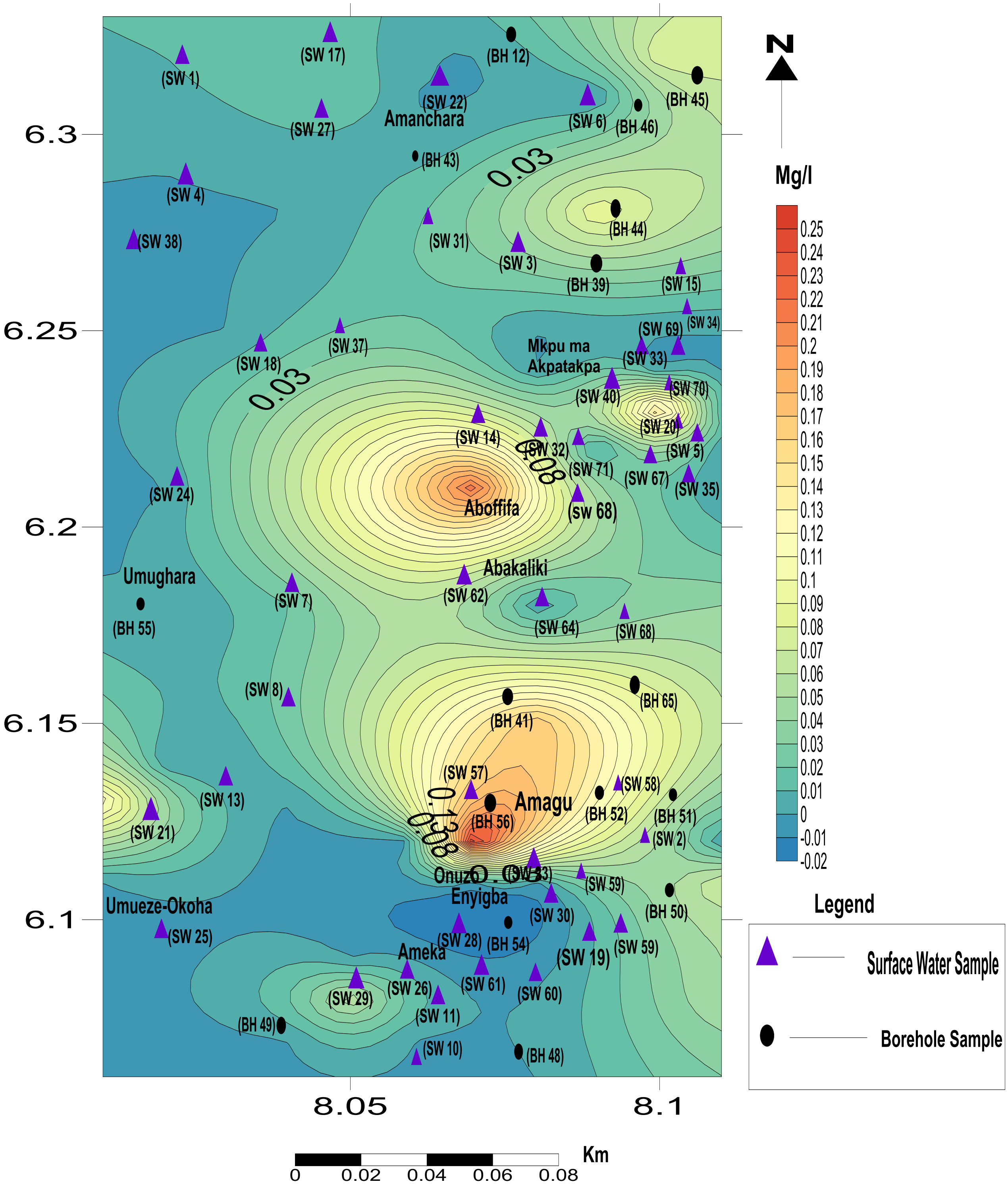

Fig 4.47: Contoured Distribution of Nickel in dry season water samples analysed

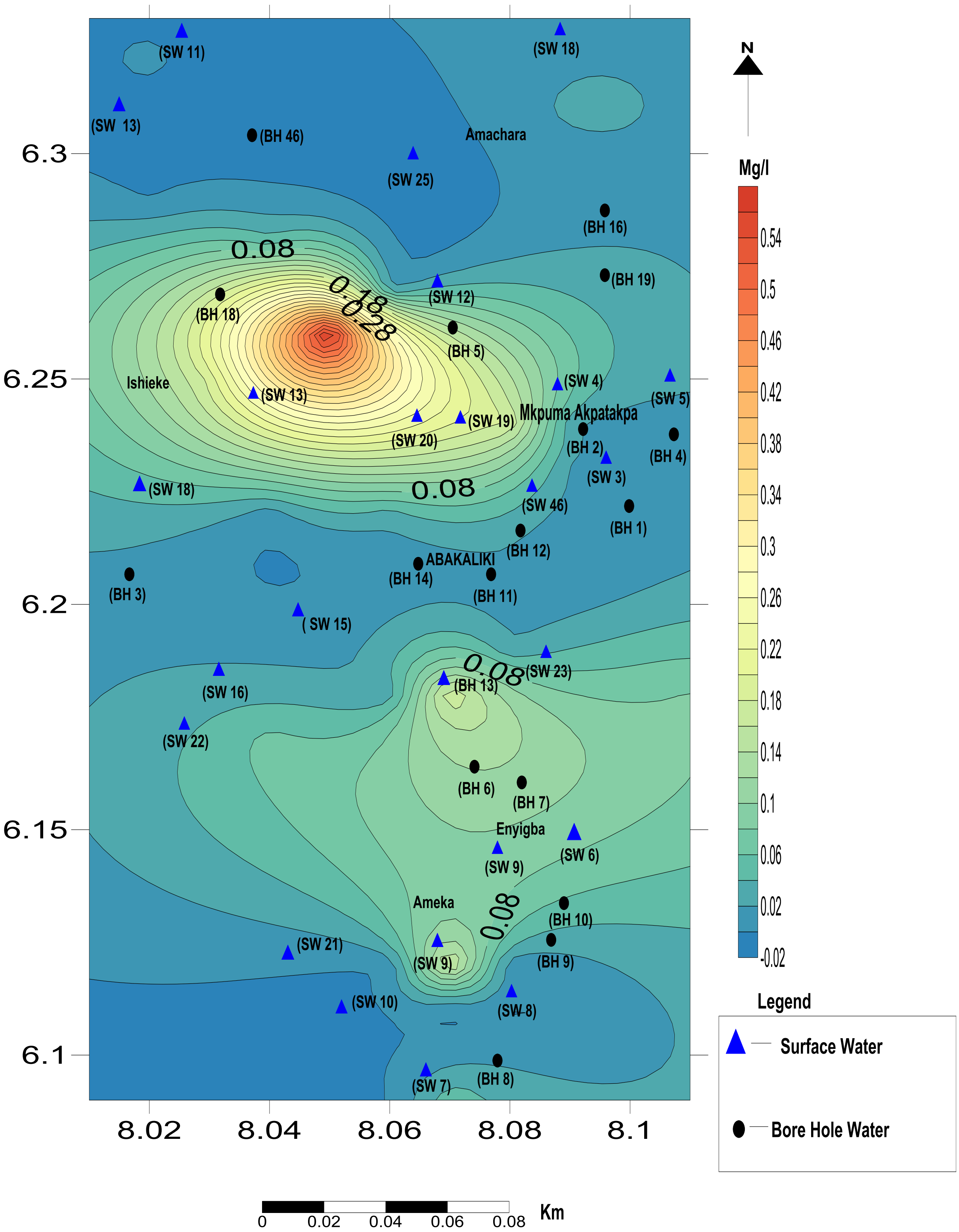

Fig 4.48: Contoured Distribution of Nickel in rainy season water samples analysed

MANGANESE

Manganese is one of the most abundant metals in the Earth's crust, usually occurring with iron, oxygen, sulphur and chlourine (ATSDR, 2012). It is anessential element for humans and other animals and occurs naturally in food and water sources. Occurrence levels in fresh water typically range from 1 to 200 mg/L, although levels as high as 10 mg/L in acidic groundwater have been reported; higher levels in aerobic waters usually associated with industrial pollution particularly in anaerobic or low oxidation conditions, and thisis the most important source for drinking-water (WHO, 2011).

The analysis shows that the concentration of manganese for dry season samples ranges from 0 mg/L (in few places, especially in groundwater samples) to 45.13 mg/L, while rainy season samples ranges from 0.042 mg/L – 63.45 mg/L. These high values were recorded in the active mines (Figs 4.49 and 4.50). The abandoned mines however recorded high values upto 26.44 mg/L. This result shows that water sources (especially mine pond water and groundwater) have higher values above the WHO, 2011guideline value of 0.4 mg/L. Contoured distribution dose not show any particular trend, except pockets of high concentrations in the mining sites. This high concentration is attributed to the dissolution of manganese from the chalcopyrite and siderite ores which underlie the area. This is controlled by the solubility, pH, Eh (oxidation-reduction potential), and the characteristics of the available anions in water (Clewell *et al*., 2003). Aschner *et al*., 2007 emphasized that the metal may exist in water in any of four oxidation states; however, Mn (II) predominates in most waters (pH 4–7), but may become oxidized under alkaline conditions at pH >8 (EPA, 1984). The principal anion associated with Mn (II) in water is usually carbonate (CO_3^{2-}) (Schaanning *et al*., 1988). This increases the concentration as the carbonate composition of the shales are readily available for reaction.

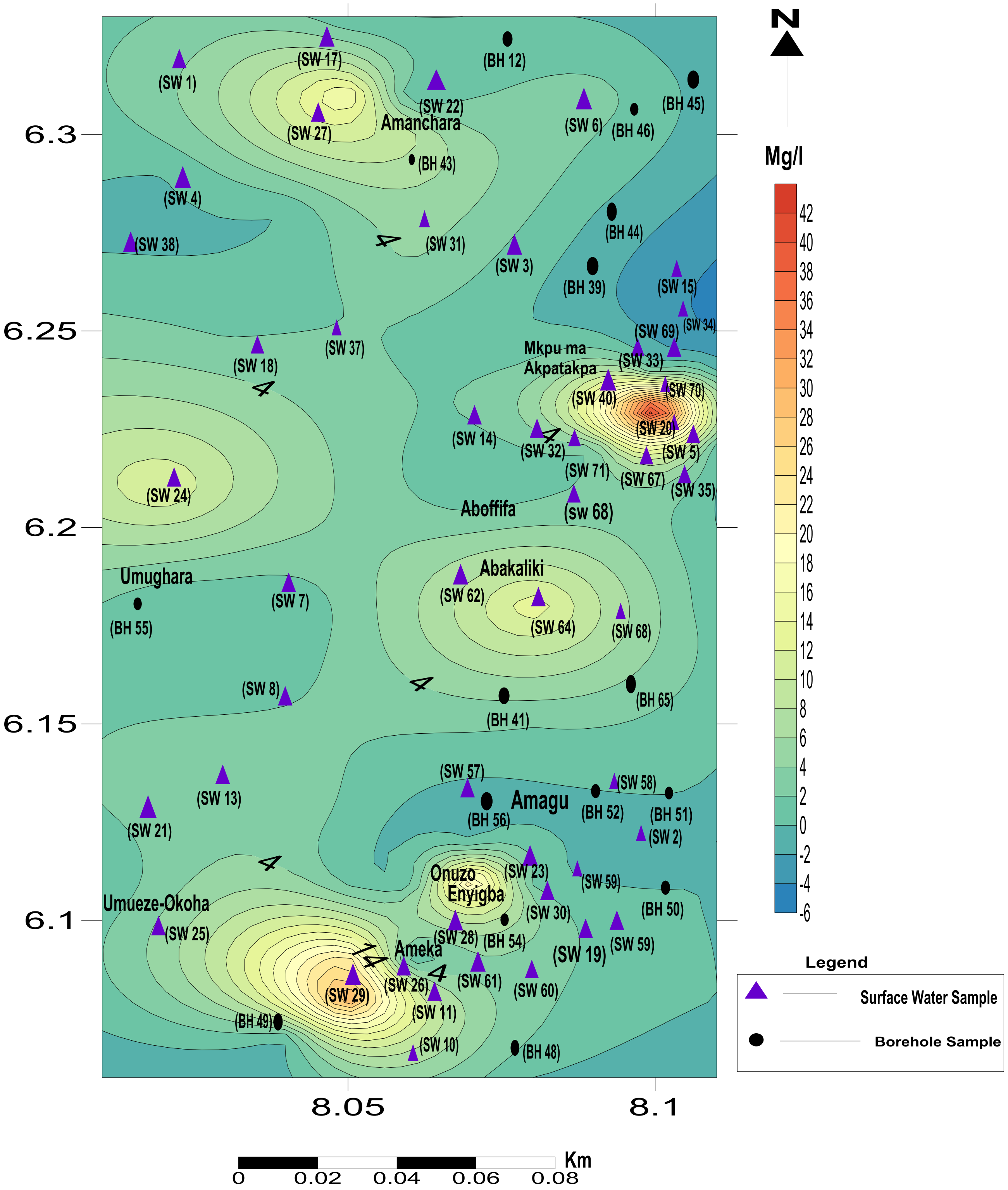

Fig 4.49: Contoured Distribution of Manganese in dry season water sample anaysed.

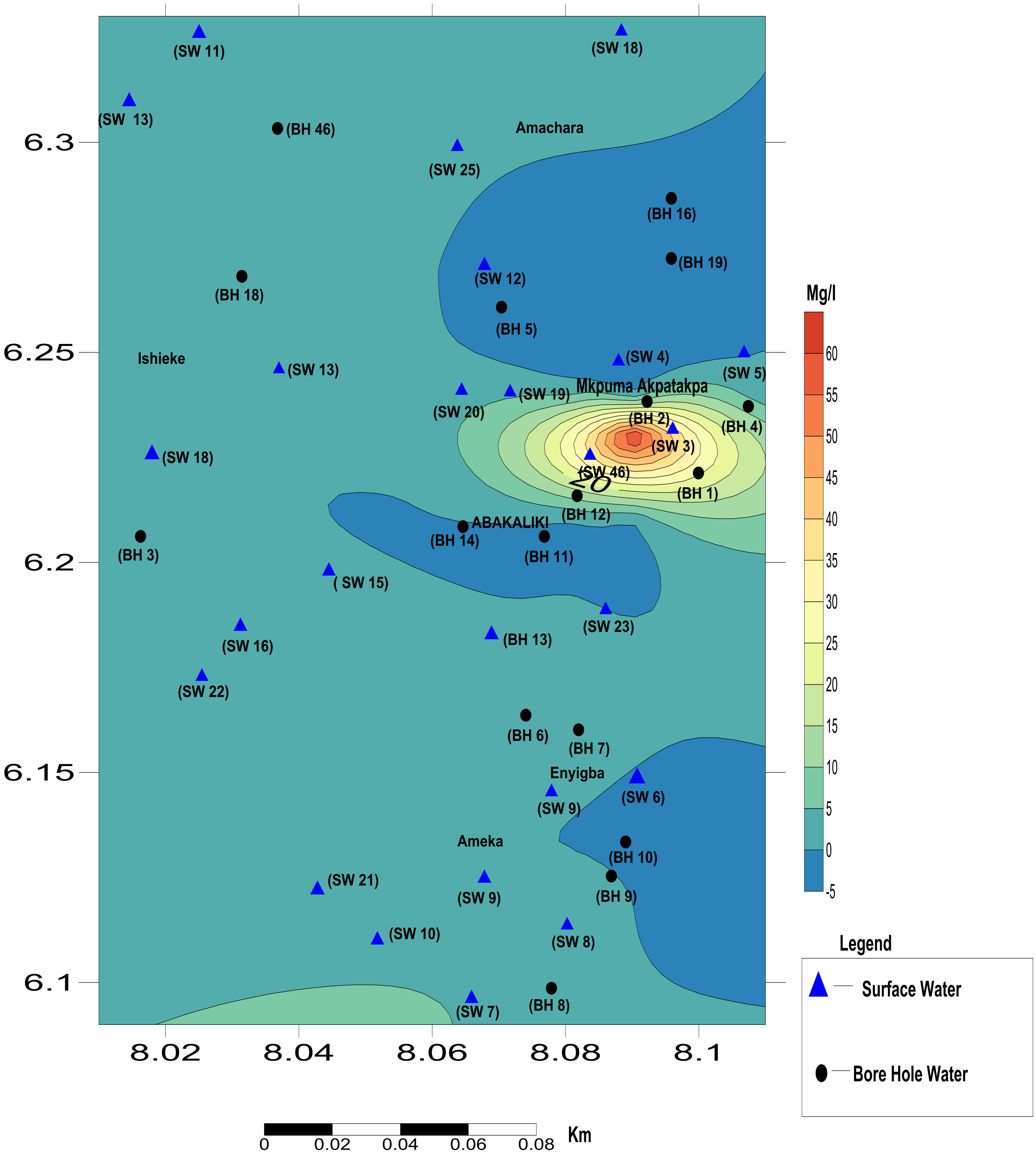

Fig 4.50: Contoured distribution of Manganese in rainy season water samples anlysed

CADMIUM

Cadmium occurs naturally in the environment. Additional releases of cadmium to the environment occur from natural sources and from processes such as combustion of fossil fuel, incineration of municipal or industrial wastes, or land application of sewage sludge or fertilizer (EPA, 1985). WHO, (2008) reveals that smoking is a significant additional source of cadmium exposure in humans. Occurrence levels in drinking water are usually less than 1 mg/L (Elinder, 1985).

From the analysis, cadmium concentration in dry season samples ranges 0mg/L (in very few places around Abakaliki and Odomoke) to 15.67 mg/L while rainy season samples ranges from 0 mg/L – 12.641 mg/L. Very high values were recorded around Mkpuma Akpatakpa mine, (15.67 mg/L and 10.62 mg/L) and the Amanku (12.05 mg/L). 80% of the samples are above the WHO 2011, guideline value of 0.003 mg/L for drinking water. Contoured distribution (Figs 4.51 and 4.52), shows this concentration around the Mkpuma Akpatakpa areas. This is acute contamination.This high concentrations can be linked to the weathering and subsequent dissolution of the chalchopyrite and pyrite ores in the area. Cadmium's mobility in water depends on several factors including the pH and the availability of organic matter. Generally, cadmium will bind strongly to organic matter and this will, for the most part, immobilize cadmium (Autier and White, 2004). Cadmium in water tends to be more available when the pH is low (acidic) (Elinder, 1992). In surface water and groundwater, cadmium can exist as the hydrated ion or as ionic complexes with other inorganic or organic substances. While soluble forms may migrate in water, cadmium is relatively nonmobile in insoluble complexes or adsorbed to sediments, which may leach into water (Elinder, 1985; EPA 1979).

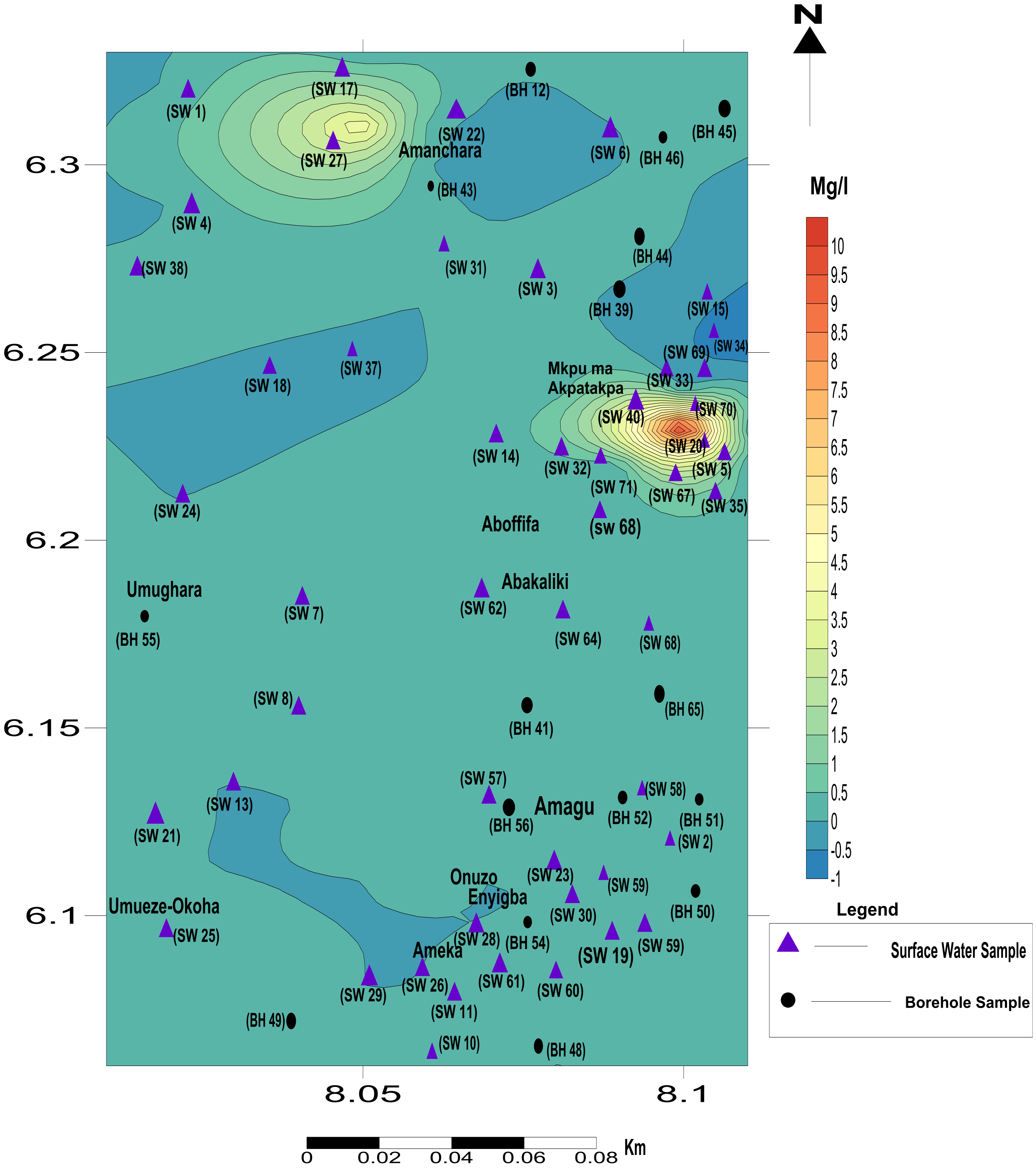

Fig 4.51: Contoured Distribution of Cadmium in dry season water samples anlysed

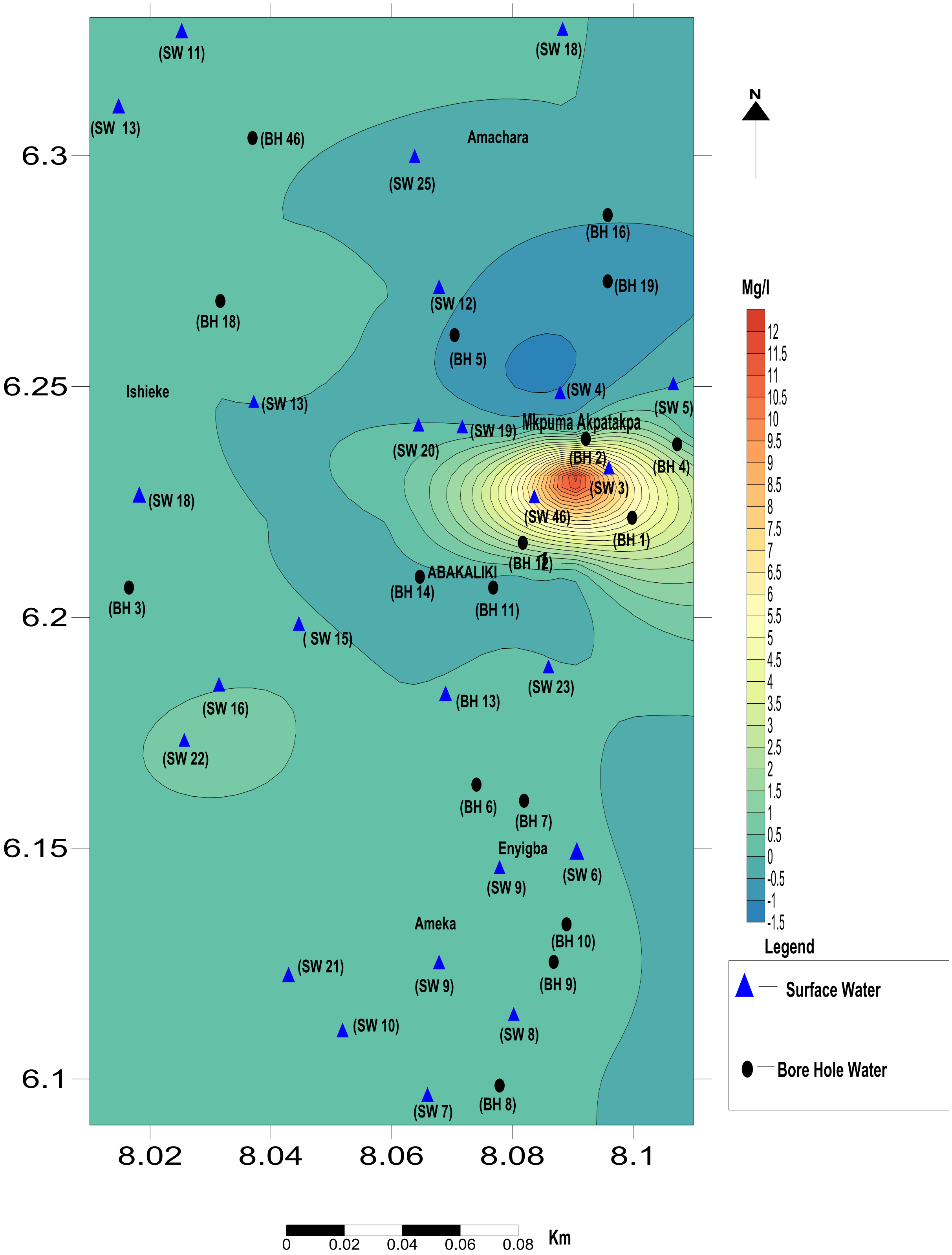

Fig 4.52: Contoured Distribution of Cadmium in rainy season water samples anlysed

SILVER

Concentration of silver in dry season water samples ranged between 0 mg/L (in very many places), to 6.056 mg/L (Figs 4.53 and 4.54), while rainy season samples ranged from 0 mg/L – 2.466 mg/L. Over 50% of samples showed concentrations above the WHO, 2011 guideline of 0.1 mg/L. These high concentrations were not recorded in the mines, but around the waste dumping areas of Umuaghara (the central waste dump of Abakaliki metropolis), Isieke and Umuezekoha. Although Lindsay and Sadiq, (1979) stated that emissions from smelting operations, manufacture and disposal of certain photographic and electrical supplies, coal combustion, and cloud seeding are some of the anthropogenic sources of silver in the biosphere, the principal sources of silver are the ores of copper, copper-nickel, lead, and lead-zinc (Sparks, 2005). This high concentration can be attributed to decomposition in wastes from the dumps. Also, since silver in soils is largely immobilized by precipitation to insoluble salts and by complexation or adsorption by organic matter, clays, and manganese and iron oxides (Smith and Carson, 1977), the concentration can be localized and silver may leach from soils into groundwater, the leaching rate increasing with low pH and increasing drainage (ATSDR, 1990). Lucassen *et al*., 2002 noted that the availability of free silver in marine environments is strongly controlled by salinity, because of the affinity of silver for the chloride ion. Silver occurs naturally mainly in the form of its very insoluble and immobile oxides, sulfides and some salts (ATSDR, 2012). It has occasionally been found in groundwater, surface waterand drinking-water at concentrations above 0.005mg/L. Levels in drinking-water treated with silver for disinfection may be above 0.05 mg/L, higher levels of silver, up to 0.1 mg/L could be tolerated (WHO, 2011). The only sign of silver overload is argyria, a condition in which skin and hair are heavily discoloured by silver in the tissues (WHO, 2008).

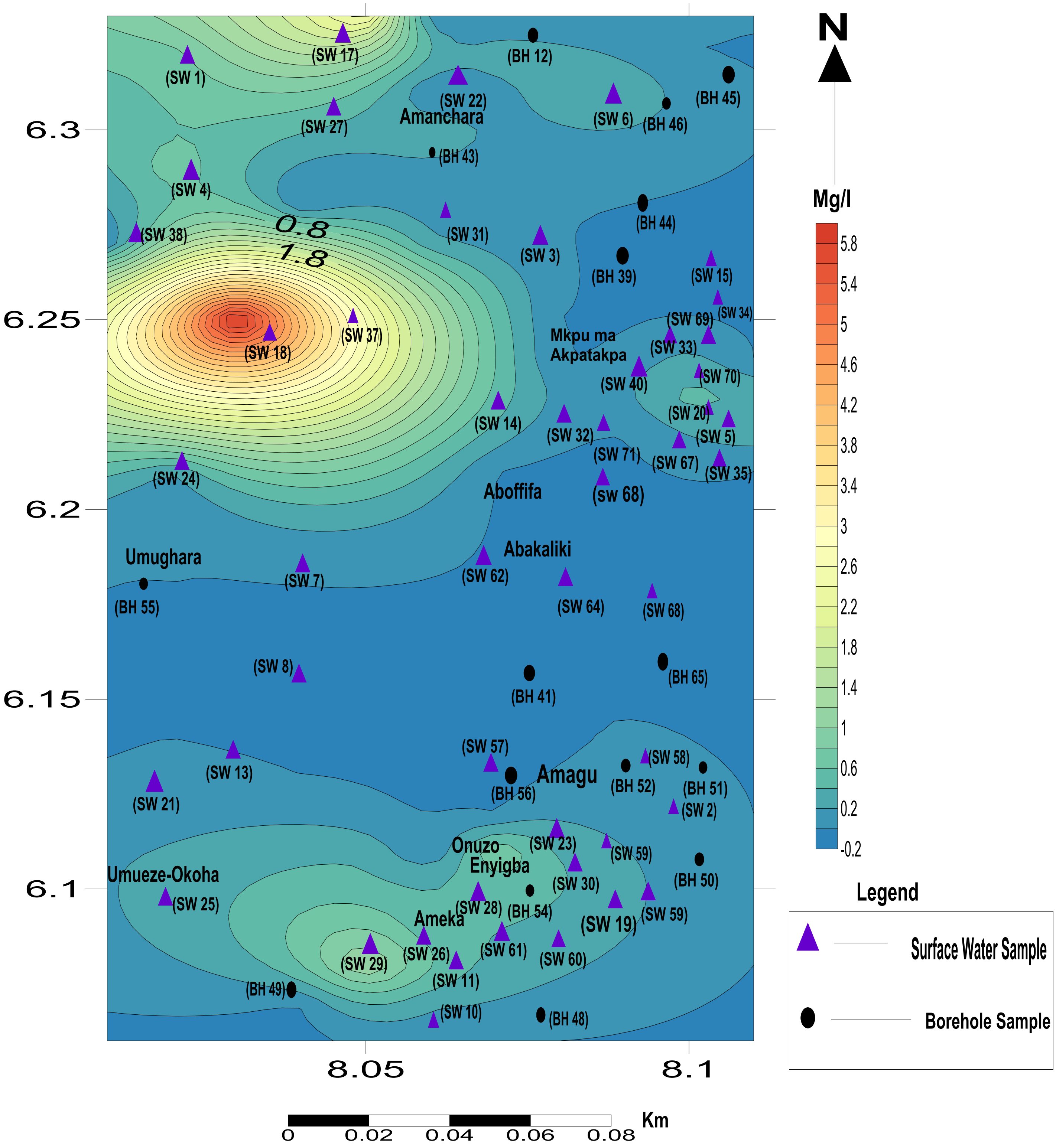

Fig 4.53: Contoured Distribution of silver in dry season water sample analysed

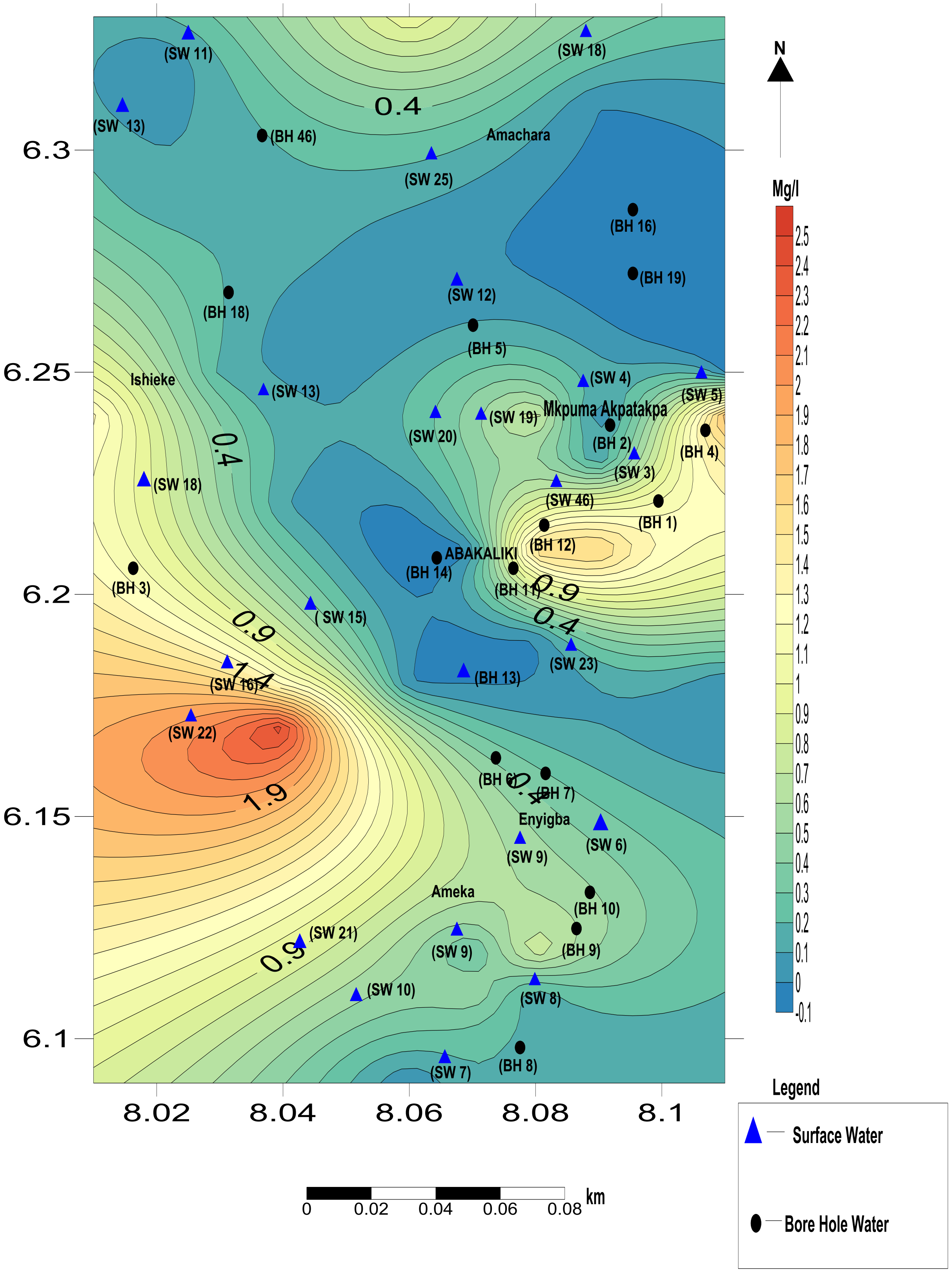

Fig 4.54: Contoured distribution of Silver in rainy season water samples analysed

MERCURY

From the analysis, concentration of mercury in dry season samples ranged from 0 – 2.647 mg/L, while rainy season samples ranged from 0- 1.004 mg/L. This indicates acute contamination of mercury in the water sources of the area (especially around the Mkpuma Akpatakpa, Amanchara and Ameka mining areas) (Figs 4.55 and 4.56), since over 60% of the samples area above the WHO, 2011 guideline of 0.006 mg/L for drinking water. This high concentration can be linked the normal breakdown of minerals in rocks and soil from exposure to wind and water, and from volcanic activity (ATSDR, 2009). Dikinya and Areola, 2010 noted that human activities since the start of the industrial age (e.g., mining, burning of fossil fuels) have resulted in additional release of mercury to the environment. Mercury associated with soils can be directly washed into surface waters during rain events. Surface runoff is an important mechanism for transporting mercury from soil into surface waters, particularly for soils with high humic content (Meili, 2013). ATSDR, (2009) noted that most of the mercury found in the environment is in the form of metallic mercury and inorganic mercury compounds. Metallic and inorganic mercury enters the air from mining deposits of ores that contain mercury, from the emissions of coal-fired power plants, from burning municipal and medical waste, from the production of cement, and from uncontrolled releases in factories that use mercury (Meilli, 1991).

The most common organic form of mercury, methylmercury, is soluble, mobile, and quickly enters water by dissollution. Sulfur-reducing bacteria are responsible for most of the mercury methylation in the environment (Gilmour and Henry, 1991). Low pH and high mercury sediment concentrations favor the formation of methylmercury, which has greater bioavailability potential for aquatic organisms than inorganic mercury compounds (WHO, 2011).

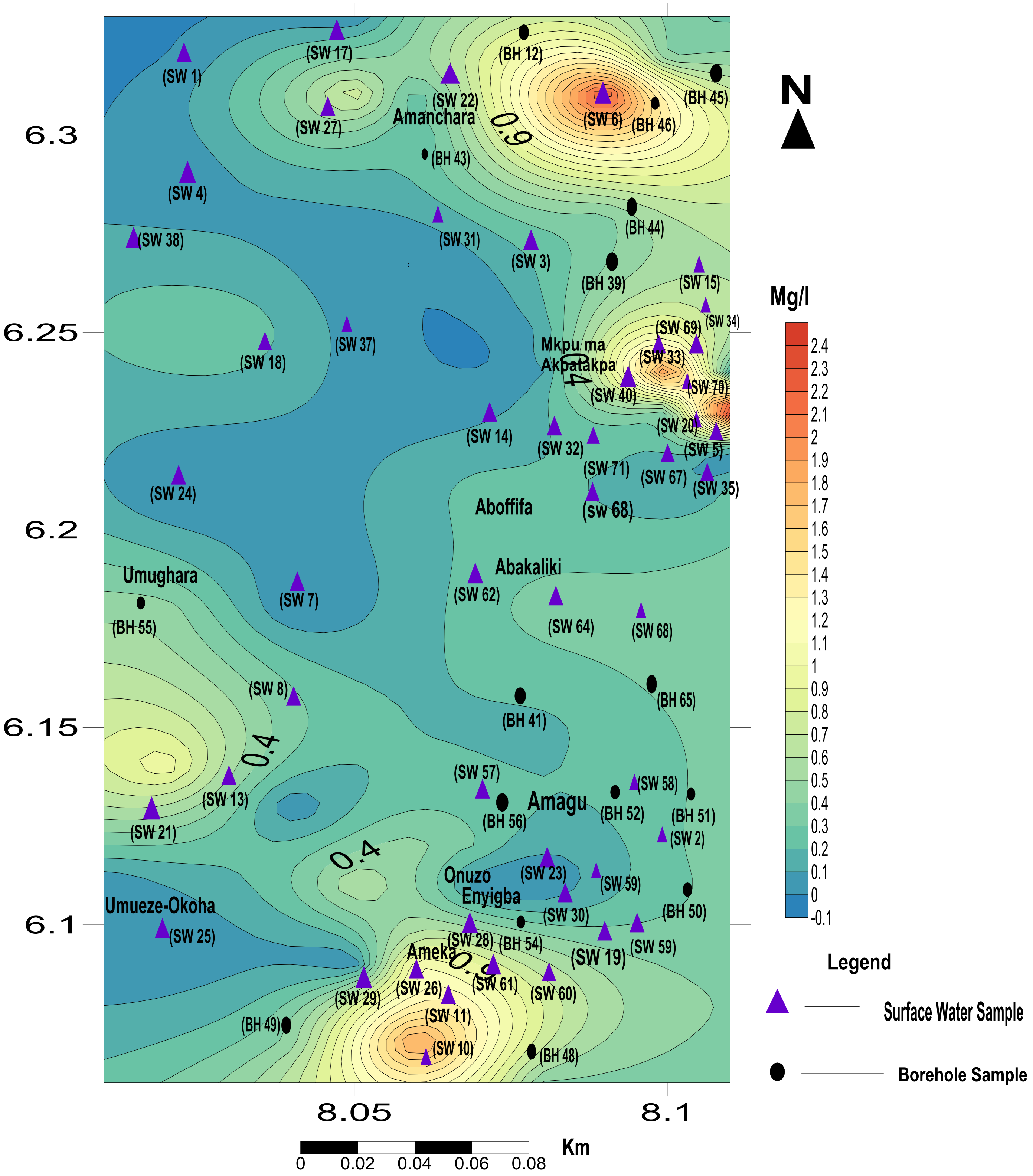

Fig 4.55: Contoured Distribution of Mercury in dry season water samples analysed.

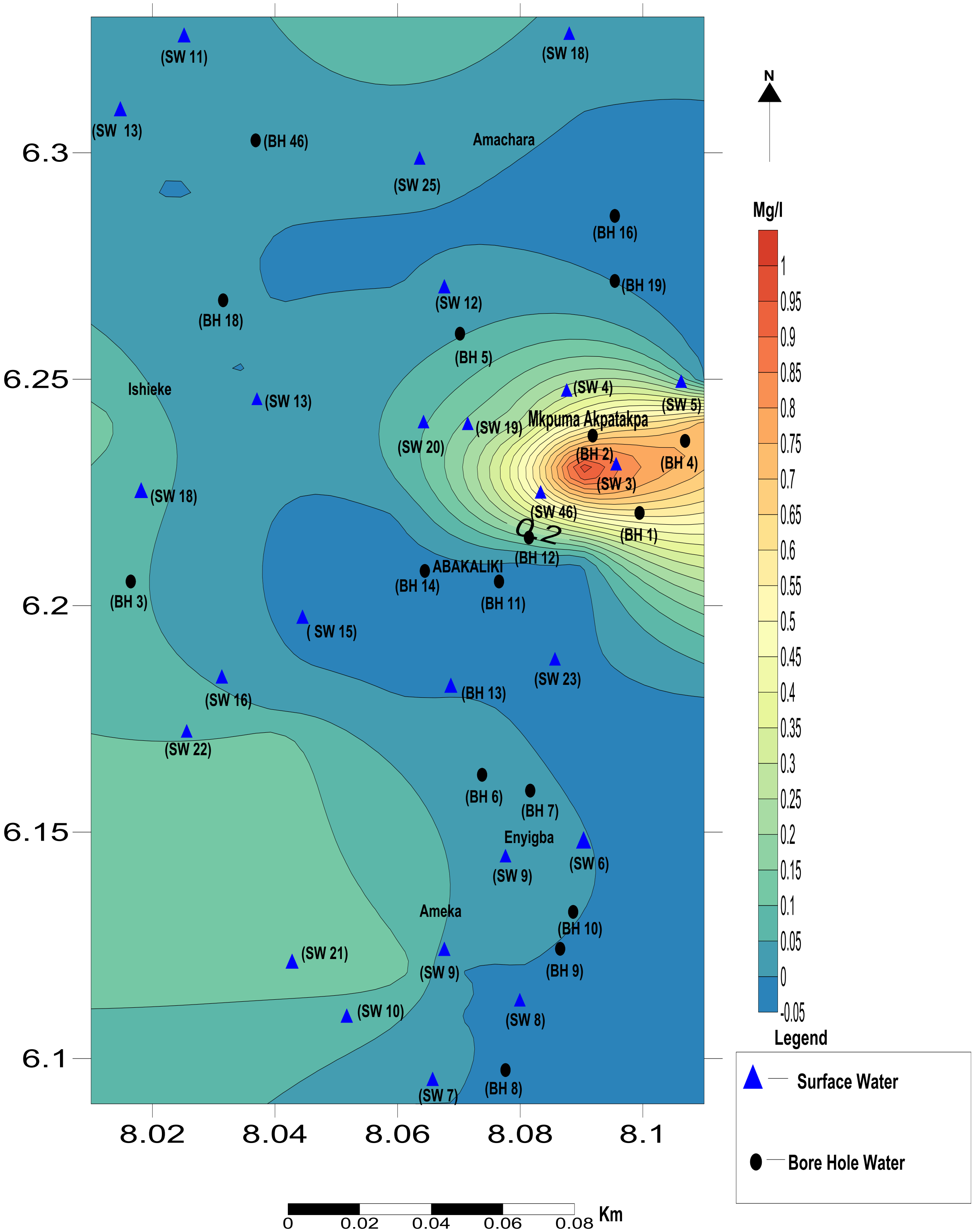

Fig 4.56: Contoured Distribution of Mercury in rainy season water samples analysed.

ARSENIC

The result shows concentration of 0 mg/L (in few places) to 4.13 mg/L for dry season samples, while rainy season samples ranged from 0 mg/L – 0.856 mg/L, with groundwater recording higher concentrations (Figs 4.57 and 4.58). This result shows that about 86% of the samples have values above the WHO, 2011 guideline of 0.01 mg/L for drinking water. This is acute contamination especially around the Mkpuma Akpatakpa mining area, Akpara River, Enyigba, Ngele River Enyigba, Enyigbe salt Lake and Ameka Pond. This emanates from the dissollution of ores. Arsenic is associated with ores containing metals, such as copper and lead, volcanic eruptions are another source of arsenic (ATSDR, 2007). Arsenic is found widely in the earth's crust often as sulphides or metal arsenides or arsenates. In water, it is mostly present as arsenate, but in anaerobic conditions, it is likely to be present as arsenite (Almela *et al*., 2002). It susually present in natural waters at concentrations of less than 1–2 mg/L. However, in waters, particularly groundwaters, where there are sulphide mineral deposits and sedimentary deposits deriving from volcanic rocks, the concentrations can be significantly elevated upto 12 mg/L (WHO, 2011). Arsenic is found in the diet, particularly in fish and shellfish, in which it is foundmainly in the less toxic organic form (Garvey *et al*., 2013).

Transport and partitioning of arsenic in water depends upon the chemical form (oxidation state and counter ion) of the arsenic and on interactions with other materials present. Soluble forms move with the water, and may be carried long distances through rivers (EPA, 1979). Barton *et al*., 1992 noted that some arsenic compounds can stick to particles in the water or sediment on the bottom of lakes or rivers, and some will be carried along by the water. However, arsenic may be adsorbed from water onto sediments or soils, especially clays, iron oxides, aluminum hydroxides, manganese compounds, and organic material (EPA, 1982; Welch *et al*.,1988). Contoured distribution of arsenic in the area shows a specific NE – SW trend, covering the SE axis of the area.

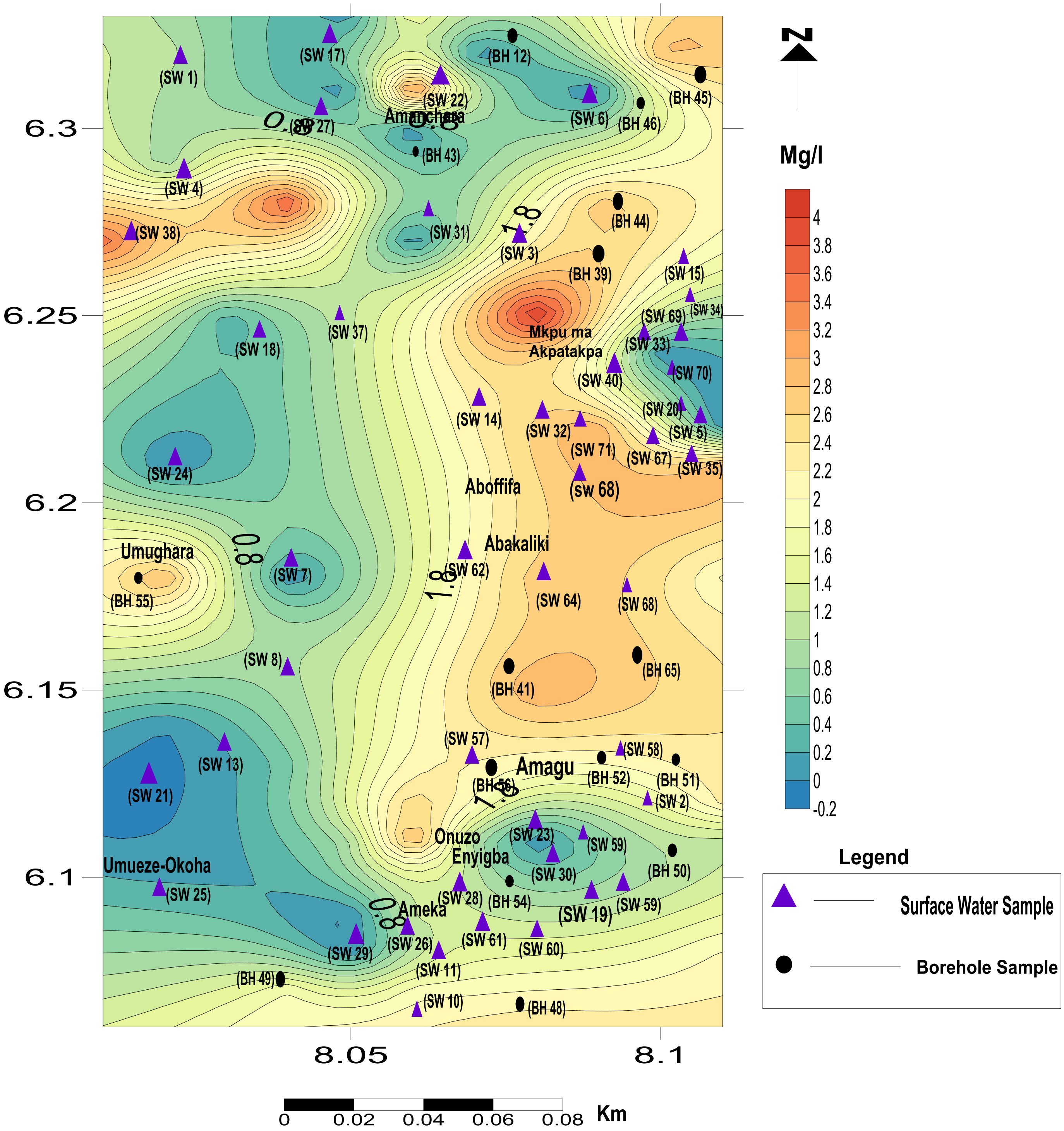

Fig 4.57: Concentration of Arsenic in dry season water samples analysed.

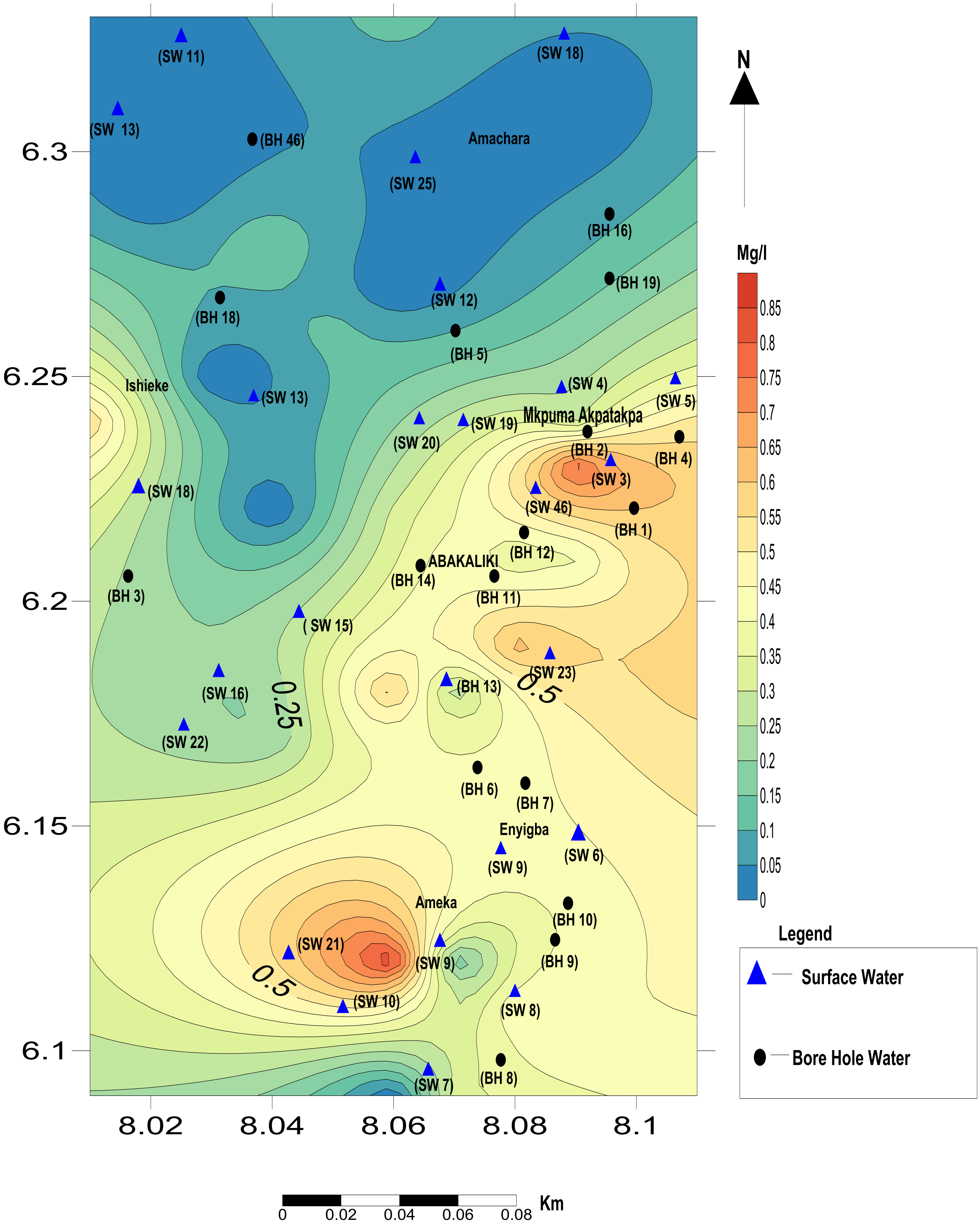

Fig 4.58: Concentration of Arsenic in rainy season water samples analysed.

SELENIUM

Result of the analysis shows that the concentration of selenium for dry season samples ranges from 0 mg/L to 2.6956 mg/L, while raining season samples ranged from 0 mg/L to 0.01 mg/L. This indicates high degree of contamination as about 60% of the samples (especially groundwater) are above the WHO, 2011 drinking water standard of 0.04 mg/L. This high values were observed around the Mkpuma Akpatakpa and Amachara mining areas, and water sources around the Isieke and Umuaghara waste dump sites (Figs 4.59 and 4.60). Contoured distribution shows no specific trend, but pockets of high concentarations in areas mentioned above. Selenium is also commonly found in rocks and soils, often in association with sulfur-containing minerals, or with silver, copper, lead, and nickel minerals (ATSDR, 2003). Occurrence levels in drinking-water vary greatly in different geographical areas but are usually much less than 0.01 mg/l (WHO, 2011). Apart from its dissolution from the sulphur – rich ores and migration from decomposed wastes (ATSDR, 2003), the high concentration can be linked to chemical behavior of selenium. The forms and fate of selenium in soil depend largely on the acidity of the surroundings and its interaction with oxygen (Hoffman and King, 1997). In the absence of oxygen when the soil is acidic, the mobility of selenium is low (HSDB, 2001). Elemental selenium that cannot dissolve in water and other insoluble forms of selenium are less mobile and will usually remain in the soil, posing smaller risk of exposure. However, in 2010, Robberecht and Grieken noted that selenium compounds that can dissolve in water are sometimes very mobile, and surface waters can receive selenium from the atmosphere by dry and wet deposition, from adjoining waters that may contain selenium, from surface runoff, and from subsurface drainage.

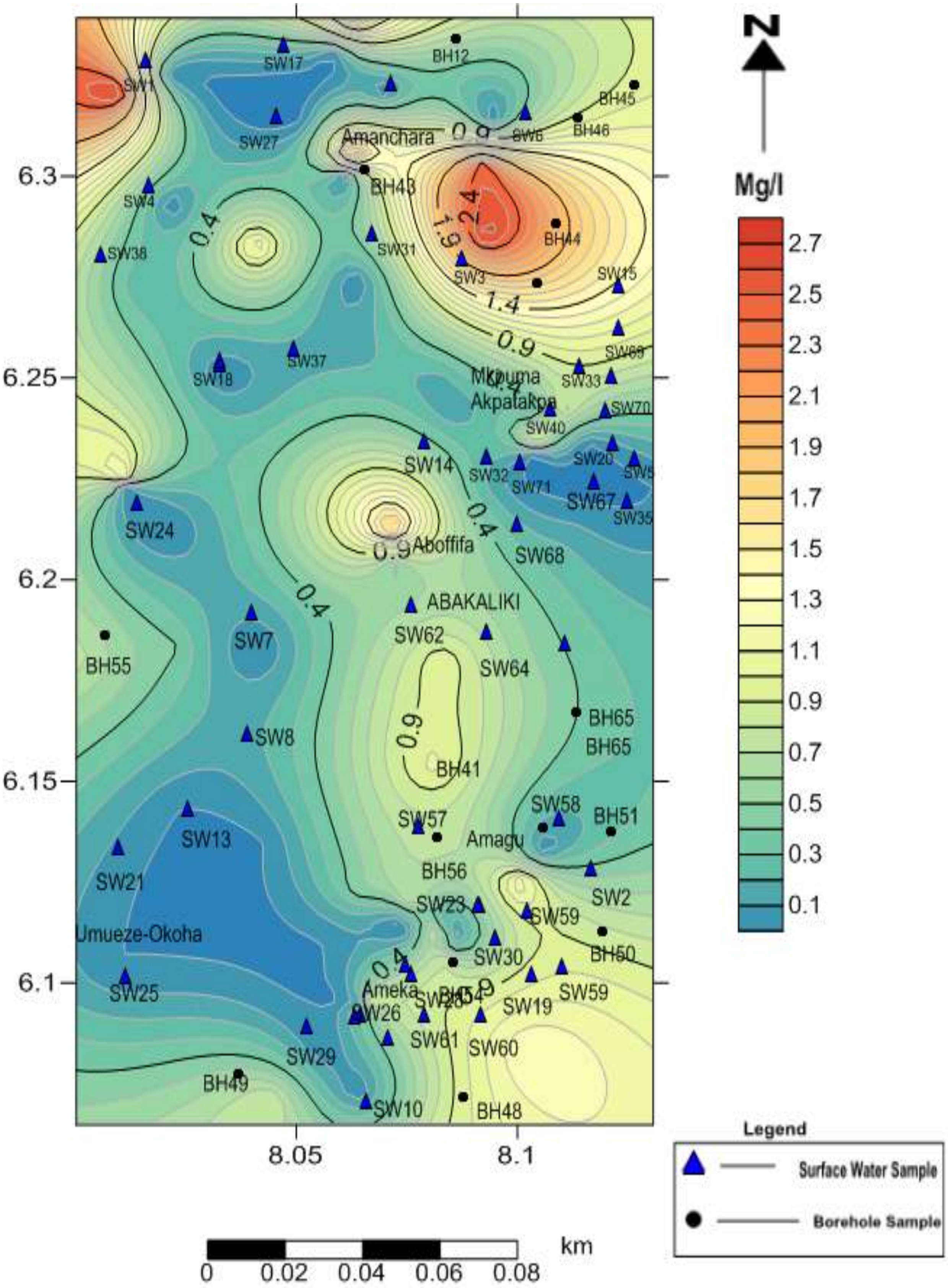

Fig 4.59: Contoured Distribution of Selenium in dry seasonwater samples analysed.

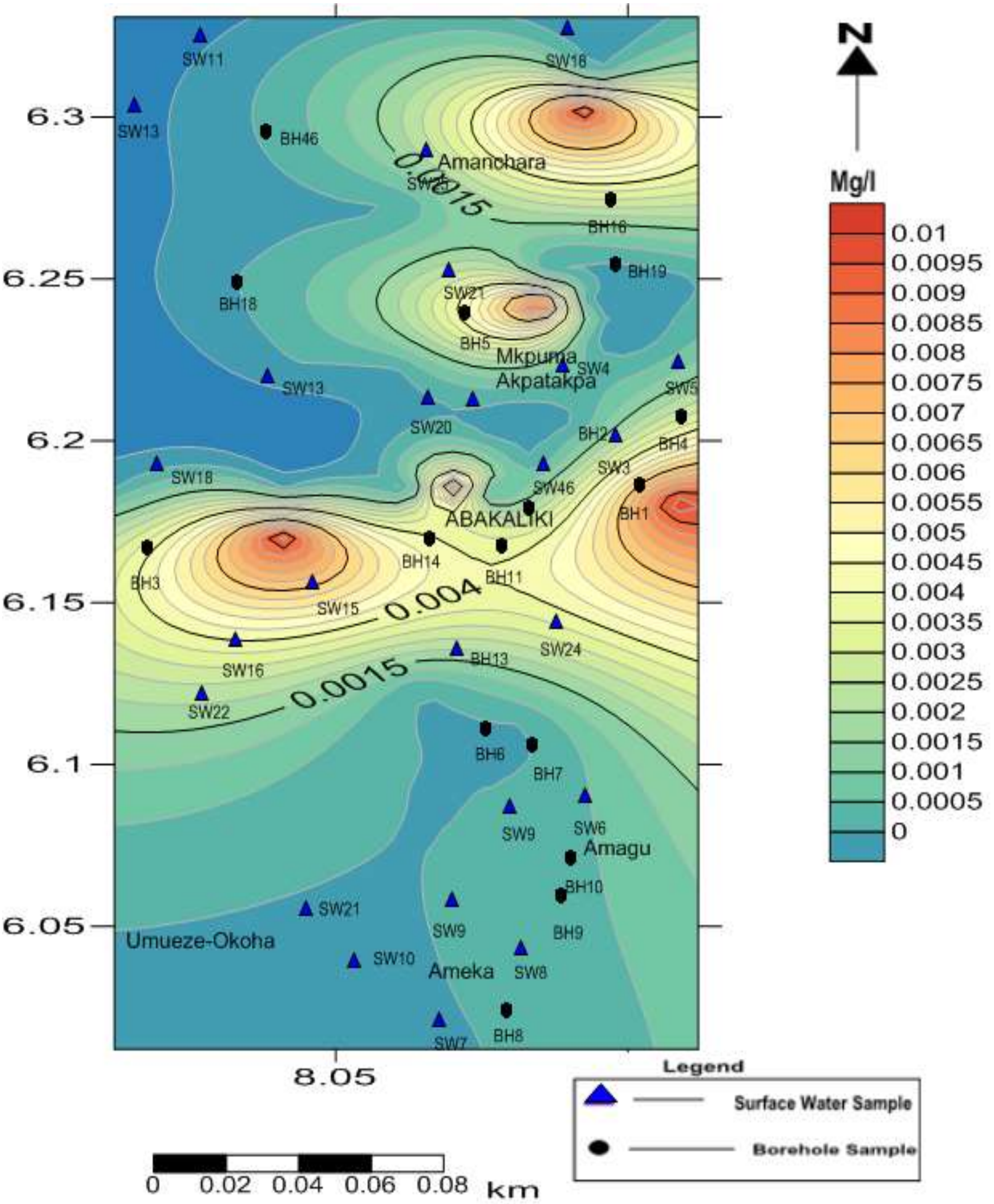

Fig 4.60: Contoured Distribution of Selenium in rainy seasonwater samples analysed.

ZINC

Result of the analysis for the dry season water samples ranged from 0.00mg/L (in most places) to 10.53 mg/L, while rainy season samples ranged from 0 mg/L to 10.42 mg/L. Although, WHO 2011 does not state a permissible limit for zinc, concentration between 3- 5 mg/L is good for healthy living (ATSDR, 2007). This result indicates that only about 10% of the samples are polluted. These high values were observed strictly in the mining sites and mine ponds of Amanchara, Mkpuma Akpatakpa, Enyigba and Ameka (Figs 4.61 and 4.62). Zinc is abundant in the earth's crust. It is a chalcophile metallic element and forms several minerals, including Sphalerite (ZnS), the commonest Zn mineral, Smithsonite ($ZnCO_3$) and Zincite (ZnO), but is also widely dispersed as a trace element in pyroxene, amphibole, mica, garnet and magnetite (Andrews and Sutherland, 2004). It is released to the environment from both natural and anthropogenic sources; however, releases from anthropogenic sources are greater than those from natural sources (Barbera, *et al*., 1991).

Apart from the dissolution of zinc in water, which increases with acidity, zinc is immobile in water (Gundersen and Steinnes, 2003). In water, zinc occurs primarily in the +2 oxidation state, it dissolves in acids to form hydrated Zn^{+2} cations and in strong bases to form zincate anions, which are hydroxo complexes, e.g., $(Zn[OH]_3)^-$, $(Zn[OH]_4)^{2-}$, and $(Zn[OH]_4[H_2O]_2)^{2-}$ (Fuhrer,1986). In most waters, zinc exists primarily as the hydrated form of the divalent cation. However, the metal often forms complexes with a variety of organic and inorganic ligands (EPA, 1984, 1987). The transport of zinc in water is controlled by anion species. In natural waters, complexing agents, such as humic acid, can bind zinc (Barcelous, 1999). Divalent zinc ion, often replaces magnesium in silicate mineral of igneous rocks; consequently, weathering of this zinc-containing bedrock gives rise to Zn^{+2} in solution (EPA 1979).

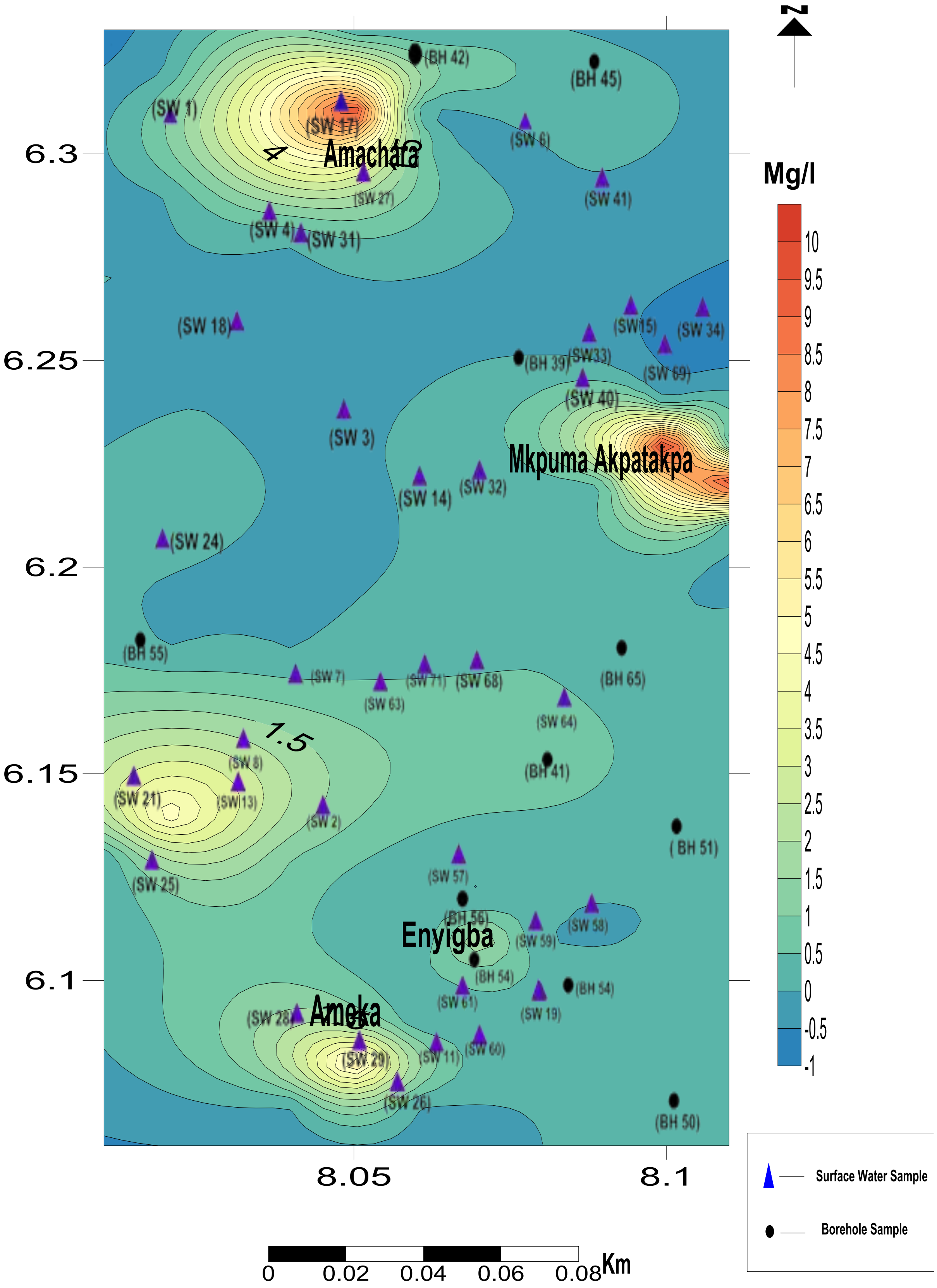

Fig 4.61: Contoured Distribution of Zinc in dry season water samples analysed.

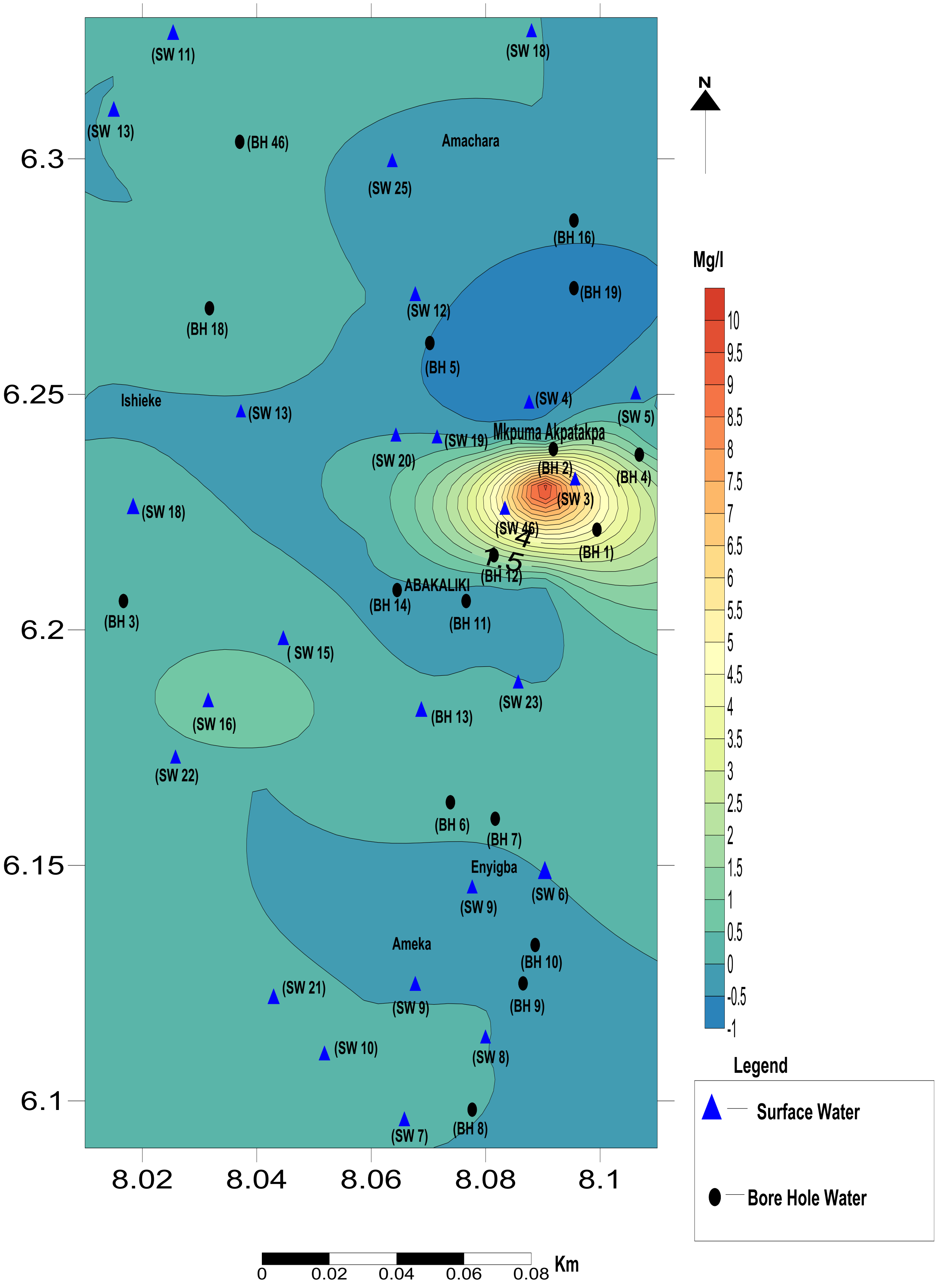

Fig 4.62: Contoured Distribution of Zinc in rainy season water samples analysed.

ALUMINIUM

Aluminium is the most abundant metallic element and constitutes about 8% of the earth's crust WHO (2011). Aluminium intake from foods, particularly those containing aluminium compounds used as food additives, represents a major source of aluminium (Brusewitz, 1984).

The result shows low concentrations of aluminium in water samples analysed. Dry season samples ranged from 0mg/L (about 74% samples), to 0.083 mg/L, while rainy season ranged from 0.001 mg/L to 0.193 mg/L. Dry season samples showed high concentrations around Mkpuma Akpatakpa and Enyigba mine sites, while the Abakaliki waste dump areas also recorded high concentrations in the rainy season (Figs 4.63 and 4.64). Aluminum enters the environment naturally through the weathering of rocks and minerals. Anthropogenic releases are in the form of air emissions, waste effluents and solid wastes primarily associated with industrial processes, such as aluminum production (Alvarez, *et al*., 1993). Because of its prominence as a major constituent of the earth's crust, natural weathering processes far exceed the contribution of releases to air, water, and land associated with human activities (Lantzy and MacKenzie, 1979). The behavior of aluminum in the environment depends upon its coordination chemistry and thecharacteristics of the local environment, especially pH. Aluminum is only sparingly soluble in water between pH 6 and 8. Because the pH of about 95% of naturally-occurring water is between 6 and 9 and since high aluminum concentrations occur in surface water bodies only when the pH is <5, the aluminum concentration in most natural waters is extremely low (Filipek *et al.*, 1987; Snoeyink and Jenkins 1980). In general, aluminum concentrations in surface waters at pH levels above 5.5 will be <0.1 mg/L (Brusewitz, 1984; Miller *et al*., 1984; Sorenson *et al*., 1974; Taylor and Symons, 1984). However, even at neutral pH levels, higher aluminium concentrations have been found in lakes with a high humic acid content (Brusewitz, 1984).

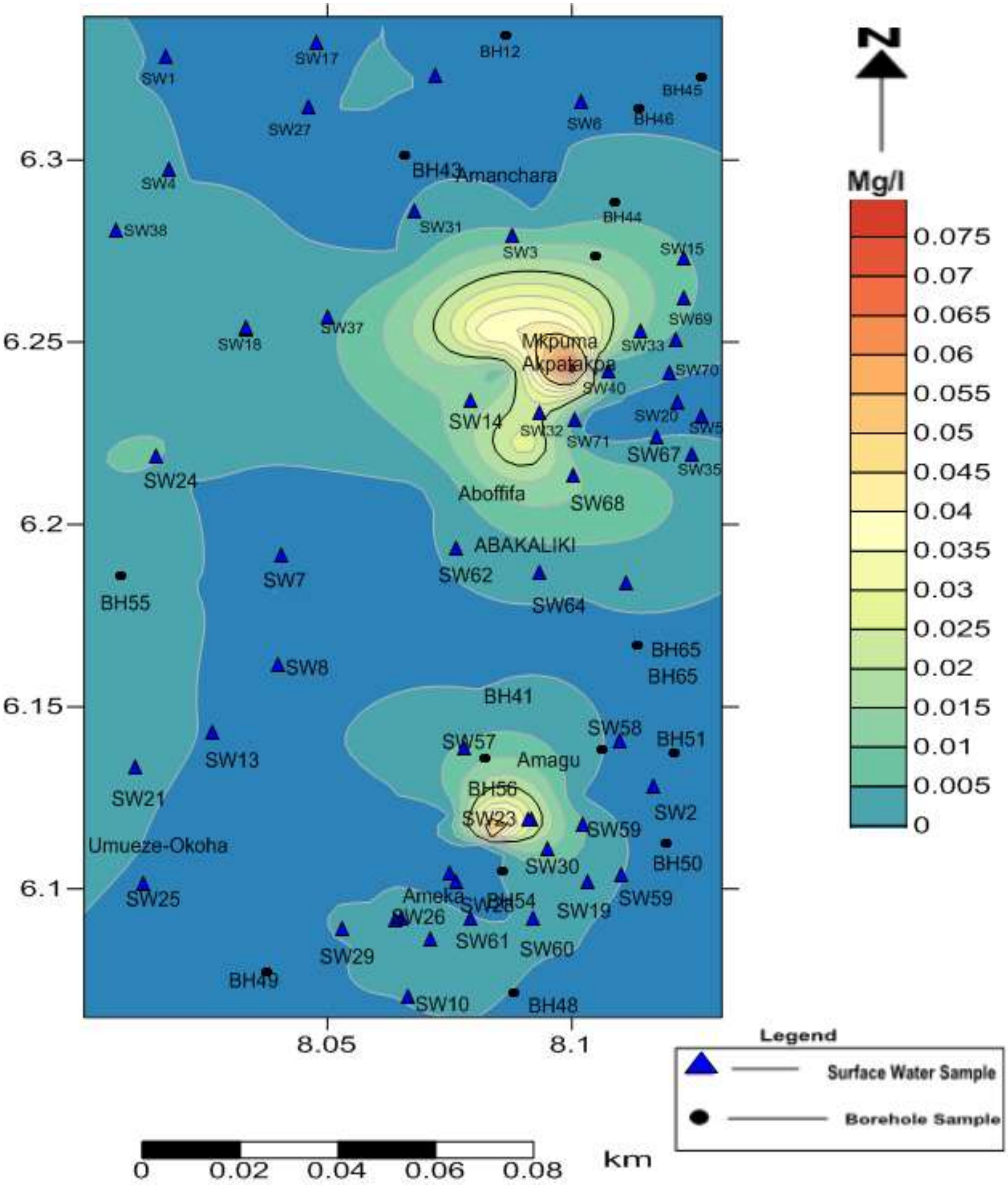

Fig 4.63: Contoured Distribution of Aluminium in dry season water samples analysed.

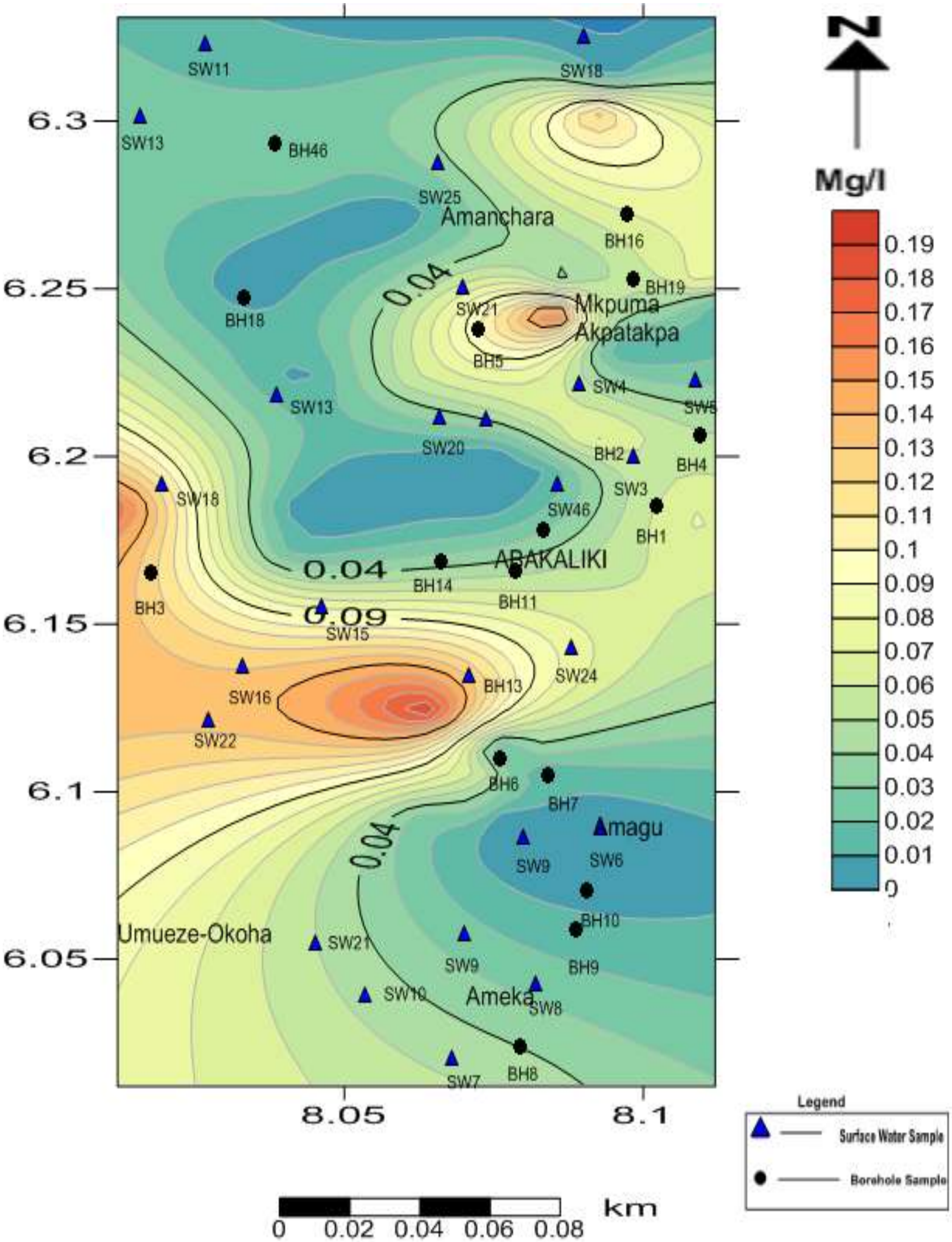

Fig 4.64: Contoured Distribution Aluminium in rainy season water samples analysed

COBALT

Cobalt is a naturally-occurring element that has properties similar to those of iron and nickel. Small amounts of cobalt are naturally found in most rocks, soil, water, plants, and animals, typically in small amounts. Cobalt is also found in meteorites (Barceloux, 1999). However, cobalt is usually found in the environment combined with other elements such as oxygen, sulfur, and arsenic.

The result shows low concentrations of cobalt in water samples analysed. Dry season samples ranged from 0 mg/L (about 74% samples) to 0.9 mg/L, while rainy season ranged from 0 mg/L to 0.549 mg/L (Figs 4.65 and 4.66). Although, no permissible limit has been established for cobalt (WHO, 2011), cobalt is highly radioactive (ATSDR, 2004), and high concentration can pose serious health risk. Contoured distribution (Fig 4.114 and 4.115) shows significant concentration around Mkpuma Akpatakpa mines and Umuaghara dump site. This can be linked to mining and weathering of volcanic rocks in the area. Cobalt may enter air and water, and settle onland from windblown dust, seawater spray, volcanic eruptions, and forest fires and may additionally get into surface water from runoff and leaching when rainwater washes through soil and rock containing cobalt (Mahara and Kudo, 2001). Mendoza *et al*., 1996 noted that many factors control the speciation and fate of cobalt in natural waters and sediments. These include the presence of organic ligands (e.g., humic acids, EDTA), the presence and concentration of anions (Cl^-, OH^-, CO_3^{-2}, HCO_3^-, SO_4^{-2}), pH, and redox potential (Eh). Acidity and redox potential have an effect on the behavior of cobalt in water. The adsorption of cobalt by particulate matter decreases with decreasing pH, since the increasing H^+ concentration competes with metal binding sites. This may lead to increased concentrations of dissolved cobalt at low pH (Andreev and Simenov, 1990).

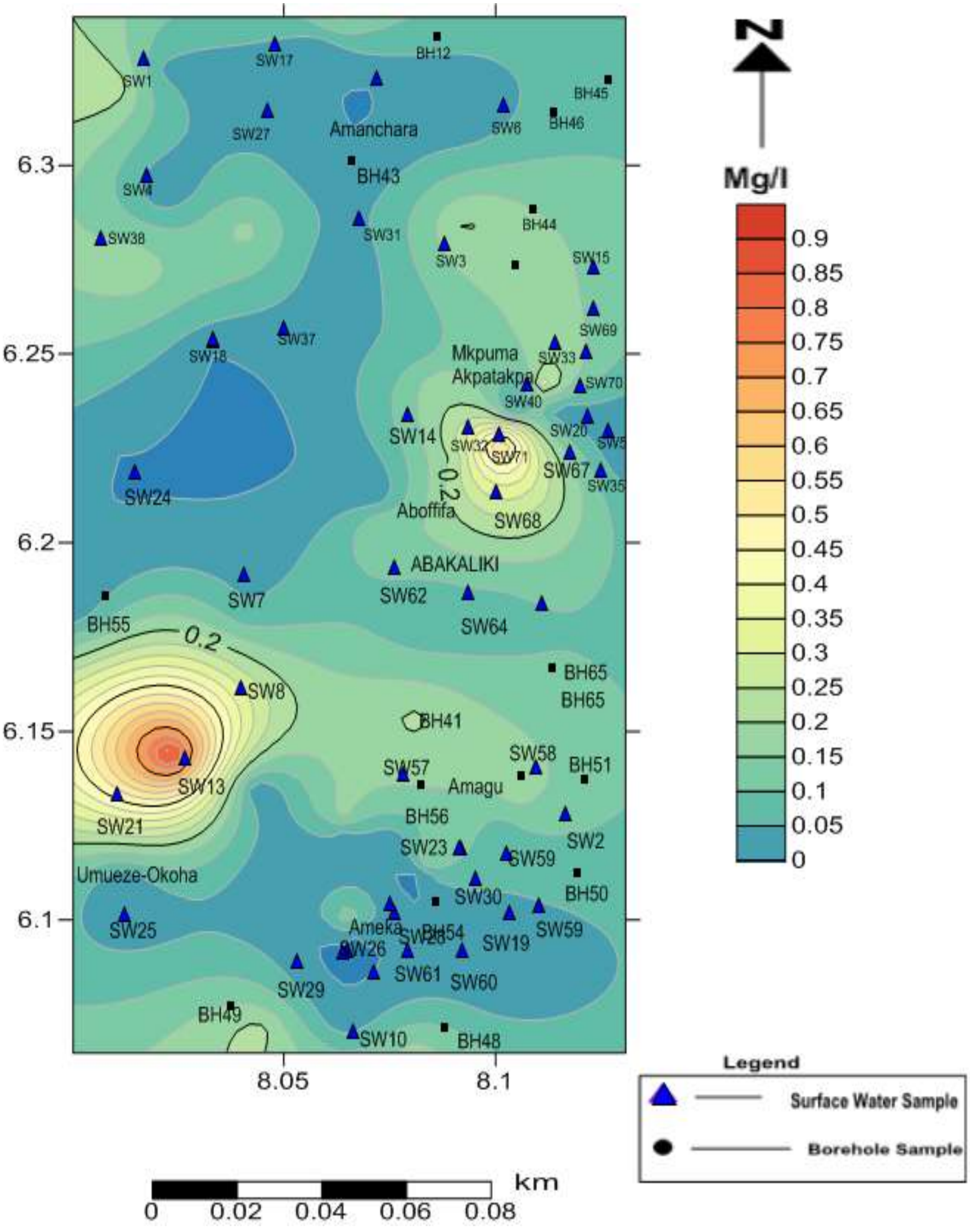

Fig 4.65: Contoured Distribution Cobalt in dry Water Samples Analysed

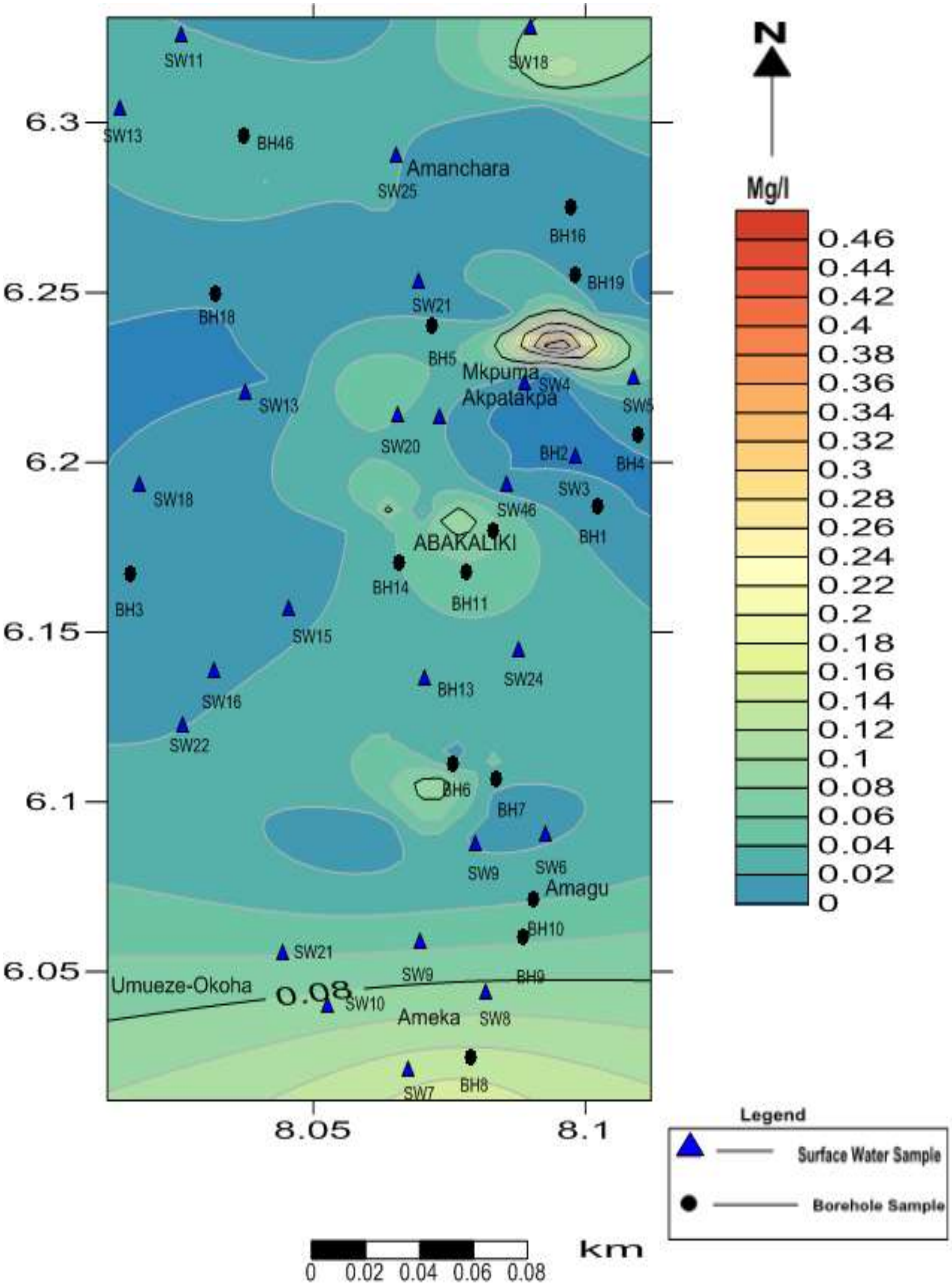

Fig 4.66: Contoured Distribution Cobalt in rainy season water samples analysed

Table 4.2: WHO 2011 Guidelines/ Nigerian Standard and Health Impact of Drinking Water

KEY: INA = INFORMATION NOT AVAILABLENS = NO STANDARD, ND = NOT DONE

S/N	**PARAMETERS**	WHO, NIG. GUIDANCE	**HEALTH IMPACT NIG. STANDARD.**
1	Appearance	Clear	None (aethetics)
2	Colour (Hz)	5	None (aesthetics
3	Qualitative odour	Unobjectional	None
4	Qualitative Taste	Unobjectional	None
5	Temperature	Ambient	None
6	Aluminum (mg/L)	0.2	Potential Neuro-Degenerative disorders
7	Arsenic (mg/l)	0.01	INA
8	Barium mg/L)	0.7	Hypertension
9	Bromine (mg/L)	NS	INA
10	Calcium Hardness (mg/L)	75	Consumer acceptability
11	Chloride (mg/L)	250	None
12	Chromium Hexavalent (mg/L)	0.05	Carcinogenic
13	Cobalt (mg/L)	NS	INA
14	Copper (mg/L)	2.0	Gastro-intestinal disorder
15	Cyanide (mg/L)	0.01	Very toxic to the thyroid & Nervous system
16	Fluoride (mg/L)	1.5	Fluorosis, skeletal tissues (bones & teeth) morbidity.
	Free chlorine (mg/L)	5	None
18	Iodine (mg/L)	0.02	INA
19	Iron (ferrous) (mg/L)	0.3	None (Aesthetics and Laundary effects)
20	Magnesium Hardness (mg/L)	50	Consumer acceptability
21	Manganese (mg/L)	0.4	Neurological Disorder
22	Molybdenum (mg/L)	NS	INA
23	Nickel (mg/L)	0.07	Possible carcinogen
24	Nitrate (mg/L)	50	Cyanosis and Asphyxia (Blue Baby) syndrome) in infants under 3 months
25	Nitrite (mg/L)	3	As Nitrate (mg/L).
26	Sodium (mg/l)	200	INA
27	Zine (mg/L)	3- 5	None
28	Selenium (mg/l)	0.04	Selenoisis
29	Mercury (mg/l)	0.006	Hypertension, Fertility problems, Abortion
30	Lead (mg/l)	0.01	Diarrhae
31	Uranium (mg/l)	0.03	INA
27	Phosphorus (mg/L)	NS	INA
28	Silver (mg/L)	0.1	INA
29	Sulphide (mg/L)	NS	None
30	Sulphate (mg/L)	250	INA
31	TDS (mg/L)	1000	None
32	Total Hardness as $CaC0_3$ (mg/L)	200	Consumer acceptability
33	Conductivity (μS cm^{-1})	1000	INA
34	Turbidity (NTU)	1	None
36	TOTAL MICROBIAL LOAD	100	INA
37	Total coliform	10	INA
26	pH	6.5-8.5	None

Table 4.3:Principal Chemical Constituents of Potable Water and their Concentration Limits and Effects on usability (adapted from Todd, 1980)

CONSTITUENT	CONCENTRATION	EFFECTS ON USABILITY OF WATER
IRON (Fe^{2+})	Generally less than 0.50mg/l in fully aerated water. Groundwater having p^H less than 8.0 may contain 10mg/l; as much as 50mg/l may occur. Acid water from thermal spring mine wastes and industrial wastes may contain more than 6000mg/l.	More that 0.1mg/l precipitates after exposure to air, causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts objectionable tastes and colours to foods and drinks. More than 0.2mg/L is objectionable for most industrial uses.
Calcium (Ca^{2+})	Generally less than 100mg/l; brines may contain as much as 75,000mg/l.	Ca and Mg combine with, HCO_3^{2-}, $CO^{2-}{}_3$, SO_4^{2-} and SO_2 to form heat retarding, pipe clogging scale in boilers and in other heat exchanging equipment. Ca and Mg combine with ions of fatty acid in soaps to form soapsuds; A high concentration of Mg has a laxative effect, especially on new users of the supply.
Magnessium (Mg^{2+})	Generally less than 50mg/l; ocean water contains more than as much as 57,000mg/l.	
Sodium (Na^{+})	Generally less than 200mg/l; about 10,000mg/l 25,000mg/l in brines.	More than 50mg/l Na and k in the pressure of suspended matter causes foaming, which accelerates scale formation and corrosion in boilers. Na and K carbonate in recirculating cooking water can cause deterioration in cooling powers. More than 65mg/l of Na can cause problem in ice manufacturing
Potassium (K^{+})	Generally less than 10mg/l as much as 100mg/L in hot springs; as much as 25,000mg/l in brines.	
Carbonate (CO_3^{2-})	Commonly less than 10mg/l in groundwater. Water high in Na may contain as much as 50mg/l of $CO^{2-}{}_3$.	Upon heating, $HCO^{2-}{}_3$ is changed into steam, CO_2 and $CO^{2-}{}_3$. The CO_3 combines with alkaline earths-principally Ca and Mg to form crust like scales of $CaCO_3$ that retards flow of heat through pipe walls and restricts flow of fluids in pipes.
Bicarbonate ($HCO^{2}{}_{3}^{-}$)	Commonly less than 500mg/l may exceed 1000mg/l in water highly charged with carbon oxide.	

Continuation of table 4.3

Sulphate (SO_4^{2-})	Commonly less than 300mg/l except in wells influenced by acid mines. As much as 200,000mg/l in brines.	SO^{2-}_4 combines with Ca^{2+} to form adherent heat retarding scale. More than 250mg/l is objectionable in some industries. Water containing about 500mg/l of SO^{2-}_4 tastes bitter, about 1000mg/l may be cathartic.
Chloride (Cl^-)	Commonly less than 10mg/l in humid regions but up to 1000mg/l in more arid regions. About 10,300mg/l in seawater and as much as 200,000mg/l in brines.	Cl^- in excess of 100mg/l imparts a salty taste. Concentrations in excess of 100mg/l may cause physiological damage. Food processing industries usually require less than 250mg/l. Textile, paper and rubber industries desire less than 100mg/l.
Flouride (F^-)	Concentrations generally do not exceed 10mg/l. Brines may be as much 1600mg/l in brines	F concentration between 0.6 and 1.7mg/l in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. In excess of 1.5mg/l causes "mottled enamel" in children's teeth. In excess of 6.0mg/l causes pronounced mottling and disfiguration of teeth.
Nitrate NO_3^{2-}	Commonly less than 10mg/l	Water containing more than 100mg/l of NO_3^{2-} is bitter tasting and may cause physiological disorders. Water in excess of 45mg/l has been reported to cause methemoglobinebia in infants
Manganese (Mn^{2+})	Generally 0.2mg/l or less. Groundwater and acid mine water contain more than 10mg/l.	More than 0.2mg/l precipitates upon oxidation; causes undesirable tastes, deposits on food during cooking; stains plumbing fixtures and laundry, fosters growths in reservoirs, filters and distribution systems.

4.4 Comparison of Dry and Rainy Season Water Analysis

Comparison of dry and rainy season analysis results of water samples shows that hydrochemical constituents are more concentrated in the dry season samples than rainy season samples. This can be due to high rate of evaporation in the dry season which causes high concentration of the chemical constituents. Lower concentrations of chemical constituents in the rainy season can be attributed to high rate of dilution and dispersion in the aqueous environment. Using the mean concentration, minimum concentrationand the maximum concentration to generate standard deviation for the dry season and raining season constituents, analytical comparison of the hydrochemical constituent using the standard deviation, shows a dispersion of constituents between the seasons giving a measure of variability. Analytically, the dry season constituents appear greater, showing a more heterogeneous distribution while the rainy season samples has a more homogenous distribution for the constituents. The dry season result indicates a higher standard deviation of 2658.04 mg/L from the mean of 88.11mg/L implying a high rate of concentration of chemical constituents which is very large, and may be due to excessive evaporation, physical and chemical factors. In the rainy season the standard deviation of 344.99mg/L from the 50.11mg/L indicates a continuous reduction in the concentration of constituents since it is smaller in value. This may be attributed to continuous rainfall, increased runoff and drastic reduction in evaporation.

Table 4.4: Summary of Statistical Analysis of some Constituents of Water Samples Analysed in both seasons.

		Mean conc. (Mg/l)		Minimum Conc.(mg/l)		Maximum Conc.(mg/l)		Standard Deviation	
S/N		A	B	A	B	A	B	A	B
1	pH	5.79	6.659	1.51	3.85	9.87	10.68	4.18	3.43
2	SO_4^{2-}	197.503	19.66	0.1	174.5	929.99	2.1	489.93	94.87
3	Cl^-	351.19	163.21	0.67	15.8	2750	444	1496.44	217.54
4	NO_3	3.735	13.248	0.012	2.006	36.00	81	19.79	42,73
5	CO_3^{2-}	70.12	161.85	0.04	2.1	324.17	442	170.55	222.68
6	Fe^{2+}	3.841	3.586	0.00	0.00	58.18	31.578	32.54	17.29
7	Mg^{2+}	18.23	4.521	0.00	0.00	178.89	12.441	29.76	17.08
8	Ca^{2+}	26.49	22.293	0.00	2.385	190.98	51.83	103.47	24.88
9	Pb	1.904	0.200	0.00	0.00	11.373	4.010	6.09	2.26
10	Cu	0.025	0.054	0.00	0.00	0.341	0.341	0.19	0.18
11	Cr	0.386	0.111	0.00	0.00	24.648	0.818	141.12	0.44
12	Ni	0.046	0.038	0.00	0.00	0.757	0.186	0.42	0.10
13	Cd	0.799	0.427	0.00	0.00	15.672	12.641	15.01	0.43
14	As	2.63	0.306	0.00	0.00	26.38	0.856	14.53	0.43
15	Hg	0.55	0.071	0.00	0.042	2.60	1.009	1.37	0.55
16	Mn	4.567	3.474	0.00	0.00	45.13	63.45	24.84	35.67
17	Zn	1.058	0.403	0.00	0.00	10.531	10.41	5.80	5.90
18	Na	36.95	7.139	0.00	1.178	120.00	11.902	61.46	
19	Ka	7.88	2.499	0.00	0.00	73.85	21.448	40.55	11.73
AVG								139.90	36.71
SUM			88.66	50.11				2658.04	344.99

A= dry season samples; B = Rainy season sample

4.5 Geochemical Assessment of Soil/Stream Sediments

4.5.1 Geochemical Survey for Soils and Stream Sediments

According to the dictionary of Earth Science, (Ailsa and Michael, 1999) geochemical soil survey is the process of collecting and analysing unconsolidated soil sediments in order to locate geochemical anomalies in the underlying rock and to use these to find ore bodies. Where the loose material or soil is stable, there is a geochemical balance between the original rock, weathering, pore water, and biological activity. The soil profile is usually layered, and in a geochemical soil survey the horizon giving the sharpest contrast between background and anomaly is chosen for analysis. Mendoza *et al*., (1996) also noted that geochemical survey of soil/ stream sediment involves the assessment of the mineral potential of an area of substantial size by determining the broad picture of metal distribution, with a view to focusing attention on the relatively more promising parts of the area. Thus, it is a method of area selection and not one of locating specific deposits. He opined that for the purpose of geochemical evaluation of an area, large target areas that permit a low sample density are employed to have a high coverage at low cost per unit area. Due to the fact that broad patterns are most likely to be formed by metal dispersion in the drainage system, stream sediment geochemical studies are outstanding tools for reconnaissance work, being a pointer to a possible occurrence of mineralization (Mcqueen, 2008; AusIMM, 2011). The underlying rationale behind stream sediment geochemical surveys is the fact that in weathering environments many minerals and particularly sulphide minerals are unstable and will break down as a result of oxidation or other chemical reactions. This results in dispersion of both ore and indicator elements in solution, in run-off and in ground water for relatively long distances within the drainage basin (Levinson, 1974; Al- momani, 2009).

Active stream sediments are fine to medium grained solid material largely derived from rocks and soil materials eroded by stream or river water from upstream in the catchment area, and depending on their particle size and stream/river water velocity are transported either in suspension or by saltation or by rolling on the stream bed. The major pathways for heavy metals are by sedimentation of particles and by the sorption of dissolved metals from surface water or ground water seepages in contact with stream sediments (Vanek *et al*., 2005; Akoto *et al*., 2008).

Kish and Machwa, (2003); and Lech *et al*., (2007) noted that geochemical stream sediment surveys are employed almost invariably for reconnaissance studies in drainage basins, because if properly collected, these stream sediments represents the best composite of materials from catchments areas upstream from sampling sites. Therefore, by sampling and analyzing stream sediments it is possible to recognize geochemical anomalies within a catchment area and trace them to their source.

4.5.2 Results/Frequencies of Element in a Given Weight of Sample

The results of geochemical analysis of soils/ stream sediments of Pb, Zn, Cu, As, Cd, Ni, Hg, and Ag in the stream bed sediments and soils are shown in Appendix 15. Appendix 15a and 15b shows the concentration of chemical constituents in mg/kg in dry seasonand rainy season samples respectively.

Table 4.5: Summary of statistical Analysis of various concentrations of Heavy metals in stream sediments/ soil in mg/kg.

Metals	Maximum conc.		Min conc (mg/kg)		Mean conc (mg/Kg)		Variance (mg/kg)(x - x)		Standard deviation
	DRY	RAINY	DRY	RAINY	DRY	RAINY	DRY	RAINY	
Zn	203	186	6.01	0.08	48.07	37.16	5.45	-5.46	29.81
Cu	206.99	115.17	0.00	0.00	13.40	15.49	-1.05	1.04	1.08
Pb	74.3	74.05	0.00	0.00	18.49	19.71	-0.61	0.61	0.37
Cd	8.25	16.46	0.00	0.00	1.08	1.56	-0.24	0.24	0.06
Cr	28.32	51	0.00	0.00	9.00	8.20	0.4	-0.4	0.16
Hg	6.03	31.2	0.00	0.00	0.37	1.83	-0.73	0.73	0.53
Ag	30.29	7.7	0.00	0.00	3.14	0.52	1.31	-1.31	1.72
As	56	19.00	0.00	0.00	11.19	1.21	5.09	-4.89	23.91

Table 4.6: Average abundance of the analyzed heavy metals in the Earth's crust and shale after Levinson, (1974).

Element	Earth's Crust	Shale
Zn	70	90
Cu	55	50
Pb	12.5	20
Cd	0.15	0.3
Cr	100	73
Hg	N/A	N/A
Ag	N/A	N/A
As	1.8	10

N/A means not available.

4.5.3 Concentration of Various Elements

4.5.3.1 Zinc (Zn)

From the analysis, zinc was well dispersed, all the samples recordred concentrations for zinc. The concentration of Zinc ranged from 6.01-203mg/kg, with a mean concentration of 48.07mg/kg, from the dry season samples, while concentration of rainy season samples ranges from 0.08mg/kg – 186mg/kg. The standard deviation is 29.81. It also has a geochemical background value that has been set at 70mg/kg in the Earth's Crust and 90mg/kg for shale (Table 4.6). The highest concentrations of zinc were recorded at the areas around Enyigba, Ameka and Mkpuma Akpatakpa, where active mining is on- going (Figs 4.67 and 4.68). This result shows higher concentrations in soils of the derelict mines than stream sediments in the area. The lowest concentration was recorded in River Abe Odomoke.

The distribution and transport of zinc in water, sediments and soils are dependent upon the species present and characteristics of the environment, especially pH, redox potential (Eh), salinity, nature and concentrations of complexing ligands, cation exchange capacity, and the concentration of zinc (Gundersen and Steinnes, 2003). Sorption is the dominant reaction, resulting in the enrichment of zinc in suspended and bed sediments (ATSDR, 2005, EPA 1979).Natural background of total zinc concentration is usually from 10- 300mg/kg dry weight in soils (Buchauer, 1973). ATSDR, (2005) stated that increased levels of zinc in soils can be attributed to natural occurrence of zinc enriched ores (as in the study area), anthropogenic sources including thedisposal of zinc wastes from metal manufacturing industries and coal ash from electric utilities, sludge and fertilizer or even through abiotic and biotic processes. Toxicity in human may occur if zinc concentration in water approaches 400mg/kg. This is characterized by symptoms of irritability, muscular stiffness, pain, loss of appetite and nausea. Zinc appears to have a protective effect against the toxicities of both cadmium and lead (Fergussion, 1990). But this is safe in the study area.

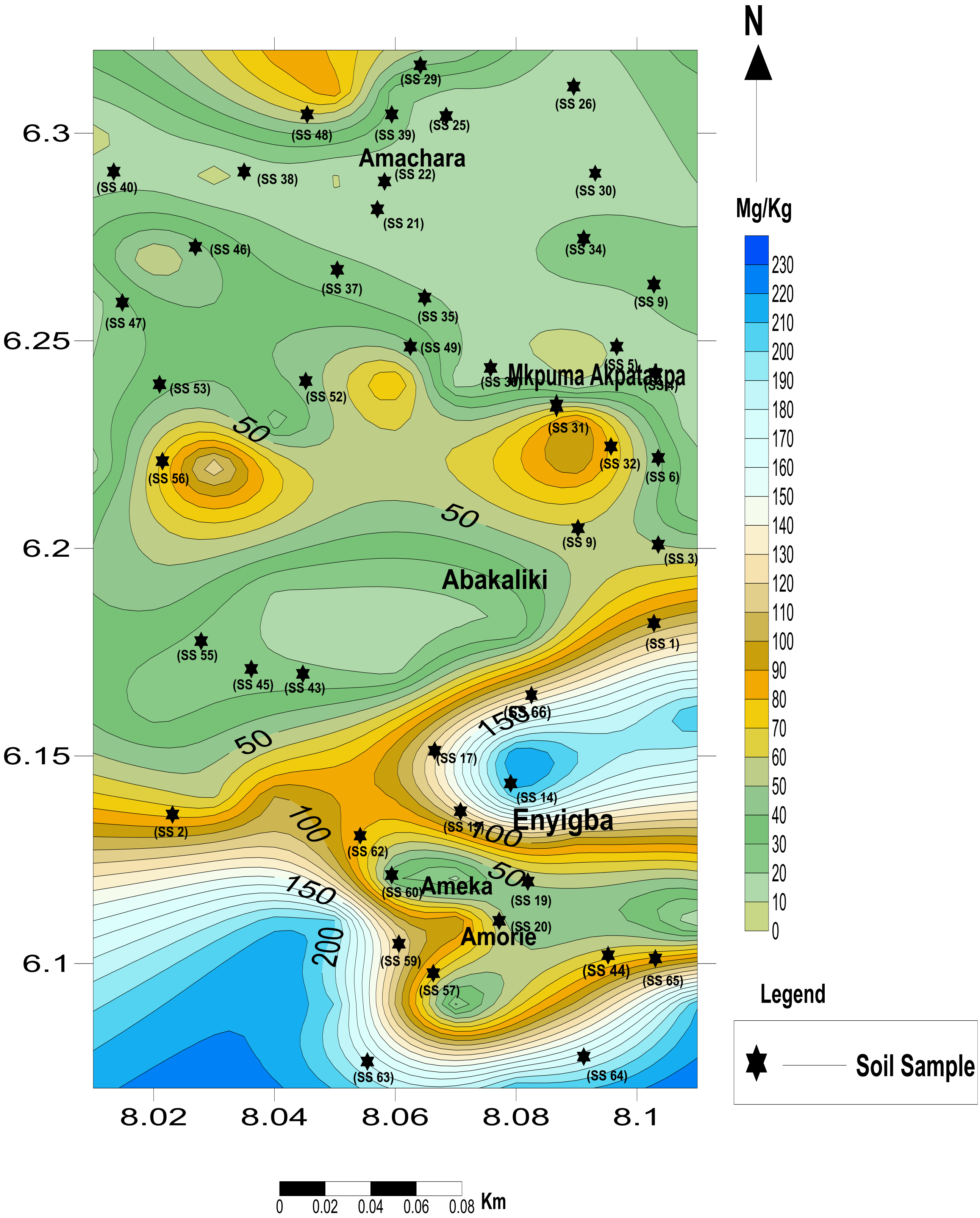

Fig 4.67: **Contoured Distribution of Zinc in dry season analysis of Stream Sediments/ Soils.**

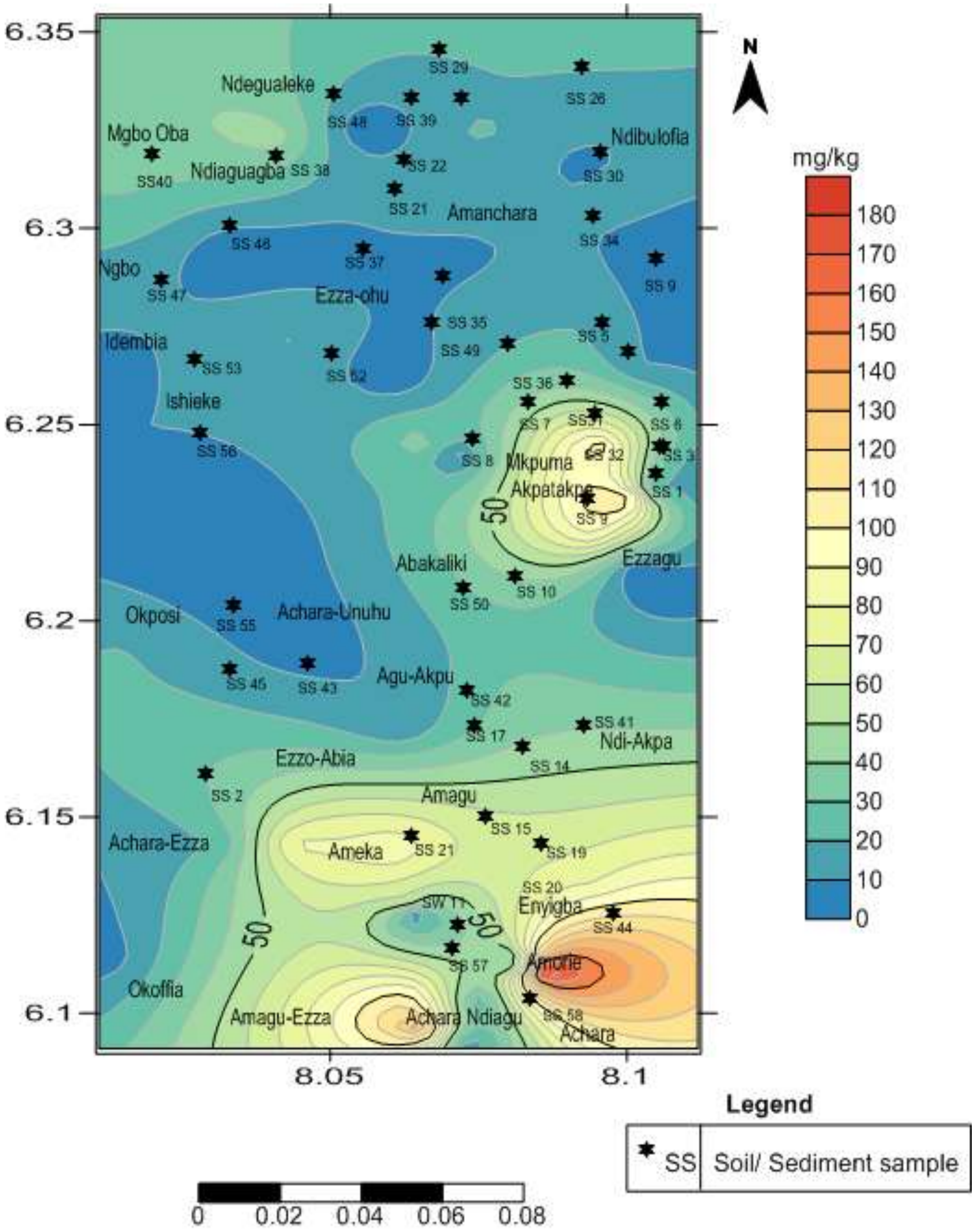

Fig 4.68: Contoured distribution zinc in rainy season soil/ stream sediment analysed

4.5.3.2 Copper (Cu)

From the results of the analysis, copper was observed in nearly all the locations except in Umuoze-Okoha and Ikenyi, it was well dispersed. Copper has a mean concentration of 13.40mg/kg anda range of 126mg/kg for the dry season samples, while rainy season samples ranges from 0.16 mg/kg – 115.17 mg/kg, with mean value of 15.49 mg/kg, the standard deviation is 1.08. Copper is more concentrated at Ameka and Aghamegu (Figs 4.69 and 4.70). Geochemical background value was set as 55mg/kg in Earth's Crust and 50mg/kg in shale.

The high concentrations of copper can be attributed to the mining activities and the chemical behavior of copper. Copper's movement in soil is determined by a host of physical and chemical interactions of copper with the soil components. Tyler and McBride,(1982), observed that most copper deposited in soil from the atmosphere, agricultural use, and solid waste and sludge disposal will be strongly adsorbed and remain in the upper centimeters of soil. In general, copper will be adsorbed to organic matter, carbonate minerals, clay minerals, or hydrous iron and manganese oxides (Callahan *et al.*, 1979; Fuhrer, 1986). Copper binds to soil much more strongly than other divalent cations, and the distribution of copper in the soil solution is less affected by pH than other metals are (Gerritse and Van Driel, 1984). In a study of competitive adsorption and leaching of metals in soil columns of widely different characteristics, copper eluted much more slowly and in much lower quantities than Zn, Cd, and Ni from two mineral soils and not at all from peat soil, which contained the greatest amount of organic matter (Tyler and McBride, 1982). Hermann and Neumann-Mahlkau, (1985) demonstrated that copper shows a pronounced solubility in the oxidizing environment, than in the reducing environment, possibly due to the formation of sulphides.

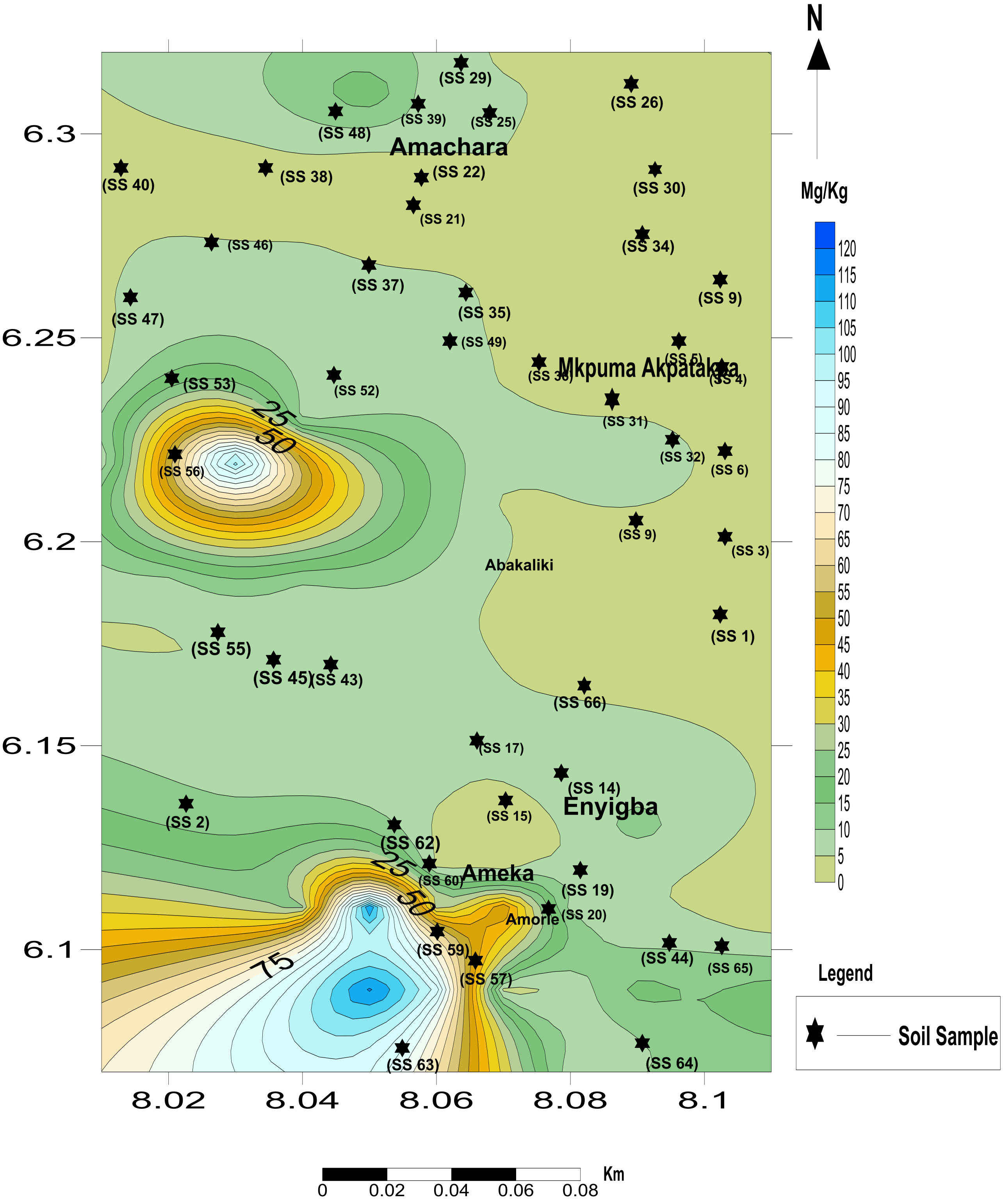

Fig 4.69: Contoured Distribution of Copper in dry season soil/ stream sediments analysed.

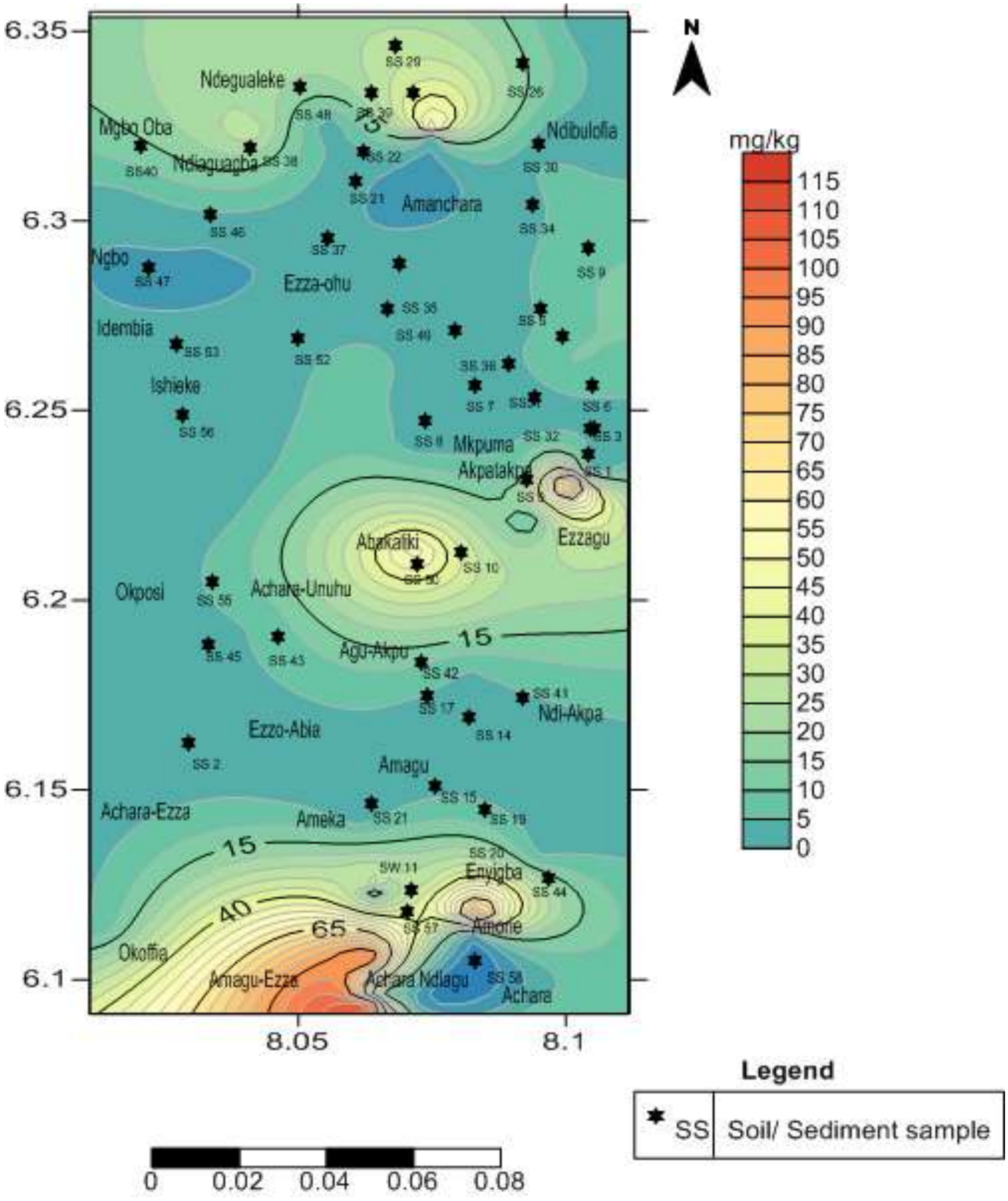

Fig 4.70: Contoured distribution of copper in rainy season soil/ stream sediments analysed.

4.5.3.3 Lead (Pb)

The regular geological source of Pb gives rise to Pb-Zn deposits in ore bodies. The result of the analysis shows that lead was well dispersed in the study area. Pb has mean concentration of 18.49mg/kg with the range of 0.00-74.3mg/kg, for the dry season samples, while the rainy season samples ranged from 0.mg/kg – 74.05mg/kg, with mean concentrations of 19.71mg/kg. The standard deviation is 0.37. The maximum concentration was recorded in samples around the Ameka and Mkpuma Akpatakpa mining area (Figs. 4.71 and 4.72).Geochemical background value was set as 12.5mg/kg in Earth's crust and 20mg/kg in shale.

ATSDR, (2007) suggested that sources of lead in dust and soil include lead that falls to the ground from the air, and weathering and chipping of lead-based paint from buildings. Landfills may contain waste from lead ore mining or other industrial activities such as battery production (Denaix *et al*., 2001). Finster *et al*., (2004) also noted that sources of lead in surface water or sediment include deposits of lead-containing dust from the atmosphere, waste water from industries that handle lead (primarily iron and steel industries and lead producers), urban runofff, and mining piles. Apart from the ores which occur in the study area, the chemistry of lead contributes to its higher concentration. Once lead falls onto soil, it sticks strongly to soil particles and remains in the upper layer of soil (ATSDR, 2007). Reddy, *et al*., (1995) concluded that the mobility of lead will increase in environments having low pH due to the enhanced solubility of lead under acidic conditions. They also opined that the accumulation of lead in most soils is primarily a function of the rate of deposition from the atmosphere. Most lead is retained strongly in soil, and very little is transported through runoff to surface water or leaching to groundwater except under acidic conditions (EPA, 1986; NSF, 1977). Lead may also be immobilized by ion exchange with hydrous oxides or clays or by chelation with humic or fulvic acids in the soil (Olson and Skogerboe, 1975).

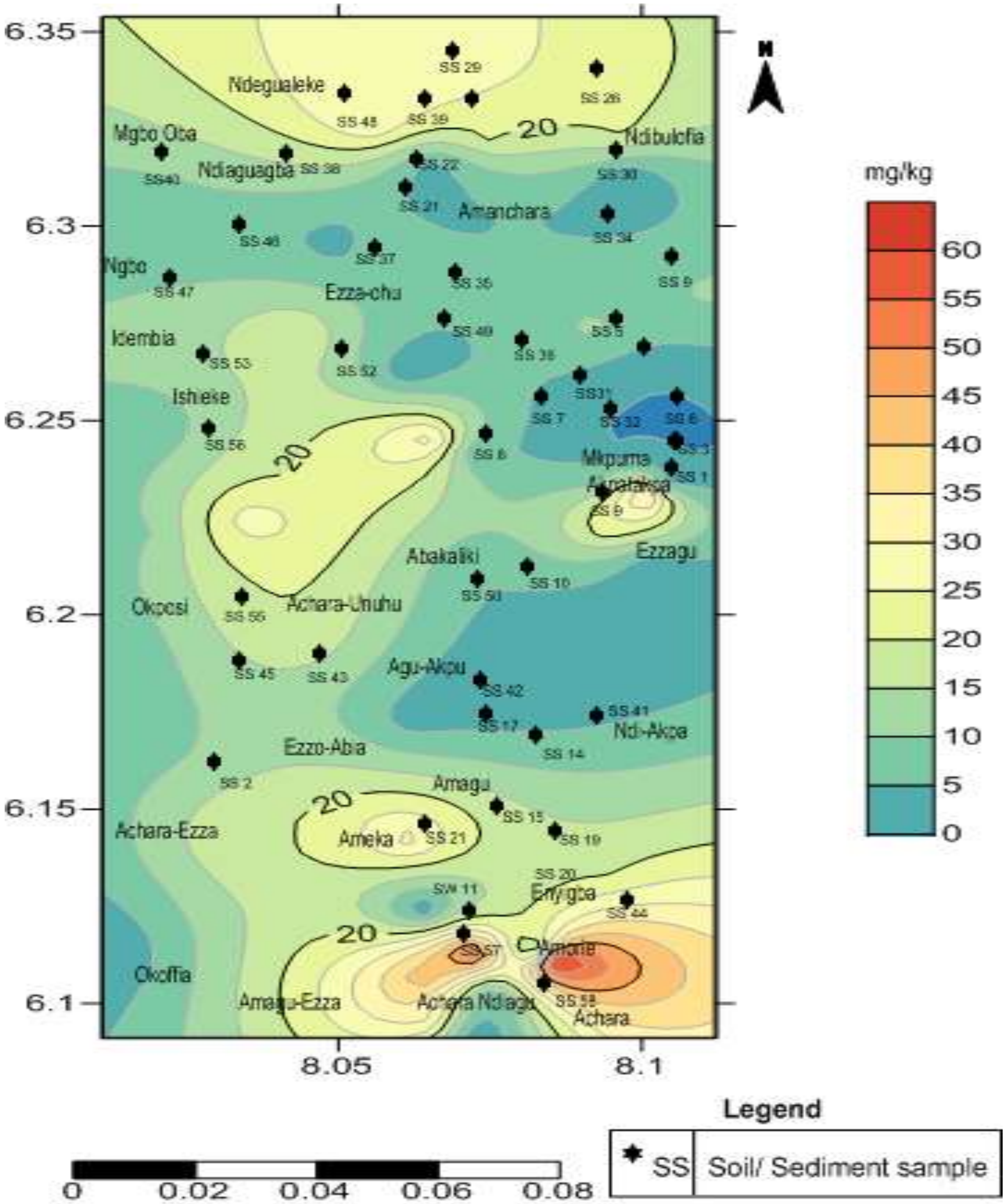

Fig 4.71: Contoured Distribution of Pb in Dry season Stream Sediments/ Soil Samples Anaysed

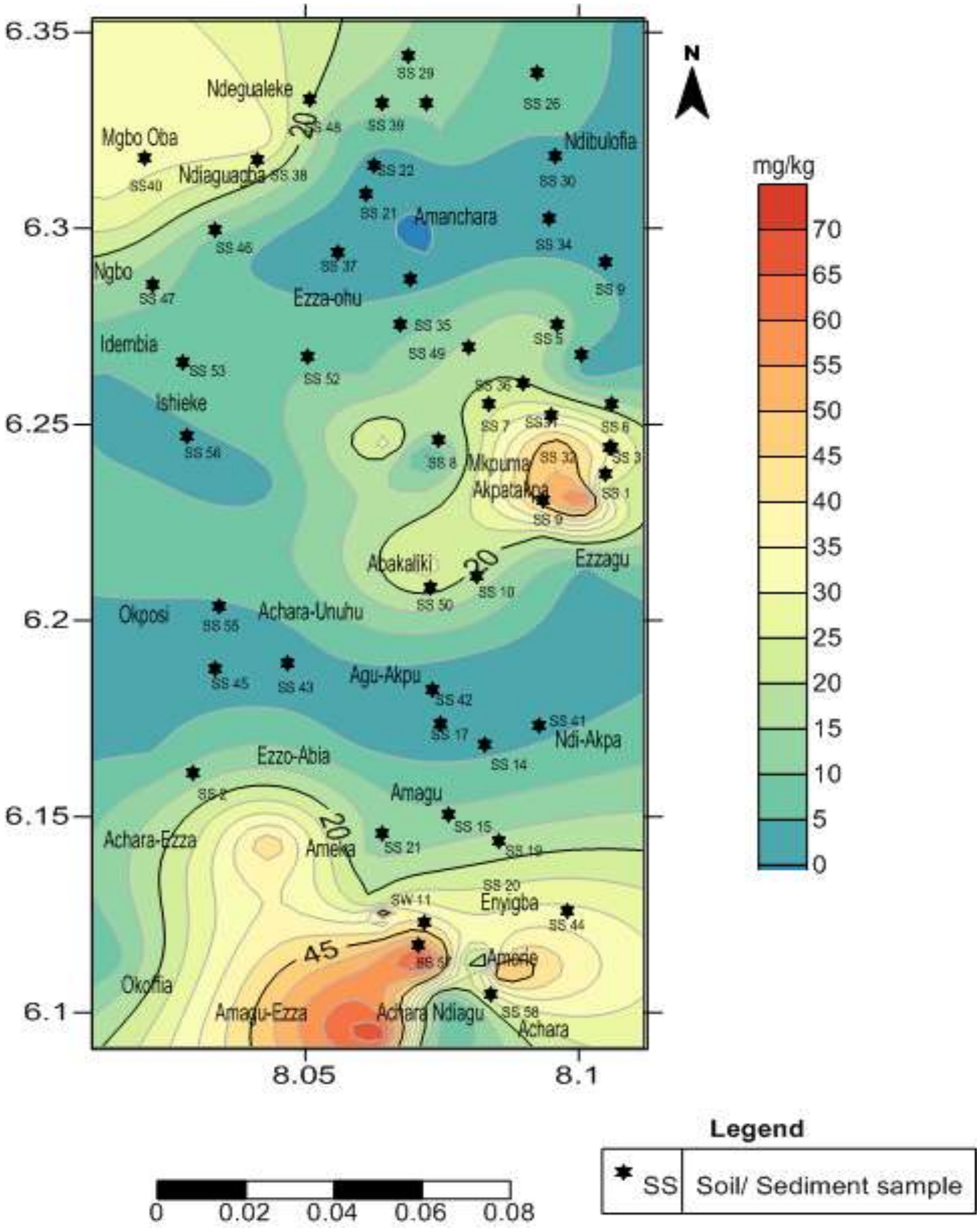

Fig 4.72: Contoured distribution of Lead in Rainy Season Stream Sediments/ soil Samples Analysed

4.5.3.4 Cadmium (Cd)

Result of the analysis shows that the concentration of cadmium ranges from 0.00-8.25mg/kg, with mean concentration of 1.08mg/kg for the dry season samples, while rainy season samples ranged from 0.00mg/kg – 16.46mg/kg with mean concentrations of 1.56mg/kg. The standard deviation is 0.06. Geochemical background value was set as 0.15mg/kg on the Earth's Crust and 0.3mg/kg in shale. This indicates very high concentration for the Ameka and Mkpuma Akpatakpa mining areas (Figs 4.73 and 4.74).

This high concentration ofcadmium is because cadmium is commonly associated with zinc, lead, and copper ores (as in the study area) (ATSDR, 2007).In soils, pH, oxidation-reduction reactions, formation of complexes and the availability of organic matter are important factors affecting the mobility of cadmium (Garvey *et al.*,2013; Harrisson *et al.*, 1981). Cadmium in soil tends to be more available when the soil pH is low (acidic) (Elinder, 1992). Generally, cadmium will bind strongly to organic matter and this will, for the most part, immobilize cadmium (Autier and White, 2004). While soluble forms may migrate in water, cadmium is relatively nonmobile in insoluble complexes or adsorbed to sediments. Although particulate and vapor cadmium may be released to the air, the net flux to soil will be positive as cadmium will eventually deposit onto soils (Kamau, 2001; Elinder, 1985). Cadmium can participate in exchange reactions on the negatively charged surface of clay minerals. In acid soils, the reaction is reversible. However, adsorption increases with pH and may become irreversible (Harrison *et al.*, 1981). Cadmium also may precipitate as insoluble cadmium compounds, or form complexes or chelates by interaction with organic matter. Available data suggest that organic matter is more effective than inorganic constituents in keeping cadmium unavailable (McBride, 1995).

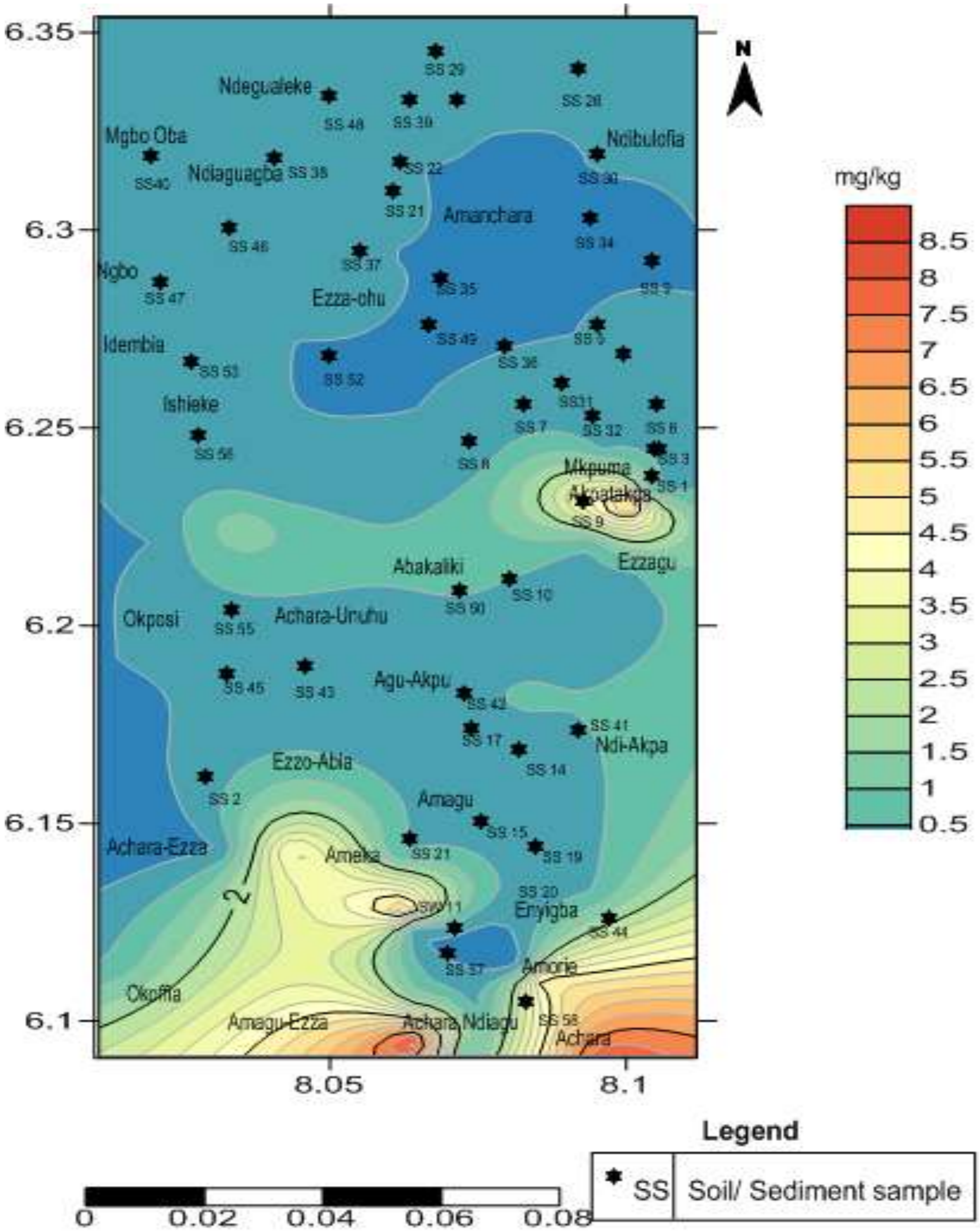

Fig 4.73: Contoured Distribution of Cadmium in dry season Stream Sediments/ Soil Samples Analysed.

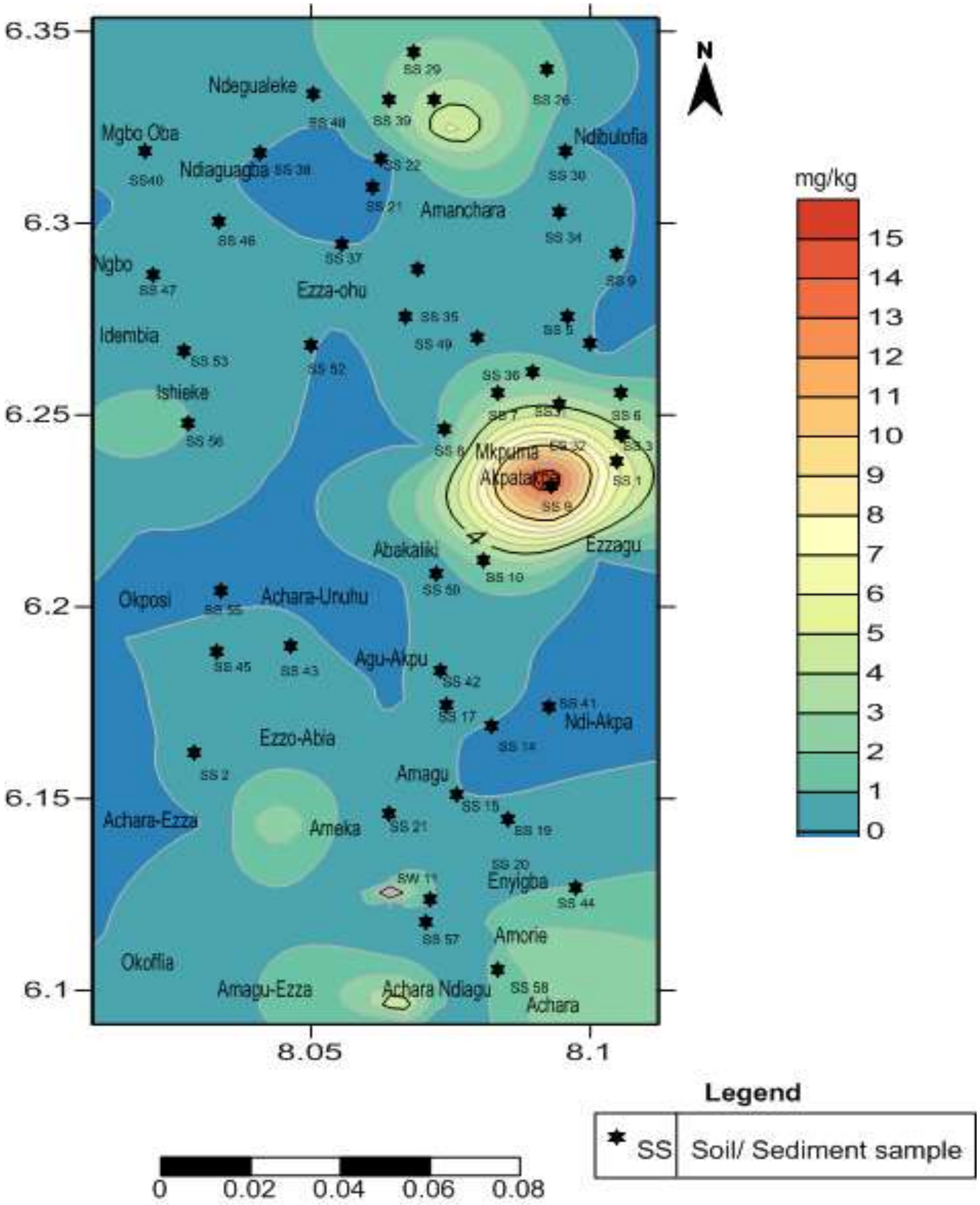

Fig 4.74: Contoured Distribution of Cadmium in dry season Stream Sediments/ Soil Samples Analysed.

4.5.3.5 Chromium (Cr)

Chromium was evenly distributed in the study area. The mean concentrationof Cr is 9.00 mg/kg with range of 0.00-28.32mg/kg for the dry season samples, while rainy season samples range from 0.00mg/kg - 51.87mg/kg with mean of 8.20mg/kg. Higher concentrations were observed around the mines than other areas (Figs 4.75 and 4.76). Geochemical background value was set as 100mg/kg in Earth's crust and 73mg/kg in shale.

Chromium occurs naturally in rocks, animals, plants, and soil, where it exists in combination with other elements to form various compounds, however, anthropogenic activities like the manufacture of chromium-based products, leather tanning and the burning of natural gas, oil, or coal can release chromium in the environment (ATSDR, 2012). The mobility of chromium in soil is dependent upon the speciation of chromium, which is a function of redox potential and the pH of the soil (Ashley *et al.*, 2003). Barnhart, 1997 and Robson, 2003 have studied the mobility of chromium in soils, and noted that in most soils chromium will be present predominantly in the chromium (III) oxidation state. This form has very low solubility and low reactivity, resulting in low mobility in the environment. Under oxidizing conditions, chromium (VI) may be present in soil as CrO_4^{-2} and $HCrO_4$ (James *et al.*, 1997). In this form, chromium is relatively soluble and mobile. A leachability study comparing the mobility of several metals, including chromium, in soil demonstrated that chromium had the least mobility of all of the metals studied (Sahuquillo *et al.*, 2003). These results support previous data finding that chromium is not very mobile in soil, especially in the trivalent oxidation state (Balasoiu *et al.*, 2001, Jardine *et al.*, 1999, Robson, 2003). These results are further supported by a leachability investigation in which chromium mobility was studied for a period of 4 years in a sandy loam (Sheppard and Thibault, 1991). Jardine *et al.*, 1999, alsonoted that in deeper soil where anaerobic conditions exist, chromium (VI) will be reduced to chromium (III) by S^{-2} and Fe^{+2} present in soil.

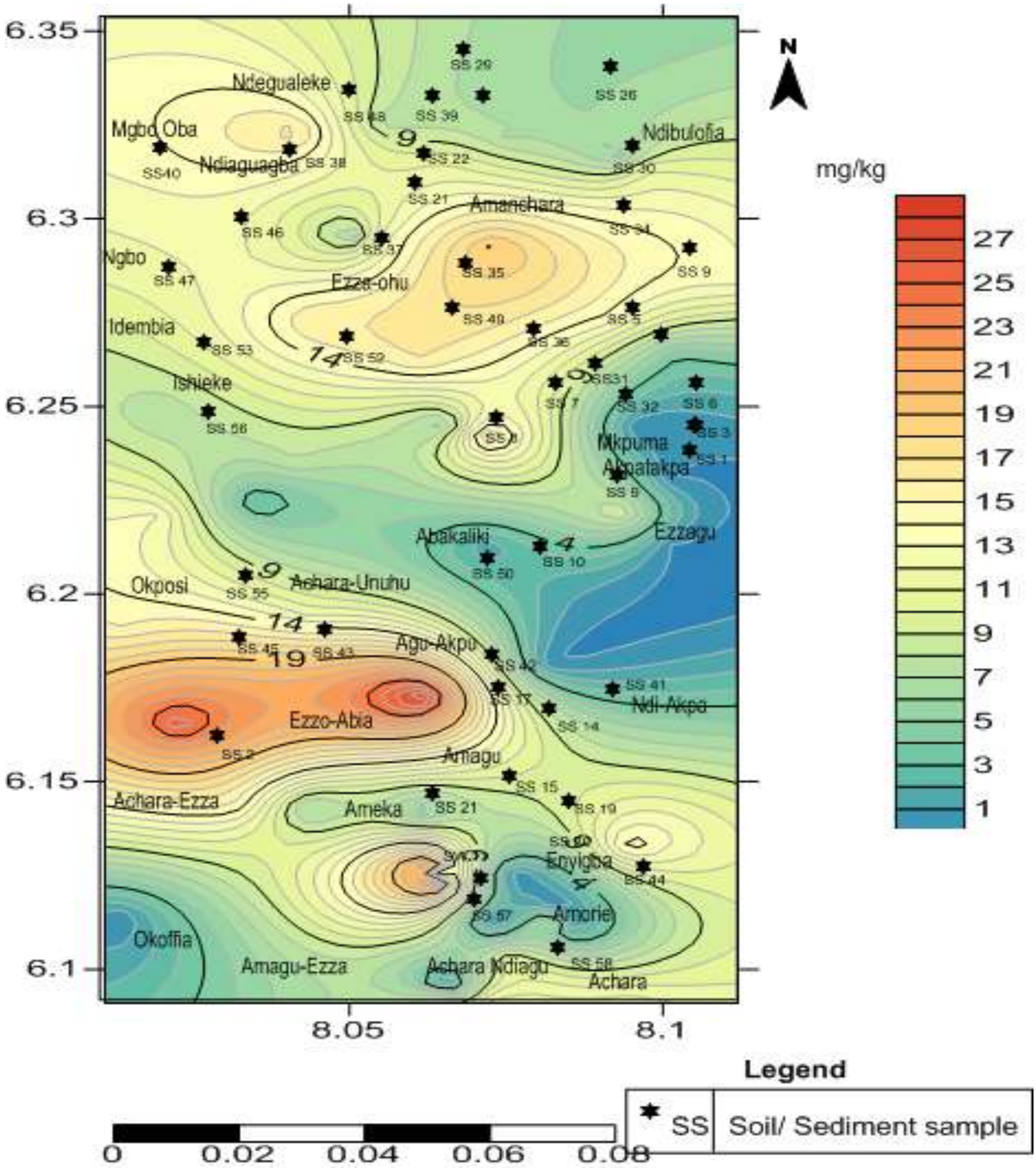

Fig 4.75: Contoured Distribution of Chromium in dry season Stream Sediments/ soil samples analysed.

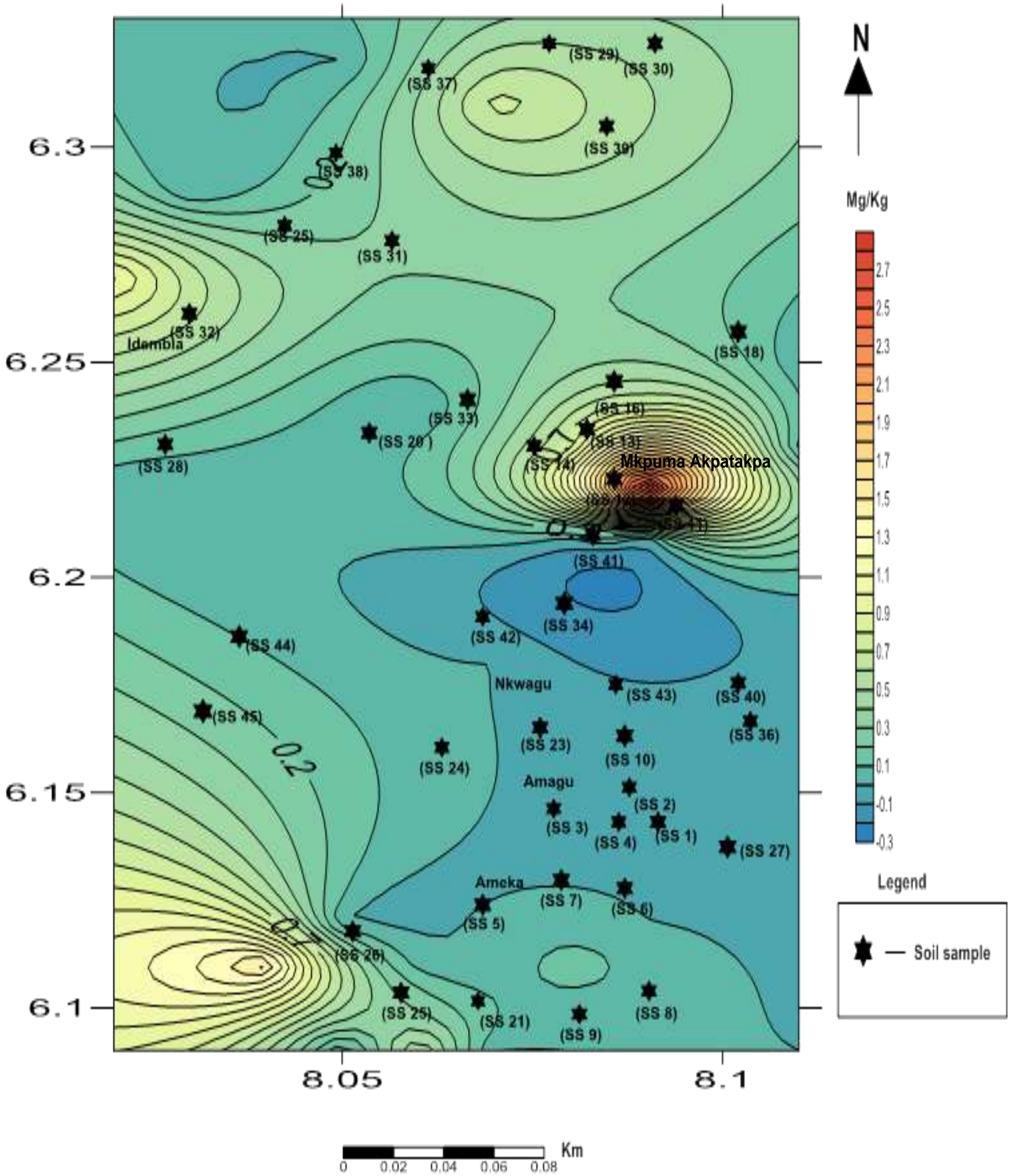

Fig 4.76: Contoured Distribution of Chromium in rainy season Stream Sediments/ soil samples analysed.

4.5.3.6 Mercury (Hg)

Low concentration of mercury was observed in the study area. Only few samples around Abakaliki area showed presence of Hg while the rest showed low concentrations (Figs 4.77 and 4.78). The mean concentration of mercury is 0.37mg/kg with the range of 0.00-6.03mg/kg for the dry season samples, while rainy season samples ranged from 0.00 – 8.1mg/kg. Its maximum concentrations were recorded at the Amanchara and the Ameka mining areas. Mercury enters the environment as the result of the normal breakdown of minerals in rocks and soil from exposure to wind and water, and from volcanic activity. Human activities such as mining and burning of fossil fuels have resulted in additional release of mercury to the environment (ATSDR, 2012). In soils and surface waters, mercury can exist in the mercuric (Hg^{+2}) and mercurous (Hg^{+1}) states as a number of complex ions with varying water solubilities (Meili, 1991).Vaporization of mercury from soils may be controlled by temperature, with emissions from contaminated soils being greater in warmer weather when soil microbial reduction of Hg^{+2} to the more volatile elemental mercury is greatest (Lindberg *et al*., 1991). Atmospheric deposition of mercury from both natural and anthropogenic sources has been identified as an indirect source of mercury to soil and sediments (Sato and Sada 1992; WHO 1990, 1991). Mercury is released to cultivated soils through the direct application of inorganic and organic fertilizers (e.g., sewage sludge and compost), lime, and fungicides containing mercury (Andersson, 1979).Glass *et al*., 1991 suggested that the concentration of mercury in the atmosphere is due to its long distance of transportation before being removed by wet or dry deposition. They estimated the residence time in the atmosphere to range from 60days to 2 years. Volatile forms of mercury released in water or soil can enter the atmosphere, but most mercury is adsorbed to soil and sediment (EPA, 1984; Meili *et al*., 1991).Mercuric mercury usually forms various complexes with chloride and hydroxide ions in soils (Andersson, 1979).

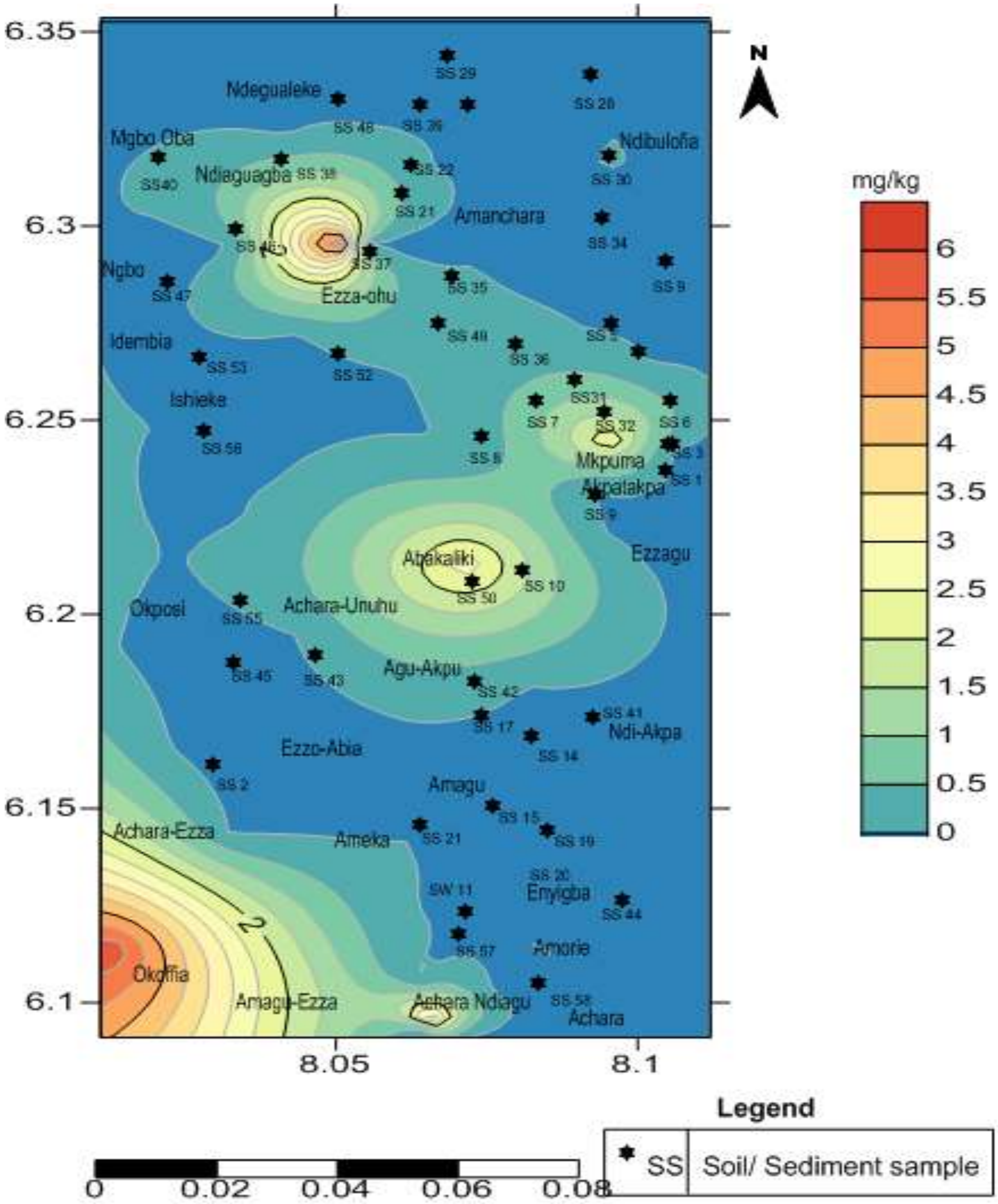

Fig 4.77: Contoured Distribution of Mercury in Stream Sediments/ Soil Samples Analysed in dry season.

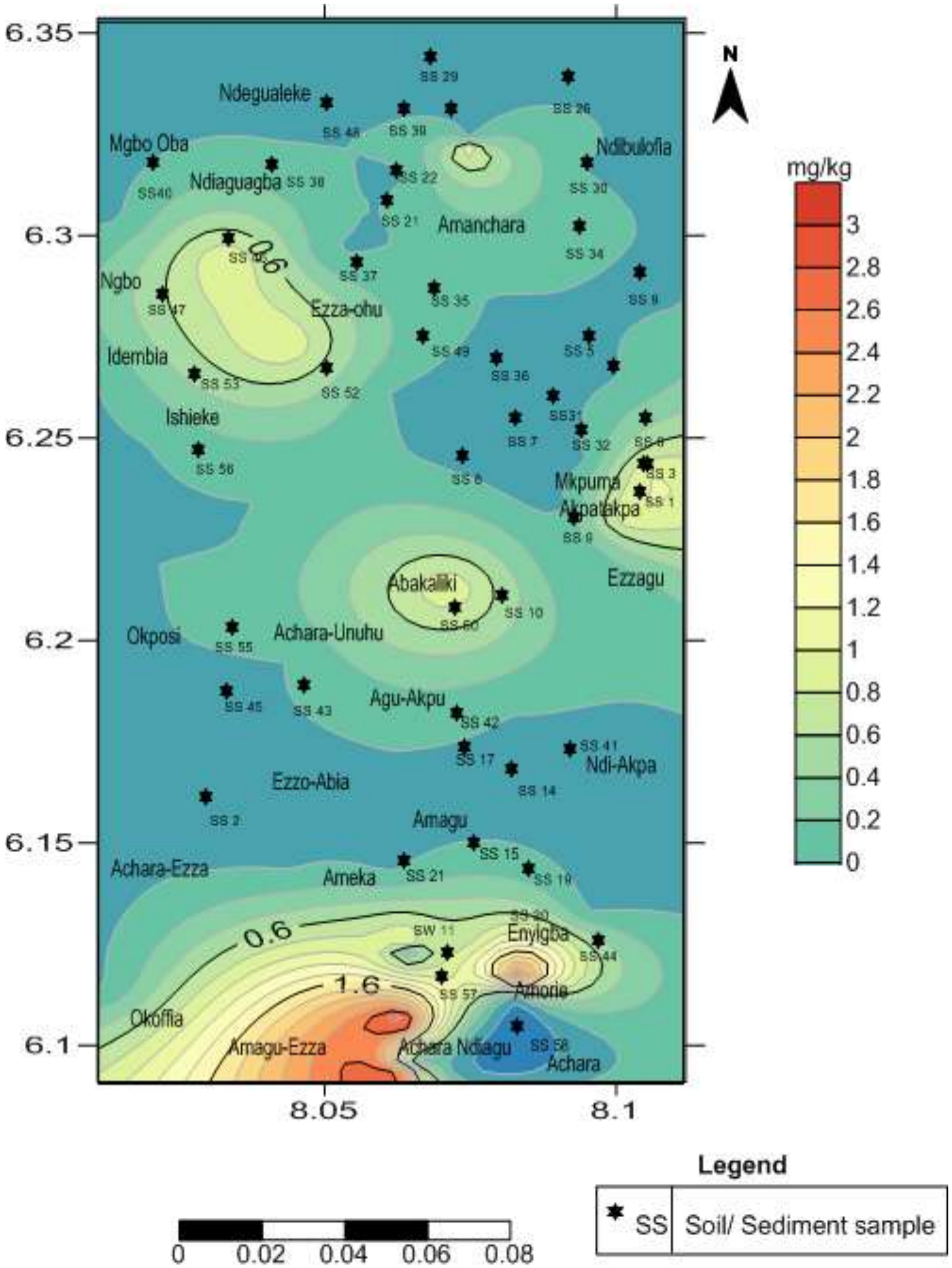

Fig 4.78: Contoured Distribution of Mercury in Stream Sediments/ Soil Samples Analysed in rainy season.

4.5.3.7 Silver (Ag)

From the result obtained, silver was not evenly distributed compared to the heavy metals in the study area. Many samples showed absence of silver for the two seasons. Maximum concentration of 30.29mg/kg and 7.7mg/kg; mean concentration of 3.14mg/kg and 0.52mk/kg was recorded for the dry and rainy seasons respectively.The mining regions of Mkpuma Akpatakpa and Enyigba showed higher concentrations (Figs 4.79 and 4.80). Silver has a standard deviation of 1.72.

Sources of silver in soils includes mines that produce silver and other metals and the natural wearing down of silver-bearing rocks and soil by the wind and rain also releases large amounts of silver into the environment (ATSDR, 1990). Apart from the weathering of chalcopyrite, galena and siderite ores which deposits silver in the study area, the mobility of silver in soils is affected by drainage (silver tends tobe removed from well-drained soils); oxidation-reduction potential and pH conditions (which determine the reactivity of iron and manganese complexes which tend to immobilize silver); and the presence of organic matter (which complexes with silver and reduces its mobility) (Boyle, 1968).

ATSDR, (1990) also noted that the factors governing the environmental fate of silver are not well characterized. While silver and its compounds are transported in the air, water, and soil, and are partitioned between these media, the mechanisms of transport and partitioning are not well-defined. No partition coefficients or constants have been determined for silver or its compounds (Dissanayake *et al*., 1983). Little information was found in the available literature on transformation of silver in water or soil (Boyle, 1968). The transport and partitioning of silver in surface waters and soils isinfluenced by the particular form of the compound. Lindsay and Sadiq, (1979) stated that under oxidizing conditions the primary silver compounds would bebromides, chlorides, and iodides, while under reducing conditions the free metal and silver sulphide would predominate.

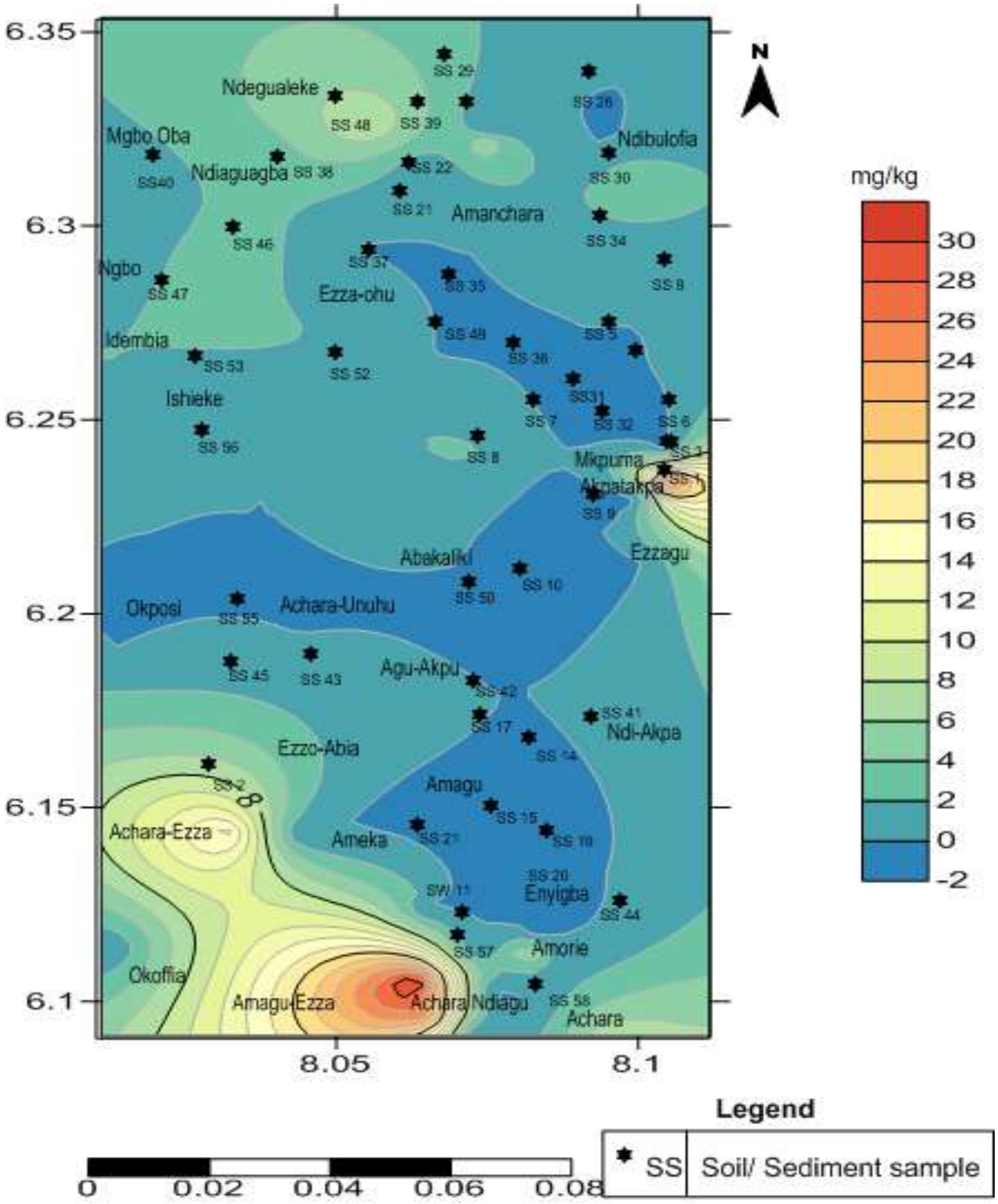

Fig 4.79: Contoured Distribution of Silver in Stream Sediments/ Soil Samples Analysed in dry season

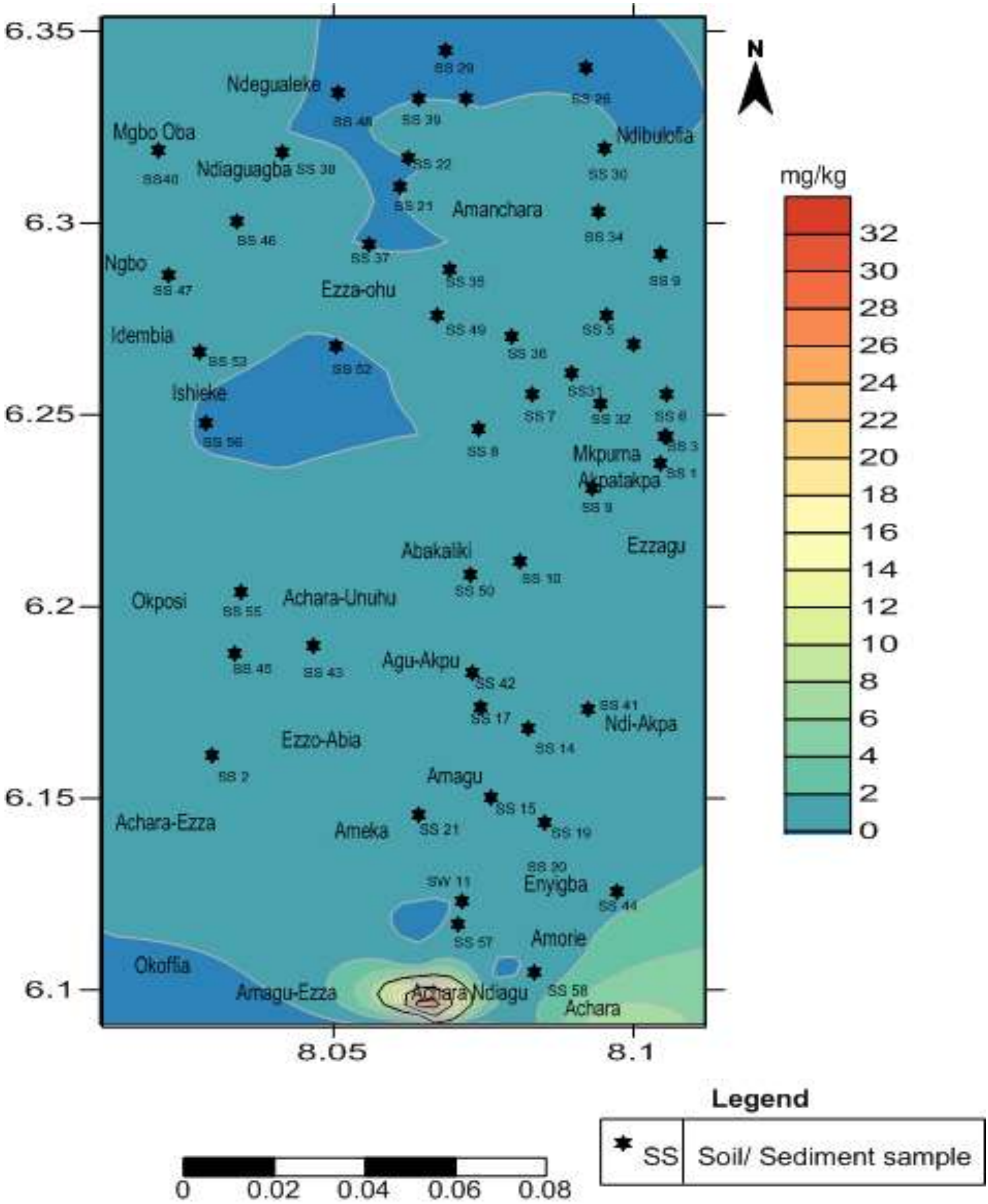

Fig 4.80: Contoured Distribution of Silver in Stream Sediments/ Soil Samples Analysed in rainy season

4.5.3.8 Arsenic (As)

Result of geochemical analysis showed that arsenic was dispersed in the study area (Figs 4.81 and 4.82). Many of the samples locations show high concentrations of Arsenic. It has a maximum concentration of 56mg/kg with mean concentration of 11.19mg/kg for the dry season samples, while rainy season samples showed very low concentration values of 0.00mg/kg (in most places) – 19.0mg/kg with mean concentration of 1.21mg/kg. The standard deviation is 23.91. Geochemical background value was set as 1.8mg/kg in Earth's crust and 10mg/kg in shale.This result indicates very high contamination for the area, especially in the mining fields of Ameka and Enyigba.

Arsenic occurs naturally in soil and in many kinds of rock, especially in minerals and ores that contain copper or lead, volcanic eruptions are another source of arsenic (ATSDR, 2007). Arsenic may enter the environment during the mining and smelting of these ores. Moore *et al*., (1988) noted that arsenic in soil may be transported by wind or in runoff or may leach into the subsurface soil. However, because many arsenic compounds tend to partition to soil or sediment under oxidizing conditions, leaching usually do not transport arsenic to any great depth (EPA, 1982; Pantsar-Kallio and Manninen, 1997; Welch, *et al.,* 1988). Sanok *et al*., 1995, also affirmed that arsenic is largely immobile in agricultural soils; therefore, it tends to concentrate and remain in upper soil layers indefinitely. Arsenic cannot be destroyed in the environment. It can only change its form, or become attached to or separated from particles (ATSDR, 2007). It may change its form by reacting with oxygen or other molecules present in air, water, or soil, or by the action of bacteria that live in soil or sediment. Merwin *et al*., 1994 and Kalbitz and Wennrich, 1998 observed that arsenic found in soil either naturally occurring or from anthropogenic releases forms insoluble complexes with iron, aluminum, and magnesium oxides found in soil surfaces, and in this form, arsenic is relatively immobile.

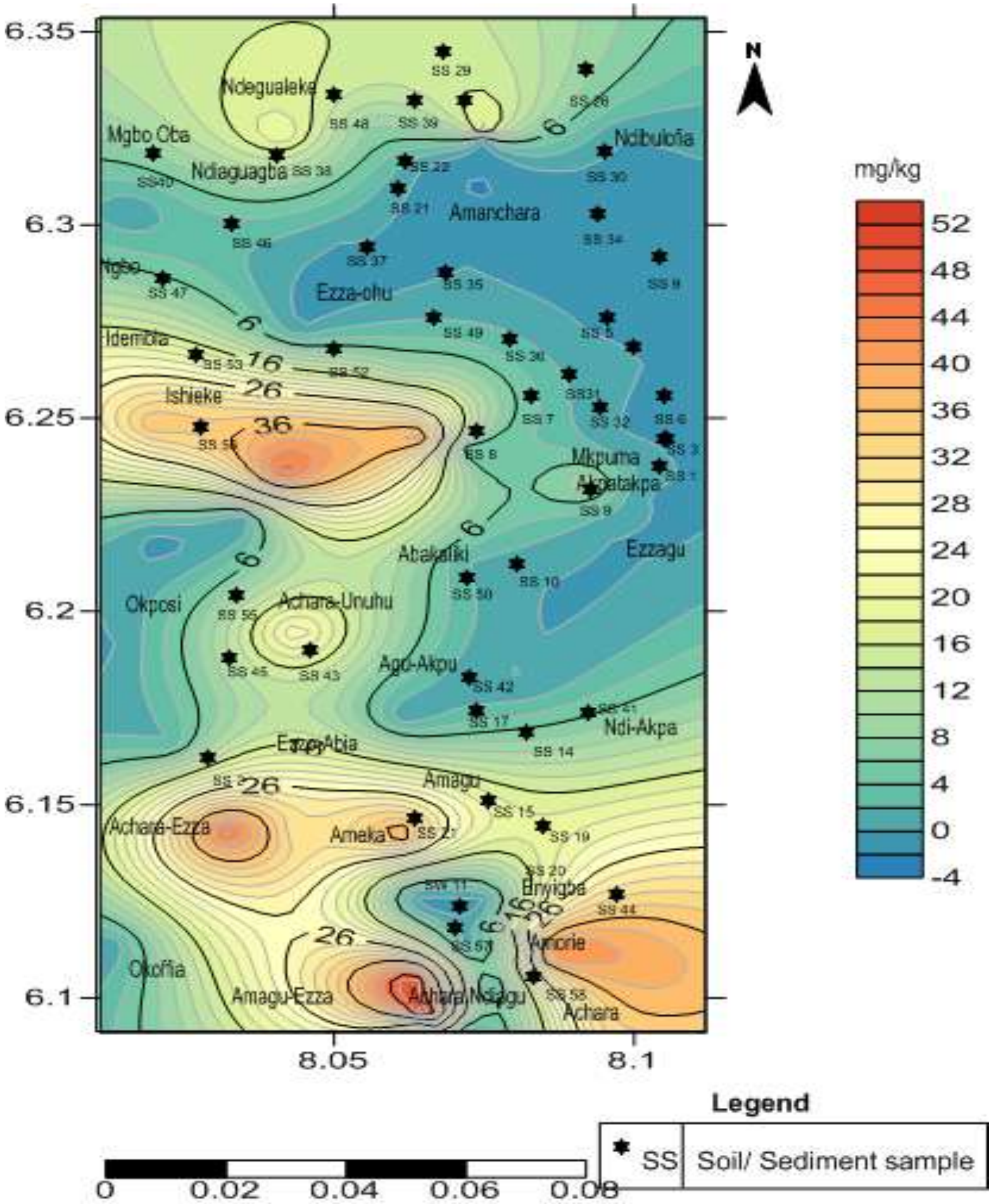

Fig 4.81: Contoured Distribution of Arsenic in Stream Sediments/ Soil Samples Analysed in dry season

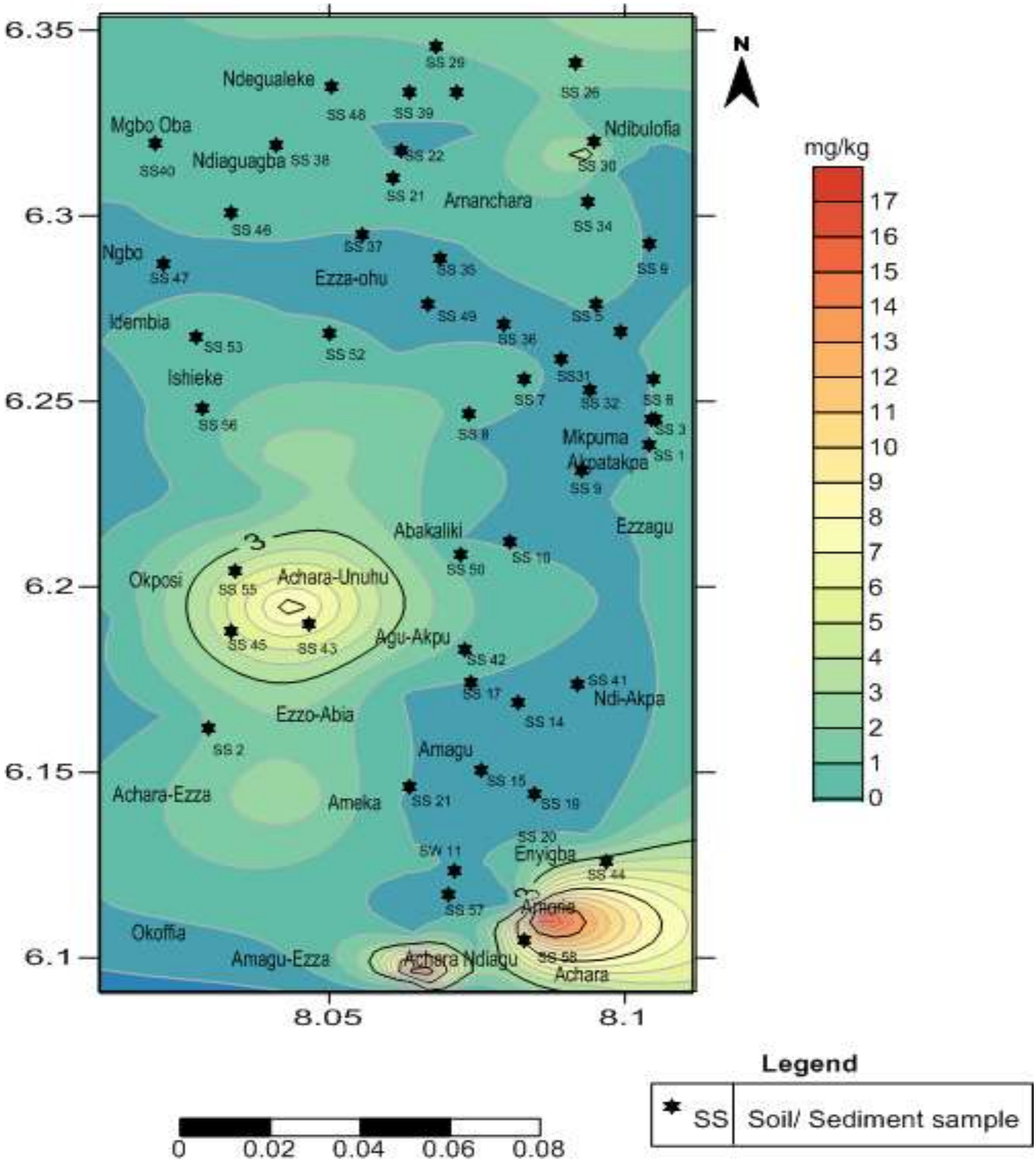

Fig 4.82: Contoured Distribution of Arsenic in Stream Sediments/ Soil Samples Analysed in rainy season

4.6 Pollution Status of the Study Area

In characterizing the contamination level in soils from Lead/Zinc mining fields of Abakaliki, the result was done using six evaluation parameters. These include; Effect Range low (ERL) and Effect Range Median (ERM), Pollution index, Geoaccumulation index, Contamination factor, Pollution load Index and Contamination Degree.

4.6.1 Effect Range Low (ERL) and Effect Range Median (ERM)

The metal concentration of stream sediments/ soils was compared with the Effect Range Low (ERL) and Effect Range Median (ERM) values used by United State Environmental protection Agency (USEPA), Mid Atlantic Integrated Assessment (MAIA) for estuaries (1997-98 summary report). This was in line with the sediment quality guideline established by Levinson, (1974). ERL is the lowest concentration of metals in stream sediments that produced adverse effects in 10% of organisms reviewed in MAIA project. The ERM shows the 50% of the organism's studies reported harmful effects. Based on ERL and ERM values, metal concentrations below the ERL values are not expected to pose any adverse effects, while levels above the ERM values are likely to be very toxic. With reference to that, three (3) assessment categories of stream sediments/ soil were observed. They include;

Good, when the metal concentration values are below the ERL value.

Intermediate, when the metal values are above ERL but below the ERM values

Poor, when the metal values are above the ERM values.

Table 4.7, shows the ERL and ERM limits for metal concentrations by USEPA, MAIA project (1997- 1998).

Table 4.7: The ERL and ERM limits for metals (US –EPA – MAIA 1998)

Metals	ERL values in mg/kg	ERM values in mg/kg
Zinc (Zn)	150	410
Copper (Cu)	34	270
Lead (Pb)	47	220
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81	370
Mercury (Hg)	0.15	0.71
Silver (Ag)	1	3.7
Arsenic (As)	8.2	70

ZINC (Zn): From table 4.15, the ERL value of Zn is 150mg/kg and the ERM value is 410mg/kg. Result of the analysis shows that zinc has a maximum concentration of 203mg/kg. This is above the ERL and below the ERM value. However, over 80% samples show low concentrations below the ERL. This indicates non toxicity in the area. But in samples from the Ameka axis, the concentration is above ERL and below the ERM value, this shows intermediate pollution in the Ameka areas. Though, Zn was evenly distributed in all the soils of the study area, the distribution in the study area shows good to intermediate pollution status in the study area.

COPPER (Cu): The highest concentration of Cu from the result of the analysis is 206.99mg/kg (at Mkpuma Akpatakpa mine site). The ERL value is 34mg/kg while the ERM value is 270mg/kg. Cu is moderately dispersed in the study area. Cu is below ERL and ERM value in over 90% of the samples analysed. Only 9.5% are above the ERL value. The high concentrations were recorded only in the mines of Ameka and Mkpuma Akpatakpa. Therefore, contamination status of Cu is both Good and intermediate in the study area.

LEAD (Pb): Pb has the highest concentration of 74.3mg/kg while the ERL is 47mg/kg and ERM value is 220mg/kg. 84% of the samples showed Pb concentration below the ERL value while16% samples are above the ERL. This also shows no contamination in the study area.

CADMIUM (Cd): The ERL value for Cd is 1.2mg/kg while the ERM value is 9.6mg/kg with highest concentration of 16.46mg/kg. 78.44% of the samples are below the ERL value while, about 21.56% of thesamples analysed are above the ERL value. Only 1.7% of the samples are above the ERM value. These are samples around the Ameka, Amorie Enyigba and Alibaruhu mines. This shows that Cd attains its toxic level in the mining areas.

CHROMIUM (Cr): Cr has the ERL value of 81mg/kg and ERM value of 370mg/kg. The maximum concentration of Cr is 51mg/kg. Cr does not reach the ERL value in all the samples analysed. Therefore, it is below the toxicity levels in the study area.

MERCURY (Hg): Hg has maximum concentration of 31.2mg/kg, ERL value as 0.15mg/kg and ERM value as 0.71mg/kg. Hg is below ERL value in about 84.48% of the samples analysed while 15.51% shows concentrations above the ERM value. These high concentrations were recorded around the mines of Ameka, Enyigba and Amanchara. This implies toxicity in the study area.

SILVER (Ag): Ag has ERL value of 1mg/kg and ERM value of 3.7mg/kg. It has highest concentration of 30.29mg/kg. 41.1% of samples show concentrations above the ERL value and 23.5% samples above the ERM value. This shows moderate pollution status for the study area.

ARSENIC (As): As has a total maximum concentration of 56mg/kg. It has ERL value of 8.2mg/kg and ERM value of 70mg/kg. About 19.82% of the samples are above the ERL value while 80.1% are below it. None is above the ERM value. This indicates good contamination status of As for the study area, (Table 4.8 and 4.9).

Table 4.8: Quality of sediments/soils for dry season samples using ERL and ERM (US-MAIA, 1998)

metal	Below ERL (%)	Above ERL (%)	Above ERM (%)	Remark
Zn	96.55	3.45	-	Good – Intermediate Contamination
Cu	93.10	6.89	-	‘’ ‘’
Pb	86.21	13.79	-	‘’ ‘’
Cd	82.76	17.24	-	Good - Intermediate Contamination
Cr	100	-	-	Good
Hg	93.10	6.89	-	Good - Intermediate Contamination
As	67.24	32.76	-	Good - Intermediate Contamination
Ag	84.48	15.51	18.96	Intermediate – poor Contamination

Table 4.9: Quality of sediments/soils for rainy season samples using ERL and ERM (US-EPA-MAIA, 1998)

Metal	Below ERL (%)	Above ERL(%)	Above ERM(%)	Remark
Zn	98	1.72	-	Good
Cu	87.93	12.08	-	Good - Intermediate
Pb	82.75	17.24	-	Good – Intermediate
Cd	75.86	24.13	3.45	Good - poor
Cr	100	-	-	Good
Hg	74.13	25.86	24.14	Good –poor
As	89.65	10.34	-	Good -Intermediate
Ag	87.93	12.06	-	Good - Intermediate

4.6.2 Pollution Index (€)

Pollution index (€) as proposed by Powell, (1992) is the ratio of individual metal concentration in soils to the ERM value for that particular metal. It expresses how many times the concentration of the individual metal is higher than the ERM for that metal in soil samples (Equation 3.2).With the ERM values as standards, it is possible to consider the pollution levels in terms of pollution index. Appendix 16a and 16b shows the calculated pollution index for dry and rainy seasons respectively.

For pollution index, when € ≥ 1 = Significant Contamination (SC), when € ≤ 1 = Insignificant Contamination (IC).

The ERM value of Zinc is 410mg/kg, the concentration of Zinc in many of the samples locations is below ERL and ERM value in many locations, its pollution index ranges (0.014 – 0.295€) and 0.0002 – 0.346€ for dry and rainy season samples respectively. This has highest enrichment of 0.346€ in samples around the Mkpuma Akpatakpa areas. Its pollution index is below the toxic level and indicates insignificant contamination.

The ERM value for Copper is 270mg/kg. Copper is below ERL value in many sample locations and also below ERM value in all the samples locations and its pollution index is below the toxic level (0.000 – 0.766€ and 0.001 – 0.427€) in the dry and rainy seasons respectively. This is insignificant contamination.

The ERM value for lead is 220mg/kg and ERL value is 47mg/kg. The concentration of lead is below the ERL value in many samples. Pollution index status shows insignificant contamination as it ranges from (0.000 – 0.337€ and 0.000 – 0.337€) in the dry and rainy seasons respectively. For Cadmium, the ERM value is 9.6mg/kg and ERL value is 1.2mg/kg Cadmium is below ERL in some of the samples and below ERM value in all the samples locations. Pollution index ranges between (0.00 –6.713€ and 0.00 – 1.715€) for dry and rainy seasons respectively. This attains its toxic level in so many sampled locations. It has significant cotamination. Chronium has ERL value of 81mg/kg and ERM value of 370mg/kg. This is below the ERL and ERM values in all the samples analysed. It shows insignificant contamination with pollution index ranges (0.00 – 0.076€ and 0.00 – 0.138€) in dry and rainy seasons respectively. Mercury has ERM value 0.71mg/kg and ERL of 0.15mg/kg. Mercury has intermediate to low in the samples analysed. It has pollution index range of (0.000 – 8.492€ and 0.00 – 4.395€) for the dry and rainy seasons respectively. This is significant contamination. Silver has ERM value of 3.7mg/kg, this value is below the ERL value in so many samples. This indicates significant contamination for the areas. Pollution index for silver range between (0.000 – 8.186€ and 0.00 – 2.081€) for the dry and rainy seasons respectively. Asernic has maximum concentration of 56mg/kg with ERM of 70mg/kg. Pollution index ranges between (0.00 – 0.800€ and 0.00 – 0.446€) for the dry and rainy seasons respectively. This shows insignificant contamination in the study area.

The results of the analysis showed that pollution index (€) for Zn, Cu, Pb, Cr and As are less than 1 (<1) while those of Cd, Hg and Ag are greater than 1 (>1) for both seasons (see tables 4.10 and 4.11). However, the existence of metals studied in soil of some locations may have been as a result of transportation of water from some mining site or fields of the study area to various Rivers, stream and soil.

4.6.3 Geoaccumulation Index (Igeo)

Geoaccumulation index (Igeo), according to Boske *et al.*, 2004 (equation 3.3), measures the geologic accumulation of pollutants and contamination in sediments (Obasi and Akudinobi, 2015).The constant 1.5 allows for natural fluctuations in content of a given substance in the environment and very small anthropogenic influences. The geoaccumulation index class is shown in table 4.12, while the calculated geoaccumulation index for dry and rainy season is shown in appendix 17a and 17b respectively.

Table 4.10: Quality of soils/ sediments of dry season using pollution index (after Powell, 1992)

Metal	Index Range	Percentage Range	Remark
Zn	0.014 - 0.295	100% < 1	IC
Cu	0.00 - 0.766	100% < 1	IC
Pb	0.00 - 0.257	100% < 1	IC
Cd	0.00 - 6.713	87.66% < 1 10.34% > 1	SC
Cr	0.00 - 0.076	100% < 1	IC
Hg	0.00 - 8.492	91.4% < 1, 8.6 > 1	SC
As	0.00 - 0.716	100% < 1	IC
Ag	0.00 - 8.186	81.04% < 1, 18.96 > 1	SC

Table 4.11: Quality of soils/ sediments of rainy season using pollution index (after Powell, 1992)

	Index Range	Percentage Range	Remark
Zn	0.001 - 0.346	100% < 1	IC
Cu	0.001 - 0.427	100% < 1	IC
Pb	0.018 - 0.337	100% < 1	IC
Cd	0.000 - 1.715	96.56% < 1 , 3.44% > 1	SC
Cr	0.000 - 0.140	100% < 1	IC
Hg	0.000 - 4.395	75.87% < 1, 24.13> 1	SC
As	0.000 - 0.446	100% < 1	IC
Ag	0.000 - 2.081	96.56% < 1, 3.44 > 1	SC

Table 4.12: Classes of Geoacculation index (Igeo)after Boske *et al*., 2004.

Class	Value	Soil/ sediment quality
0	Igeo ≤ 0	Practically uncontaminated (UC)
1	0 < Igeo < 1	Uncontaminated (UC) to moderately contaminated (MC)
2	1< Igeo < 2	Moderately contaminated
3	2 < Igeo < 3	Moderately contaminated (MC) to heavily contaminated (HC)
4	3 < Igeo < 4	Heavily contaminated (HC)
5	4 < Igeo < 5	Heavily contaminated (HC) to extremely contaminated (EC)
6	5 < Igeo < 6	Extremely contaminated (EC)

Table 4.13 Quality of soils/ stream sediments of dry season using geoaccumulation index

Metal	% UC	%UC- MC	%MC	%MC -HC	%HC	%HC - EC	%EC	REMARK
Zn	-	100	-	-	-	-	-	No Contamination
Cu	5.172	94.83	-	-	-	-	-	No Contamination
Pb	-	100	-	-	-	-	-	No Contamination
Cr	-	100	-	-	-	-	-	No Contamination
Cd	31.06	55.17	-	3.44	1.72	3.44	5.17	Heavy Contamination
As	43.10	53.45	3.45	-	-	-	-	Moderate Contamination

Table 4.14: Quality of soils/ stream sediments of rainy season using geoaccumulation index

Metal	% UC	%UC - MC	%MC	%MC -HC	%HC	%HC - EC	%EC	REMARK
Zn	-	100	-	-	-	-	-	No Contamination
Cu	-	100	-	-	-	-	-	No Contamination
Pb	5.17	94.82	-	-	-	-	-	No Contamination
Cr	15.51	84.48	-	-	-	-	-	No Contamination
Cd	41.37	31.03	12.06	1.72	3.44	3.49	6.89	Heavy Contamination
As	-	72.42	27.58	-	-	-	-	Moderate Contamination

Following the geoaccummulation index values from table 4.13 and 4.14, it can be deduced that Zinc, Copper, Lead and Chromium satisfy class 0 (practically uncontaminated) and class 1 (uncontaminated to moderately contaminated) except cadmium and arsenic for both dry and rainy seasons. Cadmium shows heavy contamination while arsenic shows moderate pollution. For cadmium, the geoaccumulation index, 31.06% of samples are practically uncontaminated, 55.17% are uncontaminated to moderately contaminated, 3.44% are moderately to heavily contaminated, 1.72% are heavily contaminated, 3.44% are heavily to extremely contaminated and 5.17% are extremely contaminated for dry season samples, while, rainy season samples shows that 41.37% of samples are practically uncontaminated, 31.03% are uncontaminated to moderately contaminated, 12.06% are moderately contaminated, 1.72% are moderately to heavily contaminated, 3.44% are heavily contaminated, 3.49% are heavily to extremely contaminated and 6.89% are extremely contaminated. The geoaccumulation index of arsenic shows that 43.10% of samples are practically uncontaminated, 53.45% are uncontaminated to moderately contaminated, and 3.45% are moderately contaminated in the dry season samples, while rainy season samples shows that 72.42% are uncontaminated to moderately, 27.58% are moderately contaminated. It is necessary to state that all the samples which show this high contamination falls within the Ameka mining district. This is due to the pollution from the drainage systems and mining activities in the area.

4.6.4 Contamination Factor

The pollution status of heavy metals in the stream bed sediment/ soils in the Pb/Zn mining fields of Abakaliki and its environs was also assessed using the contamination factor.

According to Hakanson, 1980, contamination factor (Equation 3.4) expresses the mean concentration with reference to the concentration of the metal in the earth crust.

Table 4.15 shows categories of contamination factor, while calculated values for the dry and rainy season are represented in appendix 18a and 18b respectively. Tables 4.16 and 4.17 show the quality of soil/ sediment of the area using contamination factor.

Table 4.15: Categories of Contamination Factor (CF) after Hakanson, 1980

CF < 1	Low contamination factor indicating low contamination
1 < CF < 3	Moderate contamination factor
3 < CF < 6	Considerable contamination factor
6 < CF	Very high contamination factor

Table 4.16: Quality of soils / stream sediments of dry season samples using contamination factor

Element	Mean content	Background value (Average shale)	Contamination factor	Remarks
Zn	48.07	90	0.534	Low factor
Cu	13.40	50	0.270	Low factor
Pb	18.49	20	0.925	Low factor
Cd	1.08	0.3	3.600	Considerable factor
Cr	9.00	73	0.123	Low factor
Hg	0.37	NIL	-	-
Ag	3.14	NIL	-	-
As	11.19	10	1.119	Moderate factor

Table 4.17: Quality of soils / stream sediments of dry season samples using contamination factor

Element	Mean content	Background value (Average in shale)	Contamination factor	Remarks
Zn	37.16	90	0.412	Low factor
Cu	15.487	50	0.309	Low factor
Pb	19.71	20	0.985	Low factor
Cd	1.56	0.3	5.200	Considerable factor
Cr	8.203	73	0.112	Low factor
As	19.00	10	1.900	Moderate factor

From tables 4.16 and 4.17 above, analysis of contamination factor for dry and rainy seasons shows that the contamination factor (C_f) of Zn, Cu, Pb and Cr is less than 1 (CF < 1) which implies low contamination factor of the metals. Cd has considerable contamination factor (3< CF < 6), while, As has moderate contamination factor (1< CF< 3).

4.6.5 Pollution Load Index

The Pollution Load Index (PLI) is obtainedas concentration Factors (CF). This CF is the quotient obtained by dividing the concentration of each metal. According to Harikumar *et al*., (2009), the PLI of the place arecalculated by obtaining the n-root from the n-C_fs that was obtained for all the metals (Equation 3.5). Tables 4.18 and 4.19 show PLI of soils/ sediments in dry and rainy seasons respectively. The PLI value of > 1 is polluted, whereas<1 indicates no pollution. Quality of soils / sediments using pollution load index (tables 4.18 and 4.19) reveals high pollution status for Cd.

Table 4.18: Quality of soils/ stream sediments of dry season samples using PLI

Metal	PLI	Remark
Zn	**0.415**	**No pollution**
Cu	**0.302**	**No pollution**
Pb	**0.416**	**No pollution**
Cd	**1.339**	**Pollution**
Cr	**0.163**	**No pollution**
As	**0.738**	**No pollution**

Table 4.19: Quality of soils/ stream sediments of rainy season samples using PLI

Metal	PLI	Remark
Zn	**0.200**	**No pollution:**
Cu	**0.088**	**No pollution**
Pb	**0.458**	**No pollution**
Cd	**1.472**	**Pollution**
Cr	**0.086**	**No pollution**
As	**0.723**	**No pollution**

4.6.6 Contamination Degree

Abrahim, (2005) and Abrahim and Parker, (2008) presented a modified and generalized form of the Hakanson, (1980) equation for the calculation of the overall degree of contamination as expressed in equation 3.6. Investigation for Contamination degree is very important because it shows at a glance the degree of contamination of the sample areas for all the metals analysed (Casper *et al*., 2004). It can be used to generally classify the soil with respect to the level of contamination. Table 4.20 shows the categories of classification of contamination degree, while appendixes 19a and 19b shows the contamination degree for the samples analysed in dry and rainy seasons respectively. Quality of soils and sediments are shown in tables 4.21 and 4.22 for dry and rainy seasons respectively.

Table 4.20: Categories of Contamination Degree based on Abrahim and Parker, (2008)

mCd Index	Remark
mCd < 1.5	Nil – very Low degree
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	Exremely high degree of contamination
mCd ≥ 32	Ultra high degree of contamination

Table 4.21: Quality of sediments/ soils based on Degree of Contamination for dry season samples analysed.

%very low	% Low	%Moderate	% High	% Very high	%ExtremelyHigh	% Ultra High
82.75	1.72	6.89	8.62	-	-	-

Table 4.22: Quality of sediments/ soils based on Degree of Contamination for rainy season samples analysed

%very low	% Low	% Moderate	% High	% Very high	% Extremely High	% Ultra High
70.69	5.17	13.79	8.62	1.72	-	-

The analysis of contamination degree show nill to high degree of contamination (< 1.5 to above 8), this implies low to high degree of contamination for the samples. High degrees of contamination were observed around the mining fields of Alibaruhu, Amorie, Amanchara, Mkpuma Akpatakpa, Enyigba and Ameka (Fig 4.83). This analysis corresponds with the various contoured plot and analysis on the overall level of contamination in the area, and shows the same trend for both dry and rainy seasons. The analysis of contamination degree also shows that there are no cases of extremely high and ultra high contamination in the mining fields of the study area.

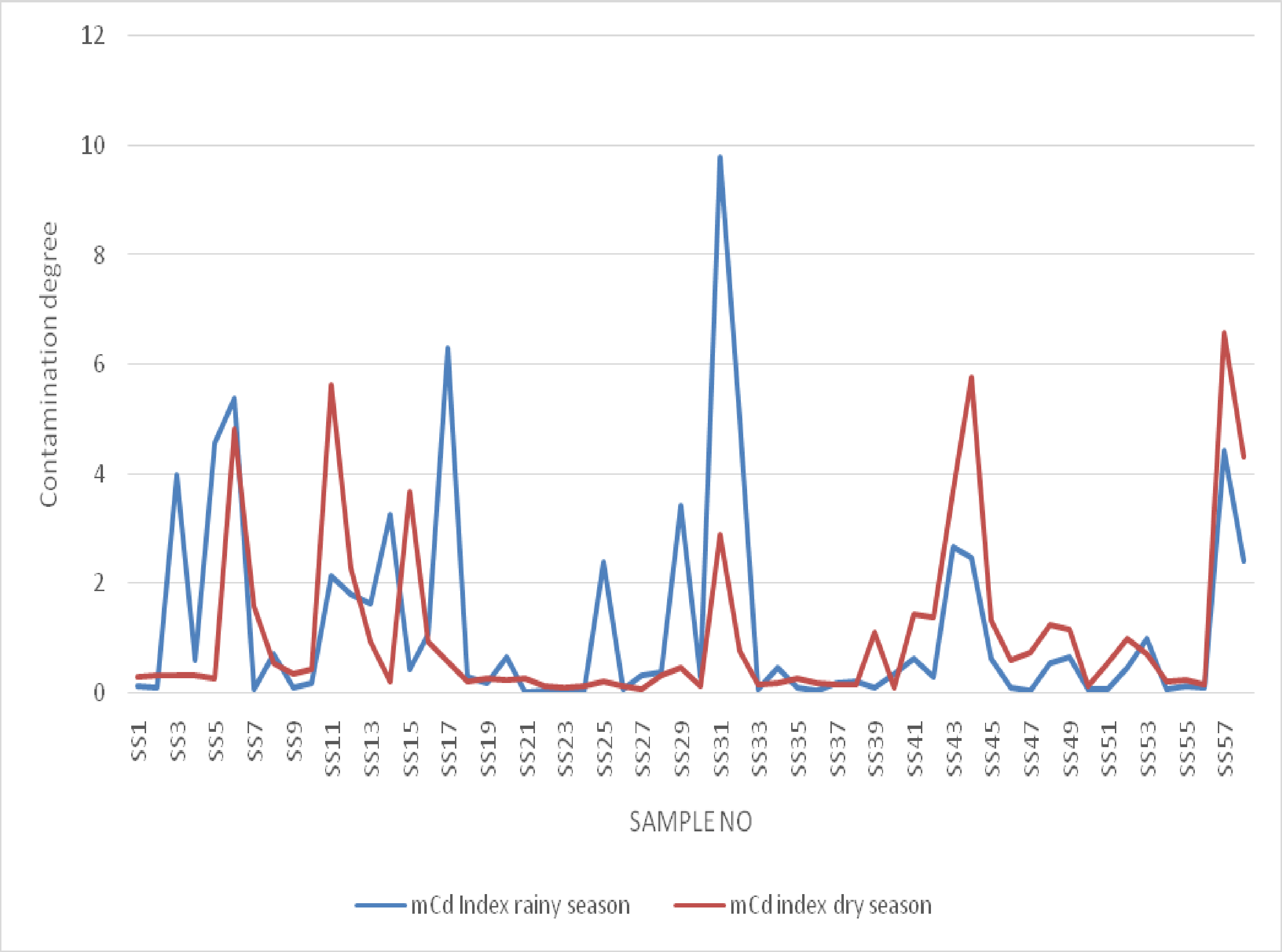

Fig 4.83: Distribution of Contamination Degree in soils/ stream sediments analysed.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Hydrogeological and geochemical assessment of the lead – zinc mining areas of Abakaliki, Ebonyi State, Southeastern Nigeria was carried out covering a total area of about 794.2km^2. These areas include Enyigba, Mkpuma Akpatakpa, Ameka, Amorie, Amanchara and Alibaruhu communities where active and abandoned mines are located.

One hundred and sixteen water samples, comprising forty – seven from groundwater sources and sixty- nine from surface water sources were analysed using Atomic Absorption Spectrophotometric and Ultra Violet / Visible Spectroscopy. One hundred and sixteen soil / stream sediments were collected and subjected to geochemical analysis using Atomic Absorbtion Spectrophotometric method, and pedologic safety analytical tools including Effect Range Low (ERL), Effect Range Median (ERM), Pollution Index (€), Geoaccumulation Index (Igeo), Contamination Factor (Cf), Pollution Load Index (PLI), and contamination degree were used to assess the impact level of mining activities in arable soils. One hundred and ten hand dug wells were sampled for geohydrological studies while surface geological mapping (including the studies of rock types and fracture pattern) was done. This study has led to the following findings:

Geologically, the area is underlain by shales, limestone, siltstone, sandstone and mudstone. The rocks has been affected by tilting and fracturing genetically linked to the Santonian Orogeny, which has induced secondary porosity on the shales, resulting to the formation of semi confined aquifer in the area.

The analysis of fracture in the area shows a major NW – SE and minor NE – SW fracture system. These fracture system controls groundwater movement. Groundwater flowstudies reveals predominance of recharge area in the axis of Abakaliki metropolis while the Enyigba, Ameka, Amorie, Alibaruhu axis are the discharge areas.

Results of hydrochemical analysis revealed that Ca^{2+}, Mg^{2+}, Fe^{2+}, K^{+} ,Na^{+} (cations) and Cl^{-}, SO_4^{2-}, NO_3^{-}, HCO_3^{-} (anions) are the major hydrochemical constituents while Al^{3+}, Mo^{2+}, Pb^{2+},Cu^{2+},Hg^{2+}, Cr^{2+}, Ni^{2+}, Cd^{2+}, As^{3+}, Ag^{+}, Mn^{2+} and Se^{2-} are the trace constituents. Concentrations of Cl^{-}, SO_4^{2-},CO_3^{-},Fe^{2+}, Mn^{2+}, Pb^{2+}, Cr^{3+}, Ni^{2+}, Cd^{2+}, As, Ag^{+}, and Se^{2-} are above the WHO, 2011 permissible guidelines for drinking water, espacially for surface water and areas close to the active mines. However, the Ameka and Mkpuma Akpatakpa mining areas recorded higher concentrations of the geochemical constituents. Physical parameters indicate acidic to slightly basic waters for the areas. The abandoned mines showed considerably lower concentrations than the active mines.

Geochemical investigation of stream sediments and soils show Intermediate Contamination (IC) to Poor Contamination (PC) for Ag, Cd and Hg using the Effect Range Low (ERL) and Effect Range Median (ERM); Cd, Hg and Ag show Significant Contamination (SC) using the Pollution Index (€); Cd show Heavy Contamination (HC) while As show Moderate Contamination (MC) using the Geoaccumulation Index (Igeo); Cd show Considerable Contamination factor (CC), while As show Moderate Contamination factor (MC) using the Contamination Factor (Cf). Pollution Load Index (PLI), show Moderate Pollution (MP) for As and High Pollution (HP) for Cd, while assessment of contamination degree show very high degree of contamination in the Mkpuma Akpatakpa and Ameka areas. The area is prone to chronic health and environmental hazards.

5.2 CONCLUSIONS

The following conclusions have been drawn from this study. The area is underlain by shales, limestone, mudstone and lenses of sandstone. These shales have been deeply fractured, with major trend in the NW – SE direction. This fracture pattern controls the groundwater movement and hydrothermal enrichment of minerals. These fractured shales are of great hydrogeologic and hydrologic significance since they form semi - confined aquifers which are the major aquifer units in the area, and controls groundwater flow. Groundwater flow direction indicates predominance of recharge area in the axis of Abakaliki metropolis while the Enyigba, Ameka, Amorie, Alibaruhu constitute the discharge areas. Hydrochemical analysis shows that concentrations of Cl^- , SO_4^{2-},CO_3^-,Fe^{2+}, Mn^{2+}, Pb^{2+}, Cr^{3+}, Ni^{2+}, Cd^{2+}, As, Ag^+, and Se^{2-} are above the WHO, 2011 permissible guidelines for drinking water, especially for surface water and areas close to the active mines. Safest water sources for various domestic uses are located around Nkwegu, Idembia, Amezekwe, Ndiechi and Umuigwe. Water sources from area about 7 km radius from active mines are heavily polluted and hence considered unfit for many domestic uses, especially for drinking. Alternative sources of of water supply would be provided for the inhabitants of such areas.

Geochemical assessment of soils and stream sediments using six different pollution indices showed high degree of contamination for Ag, As, Pb, Hg and Cd (in the order of increasing pollution indices). This implies that arable soils around the mining areas (about 5 km radius) are not suitable for food crop production as biomagnification can occur in the food chain. Hence agricultural activities should be concentrated in safe areas to minimize the risk of potential health hazards. Assessment of contamination degree show higher contamination degree for the Mkpuma Akpatakpa and Ameka areas than the Enyigba and Amanchara areas. The adverse socio – environmental implications of mining in the area includes destruction of vegetation, badland development, pollution, ecological disturbance system, destruction of buildings and health hazards.

5.3 Recommendation

Following the findings on the hydrogeological and geochemical investigation of the lead – zinc mining areas of Abakaliki, Ebonyi State, Nigeria, the following recommendations have been made:

Mining laws and Policies

In order to minimize the effects of mining, certain precautionary measures must betaken by both the government and the mining companies. The government's role is toprovide the legislation required to make it mandatory forthe companies to practice all necessary precautions intheir operations that will prevent or minimize environmental damage.

There is the need to strengthen the new law with the following inputs.

1. Government should enact laws to control and incorporate the activities of illegal miners in these areas, as they form an integral part of the mining sector.
2. Government should make policy that will mandate the mining companies to properly segregate and dump their wastes at appropriate dumping sites.
3. Government should equally ensure that mining companies restore each operational site to its original state after mining, following the Environmental Impact Assessment (EIA) plan.
4. Some of these abandoned mining pits should be used as tourist and recreational sites. This can enhance the economic life of the area.
5. Processing companies must install appropriateequipment, where necessary, for preventing orminimizing pollution;

Groundwater development and waste management

In the aspect of groundwater development and waste, the following recommendations have been made for sustainable water supply.

1. Sitting of boreholes for potable water for the community dwellers is necessary as most of the villagers often source water from impounded ponds and mine pits.
2. Adequate hydrogeochemical analysis should be carried out in the area for groundwater exploration before sitting of boreholes
3. Hydrochemical analysis of groundwater and surface waters in the area should be well carried out to ascertain the concentration of chemical constituents in the water before use.
4. The waste dumps in the Umuaghara area of Abakaliki metropolis should be relocated to the Ameka areas as the former forms the recharge areas, this poses great danger to water supply.

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Appendix 1: Trends of Joint and Fracture Azimuth in the Study Area.

Locations	**Trend of joints**
Ebonyi River at Onu-Ebonyi	N335^{0}, N320^{0}, N3270, N324^{0}, N322^{0}, N325^{0}, N314^{0}, N334^{0}, N320^{0}, N315^{0}, N325^{0}, N328^{0}, N324^{0}, N313^{0}, N321^{0}, N316^{0}, N323^{0}, N319^{0}, N318^{0} and N314^{0}
Base of juju hill	N161^{0}, N168^{0}, N156^{0}, N156^{0}, N148^{0}, N162^{0}, N162^{0}, N158^{0}, N157^{0}, N155^{0}, N162^{0}, N150^{0}, N175^{0}, N156^{0}, N142^{0}, N145^{0}, N142^{0}, N143^{0}, N159^{0} and N156^{0}
Ebonyi River at Azuoto (Ogbuchi Amachi)	N326^{0}, N327^{0}, N314^{0}, N330^{0}, N320^{0}, N318^{0}, N310^{0}, N311^{0}, N310^{0}, N320^{0}, N314^{0}, N311^{0}, N316^{0}, N304^{0}, N329^{0}, N303^{0}, N335^{0}, N305^{0}, N320^{0} and N312^{0}
Enyigba	N318^{0}, N328^{0}, N352^{0}, N330^{0}, N300^{0}, N335^{0}, N318^{0}, N320^{0}, N230^{0}, N315^{0}, N240^{0}, N336^{0}, N328^{0}, N300^{0}, N300^{0}, N172^{0}, N250^{0}, N220^{0}, N195^{0}, N200^{0}, N50^{0}, N65^{0}, N100^{0}, N120^{0}, N48^{0}, N123^{0}, N128^{0}, N140^{0}, N132^{0} and N130^{0}
Ewe River, Mkpuma Akpatakpa	N330^{o}, N340^{o}, N234^{o}, N350^{o}, N356^{o}, N334^{o}, N212^{o}, N210^{o}, N345^{o}, N324^{o}, N320^{o}, N275^{o}, N260^{o}, N315^{o}, N338^{o}, N320^{o}, N305^{o}, N294^{o}, N250^{o} and N353^{o}.
Onu – Ebonyi River, Mkpuma Akpatakpa	N312^{o}, N326^{o}, N195^{o}, N223^{o}, N324^{o}, N300^{o}, N324^{o}, N315^{o}, N324^{o}, N320^{o}, N318^{o}, N316^{o}, N330^{o}, N334^{o}, N337^{o}, N314^{o}, N290^{o}, N270^{o}, N310^{o} and N209^{o}

Appendix 2: Frequencyof joints / fracture observed at Ebonyi River in Onu-Ebonyi

Class interval (^{0})	Corresponding interval (^{0})	Frequency	Percentage (%)
0 – 30	181 – 210	0	0
31 – 60	211 – 240	0	0
61 – 90	241 – 270	0	0
91 – 120	271 – 300	0	0
121 – 150	301 – 330	18	90
151 – 180	331 – 360	2	10
TOTAL		20	100

Appendix 3: Frequencyof joints / fractures observed at Base of Juju hill

Class interval (^{0})	Corresponding interval (^{0})	Frequency	Percentage (%)
0 – 30	181 – 210	0	0
31 – 60	211 – 240	0	0
61 – 90	241 – 270	0	0
91 – 120	271 – 300	0	0
121 – 150	301 – 330	6	30
151 – 180	331 – 360	14	70
TOTAL		20	100

Appendix 4: Frequency of joints/ fractures observed at Ebonyi River at Azuoto in Ogbuchi Amachi community

Class interval (^{0})	Corresponding interval (^{0})	Frequency	Percentage (%)
0 – 30	181 – 210	0	0
31 – 60	211 – 240	0	0
61 – 90	241 – 270	0	0
91 – 120	271 – 300	0	0
121 – 150	301 – 330	18	90
151 – 180	331 – 360	2	10
TOTAL		20	100

Appendix 5: Frequency of joints/ fractures observed at Enyigba

Class interval (°)	Corresponding Interval (°)	Frequency	Percentages (%)
0-30	181-210	3	10
31-60	211-240	5	16.7
61-90	241-270	3	10
91-120	271-300	4	13.3
121-150	301-330	12	40
151-180	331-360	3	10
TOTAL		30	100

Appendix 6: Frequency of joints/ fractures observed at Ewe River, Mkpuma Akpatakpa

S/N	Class Interval (°)	Corresponding Interval (°)	Frequency	Percentage (%)
1	0 – 30	181 – 210	1	5
2	31 – 60	211 – 240	2	10
3	61 – 90	241 – 270	2	10
4	1 – 120	271 – 300	3	15
5	121 – 150	301 – 330	5	25
6	151 – 180	331 – 360	7	35
TOTAL			**20**	**100**

Appendix 7: Frequency of joints/ fractures observed at Onu-Ebonyi River, Mkpuma Akpatakpa

S/N	Class Interval (°)	Corresponding Interval (°)	Frequency	Percentage (%)
1	0 – 30	181 – 210	1	5
2	31 – 60	211 – 240	1	5
3	61 – 90	241 – 270	1	5
4	91 – 120	271 – 300	2	10
5	121 – 150	301 – 330	13	65
6	151 – 180	331 – 360	2	10
TOTAL			**20**	**100**

Appendix 8: Water Table Levels of Wells in the Study Area.

S/N	GPS LOCATION (CO-ORDINATE)		LOCATION OF WELL	WATER TABLE(m)	ELEVATION(m)	CORRECTED DATUM (m)
1	$06^{0}19^{1}41.3^{11}$	$08^{0}07^{1}12.4^{11}$	43, Igweorie str; Abakaliki.	36.08	56	19.92
2	$06^{0}19^{1}42.5^{11}$	$08^{0}07^{1}12.8^{11}$	31, Igweorie Str; Abakaliki.	22.96	59	36.04
3	$06^{0}19^{1}43.1^{11}$	$08^{0}07^{1}12.8^{11}$	30, Igweorie Str; Abakaliki.	16.4	57	40.6
4	$06^{0}19^{1}38.2^{11}$	$08^{0}07^{1}12.2^{11}$	37, Igweorie Str; Abakaliki.	29.52	52	22.48
5	$06^{0}19^{1}37.4^{11}$	$08^{0}7^{1}11.8^{11}$	25, Igweorie Str; Abakaliki.	32.8	60	27.2
6	$06^{0}19^{1}37.1^{11}$	$08^{0}07^{1}10.3^{11}$	16, Igweorie Str; Abakaliki.	29.52	61	31.48
7	$06^{0}19^{1}36.2^{11}$	$08^{0}07^{1}10.3^{11}$	13, Igweorie Str; Abakaliki.	24.928	56	31.072
8	$06^{0}19^{1}37.0^{11}$	$08^{0}07^{1}09.0^{11}$	8, Igweorie Str; Abakaliki.	32.8	54	21.2
9	$06^{0}19^{1}34.8^{11}$	$08^{0}07^{1}08.5^{11}$	7, Igweorie Str; Abakaliki.	28.536	56	27.464
10	$06^{0}19^{1}36.1^{11}$	$08^{0}07^{1}08.56^{11}$	4, Igweorie Str; Abakaliki.	31.16	57	25.84
11	$06^{0}19^{1}34.7^{11}$	$08^{0}07^{1}7.8^{11}$	5, Igweorie Str; Abakaliki.	20.664	53	32.336
12	$06^{0}19^{1}40.3^{11}$	$08^{0}07^{1}10.6^{11}$	4, Igweorie Str; Abakaliki.	36.08	54	17.92
13	$06^{0}19^{1}40.3^{11}$	$08^{0}07^{1}09.6^{11}$	6, Elias Odili Str;Abakaliki.	35.096	62	26.904
14	$06^{0}19^{1}49.6^{11}$	$08^{0}07^{1}09.0^{11}$	8, Elias Odili Str; Abakaliki.	38.048	56	17.952
15	$06^{0}19^{1}39.5^{11}$	$O8^{0}07^{1}12.8^{11}$	39, Igweorie Str; Abakaliki.	41.984	58	16.016
16	$06^{0}19^{1}46.3^{11}$	$08^{0}07^{1}14.3^{11}$	50, Igweorie Str; Abakaliki	20.336	64	43.664
17	$06^{0}19^{1}45.3^{11}$	$08^{0}07^{1}14.4^{11}$	57, Igweorie Str; Abakaliki	11.48	61	49.52
18	$06^{0}19^{1}41.8^{11}$	$08^{0}05^{1}45.6^{11}$	12^{B} Sakamori Qtrs, Amagu Str	17.384	73	55.616
19	$06^{0}19^{1}42.1^{11}$	$08^{0}5^{1}45.1^{11}$	10^{A} Sakamori Qtrs, Amagu Str	16.4	72	55.6
20	$06^{0}19^{1}42.2^{11}$	$08^{0}05^{1}46.6^{11}$	11A Sakamori Qtrs, Amagu Str	14.104	72	57.896
21	$06^{0}19^{1}41.7^{11}$	$08^{0}05^{1}44.2^{11}$	9^{B} Sakamori Qtrs, Amagu Str	16.4	70	53.6
22	$06^{0}19^{1}42.7^{11}$	$08^{0}05^{1}46.7^{11}$	13A Sakamori Qtrs, Amagu Str	18.69	72	53.31
23	$06^{0}19^{1}37.8^{11}$	$08^{0}05^{1}47.9^{11}$	18B Sakamori Qtrs Amagu str	24.928	75	50.072
24	$06^{0}19^{1}36.6^{11}$	$08^{0}05^{1}47.3^{11}$	19A Sakamori Qtrs Amagu str	19.68	75	55.32
25	$06^{0}19^{1}37.2^{11}$	$08^{0}05^{1}43.5^{11}$	1B, Sakamori Qtrs Amagu str	19.68	69	49.32
26	$06^{0}19^{1}38.9^{11}$	$08^{0}05^{1}44.1^{11}$	3B, Sakamori Qtrs Amagu str	22.96	70	47.04
27	$06^{0}19^{1}41.0^{11}$	$08^{0}05^{1}43.8^{11}$	5B, Sakamori Qtrs Amagu str	19.68	72	52.32
28	$06^{0}19^{1}45.4^{11}$	$08^{0}05^{1}31.1^{11}$	9, Nnoroom Str; Abakaliki.	11.48	74	62.52
29	$06^{0}19^{1}47.8^{11}$	$08^{0}05^{1}50.3^{11}$	24, Aloh Str, Abakaliki.	7.216	64	56.784
30	$06^{0}19^{1}48.6^{11}$	$08^{0}05^{1}52.2^{11}$	17, Aloh Str, Abakaliki	9.84	72	62.16
31	$06^{0}19^{1}48.0^{11}$	$08^{0}05^{1}51.5^{11}$	21, Aloh Str; Abakaliki	16.4	75	58.6
32	$06^{0}19^{1}58.2^{11}$	$08^{0}06^{1}07.7^{11}$	14, Ngbowo Street Kpirikpiri .	16.4	74	57.6
33	$06^{0}20^{1}02.5^{11}$	$08^{0}06^{1}08.0^{11}$	29, Ngbowo Street Kpirikpiri.	24.272	73	48.728
34	$06^{0}20^{1}05.3^{11}$	$08^{0}06^{1}09.4^{11}$	19, Ngbowo Street Kpirikpiri.	26.24	74	47.76
35	$06^{0}19^{1}00.4^{11}$	$08^{0}05^{1}25.3^{11}$	3B, Odinukwe Street.	39.36	71	31.64
36	$06^{0}19^{1}00.2^{11}$	$08^{0}05^{1}23.9^{11}$	9, Odinukwe Street.	39.36	72	32.64
37	$06^{0}21^{1}19.6^{11}$	$08^{0}04^{1}48.1^{11}$	Ugwuachara Area.	19.68	80	60.32
38	$06^{0}21^{1}18.5^{11}$	$08^{0}04^{1}48.8^{11}$	Ugwuachara Area.	16.73	71	54.3
39	$06^{0}21^{1}12.9^{11}$	$08^{0}04^{1}47.8^{11}$	Ugwuachara Area.	18.04	63	44.96
40	$06^{0}21^{1}21.9^{11}$	$08^{0}04^{1}48.5^{11}$	Ugwuachara Area.	29.52	75	45.48
41	$06^{0}21^{1}25.1^{11}$	$08^{0}04^{1}40.2^{11}$	Ugwuachara ASrea.	30.83	70	39.17
42	$06^{0}22^{1}38.4^{11}$	$08^{0}02^{1}41.0^{11}$	Ishieke Ikelegu Area.	22.63	75	52.37
43	$06^{0}22^{1}40.0^{11}$	$08^{0}02^{1}40.6^{11}$	Ishieke Ikelegu Area.	19.02	68	48.98
44	$06^{0}22^{1}40.8^{11}$	$08^{0}02^{1}40.3^{11}$	Ishieke Ikelegu	16.07	72	55.93
45	$06^{0}22^{1}57.9^{11}$	$08^{0}02^{1}35.8^{11}$	Ishieke Ikelegu Area.	33.78	72	38.22
46	$06^{0}22^{1}56.3^{11}$	$08^{0}02^{1}39.1^{11}$	Ishieke Ikelegu Area.	14.76	69	54.24
47	$06^{0}22^{1}56.0^{11}$	$08^{0}02^{1}40.6^{11}$	Ishieke Ikelegu Area.	13.12	68	54.88
48	$06^{0}22^{1}54.5^{11}$	$08^{0}02^{1}41.1^{11}$	Ishieke Ikelegu Area.	16.73	72	55.27
49	$06^{0}22^{1}56.0^{11}$	$08^{0}02^{1}43.1^{11}$	Ishieke Ikelegu Area.	15.09	78	62.91
50	$06^{0}22^{1}54.6^{11}$	$08^{0}01^{1}59.4^{11}$	Ishieke Ikelegu Area.	23.29	80	56.71
51	$06^{0}22^{1}53.7^{11}$	$08^{0}02^{1}00.9^{11}$	Ishieke Ikelegu Area.	19.68	77	57.32

52	06^{0}22^{1}56.0^{11}	08^{0}02^{1}02.1^{11}	Ishieke Ikelegu Area.	23.62	85	61.38
53	06^{0}22^{1}50.9^{11}	08^{0}02^{1}04.1^{11}	Ishieke Ikelegu Area.	22.30	82	59.7
54	06^{0}22^{1}53.7^{11}	08^{0}02^{1}05.4^{11}	Ishieke Ikelegu Area.	35.42	82	46.58
55	06^{0}22^{1}52.5^{11}	08^{0}02^{1}07.8^{11}	Ishieke Ikelegu Area.	30.18	77	46.82
56	06^{0}22^{1}52.1^{11}	08^{0}02^{1}08.0^{11}	Ishieke Ikelegu Area.	29.52	76	46.48
57	06^{0}19^{1}44.6^{11}	08^{0}05^{1}20.5^{11}	Kpirikpiri Abakaliki	11.48	77	65.52
58	06^{0}19^{1}44.4”	08^{0}05’21.0”	Kpirikpiri Abakaliki	13.12	77	63.88
59	06^{0}19’51.7”	08^{0}06’00.2”	Kpirikpiri Abakaliki	22.30	88	65.7
60	06^{0}19’51.1”	08^{0}05’59.2”	Kpirikpiri Abakaliki	24.6	79	54.4
61	06^{0}19’51.1”	08^{0}05’59.2”	Kpirikpiri Abakaliki	20.99	84	63.01
62	06^{0}19’50.8”	08^{0}05’58.4”	Kpirikpiri Abakaliki	23.29	78	54.71
63	06^{0}19’50.3”	08^{0}05’57.0”	Kpirikpiri Abakaliki	22.96	82	59.04
64	06^{0}19’51.4”	08^{0}05’55.9”	Kpirikpiri Abakaliki	16.07	78	61.93
65	06^{0}19’50.3”	08^{0}05’55.9”	Kpirikpiri Abakaliki	21.32	85	63.68
66	06^{0}19’49.1”	08^{0}05’52.9”	Kpirikpiri Abakaliki	14.76	81	66.24
67	06^{0}19’48.4”	08^{0}05’52.2”	Kpirikpiri Abakaliki	14.10	81	66.9
68	06^{0}19’47.9”	08^{0}05’51.6”	Kpirikpiri Abakaliki	13.45	80	66.55
69	06^{0}19’48.0”	08^{0}05’51.1”	Kpirikpiri Abakaliki	11.48	78	66.52
70	06^{0}19’47.8”	08^{0}05’50.4”	Kpirikpiri Abakaliki	8.53	81	72.47
71	06^{0}20’37.1”	08^{0}05’55.5”	Kpirikpiri Abakaliki	13.78	72	58.22
72	06^{0}20’37.7”	08^{0}05’53.2”	Kpirikpiri	20	74	54
73	06^{0}20’36.8”	08^{0}05’56.5”	Kpirikpiri Abakaliki	13.45	73	59.55
74	06^{0}20’36.7”	08^{0}05’58.9”	Kpirikpiri Abakaliki	17.06	70	52.92
75	06^{0}20’43.1”	08^{0}05’44.2”	Kpirikpiri Abakaliki	6.23	82	75.77
76	06^{0}20’44.5”	08^{0}05’46.6”	Kpirikpiri Abakaliki	9.51	81	71.49
77	06^{0}20’49.0”	08^{0}05’49.8”	Kpirikpiri Abakaliki	23.94	84	60.06
78	06^{0}20’47.5”	08^{0}05’49.1”	Kpirikpiri Abakaliki	22.63	78	55.37
79	06^{0}20’47.2”	08^{0}05’48.1”	Kpirikpiri Abakaliki	17.38	83	65.62
80	06^{0}20’44.8”	08^{0}05’46.6”	Kpirikpiri Abakaliki	12.79	84	71.21
81	06^{0}20‘42.5”	08^{0}05’47.4”	Kpirikpiri Abakaliki	16.4	78	61.6
82	06^{0}19’56.2”	008^{0}04’30.6”	Anti-Bomb Squatters	31.49	82	50.51
83	06^{0}19,56.8”	008^{0}04’26.4”	Anti-Bomb Squatters	27.22	80	52.78
84	06^{0}19’52.8”	008^{0}04’25.8”	Anti-Bomb Squatters	29.52	80	50.48
85	06^{0}19’52.3”	008^{0}04’25.3”	Anti-Bomb Squatters	27.55	80	52.45
86	06^{0}19’53.0”	008^{0}04’26.4”	Anti-Bomb Squatters	30.18	86	55.82
87	06^{0}19’54”	008^{0}04’30.2”	Anti-Bomb Squatters	22.96	92	69.04
88	06^{0}19’50.7”	008^{0}04’29.6”	Anti-Bomb Squatters	26.24	81	54.76
89	06^{0}19’52.2”	008^{0}04’31.1”	Anti-Bomb Squatters	27.22	89	61.78
90	06^{0}19’53.1”	008^{0}04’31.4”	Anti-Bomb Squatters	24.6	77	52.4
91	06^{0}19’52.6”	008^{0}04’32.5”	Anti-Bomb Squatters	27.22	80	52.78
92	06^0 23 44.7	008^0 11 55.6	Mkpuma Akpatakpa	22.40	71	48.6
93	06^0 33 09	008^0 05 8.43	Mkpuma Akpatakpa	23.41	59	35.59
94	06^0 30’08”	008^{0}05’7.43”	Ekbiligwe	18.20	62	43.8
95	06^{0}12’23.7”	08^{0}06’49.3”	Amagkpau Village Enyigba	22.96	48	25.04
96	06^{0}12’28.3”	08^{0}07’05.4”	Amagu Village Enyigba	36.08	52	15.92
97	06^{0}12’14.9”	08^{0}07’22.5”	Amagu Village Enyigba	36.08	72	35.92
98	06^{0}12’10.2”	08^{0}07’28.6”	Amagu Village Enyigba	26.24	69	42.76
99	06^{0}10’20.3”	08^{0}07’29.1”	Ogidiga Ndufu Alike	52.48	55	2.52
100	06^{0}10’42.8”	08^{0}08’19.0”	Enyigba mile site	11.48	56	44.52
101	06^{0}12’28.5”	08^{0}08’25.3”	Enyigba Village	32.8	49	16.2
102	06^{0}10’31.2”	08^{0}09’20.0”	Enyigba Village	32.8	51	18.2
103	06^{0}12’17.9”	08^{0}07’23.3”	Ndufu Alike	29.52	48	18.48
104	06^{0}13’12.1”	08^{0}08’15.0”	Ndufu Alike	39.36	62	22.64
105	06^{0}30’10.0”	08^{0}08’14.0”	Amanchara	35.81	71	35.18
106	06^{0}24’29.1”	08^{0}10’13.12”	Mkpuma Akpatakpa	30.2	64	33.17
107	06^{0}24’20.3”	08^{0}08’55.6”	Mkpuma Akpatakpa	29.68	74	44.32
108	06^{0}33’ 8.22”	08^{0}06’28.32”	Ugbodo	22.41	53	30.58
109	06^{0}24’31.4”	08^{0}10’47.72”	Ngbo Agbaja	39.48	62	22.52
110	06^{0}21’29.25”	08^{0}07’16.43”	Ngbo Agbaja	34.12	60	25.88

Appendix 9a: Values of Physical Constituents in Surface Water Samples Analysed (Dry Season)

S/N	Sample No	Location	Co –odinates Latitude	Longitude	pH	Electrical Conductivity us/cm	Turbidity NTU	TDS mg/l	Temperature (O◦)
1	OP/SW 1	Ebonyi River, Ndegualeke	06^{o} 32' 52.1"N	008^{o} 02' 08.6"E	5.36	48	849	68.9	27
2	OP/SW 2	Enyigba mine site (Active)	06^{o} 11' 11.2"N	008^{o} 08' 53.1"E	4.06	41.6	107	70.3	28
3	OP/SW 3	Ebonyi River, Umuigwe	06^{o} 27' 40.9"N	008^{o} 06' 41.6"E	5.73	44	849	76.14	26
4	OP/SW 4	Ebonyi River Odomoke	06^{o} 29' 31.8"N	008^{o} 02' 14.7"E	6.35	47	23	70.14	27
5	OP/SW 5	Ebonyi River, Obeagu Ikenyi	06^{o} 22' 38.9"N	008^{o}11' 30.6"E	5.87	57	92	69.76	25
6	OP/SW 7	Iyiokwu River, Abakaliki	06^{o} 18' 48"N	008^{o} 04' 10.6"E	6.5	0.17	453	144	27
7	OP/SW 8	Aguakpu River, Abakaliki	06^{o} 18' 12.5"N	008^{o} 04' 08.8"E	6.7	0.19	18	281	26
8	OP/SW 9	River Ololo, Mkpuma Akpatakpa	06^{o} 23' 44.9"N	008^{o} 11' 55.4"E	4.56	101	804	73.7	27
9	OP/SW 11	Ameka mine site (Active)	06^{o} 09' 48"N	008^{o}06' 56"E	1.51	24.4	793	71.5	27
10	OP/SW 12	Ohamini River, Ohamini	06^{o} 13' 51.1"N	008^{o}04' 29.45"E	7.9	2.5	245	47	26
11	OP/SW 13	Ngele Ocha, Ezza Abia	06^{o} 14' 36.42"N	008^{o} 02' 36.03"E	6.8	0.43	76	127	25
12	OP/SW 15	River Ololo, Okaria Agbaja	06^{o} 24' 29.4"N	008^{o} 10' 48.7"E	3.3	27.3	280	32.7	26
13	OP/SW 16	Ameri Salt lake Enyigba	06^{o} 08' 48"N	008^{o} 05' 56"E	4.88	18.4	810	70.9	27
14	OP/SW 17	River Ogbogbo Ekebiligwe	06^{o} 33' 08"N	008^{o} 05' 8.34"E	6.51	29	175	78.4	25
15	OP/SW 18	Ngele Okoro, Ebonie	06^{o} 25' 06.9"N	008^{o}03' 29.6"E	6.1	124	847	67.3	27
16	OP/SW 19	Ameka mine site (Abandone)	06^{o} 10' 48"N	008^{o}08' 2.5"E	5.13	17.45	703	88.5	28
17	OP/SW 20	Mkpuma Akpatakpa Mine site (Active)	06^{o} 23' 35.04"N	008^{o} 10' 40.8"E	3.33	918	394	79.2	28
18	OP/SW 21	Ndiezzagu- Umuaru	06^{o} 13' 25"N	008^{o}01' 05.28"E	8.04	21.8	286	50.5	27
19	OP/SW 22	Amanchara Mine Site (Active)	06^{o} 32' 06"N	008^{o}07' 01.2"E	2.87	61	30	54.7	28
20	OP/SW 23	Enyigba mine site (Active)	06^{o} 11' 57"N	008^{o}07' 22"E	1.01	617	848	88.3	27
21	OP/SW 25	Okpuriwa - Egbu River	06^{o} 11' 05"N	008^{o}01' 16"E	6.75	64	564	86.4	25
22	OP/SW 26	Enyigba mine site (Active)	06^{o} 09' 54"N	008^{o} 06' 02"E	1.14	404	56	67.4	28
23	OP/SW 27	Ebonyi River Odomoke	06^{o} 31.05"N	008^{o} 05' 14. 02"E	6.5	475	854	62.1	25
24	OP/SW 28	Onuzu, mine site, Enyigba (Active)	06^{o} 11' 02.9"N	008^{o}05' 56"E	1.2	406	190	68.9	27
25	OP/SW 29	Alibaruhu mine site Enyigba(Active)	06^{o} 09' 58'N	008^{o}05' 27"E	0.96	75	794	70.18	28
26	OP/SW 30	Akpara River, Enyigba	06^{o} 11' 28.09"N	008^{o}07' 49.23"E	1.15	57	440	69.94	26
27	OP/SW 31	River Oyirigbo, Amanchara	06^{o} 30' 09"N	008^{o}06' 15.02"E	3.04	126	448	73.6	25
28	OP/SW 32	River Ebonyi Ngbo Agbaja	06^{o} 22' 21.57"N	008^{o}09' 08.22"E	7.12	357	68	1.01	24
29	OP/SW 33	River Abe, Mkpuma	06^{o} 24' 30.16"N	008^{o}10' 14.13"E	3.98	266	22	2.2	26
30	OP/SW 34	Obeagu Ikenyi	06^{o} 24' 20.08"N	008^{o} 11' 11.38'E	6.72	577	20	2	25
31	OP/SW 36	Ndiabor Ishiagu	06^{o} 21' 05.46"N	008^{o} 11' 23.15"E	6.16	799	26	1.7	26
32	OP/SW 38	Ndioke	06^{o} 2' 73.12"N	008^{o} 01' 48.7"E	6.19	142	945	4.9	25
33	OP/SW 39	Edenyaka	06^{o} 25' 18.5"N	008^{o} 08' 25.2"E	7.22	393	44	1.2	27
34	OP/SW 40	River Abe, Mkpuma Akpatakpa	06^{o} 24' 21.4" N	008^{o} 08' 56.6"E	4.36	118	850	3.2	26
35	OP/SW 57	Akpara River, Enyigba	06^{o} 12" 80.4"N	008^{o} 06' 38.7"E	6.24	120.2	22	10	25
36	OP/SW 58	Ngele River Enyigba	06^{o} 11' 54.3"N	008^{o} 008' 34.1"E	6.2	331	323	8	25
37	OP/SW 59	Enyigbe salt Lake	06^{o} 11' 31.2"N	008^{o} 08" 22.1"E	9.87	137.9	433	4	29
38	OP/SW 60	Ameka Pond	06^{o} 09' 54.5"N	008^{o} 06' 69.1"E	6.33	82.7	848	8	26
39	OP/SW 61	Ameka Stream, Ameka	06^{o} 09' 35"N	008^{o}06' 30.8"E	6.69	388	9	2	24
40	OP/SW 62	Ebonyi River Ndiechi	06^{o} 18' 10.08"N	008^{o}02.3"E	7.19	263	246	8	27
41	OP/SW 63	Ekaeru inyimogu	06^{o} 20' 45.01"N	008^{o} 07' 21.12"E	7.53	273	131	1.6	28

42	OP/SW 64	Ebonyi R.Obusue	06^{o} 18' 01.05"N	008^{o}08' 28.06"E	6.56	172.4	168	4	25
43	OP/SW 67	River Abe, Mkpuma Akpatakpa	06^{o} 21' 28.28"N	008^{o}07' 15.49"E	6.61	98.5	115	28.4	27
44	OP/SW 68	River Onuebonyi, Ngbo Agbaja	06^{o} 24' 29.43"N	008^{o} 10' 48.74"E	6.68	88.3	157	34.2	27
45	OP/SW 69	Ngele Oru,Igbohuotum	06^{o} 23' 35.4"N	008^{o}10' 40.82"E	4.76	79.8	844	21.6	26
46	OP/SW 70	Mkpuma Akpatakpa mine site (Active)	06^{o} 21' 28.28"N	008^{o} 07' 15.49"E	5.75	850	940	50	28
47	OP/SW 71	Eboyi River, Ngbo agbaja	06^{o} 21' 28.28"N	008^{o} 07' 15.49"E	4.89	78.2	41	17.4	27

Appendix 9b: Values of Physical Constituents of Groundwater Samples Analysed (Dry Season)

S/N	Sample No	Location	Co –odinates		pH	Electrical Conductivity us/cm	Turbidity NTU	TDS mg/l	Temperature (◦C)
			Latitude	Longitude					
1	OP/BH 6	Awumini, Nwofe (borehole)	06^{o} 31' 30"N	008^{o} 09' 4.4"E	6.25	152	849	71.58	28
2	OP/BH 10	Amorie (borehole)	06^{o} 07' 32.08"N	008^{o} 06' 42.6"E	6.47	327	458	53	24
3	OP/BH 14	Oganga (Borehole)	06^{o} 22' 30.9"N	008^{o} 13' 06.9"E	3.12	345	848	43	26
4	OP/BH 24	Ndiabor Ohoke (Borehole)	06^{o} 21' 22.25"N	008^{o} 02' 8. 2"E	5.99	79	61	67.2	26
5	OP/BH 35	Okaria Agbaja, Iboko(borehole)	06^{o} 22' 45.39"N	008^{o}11' 10.63"E	6.03	376	5	1.3	27
6	OP/BH 37	Ndiachi	06^{o} 28' 28.5"N	008^{o} 04' 10.01"E	7.17	257	8	0.8	26
7	OP/BH 41	Okpuitomo, Ikwo (Borehole)	06^{o} 15' 40.5"N	008^{o} 08' 10.2"E	4.72	103	851	4	26
8	OP/BH 42	Ugbodo (Borehole)	06^{o} 3' 39.23"N	008^{o}06" 27.31"E	6.61	98.5	115	28.4	26
9	OP/BH 43	Onyirigbo (Borehole)	06^{o} 30' 46.54"N	008^{o}06' 22.6"E	6.68	88.3	157	34.2	26
10	OP/BH 44	Ndiechi	06^{o} 28' 50.18"N	008^{o}09' 25.74"E	4.78	79.8	844	21.6	26
11	OP/BH 45	Amachara pri. Sch.[Borehole]	06^{o} 32' 09.16"N	008^{o}10' 36.33"E	5.75	850	940	50	27
12	OP/BH 46	ST.Agustus.Nwofe [Borehole]	06^{o} 30' 32.89"N	008^{o}09' 24.01"E	4.87	78.2	41	17.4	27
13	OP/BH 47	Amezekwe [Borehole]	06^{o} 07' 11.38"N	008^{o} 04' 41.26"E	7.09	648	45	4.2	25
14	OP/BH 48	Amegu [Borehole]	06^{o} 06' 48.02"N	008^{o}08' 08.12"E	7.07	543	187	4	26
15	OP/BH 49	Onyikwa [Borehole]	06^{o} 08' 34.18"N	008^{o} 10' 21.08"E	7.03	418	13	3.8	28
16	OP/BH 50	Mbbabo [Borehole]	06^{o} 10' 48.06"N	008^{o} 11' 05.11"E	6.99	420	5	3	27
17	OP/BH 51	Eketabe [Borehole]	06^{o} 12' 52.15"N	008^{o} 10' 12.18"E	7.05	521	47	3.4	25
18	OP/BH 52	Close to Enyigba [Borehole]	06^{o} 12' 06.4" N	008^{o}07' 55.9"E	6.99	587	41	16	28
19	OP/BH 53	Close to enyigba salt lake[Borehole]	06^{o} 10' 58.6"N	008^{o}08' 33.8"E	6.71	357	91	4	29
20	OP/BH 54	Close to general hospital Ameka[Borehole]	06^{o} 10' 07.9"N	008^{o} 06' 51.1"E	6.97	325	52	18	26
21	OP/BH 55	Umuaghara [Borehole]	06^{o} 18' 32.08"N	008^{o} 02' 25.11"E	6.95	419	15	8	28
22	OP/BH 56	Elinwaovu hospital[Borehole]	06^{o} 12' 36.8"N	008^{o} 06' 43.41"E	7.05	605	19	10	26
23	OP/BH 65	Ndiugbaleze [Borehole]	06^{o} 18' 12.06"N	008^{o}10' 08.15"E	6.44	85.4	738	16	26
24	OP/BH 66	ST.Agustus.Nwofe [Borehole]	06^{o} 22' 58"N	008^{o}10' 11.42"E	7.39	457	871	1	28

Appendix 10a: Concentrations of Major Chemical Constituents of Surface Water Samples Analysed (Dry Season)

S/N	Sample No	Place/ Village	Co –odinate		Cl mg/l	SO_4^{-2} mg/l	NO_3 mg/l	CO_3^{2-} mg/l	Fem g/l	Mg mg/l	K mg/l	Na mg/l	Ca mg/l
			Latitude	Longitude									
1	OP/SW 1	Ebonyi River, Ndegualeke	06° 32' 52.1"N	008° 02' 08.6"E	62	64	1.22	517.9	20.5	0	6.314	6.9821	5.7
2	OP/SW 2	Enyigba mine site (Active)	06° 11' 11.2"N	008° 08' 53.1"E	33	73	1.09	136.3	1.06	0	5.867	0	5.4
3	OP/SW 3	Ebonyi River, Umuigwe	06° 27' 40.9"N	008° 06' 41.6"E	57	61	1.13	324.2	15.4	0	6.646	6.1588	9.4
4	OP/SW 4	Ebonyi River Odomoke	06° 29' 31.8"N	008° 02' 14.7"E	14	51	1.1	117.5	0.15	17.678	3.523	6.1038	5.31
5	OP/SW 5	Ebonyi River, Obeagu Ikenyi	06° 22' 38.9" N	008° 011' 30.6"E	30	44	0.33	113.8	0.66	0	6.315	3.4334	5.4
6	OP/SW 7	Iyiokwu River, Abakaliki	06° 18' 48"N	008° 04' 10.6"E	12	1	25	0.17	0.32	45	5.225	4.002	17
7	OP/SW 8	Aguakpu River, Abakaliki	06° 18' 12.5"N	008° 04' 08.8"E	0.67	3.2	36	0.15	0.4	65	2.228	5.432	23
8	OP/SW 9	River Ololo, Mkpuma Akpatakpa	06° 23' 44.9"N	008° 11' 55.4"E	27	78	0.88	181	6.49	0	0	8.1325	0
9	OP/SW 11	Ameka mine site (Active)	06° 09' 48"N	008° 006' 56"E	1950	65	0.37	72.3	0	13.6	2.273	4.4531	0
10	OP/SW 12	Ohamini River, Ohamini	06° 13' 51.1"N	008° 004' 29.45"E	5.92	2.8	0.03	0.04	4.1	57.54	0.894	9.112	48
11	OP/SW 13	Ngele Ocha, Ezza Abia	06° 14' 36.42"N	008° 02' 36.03"E	3	0.1	0.01	0.07	6.43	178.89	5.226	6.054	67
12	OP/SW 15	River Ololo, Okaria Agbaja	06° 24' 29.4"N	008° 10' 48.7"E	47	45	0.11	231.6	0.93	0	3.3	5.6984	4.1
13	OP/SW 16	Ameri Salt lake Enyigba	06° 08' 48"N	008° 05' 56"E	2500	99	0.19	156.6	0.54	41.55	8.611	0	0
14	OP/SW 17	River Ogbogbo Ekebiligwe	06° 33' 08"N	008° 05' 8.34"E	28	56	0.43	69.81	0.14	18.849	4.996	3.4199	0
15	OP/SW 18	Ngele Okoro, Ebonie	06° 25' 06.9"N	008° 003' 29.6"E	95	72	0.22	156.1	11.4	0	7.043	2.6346	0
16	OP/SW 19	Ameka mine site (Abandone)	06° 10' 48"N	008° 008' 2.5"E	45	91	0.39	150.9	1.57	7.7737	5.235	6.0312	0
17	OP/SW 20	Mkpuma Akpatakpa Mine site (Active)	06° 23' 35.04"N	008° 10' 40.8"E	900	45	0.56	147.6	55	26.315	6.362	0.7916	3.22
18	OP/SW 21	Ndiezzagu- Umuaru	06° 13' 25"N	008° 001' 05.28"E	66	23	0.07	62.1	18.3	88.29	2.002	6.58	70
19	OP/SW 22	Amanchara Mine Site (Active)	06° 32' 06"N	008° 007' 01.2"E	165	93	0.98	141.5	0.83	0	6.942	5.0001	3.11
20	OP/SW 23	Enyigba mine site (Active)	06° 11' 57"N	008° 007' 22"E	237	47	0.48	89.62	3.01	36.003	2.842	0	0
21	OP/SW 25	Okpuriwa - Egbu River	06° 11' 05"N	008° 001' 16"E	42	34.2	0.09	67.45	2.09	69.65	4.32	4.004	45
22	OP/SW 26	Enyigba mine site (Active)	06° 09' 54"N	008° 06' 02"E	54	48	0.19	93.46	2.49	0	6.501	4.2408	0
23	OP/SW 27	Ebonyi River Odomoke	06° 31' 31.05"N	008° 05' 14. 02"E	34	45	0.19	100.9	17.1	10.764	6.233	3.5597	2.44
24	OP/SW 28	Onuzu, mine site, Enyigba (Active)	06° 11' 02.9" N	008° 005' 56"E	2400	38	0.14	134	1.38	0	3.654	3.9083	8.33
25	OP/SW 29	Alibaruhu mine site Enyigba(Active)	06° 09' 58''N	008° 005' 27"E	4050	54	0.53	301.9	58.2	26.717	11.82	1.5005	2.43
26	OP/SW 30	Akpara River, Enyigba	06° 11' 28.09"N	008° 007' 49.23"E	2750	42	0.22	194.8	1.79	0	4.352	3.1184	0
27	OP/SW 31	River Oyirigbo, Amanchara	06° 30' 09"N	008° 006' 15.02"E	2500	68	0.29	103.8	0.35	0	5.658	5.7511	0
28	OP/SW 32	River Ebonyi Ngbo Agbaja	06° 22' 21.57"N	008° 009' 08.22"E	33	288.1	11.8	3.808	0	19.557	2.025	0	49.03
29	OP/SW 33	River Abe, Mkpuma	06° 24' 30.16"N	008° 010' 14.13"E	37	366.2	2.05	12.89	0	17.069	3.032	120	33.45
30	OP/SW 34	Obeagu Ikenyi	06° 24' 20.08"N	008° 11' 11.38'E	30	337.4	10.3	13.22	0	3.713	1.822	10.8	0.07
31	OP/SW 36	Ndiabor Ishiagu	06° 21' 05.46"N	008° 11' 23.15"E	45	308.6	9.76	12.95	0	2.945	12.64	96.444	13.6
32	OP/SW 38	Ndioke	06° 2' 731.2"N	008° 01' 48.7"E	48	658.4	2.5	14.67	0	16.635	3.101	107.89	34.78
33	OP/SW 39	Edenyaka	06° 25' 18.5"N	008° 08' 25.2"E	40	288.1	1.58	12.11	0	20.444	4.882	0	41.35
34	OP/SW 40	River Abe, Mkpuma Akpatakpa	06° 24' 21.4" N	008° 08' 56.6"E	45	411.5	3	11.68	1.02	7.663	5.385	0	7.516
35	OP/SW 57	Akpara River, Enyigba	06° 12" 80.4"N	008° 06' 38.7"E	42	288.1	2.5	12.66	0.59	14.942	9.082	73.243	37.49
36	OP/SW 58	Ngele River Enyigba	06° 11' 54.3"N	008° 008' 34.1"E	37	54	2.17	9.787	0	0.024	0.032	0	
37	OP/SW 59	Enyigbe salt Lake	06° 11' 31.2"N	008° 08" 22.1"E	40	246.9	2.65	14.12	0.63	19.23	12.85	48.95	34.95
38	OP/SW 60	Ameka Pond	06° 09' 54.5"N	008° 06' 69.1"E	92	205.8	2.79	11.01	6.78	3.288	15.29	114.91	15.58
39	OP/SW 61	Ameka Stream, Ameka	06° 09' 35"N	008° 006' 30.8"E	55	144	2.3	10.11	0	18.867	15.42	96.437	51.48
40	OP/SW 62	Ebonyi River Ndiechi	06° 18' 10.08"N	008° 0002.3"E	33	246.9	11.1	13.33	0	19.701	4.319	51.748	38.81

41	OP/SW 63	Ekaeru inyimogu	06^{o} 20' 45.01"N	008^{o} 007' 21.12"E	40	304.5	10.5	13	0	19.597	4.775	61.25	191
42	OP/SW 64	Ebonyi R.Obusue	06^{o} 18' 01.05"N	008^{o} 008' 28.06"E	47	312.7	13.2	12.35	15.6	18.774	36.71	100.7	15.88
43	OP/SW 67	River Abe, Mkpuma Akpatakpa	06^{o} 21' 28.28"N	008^{o} 007' 15.49"E	52	329.1	2	10.44	3.12	7.82	8.005	7.4258	28.43
44	OP/SW 68	River Onuebonyi, Ngbo Agbaja	06^{o} 24' 29.43"N	008^{o} 10' 48.74"E	37	292.2	4.11	11.11	1.01	2.079	5.63	5.2207	22.32
45	OP/SW 69	Ngele Oru,Igbohuotum	06^{o} 23' 35.4"N	008^{o} 010' 40.82"E	39	333.3	1.89	12.67	0	1.756	4.601	5.9911	0.013
46	OP/SW 70	Mkpuma Akpatakpa mine site (Active)	06^{o} 21' 28.28"N	008^{o} 07' 15.49"E	2360	510.3	3.46	10.66	7.86	1.259	20.25	5.5752	19.43
47	OP/SW 71	Eboyi River, Ngbo agbaja	06^{o} 21' 28.28"N	008^{o} 07' 15.49"E	47	238.7	1.78	11.78	0	0.321	2.749	7.8315	8.54

Appendix 10b: Concentrations of Major Chemical Constituents of Groundwater Samples Analysed (Dry Season)

S/N	Sample No	Place/ Village	Co –odinate Latitude	 Longitude	Cl mg/l	SO_4^{-2} mg/l	NO_3 mg/l	CO_3^{2-} mg/l	Fe mg/l	Mg mg/l	K mg/l	Na mg/l	Ca mg/l
1	OP/BH 6	Awumini, Nwofe (borehole)	06^o 31' 30"	008^o 09' 4.4"	30	54	1.07	400.5	0	0	4.902	5.3264	4.92
2	OP/BH 10	Amorie (borehole)	06^o 07' 32.08"	008^o 06' 42.6"	204	45	1.07	199.2	0.37	25.619	8.228	1.4442	5.1
3	OP/BH 14	Oganga (Borehole)	06^o 22' 30.9"	008^o 13' 06.9"	2250	84	0.27	236.8	2.78	0	6.105	6.3872	4.2
4	OP/BH 24	Ndiabor Ohoke (Borehole)	06^o 21' 22.25"	008^o 020' 8. 2"	37	22	0.18	89.62	0	18.168	4.317	4.8955	0
5	OP/BH 35	Okaria Agbaja, Iboko(borehole)	06^o 22' 45.39"	008^o 011' 10.63"	36	259.2	10.7	12.02	0	19.172	4.332	0	51.99
6	OP/BH 37	Ndiachi	06^o 28' 28.5"	008^o 04' 10.01"	55	205.8	1.71	11.06	0	19.619	4.126	0	45.22
7	OP/BH 41	Okpuitomo, Ikwo (Borehole)	06^o 15' 40.5"	008^o 08' 10.2"	53	452.7	3.68	12.01	0.08	10.658	5.187	82.317	12.79
8	OP/BH 42	Ugbodo (Borehole)	06^o 3' 39.23"	008^o 006" 27.31"	52	329.1	2.44	10.44	0	19.604	1.505	110.62	32.95
9	OP/BH 43	Onyirigbo (Borehole)	06^o 30' 46.54"	008^o 006' 22.6"	37	292.2	4.11	11.11	0	19.563	1.26	114.91	45.03
10	OP/BH 44	Ndiechi	06^o 28' 50.18"	008^o 009' 25.74"	39	333.3	1.89	12.67	0	19.527	1.378	111.93	37.24
11	OP/BH 45	Amachara pri. Sch.[Borehole]	06^o 32' 09.16"	008^o 010' 36.33"	2360	510.3	3.46	10.66	0	19.338	2.436	103.38	24.38
12	OP/BH 46	ST.Agustus.Nwofe [Borehole]	06^o 30' 32.89"	008^o 009' 24.01"	47	238.7	1.78	11.78	0	20.449	8.542	101.74	8.579
13	OP/BH 47	Amezekwe [Borehole]	06^o 07' 11.38"	008^o 04' 41.26"	55	222.2	2.9	12.43	0	17.521	13.28	82.444	9.884
14	OP/BH 48	Amegu [Borehole]	06^o 06' 48.02"	008^o 008' 08.12"	54	201.6	3.47	11.15	0	17.815	12.43	73.825	19.61
15	OP/BH 49	Onyikwa [Borehole]	06^o 08' 34.18"	0008^o 10' 21.08"	92	185.2	1.81	9.808	0	19.853	3.928	100.1	26.83
16	OP/BH 50	Mbbabo [Borehole]	06^o 10' 48.06"	008^o 11' 05.11"	97	164.6	2.7	11.84	0	20.073	6.573	109.71	26.33
17	OP/BH 51	Eketabe [Borehole]	06^o 12' 52.15"	008^o 101' 12.18"	40	205.8	4.17	12.11	0.02	14.151	9.076	83.117	20.59
18	OP/BH 52	Close to Enyigba [Borehold]	06^o 12' 06.4"	008^o 007' 55.9"	4.5	337.4	2.04	12.65	0	15.167	9.619	81.673	32.71
19	OP/BH 53	Close to enyigba salt lake[Borehold]	06^o 10' 58.6"	008^o 008' 33.8"	4.7	930	1.86	10.79	0	3.124	73.85	10.682	26.58
20	OP/BH 54	Close to general hospital Ameka[Borehold]	06^o 10' 07.9"	008^o 06' 51.1"	3.7	703.7	2.65	9.919	0	19.404	4.437	115.85	191
21	OP/BH 55	Umuaghara [Borehole]	06^o 18' 32.08"	008^o 02' 25.11"	3.6	662.5	2.39	11.64	0	19.571	12.23	102.76	43.94
22	OP/BH 56	Elinwaovu hospital[Borehold]	06^o 12' 36.8"	008^o 06' 43.41"	3.7	78.19	1.97	12	0	9.69	16.6	84.953	15.63
23	OP/BH 65	Ndiugbaleze [Borehold]	06^o 18' 12.06"	008^o 010' 08.15"	32	267.5	12	3.991	2.23	6.116	32.54	54.187	9.017
24	OP/BH 66	ST.Agustus.Nwofe [Borehold]	06^o 22' 58"	008^o 010' 11.42"	38	242.8	10.1	12.62	0	20.582	5.771	50.791	191

Appendix 11a: Concentration of Minor Chemical Constituent in Surface Water (Dry season)

S/N	Sample No	Place/ Village	Co –odinate Latitude	Longitude	Pb (mg/l)	Cu (mg/l)	Cr (mg/l)	Ni (mg/l)	Mn (mg/l)	Cd (mg/l)	Ag (mg/l)	Co (mg/l)	Hg (mg/l)	As (mg/l)	Se (mg/l)	Al (mg/l)	Zn (mg/l)
1	OP/SW 1	Ebonyi River, Ndegualeke	06^{o} 32' 52.1"	008^{o} 02' 08.6"	0	0.012	0	0.01	3.047	0.056	0.715	0.04	0	1.11	0	0	0
2	OP/SW 2	Enyigba mine site (Active)	06^{o} 11' 11.2"	008^{o} 08' 53.1"	0.02	0.009	0	0	1.043	0.046	0.358	0.05	0	0	0	0	0
3	OP/SW 3	Ebonyi River, Umuigwe	06^{o} 27' 40.9"	008^{o} 06' 41.6"	0	0	0	0.02	4.362	0.002	0.271	0.01	0	0	0	0	0
4	OP/SW 4	Ebonyi River Odomoke	06^{o} 29' 31.8"	008^{o} 02' 14.7"'	0.02	0	0	0	0	0	0.706	0	0	0.88	0	0	0
5	OP/SW 5	Ebonyi River, Obeagu Ikenyi	06^{o} 22' 38.9"	008^{o} 011' 30.6"	0	0	0	0	0	0	0.303	0	0	0	0.0001	0.01	9.9844
6	OP/SW 7	Iyiokwu River, Abakaliki	06^{o} 18' 48"	008^{o} 04' 10.6"	0	0	0.02	0.02	0.06	0	0	0.05	0	0	0	0	0.2698
7	OP/SW 8	Aguakpu River, Abakaliki	06^{o} 18' 12.5"	008^{o} 04' 08.8"	0	0.003	0.04	0	0.02	0	0	0.06	1.002	0	0	0	0.03
8	OP/SW 9	River Ololo, Mkpuma Akpatakpa	06^{o} 23' 44.9"	008^{o} 11' 55.4"	4	0.016	0.17	0.01	7.674	0	0.352	0	2.6	0	0	0	0.0625
9	OP/SW 11	Ameka mine site (Active)	06^{o} 09' 48"	008^{o} 006' 56"	0	0	0	0	0.004	0	0.424	0	1.1	1.22	0	0	0
10	OP/SW 12	Ohamini River, Ohamini	06^{o} 13' 51.1"	008^{o} 004' 29.45"	0	0	0	0	4.09	0	0	0.01	0.001	0.52	0	0	1.01
11	OP/SW 13	Ngele Ocha, Ezza Abia	06^{o} 14' 36.42"	008^{o} 02' 36.03"	0.09	0	0	0	3.08	0	0	0.9	0.98	0	0.001	0	5.003
12	OP/SW 15	River Ololo, Okaria Agbaja	06^{o} 24' 29.4"	008^{o} 10' 48.7"	0.52	0	0	0	1.286	0	0.241	0	2	0	0	0	0
13	OP/SW 16	Ameri Salt lake Enyigba	06^{o} 08' 48"	008^{o} 05' 56"	0.69	0.004	0.2	0.06	31.39	0	1.252	0.02	0.8	0	0	0	5.8891
14	OP/SW 17	River Ogbogbo Ekebiligwe	06^{o} 33' 08"	008^{o} 05' 8.34"	0	0	0.11	0.02	0	0	2.549	0	0	0.11	0.002	0	0
15	OP/SW 18	Ngele Okoro, Ebonie	06^{o} 25' 06.9"	008^{o} 003' 29.6"	0.89	0	0	0	1.701	0	6.056	0	0.3	0.28	0	0	0
16	OP/SW 19	Ameka mine site (Abandone)	06^{o} 10' 48"	008^{o} 008' 2.5"	1.73	0	0	0.06	29.44	12.05	0.294	0.02	0.4	0	0	0	10.07
17	OP/SW 20	Mkpuma Akpatakpa Mine site (Active)	06^{o} 23' 35.04"	008^{o} 10' 40.8"	5.42	0.065	0	0.16	45.13	10.62	0.464	0.21	0.3	0.79	0.006	0	10.531
18	OP/SW 21	Ndiezzagu- Umuaru	06^{o} 13' 25"	008^{o} 001' 05.28"	0.05	0	0	0.12	2.054	0.12	0.01	0.17	0.6	0	0	0	0
19	OP/SW 22	Amanchara Mine Site (Active)	06^{o} 32' 06"	008^{o} 007' 01.2"	1.15	0.03	0	0	1.258	0.014	0.286	0	0.8	0	0	0	0.9696
20	OP/SW 23	Enyigba mine site	06^{o} 11' 57"	008^{o} 007' 22"	0.6	0.045	0	0	23.24	0	0.793	0.01	0	0.91	0	0	2.0926

		(Active)															
21	OP/SW 25	Okpuriwa - Egbu River	06^{o} 11' 05"	008^{o} 001' 16"	0.01	0.001	0	0	0.2	0	0.17	0	0	0	0	0	0.14
22	OP/SW 26	Enyigba mine site (Active)	06^{o} 09' 54"	008^{o} 06' 02"	2.08	0	14.6	0	0.398	0	0.252	0	0	0.63	0	0	0.2072
23	OP/SW 27	Ebonyi River Odomoke	06^{o} 31' 31.05"	008^{o} 05' 14. 02"	6.14	0.341	0	0.02	16.67	4.054	0.533	0.04	0.8	0.1	0.005	0	10.239
24	OP/SW 28	Onuzu, mine site, Enyigba (Active)	06^{o} 11' 02.9"	008^{o} 005' 56"	0.12	0.026	0	0	1.248	0	0.343	0	0.6	0.98	0	0	0.2355
25	OP/SW 29	Alibaruhu mine site Enyigba(Active)	06^{o} 09' 58'	008^{o} 005' 27"	5.06	0.102	0	0	23.44	0	0.779	0.02	0	0	0	0	1.4804
26	OP/SW 30	Akpara River, Enyigba	06^{o} 11' 28.09"	008^{o} 007' 49.23"	0.59	0.012	0	0	1.651	0.035	2.022	0	1.5	0	0.009	0	0.2365
27	OP/SW 31	River Oyirigbo, Amanchara	06^{o} 30' 09"	008^{o} 006' 15.02"	0.08	0.043	0	0	8.814	0.034	0.35	0	0.2	0	0	0	0.9315
28	OP/SW 32	River Ebonyi Ngbo Agbaja	06^{o} 22' 21.57"	008^{o} 009' 08.22"	2.03	0	0	0	2.5	0.172	0	0.22	0.244	2.98	0.2608	0.03	0.386
29	OP/SW 33	River Abe, Mkpuma	06^{o} 24' 30.16"	008^{o} 010' 14.13"	2.83	0	0	0	0	0.314	0	0.12	0.15	0.26	0.2695	0.083	0.399
30	OP/SW 34	Obeagu Ikenyi	06^{o} 24' 20.08"	008^{o} 11' 11.38'	2	0	0	0.02	0	0.127	0	0.29	0.284	1.54	0.8184	0.002	0.03
31	OP/SW 36	Ndiabor Ishiagu	06^{o} 21' 05.46"	008^{o} 11' 23.15"	2.63	0	0	0	0	0.274	0	0.24	0.219	3	0.1698	0.009	0.228
32	OP/SW 38	Ndioke	06^{o} 2' 731.2"	008^{o} 01' 48.7"	3	0.026	0	0	0	0.086	0	0.19	0.166	3.55	0.1863	0.005	0.012
33	OP/SW 39	Edenyaka	06^{o} 25' 18.5"	008^{o} 08' 25.2"	2.87	0.039	0	0	0.115	0.323	0	0.07	0.118	4.13	0.1973	0.04	0.05
34	OP/SW 40	River Abe, Mkpuma Akpatakpa	06^{o} 24' 21.4"	008^{o} 08' 56.6"	3.26	0.078	0	0	2.729	0.194	0	0.18	0.082	2.68	0.1158	0.006	0.678
35	OP/SW 57	Akpara River, Enyigba	06^{o} 12" 80.4"	008^{o} 06' 38.7"	0	0.028	0.8	0.06	0.221	1.459	0.132	0.17	0.481	2.25	0.4572	0	0.032
36	OP/SW 58	Ngele River Enyigba	06^{o} 11' 54.3"	008^{o} 008' 34.1"	0.44	0.027	0.24	0.11	0.3	0.736	0	0.15	0.188	2.47	0.1092	0.065	0.034
37	OP/SW 59	Enyigbe salt Lake	06^{o} 11' 31.2"	008^{o} 08" 22.1"	2.73	0	0.02	0	2.059	0.618	0	0	0.101	2.64	0.8949	0.001	0.47
38	OP/SW 60	Ameka Pond	06^{o} 09' 54.5"	008^{o} 06' 69.1"	0.91	0	0.89	0	0.062	0.359	0	0	0.212	2.64	0.8488	0.002	0.228
39	OP/SW 61	Ameka Stream, Ameka	06^{o} 09' 35"	008^{o} 006' 30.8"	1.29	0	0	0.15	10.97	2.17	0	0	0.315	0.76	0.3209	0.007	9.885
40	OP/SW 62	Ebonyi River Ndiechi	06^{o} 18' 10.08"	008^{o} 0002.3"	0.81	0	0.02	0.09	0	0.357	0	0.01	0.354	1.98	0.7516	0.001	0
41	OP/SW 63	Ekaeru inyimogu	06^{o} 20' 45.01"	008^{o} 007' 21.12"	1.31	0.059	0	0.22	0.117	0.281	0	0.15	0.244	2.06	0.4788	0	0.111
42	OP/SW 64	Ebonyi R.Obusue	06^{o} 18' 01.05"	008^{o} 008' 28.06"	2.14	0	0	0	13.49	0.262	0	0.05	0.354	2.71	0.9841	0	0.455
43	OP/SW 67	River Abe, Mkpuma Akpatakpa	06^{o} 22' 58"	008^{o} 010' 11.42"	3.56	0.048	0	0.13	0.053	0.019	0.303	0	1.506	0.93	1.154	0.002	0.007
44	OP/SW 68	River Onuebonyi, Ngbo Agbaja	06^{o} 21' 28.28"	008^{o} 007' 15.49"	3.96	0.034	0	0.14	3.293	0.011	0.229	0	2.012	0.88	1.86	0.001	0.03
45	OP/SW 69	Ngele Oru,Igbohuotum	06^{o} 24' 29.43"	008^{o} 10' 48.74"	4.13	0.087	0	0.21	0.223	0.013	0.024	0.02	2.229	0.53	0.432	0	0.007
46	OP/SW 70	Mkpuma Akpatakpa mine site (Active)	06^{o} 23' 35.4"	008^{o} 010' 40.82"	11.4	0.082	0	0.06	40.44	0.037	0.215	0	2.347	0.67	1.22	0.01	0.011
47	OP/SW 71	Eboyi River, Ngbo agbaja	06^{o} 21' 28.28"	008^{o} 07' 15.49"	4.18	0.121	0	0.76	2.712	15.67	0.3	0	1.805	0.18	2.33	0.008	0.014

Appendix 11b: Concentration of Minor Chemical Constituents of Groundwater Samples Analysed (Dry Season)

S/N	Sample No	Location	Co –odinates		Pb mg/l	Cu mg/l	Cr mg/l	Ni mg/l	Mn mg/l	Cd mg/l	Ag mg/l	Co mg/l	Hg mg/l	As mg/l	Se mg/l	Al mg/l	Zn
			Latitude	Longitude													
1	OP/BH 6	Awumini, Nwofe (borehole)	06° 31' 30"N	008° 09' 4.4"E	0.04	0	0	0	2.901	0	0.354	0.01	2.3	0	0	0	0
2	OP/BH 10	Amorie (borehole)	06° 07' 32.08"N	008° 06' 42.6"E	0	0	0	0	9.914	0.061	0.243	0.01	1.9	1.88	0.0005	0.0001	0
3	OP/BH 14	Oganga (Borehole)	06° 22' 30.9"N	008° 13' 06.9"E	4.29	0	0	0	4.576	0	0.253	0	0.7	0	0	0	0
4	OP/BH 24	Ndiabor Ohoke (Borehole)	06° 21' 22.25"N	008° 020' 8. 2"E	0	0	0	0	12.1	0	0.191	0	0	0	0	0	0.157
5	OP/BH 35	Okaria Agbaja, Iboko(borehole)	06° 22' 45.39"N	008° 011' 10.63"E	3.2	0	0	0	1.134	0.238	0.04	0.01	0.15	4.01	1.2505	0	1.72
6	OP/BH 37	Ndiachi	06° 28' 28.5"N	008° 04' 10.01"E	2	0.002	0	0	0	0.305	0	0.17	0.071	3.739	1.2314	0	0.086
7	OP/BH 41	Okpuitomo, Ikwo (Borehole)	06° 15' 40.5"N	008° 08' 10.2"E	4.19	0.158	0	0.17	2.149	0.115	0	0.21	0.175	3	1.0429	0	0.774
8	OP/BH 42	Ugbodo (Borehole)	06° 3' 39.23"N	008° 006" 27.31"E	2.73	0.028	0	0	0	0.374	0	0.17	0.372	1.61	2.0	0	0
9	OP/BH 43	Onyirigbo (Borehole)	06° 30' 46.54"N	008° 006' 22.6"E	2.77	0	0	0	0	0.264	0	0	0.223	3.48	2.1391	0	0.036
10	OP/BH 44	Ndiechi	06° 28' 50.18"N	008° 009' 25.74"E	2.26	0	0	0.09	0	0.278	0	0.21	0.372	2.73	2.6608	0	0
11	OP/BH 45	Amachara pri. Sch.[Borehole]	06° 32' 09.16"N	008° 010' 36.33"E	2.43	0.008	0	0.08	0	0.433	0	0.24	0.363	2.86	2.6782	0	0
12	OP/BH 46	ST.Agustus.Nwofe [Borehole]	06° 30' 32.89"N	008° 009' 24.01"E	2.76	0.022	0	0.06	0	0.447	0	0.06	0.249	2.94	2.4869	0	0
13	OP/BH 47	Amezekwe [Borehole]	06° 07' 11.38"N	008° 04' 41.26"E	1.88	0.051	0	0	0	0.382	0	0.22	0.445	1.79	0.8232	0	0
14	OP/BH 48	Amegu [Borehole]	06° 06' 48.02"N	008° 008' 08.12"E	1.66	0.032	0.09	0	0	0.509	0	0.18	0.384	2.36	0.8258	0	0
15	OP/BH 49	Onyikwa [Borehole]	06° 08' 34.18"N	0008° 10' 21.08"E	1.87	0.054	0	0.05	0	0.164	0	0	0.395	2.02	1.3095	0	0.038
16	OP/BH 50	Mbbabo [Borehole]	06° 10' 48.06"N	008° 11' 05.11"E	2.76	0.002	0	0.07	0	0.318	0	0.05	0.334	1.11	0.9729	0	0.107
17	OP/BH 51	Eketabe [Borehole]	06° 12' 52.15"N	008° 101' 12.18"E	2.63	0.018	0	0	0.002	0.343	0	0.08	0.383	2.26	1.2503	0	0.021
18	OP/BH 52	Close to Enyigba [Borehole]	06° 12' 06.4" N	008° 007' 55.9"E	1.76	0	0	0.26	0.093	0.353	0	0	0.294	1.94	0.7091	0	0
19	OP/BH 53	Close to enyigba salt lake[Borehole]	06° 10' 58.6"N	008° 008' 33.8"E	0.95	0	0	0.04	0.066	0.144	0	0	0.48	0.43	0.795	0	0.002
20	OP/BH 54	Close to general hospital Ameka[Borehole]	06° 10' 07.9"N	008° 06' 51.1"E	2.33	0	0	0	0.135	0.088	0	0.14	0.396	2.93	0.2999	0	0
21	OP/BH 55	Umuaghara [Borehole]	06° 18' 32.08"N	008° 02' 25.11"E	1.93	0	0	0	0	0.378	0	0.13	0.448	2.9	0.4166	0	0
22	OP/BH 56	Elinwaovu hospital[Borehole]	06° 12' 36.8"N	008° 06' 43.41"E	2.08	0.067	0	0	0	0.245	0	0.05	0.437	2.53	0.5103	0	0
23	OP/BH 65	Ndiugbaleze [Borehole]	06° 18' 12.06"N	008° 010' 08.15"E	1.97	0	0	0.04	0.591	0.272	0	0.07	0.392	1.97	0.5437	0	0.18
24	OP/BH/66	ST.Agustus.Nwofe [Borehole]	06° 22' 58"N	008° 010' 11.42"E	3.8	2.428	10.1	1.26	0	0	2.058	0.58	0.791	1.91	0	0	0

Appendix 12a: Values of Physical Parameters of Surface Water Samples Analysed (Rainy Season)

S/N	Sample No	Location	LATITUDE LONGITUDE	pH	Temperature (ºC)	Turbidity (NTU)	Conductivity µs/cm	TDS (mg/l)
1	OP/SW1	River Ikenyi	N060 201 57.811 E080 091 11.211	10.68	21	33.1	14.37	8.45
2	OP/SW2	Ebonyi River	N06 021 24.511E080 081 11.611	6.31	19	30.2	12.64	9.28
3	OP/SW3	Mine Site Mkpuma Akpatakpa	N060 231 34.511E080 091 45.211	4.89	24	26.1	16.86	13.67
4	OP/SW4	River Ololo Mkpuma	N06 0241 27.311E080 091 24.711	5.38	20	6.5	22.26	19.22
5	OP/SW5	Ekerigate	N060 251 14.5111E080 111 05.411	5.74	18.6	18.2	25.66	19.53
6	OP/SW6	Enyigba Lake	N06 0111 30.011E080 081 21.811	10.41	19	17	14.3	19.7
7	OP/SW7	Ameka	N060 091 27.511E080 06 122.011	5.59	21	9	12.9	20.16
8	OP/SW8	Amorie Mine	N060 101 06.311E080 081 32.011	5.7	22	3	10.8	33.74
9	OP/SW9	Ameri River	N06 0101 51.011E080 071 25.711	5.74	17	14	11.4	19.75
10	OP/SW10	Ameka mine	N060 091 39.311E080 061 22.611	5.82	17.9	9	9.8	15.63
11	OP/SW11	Ebonyi River, Ndegualeke	N06 0 321 52.111E080 021 08.611	6.8	18	26	12.81	10.41
12	OP/SW12	Ebonyi River,Umuigwe	N060 271 40.911E080 061 41.611	7.36	19.5	31.2	13.62	11.44
13	OP/SW13	Ebonyi River, Odomoke	N06 0291 31.811E080 021 14.711	7.06	18	28.6	15.01	2.61
14	OP/SW14	Ebonyi River, Enyibichiri	N060 22138.911E08 0041 30.611	8.01	17.8	20.11	20.83	1.95
15	OP/SW15	Iyiokwu River, Abakaliki	N060 181 4811E080 041 10.611	6.85	18	6.05	13.58	27.16
16	OP/SW16	Igiokwu River, Abakaliki	N060 171 12.511E080 041 08.811	7.92	19	8.99	12.44	21.84
17	OP/SW17	Ngele Okoro, Ebonie	N060 251 06.911E080 031 29.611	8.16	17.3	4.01	9.88	18.99
18	OP/SW18	River Oyirigbo, Amanchara	N060 331 0911E080 061 15.0211	6.5	18	6.28	16.26	6.44
19	OP/SW19	River Abe, Mkpuma Akpatakpa	N060241 21.411E08008 156.611	5.92	18	25.1	11.56	12.48
20	OP/SW20	Akpara River, Enyigba	N6026 180.411E080 051 38.711	6.67	20	18.01	10.12	10.14

Appendix 12b: Values of Physical Parameters of Groundwater Samples Analysed (Rainy Season)

Water S/N	Sample No	Location	LATITUDE LONGITUDE	pH	Temperature (ºC)	Turbidity (NTU)	Conductivity µs/cm	TDS (mgLl)
1	OP/BH1	Mkpuma Akpatakpa Pri. Sch.	N06^0 23^1 02.9^{11}E08^0 09^1 41.1^{11}	5.81	25	38.2	24.78	15.54
2	OP/BH2	Mkpuma Akpatakpa.	N06 ^{0}24^{1}22.1^{11}E08^0 10^1 17.6^{11}	5.81	23	8.7	21.56	21.85
3	OP/BH3	Umuagharu	N06^0 18^1 48.3^{11}E08^0 01^1 21.2^{11}	5.27	22.8	3.5	20.17	12.22
4	OP/BH4	Igbuhuotum Square	N06^0 24^1 59.5^{11}E08^0 11^1 20.4^{11}	6.18	23	3.9	28.26	11.87
5	OP/BH5	Comm. Sch. Igbuhuotum	N06^0 25^1 20^{11}E08^0 08^1 59.6^{11}	4.65	22	24.3	12.23	20.28
6	OP/BH6	Elinwovu Hospital	N06 ^{0}12^1 36.8^{11}E08^0 06^1 43.2^{11}	6.08	18.9	40	15.51	17.4
7	OP/BH7	Olua Enyigba	N6012106.6 E08^0 07^1 55.9^{11}	6.31	20.3	5	12.23	12.5
8	OP/BH8	Ndufu-Alike Ikwo	N06^0 09^1 22.1^{11}E08^0 07^1 58.6^{11}	10.63	19	4	22.56	22.3
9	OP/BH9	Alibaruhu	N06^0 10^1 58.4^{11}E08^0 08^1 33.8^{11}	6.19	21	12	22.72	18.76
10	OP/BH10	Ishiagu Pri. Sch.	N06^0 11^1 32.8^{11}E08^0 07^1 58.8^{11}	5.93	24	5	13.65	19.82
11	OP/BH11	Mechanic site, Ai	N06^0 18^1 41.7^{11}E08^0 07^1 46.1^{11}	7.21	20	0.01	17.44	0.44
12	OP/BH12	Ekaeru Inyimagu	N06^0 19^1 43.1^{11}N08^0 08^1 42.5^{11}	7.2	21	0.01	12.65	0.76
13	OP/BH13	Nwagu	E06^0 18^1 50.9^{11}N08^0 06^1 32.4^{11}	3.85	19	0.01	10.16	1.62
14	OP/BH14	22,Nsukka str	E06^0 18^1 42.6^{11}N08^0 06^1 21.1^{11}	5.27	17.8	0.01	11.67	0.42
15	OP/BH15	Inyimagu Ebonyi	E06^0 20^1 15.7^{11}N08^0 07 ^{1}52.3^{11}	6.5	18.2	0.07	11.92	1.8
16	OP/BH16	Awumini, Nwofe	N06^0 31^1 30.2^{11}E08^0 09^1 4.4^{11}	7.65	20	2.05	10.62	11.3
17	OP/BH17	Ogbaga	N06^0 22^{1}30.9^{11}E08^0 06^1 06.9^{11}	8.01	18	18.91	26.92	0.361
18	OP/BH18	Obeagu Ezza Olu	N06^0 28^1 29.5^{11}E8^{0}04^{1}11^{11}	5.95	23	9	16.26	11.92
19	OP/BH19	St. Augustine, Nwofe	N06^0 30^1 32.9^{11}E08^{0}09^{1}24^{11}	7.28	20	12.18	26.81	13.62
20	OP/BH20	Ndi Ngbaleze	N06^0 18^1 12.06^{11}E08^{0}10^{1}08.2^{11}	7.06	22	13.19	12.96	14.81

Appendix 13a: Concentration of Major Chemical Constituents of Surface Water Samples Analysed (Rainy Season)

Water S/N	Sample No	Location	Latitude and Longitude	Cl$^-$ mg/l	NO$_3^-$ mg/l	SO$_4^-$ mg/l	CO$_3^-$ mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Fe mg/l
1	OP/SW1	River Ikenyi	N06^0 20^1 57.8^{11}E08^0 09^1 11.2^{11}	181	5.914	6.58	82	3.653	0	8.888	0.34	6.044
2	OP/SW2	Ebonyi River	N06 ^{0}21^1 24.5^{11}E08^0 08^1 11.6^{11}	262	5.487	18.92	74	10.72	0	7.887	0.229	2.841
3	OP/SW3	Mine Site Mkpuma Akpatakpa	N06^0 23^1 34.5^{11}E08^0 09^1 45.2^{11}	267	5.081	35.38	126	51.281	10.589	11.902	7.703	1.551
4	OP/SW4	River Ololo Mkpuma	N06 ^{0}24^1 27.3^{11}E08^0 09^1 24.7^{11}	265	5.569	13.57	172	3.794	0	8.704	0.273	2.866
5	OP/SW5	Ekerigate	N06^0 25^1 14.51^{11}E08^0 11^1 05.4^{11}	16.5	5.02	16.46	5	4.017	0	8.691	0.296	4.044
6	OP/SW6	Enyigba Lake	N06 ^{0}11^1 30.0^{11}E08^0 08^1 21.8^{11}	173	6.178	19.34	134	2.385	0	3.934	0.421	2.464
7	OP/SW7	Ameka	N06^0 09^1 27.5^{11}E08^0 06 ^{1}22.0^{11}	175	70	4.532	70	7.45	0.995	4.371	0.025	31.578
8	OP/SW8	Amorie Mine	N06^0 11^1 06.3^{11}E08^0 08^1 32.0^{11}	444	62	6.077	62	49.978	10.692	8.027	2.308	1.197
9	OP/SW9	Ameri River	N06 ^{0}10^1 51.0^{11}E08^0 08^1 25.7^{11}	214	11.4	4.654	114	7.166	0	8.865	0	9.706
10	OP/SW10	Ameka mine	N06^0 09^1 39.3^{11}E08^0 06^1 22.6^{11}	230	72	5.853	72	9.221	0	9.091	0	2.232
11	OP/SW11	Ebonyi River, Ndegualeke	N06 ^{0} 32^1 52.1^{11}E08^0 02^1 08.6^{11}	120	4.184	10.12	168	3.461	10.41	5.512	1.12	0.004
12	OP/SW12	Ebonyi River,Umuigwe	N06^0 27^1 40.9^{11}E08^0 06^1 41.6^{11}	182	5.621	2.106	241	27.28	8.125	6.081	1.211	0.271
13	OP/SW13	Ebonyi River, Odomoke	N06 ^{0}29^1 31.8^{11}E08^0 02^1 14.7^{11}	156	4.266	4.226	301	38.411	5.101	11.111	0.181	0.071
14	OP/SW14	Ebonyi River, Enyibichiri	N06^0 22^{1}38.9^{11}E08 ^{0}04^1 30.6^{11}	140	5.921	9.26	292	40.29	4	6.008	2.108	0.126
15	OP/SW15	Iyiokwu River, Abakaliki	N06^0 18^1 48^{11}E08^0 04^1 10.6^{11}	236	64	30.14	210	21.4	9.921	9.129	0	6.225
16	OP/SW16	Igiokwu River, Abakaliki	N06^0 17^1 12.5^{11}E08^0 04^1 08.8^{11}	74	81	5.34	248	10.41	3.363	4.331	0.168	0.518
17	OP/SW17	Ngele Okoro, Ebonie	N06^0 25^1 06.9^{11}E08^0 03^1 29.6^{11}	182	4.32	8.112	141	2.61	1.002	6.616	0	0.515
18	OP/SW18	River Oyirigbo, Amanchara	N06^0 33^1 09^{11}E08^0 06^1 15.02^{11}	109	6.101	10.26	121	5.212	0.06	5.012	0.129	0.771
19	OP/SW19	River Abe, Mkpuma Akpatakpa	N06^{0}24^1 21.4^{11}E08^{0}08 ^{1}56.6^{11}	218	5.44	13.58	276	6.822	0.067	7.171	2.301	5.28
20	OP/SW20	Ebonyi River Agubuta.	N6^{0}26 ^{1}80.4^{11}E08^0 05^1 38.7^{11}	36	3.81	6.18	142	4.701	0.545	4.661	0.011	4.99

Appendix 13b: Concentration of Major Chemical Constituents of GroundwaterSamples Analysed (Rainy Season)

Water S/N	Sample No	Location	Latitude/ Longitude	Cl^{-} mg/l	NO$_3^{-}$mg/l	SO$_4^{-}$ mg/l	CO$_3^{-}$ mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Fe mg/l
1	OP/BH1	Mkpuma Akpatakpa Pri. Sch.	N06^{0} 23^{1} 02.9^{11} E08^{0} 09^{1} 41.1^{11}	229	5.243	8.64	306	51.029	8.392	7.57	5.826	0.682
2	OP/BH2	Mkpuma Akpatakpa.	N06 ^{0}24^{1} 22.1^{11} E08^{0} 10^{1} 17.6^{11}	202	5.925	30.86	306	41.632	5.954	7.195	0.019	4.003
3	OP/BH3	Umuagharu	N06^{0} 18^{1} 48.3^{11} E08^{0} 01^{1} 21.2^{11}	17.3	4.817	9.46	202	33.118	2.814	6.07	1.919	11.658
4	OP/BH4	Igbuhuotum Square	N06^{0} 24^{1} 59.5^{11} E08^{0} 11^{1} 20.4^{11}	26.1	5.569	25.51	442	33.797	0	5.894	0.003	0.606
5	OP/BH5	Comm. Sch. Igbuhuotum	N06^{0} 25^{1} 20^{11} E08^{0} 08^{1} 59.6^{11}	24	2.743	16.04	72	4.99	0	8.351	0	3.754
6	OP/BH6	Elinwovu Hospital	N06 ^{0}12^{1} 36.8^{11} E08^{0} 06^{1} 43.2^{11}	155	6.077	14.4	62	28.54	1.683	8.951	1.003	5.457
7	OP/BH7	Olua Enyigba	N6012106.6 E08^{0} 07^{1} 55.9^{11}	15.8	5.691	30.86	152	26.424	0	6.525	1.138	20.46
8	OP/BH8	Ndufu-Alike Ikwo	N06^{0} 09^{1} 22.1^{11} E08^{0} 07^{1} 58.6^{11}	214	5	16.87	72	51.058	8.865	5.623	16.784	1.483
9	OP/BH9	Alibaruhu	N06^{0} 10^{1} 58.4^{11} E08^{0} 08^{1} 33.8^{11}	181	4.39	23.45	130	46.561	6.756	8.58	7.169	3.118
10	OP/BH10	Ishiagu Pri. Sch.	N06^{0} 11^{1} 32.8^{11} E08^{0} 07^{1} 58.8^{11}	145	6.422	12.75	110	49.553	8.004	8.267	7.3	4.358
11	OP/BH11	Mechanic site, Ai	N06^{0} 18^{1} 41.7^{11} E08^{0} 07^{1} 46.1^{11}	202	5.73	174.5	28	51.83	9.676	8	3.002	0.512
12	OP/BH12	Ekaeru Inyimagu	N06^{0} 19^{1} 43.1^{11} E08^{0} 08^{1} 42.5^{11}	119	5.06	26.3	236	29.36	8.832	1.178	0.197	0.731
13	OP/BH13	Nwagu	N06^{0} 18^{1} 50.9^{11} E08^{0} 06^{1} 32.4^{11}	171	5.08	2.1	72	5.243	1.643	9.425	1.188	0
14	OP/BH14	22,Nsukka str	N06^{0} 18^{1} 42.6^{11} E08^{0} 06^{1} 21.1^{11}	385	6.08	27.2	176	19.29	7.048	6.306	21.448	0.265
15	OP/BH15	Inyimagu Ebonyi	N06^{0} 20^{1} 15.7^{11} E08^{0} 07 ^{1}52.3^{11}	274	4.45	96.9	66	41.03	0.125	5.521	6.067	0.004
16	OP/BH16	Awumini, Nwofe	N06^{0} 31^{1} 30.2^{11} E08^{0} 09^{1} 4.4^{11}	62	3.26	4.92	216	26.14	6.001	4.011	0	0.926
17	OP/BH17	Ogbaga	N06^{0} 22^{1}30.9^{11} E08^{0} 06^{1} 06.9^{11}	78	4.16	8.14	182	5.62	8.261	6.821	1.06	0.261
18	OP/BH18	Obeagu Ezza Olu	N06^{0} 28^{1} 29.5^{11} E8^{0}04^{1}11^{11}	101	2.006	6.78	109	6.81	9.206	9.222	6.001	0.881
19	OP/BH19	St. Augustine, Nwofe	N06^{0} 30^{1} 32.9^{11} E8^{0}09^{1}24^{11}	211	3.92	14.05	312	13.46	10.281	10.001	0.002	0.991
20	OP/BH20	Ndi Ngbaleze	N06^{0} 18^{1} 12.06^{11} E8^{0}10^{1}08.2^{11}	36	5.012	6.08	172	16.01	12.441	6.06	1.02	0.001

Appendix 14a: Concentration of Minor Chemical Constituents of Surface Water Samples Analysed(Rainy Season)

S/N	SAMPLE NO	Location	Latitude/ LONGITUDE	Se mg/l	Al mg/l	As mg/l	Mn mg/l	Ag mg/l	Cu mg/l	Hg mg/l	Pb mg/l	Zn mg/l	Co mg/l	Ni mg/l	Cd mg/l	Cr mg/l
1	OP/SW1	River Ikenyi	N06^{0} 20^{1} 57.8^{11} E08^{0} 09^{1} 11.2^{11}	0	0.074	0.388	0.104	1.627	0.028	0	0	0	0	0.002	0.078	0.095
2	OP/SW2	Ebonyi River	N06 ^{0}21^{1} 24.5^{11} E08^{0} 08^{1} 11.6^{11}	0	0.059	0.361	0.042	1.599	0.044	0	0	0	0	0.017	0.062	0.021
3	OP/SW3	Mine Site Mkpuma Akpatakpa	N06^{0} 23^{1} 34.5^{11} E08^{0} 09^{1} 45.2^{11}	0	0.017	0.785	63.45	0.104	0.121	1.009	4.01	10.4	0.549	0.018	12.641	0.14
4	OP/SW4	River Ololo Mkpuma	N06 ^{0}24^{1} 27.3^{11} E08^{0} 09^{1} 24.7^{11}	0	0.057	0.29	0.243	0.009	0.25	0.504	0	0.17	0.104	0.026	0.145	0.099
5	OP/SW5	Ekerigwe	N06^{0} 25^{1} 14.51^{11} E08^{0} 11^{1} 05.4^{11}	0	0.075	0.374	0.131	0	0.033	0	0	0	0	0.022	0.142	0.181
6	OP/SW6	Enyigba Lake	N06 ^{0}11^{1} 30.0^{11} E08^{0} 08^{1} 21.8^{11}	0	0.039	0	0.981	0,023	0.012	0	0.292	0	0.047	0	0.055	0.057
7	OP/SW7	Ameka	N06^{0} 09^{1} 27.5^{11} E08^{0} 06 ^{1}22.0^{11}	0	0.026	0	6.936	0	0	0	0	0.16	0	0	0.047	0
8	OP/SW8	Amorie Mine	N06^{0} 10^{1} 06.3^{11} E08^{0} 08^{1} 32.0^{11}	0	0.017	0.398	32.891	0	0.011	0	0	0.01	0.012	0.021	0.039	0.061
9	OP/SW9	Ameri River	N06 ^{0}10^{1} 51.0^{11} E08^{0} 07^{1} 25.7^{11}	0	0.06	0.229	0.973	0	0.026	0	0	0	0.105	0.027	0.098	0
10	OP/SW10	Ameka mine	N06^{0} 09^{1} 39.3^{11} E08^{0} 07^{1} 22.6^{11}	0	0.03	0.174	0.074	0	0.026	0	0	0	0.07	0.032	0.034	0
11	OP/SW11	Ebonyi River, Ndegualeke	N06 ^{0} 18^{1} 52.1^{11} E08^{0} 07^{1} 08.6^{11}	0.01	0.005	0	0.261	0	0.001	0	0	0	0	0.002	0	0.019
12	OP/SW12	Ebonyi River,Umuigwe	N06^{0} 19^{1} 40.9^{11} E08^{0} 08^{1} 41.6^{11}	0	0.012	0	0.152	0	0.002	0	0	0	0	0.016	0.009	0
13	OP/SW13	Ebonyi River, Odomoke	N06 ^{0}27^{1} 31.8^{11} E08^{0} 06^{1} 14.7^{11}	0	0.005	0.001	0.771	0.12	0.341	0	0.212	0	0.021	0	0.03	0.012
14	OP/SW14	Ebonyi River, Enyibichiri	N06^{0} 22^{1}38.9^{11} E08 ^{0}04^{1} 30.6^{11}	0	0.006	0	0.141	0.114	0.192	0	0.012	0	0	0.008	0	0
15	OP/SW15	Iyiokwu River, Abakaliki	N06^{0} 18^{1} 48^{11} E08^{0} 04^{1} 10.6^{11}	0	0.006	0.218	2.216	1.252	0.051	0.02	0	1.01	0.016	0.034	0.618	0.818
16	OP/SW16	Igiokwu River, Abakaliki	N06^{0} 17^{1} 12.5^{11} E08^{0} 04^{1} 08.8^{11}	0.01	0.017	0.201	1.41	2.466	0.004	0.121	0.02	0	0	0.066	0.555	0.666
17	OP/SW17	Ngele Okoro, Ebonie	N06^{0} 25^{1} 06.9^{11} E08^{0} 03^{1} 29.6^{11}	0	0.004	0	0.125	0.177	0.012	0	0	0	0.001	0.186	0	0
18	OP/SW18	River Oyirigbo, Amanchara	N06^{0} 33^{1} 09^{11} N08^{0} 06^{1}15.2^{11}	0	0.001	0.124	0.341	0.992	0.021	0.101	0.126	0.06	0.013	0	0.101	0

19	OP/SW19	River Abe, Mkpuma Akpatakpa	N06^{0}24^{1} 21.4^{11} E08^{0}08 ^{1}56.6^{11}	0.01	0.18	0.342	4.166	0.776	0.061	0.251	0.033	0.02	0.006	0.178	0.059	0.161
20	OP/SW20	Akpara River, Enyigba	N6^{0}26 ^{1}80.4^{11} E08^{0} 05^{1} 38.7^{11}	0	0.001	0.121	2.141	0	0.127	0.01	0.036	0.07	0.001	0.058	0.129	0.441

Appendix 14b: Concentration of Minor Chemical Constituents of Groundwater Samples Analysed (Rainy Season)

S/N	Sample No	Location	Latitude/ Longitude	Se mg/l	Al mg/l	As mg/l	Mn mg/l	Ag mg/l	Cu mg/l	Hg mg/l	Pb mg/l	Zn mg/l	Co mg/l	Ni mg/l	Cd mg/l	Cr mg/l
1	OP/BH1	Mkpuma Akpatakpa Pri. Sch.	N06^{0} 23^{1} 02.9^{11} E08^{0} 09^{1} 41.1^{11}	0	0.018	0.483	2.088	2.021	0.034	0.414	0	1.35	0.001	0	0.155	0.116
2	OP/BH2	Mkpuma Akpatakpa.	N06 ^{0}24^{1} 22.1^{11} E08^{0} 10^{1} 17.6^{11}	0	0.037	0.519	1.396	1.793	0.053	0.074	0	0.07	0.027	0.016	0.105	0.137
3	OP/BH3	Umuagharu	N06^{0} 18^{1} 48.3^{11} E08^{0} 01^{1} 21.2^{11}	0	0.171	0.553	0.378	1.329	0.041	0.121	0	0	0	0.067	0.079	0.039
4	OP/BH4	Igbuhuotum Square	N06^{0} 24^{1} 59.5^{11} E08^{0} 11^{1} 20.4^{11}	0	0.016	0.563	2.532	0.53	0.024	0	0	2.09	0	0.015	0.258	0.127
5	OP/BH5	Comm. Sch. Igbuhuotum	N06^{0} 25^{1} 20^{11} E08^{0} 08^{1} 59.6^{11}	0	0.038	0.358	0.404	0.793	0.06	0	0	0	0.042	0.007	0.087	0.121
6	OP/BH6	Elinwovu Hospital	N06 ^{0}12^{1} 36.8^{11} E08^{0} 06^{1} 43.2^{11}	0	0.193	0.856	0.069	0.531	0.08	0.124	0.212	0	0.04	0.004	0.095	0.025
7	OP/BH7	Olua Enyigba	N6^{0}012106.6^{11} E08^{0} 07^{1} 55.9^{11}	0	0.049	0.146	0.297	0.286	0.13	0	0	0	0.154	0.171	0.083	0
8	OP/BH8	Ndufu-Alike Ikwo	N06^{0} 09^{1} 22.1^{11} E08^{0} 07^{1} 58.6^{11}	0	0.004	0.329	0.731	0.195	0.031	0	0	0	0.023	0.053	0.061	0
9	OP/BH9	Alibaruhu	N06^{0} 10^{1} 58.4^{11} E08^{0} 08^{1} 33.8^{11}	0	0.011	0.449	0.428	0.131	0.012	0	0	0	0.025	0	0.024	0
10	OP/BH10	Ishiagu Pri. Sch.	N06^{0} 11^{1} 32.8^{11} E08^{0} 07^{1} 58.8^{11}	0	0.012	0.295	2.379	0.049	0.004	0	0	0.06	0.006	0	0.008	0
11	OP/BH11	Mechanic site, Ai	N06^{0} 18^{1} 41.7^{11} E08^{0} 07^{1} 46.1^{11}	0	0.006	0.258	0.775	0	0.051	0	0.802	0.06	0.113	0.181	0.987	0.285
12	OP/BH12	Ekaeru Inyimagu	N06^{0} 19^{1} 43.1^{11} E08^{0} 08^{1} 42.5^{11}	0	0.006	0.626	0.693	0	0.023	0	0.38	0.11	0.001	0.024	0.208	0.124
13	OP/BH13	Nwagu	N06^{0} 18^{1} 50.9^{11} E08^{0} 06^{1} 32.4^{11}	0	0.006	0.577	2.645	0	0.018	0	0.332	0.21	0.101	0.026	0.033	0.04
14	OP/BH14	22,Nsukka str	N06^{0} 18^{1} 42.6^{11} E08^{0} 06^{1} 21.1^{11}	0	0.006	0.435	0.209	0	0.008	0	0.683	0	0.024	0.031	0	0.373
15	OP/BH15	Inyimagu Ebonyi	N06^{0} 20^{1} 15.7^{11} E08^{0} 07 ^{1}52.3^{11}	0	0.005	0.429	0.172	0	0.028	0	0.652	0	0.022	0.015	0	0.08
16	OP/BH16	Awumini, Nwofe	N06^{0} 31^{1} 30.2^{11} E08^{0} 09^{1} 4.4^{11}	0	0.006	0	1.301	0	0.001	0.001	0	0	0.111	0.024	0	0.018
17	OP/BH17	Ogbaga	N06^{0} 22^{1}30.9^{11} E08^{0} 06^{1} 06.9^{11}	0	0.056	0.312	0.962	0.009	0.002	0	0	0.02	0.064	0.031	0	0
18	OP/BH18	Obeagu Ezza Olu	N06^{0} 28^{1} 29.5^{11} E08^{0} 04^{1} 11^{11}	0	0.026	0.141	3.046	0.018	0.031	0	0	0.05	0.041	0.053	0	0.123
19	OP/BH19	St. Augustine, Nwofe	N06^{0} 30^{1} 32.9^{11} E08^{0} 09^{1} 24^{11}	0.01	0.126	0.342	0.154	0.001	0.061	0.12	0.01	0.01	0	0.017	0.056	0.024
20	OP/BH20	Ndi Ngbaleze	N06^{0} 18^{1}12.06^{11} E08^{0} 10^{1} 80.2^{11}	0.01	0.072	0.566	0.761	0.012	0.12	0	0.201	0.21	0.001	0.081	0.008	0.039

Appendix 15a: Concentrations of Chemical Constituents in mg/kg for Stream sediments/Soil Samples Analysed in Dry Season.

S\N	SAMPLE LOCATION	Latitude	Longitude	P^H	EC (µS/cm)	Zn	Cu	Pb	Cd	Cr	Hg	Ag	As
1	Egwudigwu	6^0 21’ 30.06”	8^0 10’ 11.12”	7.39	457	18.89	0.13	1.05	0.44	0	0	0	0
2	Umueze – Okoha	6^0 11’ 38.29”	8^0 01’ 30.48”	6.75	64	9.29	0	0.13	0.57	0	5.86	0	0.09
3	Ikenyi	6^0 23’ 35.4”	8^0 10’ 40.82”	3.33	918	10.43	0	3.51	0.5	0	0	30.09	0.41
4	Ighohutom	6^0 24’ 29.43”	8^0 10’ 48.74”	3.34	27.8	16.62	1.11	0.89	0.52	0.6	0	0	0
5	Okaria Nkaliki	6^0 24’ 44.49”	8^0 09’ 55.44”	6.68	88.3	6.58	0	0	0.48	0	2.48	0	0.28
6	Mkpuma AkpataKpa	6^0 23’ 10.09”	8^0 10’ 10.69”	3.32	910	120.59	206.99	38.98	6.445	0	0	0	0
7	Aghamegu	6^0 22’ 48.27”	8^0 03’ 48.39”	4.41	94	121.35	106.22	27.77	1.401	2.56	0	0	0
8	Aboffia	6^0 21’ 28.28”	8^0 07’ 15.49”	4.89	78.2	52.16	4.23	5.78	0.62	1.29	2.8	0	2.1
9	Ohoke	6^0 26’ 40.06”	8^0 10’ 17.12”	5.48	29.8	26.65	1.19	1.08	0.5	4.29	0	0	0
10	Ebonyi River, Ndiegu	6^0 18’ 15.18”	8^0 08’ 16.29”	6.56	172.4	21.77	0.93	0.26	0.57	0	0	0	0
11	Ameka 1	6^0 09’ 32.9”	8^0 06’ 38.6”	6.69	385	109.31	93.43	26.52	8.14	7.82	0	19.84	20.9
12	Ameka 2	6^0 10’ 56.9”	8^0 06’ 38.1”	3.26	107.8	108.09	28.13	43.05	1.392	6.98	0	30.29	50.12
13	Enyigba 1	6^0 11’ 05.4”	8^0 08’ 30.6”	9.87	137.4	42.78	8.2	21.13	0.22	0.22	0	0	32.13
14	Amegu 1	6^0 12’ 53.1”	8^0 07’ 57.6”	6.24	120.2	14.96	3.06	16.79	0.09	0	0	0	0
15	Amagu 2	6^0 12’ 06.1”	8^0 06’ 30.1”	6.18	102.1	29.14	4.06	5.86	6.29	23.68	0	2.61	0
16	Ameri salt lake	6^0 11’ 29.8”	8^0 07’ 21.8”	8.26	92	103.9	51.73	56.62	0.17	0	0	0	0
17	Akpara river Enyigba	6^0 12’ 49.9”	8^0 06’ 38.7”	6.22	120	18.9	2.46	0.66	0.92	10.35	0	0	0.01
18	Elinwobvu, Enyigba	6^0 12’ 37.2”	8^0 06’ 40.2”	6.17	86	21.52	2.93	0	0.2	24.66	0	0	0.201
19	Ameri	6^0 10’ 26.5”	8^0 07’ 51.1”	6.33	192	22.64	3.77	2.66	0.3	10.45	0	0	0
20	Amorie	6^0 09’ 18.4”	8^0 07’ 23.6”	6.69	388	17.62	2.77	0	0.33	12.23	0	0	0
21	Ndiefi	6^0 29’ 05.05”	8^0 05’ 10.12”	8.67	96	9.6	0.99	1.95	0.39	6.67	6.03	0	0
22	Ugbodo road, Egwudinagu	6^0 29’ 53.79”	8^0 05’ 55.11”	7.69	27	12.73	2.84	7.94	0.02	12.22	0	0	0
23	Egwudinagu	6^0 31’ 55.81”	8^0 06’ 58.39”	8.25	38	23.43	6.13	2.37	0	10.83	0	0	0
24	Ojiegbe	6^0 29’ 26.49”	8^0 07’ 26.85”	7.53	209	15.08	4.99	5.45	0	19.27	0	0	0
25	Amanchara	6^0 32’ 18.07”	8^0 07’ 48.13”	4.06	78.6	48.97	4.23	12.87	0	6.9	0	6.01	0.1
26	Nwofe road, Amanchara	6^0 32’ 31.53”	8^0 09’ 07.29”	7.19	278	15.18	3.66	8.34	0.01	7.28	0	0	0

27	River Awumini, Ndiechi	6^0 31’ 31.78”	8^0 07’ 07.16”	6.99	112	17.78	5.82	0.12	0	10.97	0	3.62	0
28	Nwofe	6^0 35’ 36.75”	8^0 10’ 37.02”	5.62	118	35.05	5.05	16.43	0	5.42	0	0	6.41
29	Amachara abandoned Pb - Zn mine	6^0 32’ 37.25”	8^0 07’ 05.1”	4.32	282	29.63	2.68	9.56	0	7.15	0	0	19.1
30	Ndiugbala	6^0 31’ 06.04”	8^0 09’ 34.52”	6.25	152	13.47	2.4	9.87	0	5.6	0	0	0
31	Mkpuma Akpatakpa abandoned Pb - Zn mine	6^0 23’ 031.1”	8^0 09’ 23.7”	3.33	920	101.32	5.19	50.91	3.74	5.09	0	0	10.25
32	Mkpuma Akpatakpa abandoned Pb - Zn mine	6^0 22’ 14.8”	8^0 09’ 39.5”	2.98	813	96.74	9.51	22.92	0.62	9.07	0	0	0.5
33	Ndiagu-obovu Village	6^0 28’ 26.7”	8^0 11’ 19.5”	6.42	148	18.85	4.24	11.1	0	13.2	0	0	0
34	River Abe, Ndiagalegu	6^0 27’ 30.9”	8^0 09’ 15.6”	6.46	272	25.12	4.49	11.02	0	13.49	0	0	0
35	Agubata	6^0 26’ 18.1”	8^0 06’ 10.17”	6.68	232	23.62	5.79	1.08	0	15.89	0	0	10.34
36	Ngele Akpu Oyege	6^0 24’ 16.4”	8^0 07’ 16.9”	8.29	72	13.95	4.52	6.54	0	16.82	0	2.27	4.2
37	River Abe, Obeagu	6^0 27’ 26.4”	8^0 04’ 36.9”	7.26	274	26.77	5.96	5.71	0	16.04	0	2.15	0
38	River Abe, Odomoke	6^0 29’ 46.3”	8^0 03’ 29.2”	8.10	26.8	6.01	1.89	6.78	0.04	12.17	0	3.32	2.4
39	Ekebiligwe	6^0 32’ 56.9”	8^0 05’ 55.6”	6.78	342	86.3	18.96	62.07	0.41	7.58	0	8.19	7.9
40	Ndiaguegbe	6^0 30’ 36.2”	8^0 01’ 55.8”	9.00	27	6.83	3.9	6.28	0	12.52	0	0	0
41	Eketabe	6^0 13’ 31.8”	8^0 09’ 44.7”	6.88	231	96.16	11.84	58.28	0.49	14.83	0	0	26.4
42	River Akpara, Enyigba	6^0 14’ 21.6”	8^0 06’ 14.9”	4.10	827	90.28	6.12	32.37	0.47	4.97	0	0	39.2
43	Agalegu	6^0 14’ 31.6”	8^0 04’ 34.9”	3.48	542	103	8.91	66.26	4.33	6.17	0	0	30.1
44	Mbabo	6^0 09’10.6”	8^0 09’ 14.8”	4.18	241	103.55	16.91	65.75	7.91	12.74	0	7.65	32.2
45	River Akpara, Agalegu	6^0 14’ 32.2”	8^0 03’ 20.28”	6.89	268	57.13	8.79	33.59	0.02	14.68	0	17.28	46.5
46	Alibaruhu	6^0 27’ 50.25”	8^0 02’40.28”	6.18	37	60.76	6.16	9.8	0.13	7.6	0	7.75	18.7
47	River Ogorube, Ngbo	6^0 26’ 12.25”	8^0 01’ 10.28”	7.25	48	15.71	4.56	12.03	0.4	8.97	0	2.04	22.2
48	River Ogbogbo, Izzi	6^0 32’ 31.15”	8^0 04’14.78”	5.68	281	84.2	10.83	64.78	0.27	16.53	0	4	20
49	River Atang Ndiokabi	6^0 24’ 52.25”	8^0 06’ 05.28”	5.78	301	83.19	8.76	33.17	0.06	6.33	0	2.07	39.8

50	Agbaja	6^{0} 17’ 26.26”	8^{0} 06’ 15.23”	8.18	56	17.2	7.06	2.71	0	28.32	0	0.74	0
51	Mgbabor	6^{0} 19’ 46.28”	8^{0} 04’ 36.13”	8.26	97	19.36	9.86	3.73	0.05	11.74	0	0	24.3
52	Otere Offie	6^{0} 23’53.19”	8^{0} 04’ 10.3”	7.41	92	23.24	7.73	6.03	0.16	7.91	0	0	46.2
53	Idembia	6^{0} 24’ 08.9”	8^{0} 01’ 41.6”	7.28	108	21.13	3.94	5.77	0	7.15	0	0.68	36.1
54	Umuoghara	6^{0} 19’ 10.5”	8^{0} 01’ 38.1”	6.66	128	47.11	8	5.64	0	15.05	0	0	0
55	Agharugha	6^{0} 16’ 55.4”	8^{0} 02’ 26.8”	6.89	27	26.9	6.72	8.58	0	25.81	0	5.29	2
56	Idembia	6^{0} 22’ 10.7”	8^{0} 01’ 09.5”	7.29	47	14.51	5.58	10.21	0	13.11	0	0	0
57	Ameka 3	6^{0} 09' 54.4'’	8^{0} 06' 55.2”	2.98	929	202	16.7	74.3	8.25	0.1	4	24.6	56
58	Enyigba 3	6^{0} 11' 11'’	8^{0} 08' 53'’	3.43	816	203	4	67	4.81	0.8	0	1.5	42

Appendix 15b: Concentrations of Chemical Constituents in mg/kg for Stream Sediments/ Soil Samples Analysed in Rainy Season

S/ N	LOCATION	LONGITUDE	LATITUDE	P^H	EC	Zn	Cu	Pb	Cd	Cr	Hg	Ag	As
1	Egwudinagu	06º 21′ 30.08″	08º10′11.112″	8.02	37	1.80	28.19	4.120	0.00	0.00	0.00	0.00	0.00
2	Umuezekoha	06º 11′ 38.20″	08º 01′ 30.48″	6.28	48	5.120	5.520	5.810	0.00	15.08	0.00	0.00	0.0
3	Ikenyi	06º 23′ 35.4″	08º 10′ 40.6″	4.48	11.8	22.71	1.260	23.63	6.60	37.97	1.00	0.370	0.00
4	Igbuhuotum	06º 24′14.51″	08º 10′ 48.54″	4.12	17.8	36.59	4.110	36.27	0.250	31.12	1.00	0.240	0.00
5	Okaria Nkaliki	06º 24′ 44.49″	08º 09′ 55.44″	4.19	10.7	107.0	4.260	49.23	7.070	7.960	0.00	0.230	0.00
6	Mkpuma Akpatakpa	06º 23′ 10.09″	08º 10′ 10.09″	3.26	12.10	107.58	102.66	65.47	7.670	13.65	1.00	0.640	0.00
7	Aghamegu	06º 22′ 46.23″	08º 03′ 48.39″	6.92	11.11	0.810	1.660	6.640	0.00	2.00	0.00	0.170	0.00
8	Aboffia	06º 21′ 28.25″	08º 07′ 15.6″	6.12	18.48	31.31	54.21	27.23	0.390	13.44	1.00	0.560	0.00
9	Ohoke	06^0 26' 40.06’'	08^0 10' 17.1’'	7.48	13.62	10.90	10.60	0.520	0.000	2.100	0.10	0.050	0.00
10	Ebonyi River, Ndiegu	06^0 18' 15.18’'	08^0 08' 16.9’'	4.01	10.82	33.80	4.70	0.000	0.20	0.60	0.00	0.000	0.10
11	Ameka 1	06º 09′ 32.9″	08º 06′ 38.6″	2.26	13.1	105.01	115.17	67.20	1.620	51.00	28.0	0.210	0.10
12	Ameka 2	06º 10′ 56.9″	08º 06′ 36.9″	2.58	11.2	96.80	102.68	56.01	1.500	49.26	31.2	1.210	0.10
13	Enyigba 1	06º 11′ 05.8″	08º 08′ 30.6″	3.42	10.3	84.73	96.21	27.93	1.610	0.00	29.0	1.7	2.09
14	Amegu 1	06º 12′ 53.1″	08º 07′ 57.6″	5.21	32.8	52.08	32.61	31.21	0.080	12.04	8.10	0.010	0.00
15	Amegu 2	06º 12′ 06.9″	08º 06′ 30.7	6.18	34.5	52.08	32.61	20.00	0.100	8.120	1.00	0.010	0.00
16	Ameri Salt lake	06º 11′ 29.8″	08º 07′ 21.8″	6.77	13.8	50.70	40.12	74.05	0.310	25.60	1.00	0.570	0.00
17	Akpara River, Enyigba	06º 12′ 50″	08º 06′ 38.7″	7.29	9.4	2.90	31.98	60.07	10.21	1.650	1.00	0.150	1.00
18	Elinwobvu, Enyigba	06º 12′ 37.2″	08º 06′ 40.2″	6.88	21.7	15.18	4.180	29.60	0.00	1.30	0.00	0.010	0.00
19	Ameri	06º 10′ 26.5″	08º 07′ 51.1″	6.71	20.3	17.66	1.260	1.490	0.220	2.940	0.00	0.00	0.00
20	Amorie	06º 09′ 18.5	08º 07′23.12″	5.20	10.6	9.810	1.010	10.00	0.00	1.410	0.00	0.000	0.00
21	Ndiefi	06º29′ 05.05″	08º05′10.18″	6.87	8.13	5.680	0.160	0.600	0.00	1.410	0.00	0.000	0.00
22	Ugbodo road, Egwudinagu	06^0 29' 53,07’'	08^0 05' 47’'	6.89	20.1	9.10	1.10	1.800	0.00	7.100	0.00	0.00	0.00
23	Egwudinagu	06^0 31' 55.8’'	08^0 06' 53.39’'	6.59	11.4	14.90	2.10	0.280	0.000	0.900	0.00	0.00	0.00
24	Ojiegbe	06^0 29' 26.49’'	08^0 07' 26.9’'	7.18	12.1	9.030	1.340	0.000	0.200	0.000	0.00	0.00	0.00
25	Amanchara	06º 32′ 18.07″	08º 07′ 48.13	4.89	27.16	18.91	1.820	10.05	4.100	1.400	1.00	0.710	0.00
26	Nwofe rd, Amanchara	06º 32′ 31.53″	08º 09′ 07.26″	5.86	13.4	11.06	1.660	5.230	0.00	1.600	0.00	0.00	0.00
27	R. Awumini, Ndiechi	06^0 31' 31.08’'	08^0 09'07. 28’'	8.21	10.86	12.90	6.700	0.010	0.500	0.100	0.00	0.060	0.00
28	Nwofe	06^0 35' 36 05’'	08^0 10' 37.02’'	6.74	9.8	26.30	0.700	5.200	0.000	0.110	0.00	0.000	3.00
29	Abandoned Pb-Zn Amanchara	06º32′37.25″	08º 07′ 05″	4.41	39.2	21.96	56.68	10.01	5.60	5.120	0.00	0.060	0.00
30	Ndiugbala	06^0 31' 06.04’'	08^0 09' 34.52’'	6.92	10.4	6.740	2.030	0.300	0.400	2.800	0.00	0.000	3.80
31	Mkpuma Akpatakpa 1	06º 23′ 31.4″	08º 09′ 25.0″	2.52	36.4	99.90	12.06	48.67	16.46	12.03	0.00	0.770	0.00
32	Mkpuma Akpatakpa 2	06º 22′ 14.5″	08º 09′ 39.5″	3.40	48.1	89.51	9.26	19.04	8.360	10.16	0.00	0.240	0.00
33	Ndiagu Obovu	6^0 28' 26.7’'	8^0 11' 19.5’'	8.92	17.8	4.560	12.10	3.80	0.00	1.09	0.00	0.00	0.00
34	R. Abe, Ndiagalegu	06^0 27' 30.9’'	08^0 09' 15.8’'	6.63	11.01	21.03	3.400	20.70	0.40	9.500	0.00	1.30	0.00

35	Agubata	06º26′18.25″	08º 06′ 10″	8.11	13.21	1.980	6.990	10.01	0.00	1.080	0.00	0.02	0.00
36	Ngele Akpu, Oyege	06º 24′ 18.5″	08º 07′ 16.7″	6.46	9.2	5.010	1.260	1.420	0.000	10.32	0.00	0.220	0.00
37	River Abe, Obeagu	06º 27′ 27.8″	08º 04′ 36.2″	6.01	8.08	21.24	1.120	9.940	0.070	12.70	1.00	0.010	0.00
38	River Abe, Odomoke	06º 29′ 46.5″	08º 03′ 29.8″	7.48	10.06	2.220	0.210	7.120	0.260	4.170	1.00	0.600	0.00
39	Ekebiligwe	06º 32′ 56.06″	08º 05′55.6″	8.27	11.40	0.080	1.120	10.60	0.00	1.00	0.00	0.000	0.00
40	Ndiaguegbe	06º 30′ 39.3″	08º 01′ 55.6″	6.26	10.02	27.75	1.160	29.09	0.00	23.86	0.00	0.660	0.00
41	Eketabe	06º 13′ 27.5″	08º 09′ 44.7″	5.71	9.06	80.68	4.410	26.29	0.450	0.00	0.00	0.700	0.00
42	River Akpara, Enyigba	6^0 14' 21.6’’	8^0 06' 14.5’’	4.83	29.5	87.41	2.50	13.90	0.00	9.00	0.00	0.500	0.00
43	Agalegu	6^0 14' 31.6’’	8^0 04' 34.3’’	4.98	44.6	81.30	7.40	44.70	2.90	2.50	0.00	1.600	29.80
44	Mbabo	6^0 09' 10’’	8^0 09' 45’’	5.29	56.98	93.20	7.10	21.80	2.80	9.10	0.00	7.70	31.20
45	River Akpara, Agalegu	06º 14′ 32.4″	08º 03′ 20.8″	6.81	29.02	22.66	6.610	27.06	0.00	11.87	0.00	0.970	19.00
46	Alibaruhu	06º 11′ 33.6″	08º 08′ 23.1″	5.12	28.1	30.56	0.600	3.910	0.010	6.610	0.00	0.740	0.00
47	River Ogorube, Ngbo	06º 26′ 55.0″	08º 01′ 10.2″	8.76	21	6.980	1.120	5.06	0.00	0.500	0.00	0.020	0.00
48	River Ogbogbo, Izzi	06º 32′ 31.15″	08º 04′ 14.8″	6.71	13.01	45.10	28.81	34.41	0.110	8.120	0.00	0.00	1.00
49	River Atang Ndiokabi	06º 24′ 52.1″	08º 06′ 05.28″	6.42	19.2	36.61	6.920	28.17	0.00	4.110	0.00	0.760	20.10
50	Agbaja	6^0 17' 26.26’’	8^0 06' 15.23’’	8.99	17.2	10.01	5.700	1.540	0.00	11.30	0.00	0.210	0.00
51	Mgbabor	6^0 19' 46.28’’	8^0 04' 36.13’’	9.28	9.81	4.650	6.120	2.310	0.010	4.800	0.00	0.00	8.80
52	Otere Offie	06º 23′ 53.25″	08º 04′ 10.5″	9.98	6.44	9.270	1.820	1.980	0.020	5.00	0.00	0.00	25.0
53	Idembia	06º 24′ 08.7″	08º 01′ 9.5″	5.69	26.1	10.08	3.610	4.440	1.700	0.00	0.00	0.030	0.00
54	Umuaghara	6^0 19' 10.5’’	8^0 01' 38.4’’	5.21	10.08	21.39	3.080	3.110	0.00	0.030	0.00	1.30	0.00
55	Agharugha	06º 16′ 55.3″	08º 02′ 26.0″	5.69	18.02	28.09	3.010	5.140	0.000	10.21	0.00	0.46	0.00
56	Idembia	06º 22′ 10.7″	08º 01′ 09.8″	8.27	2.16	4.640	2.110	7.850	0.00	8.520	0.00	0.00	0.00
57	Ameka 3	6^0 09' 54.4’’	8^0 06' 52.5’’	3.26	14	142.0	6.080	65.20	5.920	0.010	0.00	4.10	19.00
58	Enyigba 3	6^0 11' 11’’	08^0 08' 53’’	2.91	29	186.0	3.300	56.20	2.300	0.400	0.00	0.300	19.00

Appendix 16a: Pollution Index (€) for Soil/ stream sediments Samples of dry season samples.

S/N		Zn	Cu	Pb	Cd	Cr	Hg	Ag	As
1	Egwudigwu	0.046	0.000	0.004	0.045	0.000	0.000	0.000	0.000
2	Umueze – Okoha	0.022	0.000	0.000	0.059	0.000	8.253	0.000	0.001
3	Ikenyi	0.025	0.000	0.015	0.052	0.000	0.000	8.132	0.005
4	Ighohutom	0.0040	0.004	0.004	0.054	0.001	0.000	0.000	0.000
5	Okaria Nkaliki	0.016	0.000	0.000	0.050	0.000	3.492	0.000	0.004
6	Mkpuma AkpataKpa	0.294	0.766	0.177	6.713	0.000	0.000	0.000	0.000
7	Aghamegu	0.295	0.393	0.126	1.459	0.006	0.000	0.000	0.000
8	Aboffia	0.127	0.015	0.026	0.064	0.003	3.943	0.000	0.030
9	Ohoke	0.065	0.004	0.004	0.052	0.011	0.000	0.000	0.000
10	Ebonyi River, Ndiegu	0.053	0.003	0.001	0.059	0.000	0.000	0.000	0.000
11	Ameka 1	0.266	0.346	0.120	1.084	0.021	0.000	5.362	0.298
12	Ameka 2	0.263	0.104	0.193	1.450	0.018	0.000	8.186	0.716
13	Enyigba 1	0.104	0.030	0.096	0.022	0.001	0.000	0.000	0.459
14	Amegu 1	0.036	0.011	0.076	0.009	0.000	0.000	0.000	0.000
15	Amagu 2	0.071	0.015	0.026	1.071	0.064	0.000	0.705	0.000
16	Ameri salt lake	0.253	0.191	0.257	0.017	0.000	0.000	0.000	0.000
17	Akpara river Enyigba	0.046	0.009	0.003	0.095	0.027	0.000	0.000	0.000
18	Elinwobvu, Enyigba	0.052	0.010	0.000	0.020	0.066	0.000	0.000	0.002
19	Ameri	0.053	0.013	0.012	0.031	0.028	0.000	0.000	0.000
20	Amorie	0.042	0.010	0.000	0.034	0.033	0.000	0.000	0.000
21	Ndiefi	0.023	0.003	0.000	0.040	0.018	8.492	0.000	0.000
22	Ugbodo road, Egwudinagu	0.031	0.010	0.036	0.002	0.033	0.000	0.000	0.000
23	Egwudinagu	0.057	0.022	0.010	0.000	0.029	0.000	0.000	0.000
24	Ojiegbe	0.036	0.018	0.024	0.000	0.052	0.000	0.000	0.000
25	Amanchara	0.119	0.015	0.058	0.000	0.018	0.000	1.624	0.000
26	Nwofe road, Amanchara	0.037	0.013	0.037	0.001	0.019	0.000	0.000	0.001
27	River Awumini, Ndiechi	0.043	0.021	0.001	0.000	0.029	0.000	0.978	0.000
28	Nwofe	0.085	0.018	0.074	0.000	0.014	0.000	0.000	0.091
29	Amachara abandoned mine site	0.072	0.009	0.043	0.000	0.019	0.000	0.000	0.272
30	Ndiugbala	0.032	0.008	0.044	0.000	0.015	0.000	0.000	0.000
31	Mkpuma Akpatakpa abandoned mine	0.247	0.019	0.231	0.389	0.013	0.000	0.000	0.146
32	Mkpuma Akpatakpa abandoned mine	0.235	0.035	0.104	0.064	0.024	0.000	0.000	0.007
33	Ndiagu-obovu Village	0.045	0.015	0.050	0.000	0.035	0.000	0.000	0.000
34	River Abe, Ndiagalegu	0.061	0.016	0.050	0.000	0.036	0.000	0.000	0.000
35	Agubata	0.057	0.014	0.004	0.000	0.042	0.000	0.000	0.147
36	Ngele Akpu Oyege	0.034	0.016	0.029	0.000	0.045	0.000	0.613	0.060
37	River Abe, Obeagu	0.065	0.022	0.025	0.000	0.043	0.000	0.581	0.000
38	River Abe, Odomoke	0.014	0.007	0.030	0.004	0.032	0.000	0.897	0.034
39	Ekebiligwe	0.210	0.070	0.282	0.042	0.020	0.000	2.213	0.112
40	Ndiaguegbe	0.016	0.014	0.028	0.000	0.033	0.000	0.000	0.000
41	Eketabe	0.234	0.043	0.264	0.051	0.040	0.000	0.000	0.377
42	River Akpara, Enyigba	0.220	0.022	0.147	0.048	0.013	0.000	0.000	0.560

43	Agalegu	0.251	0.033	0.301	0.451	0.016	0.000	0.000	0.430
44	Mbabo	0.252	0.062	0.298	1.064	0.034	0.000	2.067	0.460
45	River Akpara, Agalegu	0.139	0.032	0.152	0.002	0.039	0.000	4.670	0.664
46	Alibaruhu	0.148	0.022	0.044	0.013	0.020	0.000	2.094	0.267
47	River Ogorube, Ngbo	0.038	0.016	0.054	0.041	0.024	0.000	0.551	0.317
48	River Ogbogbo, Izzi	0.205	0.040	0.294	0.028	0.044	0.000	1.081	0.285
49	River Atang Ndiokabi	0.202	0.032	0.150	0.000	0.017	0.000	0.559	0.568
50	Agbaja	0.041	0.026	0.012	0.000	0.076	0.000	0.200	0.000
51	Mgbabor	0.047	0.036	0.016	0.005	0.031	0.000	0.000	0.347
52	Otere Offie	0.056	0.028	0.027	0.016	0.019	0.000	0.000	0.658
53	Idembia	0.051	0.014	0.026	0.000	0.040	0.000	0.183	0.515
54	Umuoghara	0.114	0.029	0.025	0.000	0.040	0.000	0.000	0.000
55	Agharugha	0.065	0.024	0.039	0.000	0.069	0.000	1.429	0.028
56	Idembia	0.035	0.020	0.046	0.000	0.035	0.000	0.000	0.000
57	Ameka 3	0.492	0.061	0.337	0.859	0.000	5.633	6.648	0.800
58	Enyigba 3	0.495	0.014	0.304	0.501	0.002	0.000	0.405	0.600

Appendix 16 b: Pollution Index (€) for Soil/ stream sediments Samples of rainy season samples.

S/N		Zn	Cu	Pb	Cd	Cr	Hg	Ag	As
1	Egwudigwu	0.004	0.104	0.019	0.000	0.000	0.000	0.000	0.000
2	Umueze – Okoha	0.012	0.020	0.026	0.000	0.041	0.000	0.000	0.000
3	Ikenyi	0.055	0.005	0.107	0.688	0.103	1.408	0.100	0.000
4	Ighohutom	0.089	0.015	0.165	0.026	0.084	1.408	0.065	0.000
5	Okaria Nkaliki	0.261	0.016	0.224	0.736	0.022	0.000	0.062	0.000
6	Mkpuma AkpataKpa	0.262	0.380	0.298	0.799	0.037	1.408	0.173	0.000
7	Aghamegu	0.002	0.006	0.030	0.000	0.005	0.000	0.046	0.000
8	Aboffia	0.076	0.201	0.124	0.041	0.036	1.408	0.151	0.000
9	Ohoke	0.027	0.039	0.002	0.000	0.006	0.141	0.014	0.000
10	Ebonyi River, Ndiegu	0.082	0.017	0.000	0.021	0.002	0.000	0.000	0.001
11	Ameka 1	0.256	0.427	0.305	0.169	0.138	39.437	0.057	0.001
12	Ameka 2	0.236	0.380	0.255	0.156	0.133	43.944	0.327	0.001
13	Enyigba 1	0.207	0.356	0.127	0.168	0.000	40.845	0.459	0.029
14	Amegu 1	0.127	0.121	0.142	0.008	0.033	11.408	0.003	0.000
15	Amagu 2	0.127	0.121	0.091	0.010	0.022	1.408	0.003	0.000

16	Ameri salt lake	0.124	0.149	0.337	0.032	0.069	1.408	0.154	0.000
17	Akpara river Enyigba	0.007	0.118	0.273	1.064	0.004	1.408	0.041	0.0142
18	Elinwobvu, Enyigba	0.037	0.015	0.135	0.000	0.003	0.000	0.003	0.000
19	Ameri	0.043	0.005	0.007	0.023	0.008	0.000	0.000	0.000
20	Amorie	0.024	0.004	0.045	0.000	0.004	0.000	0.000	0.000
21	Ndiefi	0.014	0.001	0.003	0.000	0.004	0.000	0.000	0.000
22	Ugbodo road, Egwudinagu	0.022	0.004	0.008	0.000	0.019	0.000	0.000	0.000
23	Egwudinagu	0.036	0.008	0.001	0.000	0.002	0.000	0.000	0.000
24	Ojiegbe	0.022	0.005	0.000	0.021	0.000	0.000	0.000	0.000
25	Amanchara	0.046	0.007	0.046	0.427	0.004	1.408	0.192	0.000
26	Nwofe road, Amanchara	0.027	0.006	0.024	0.000	0.004	0.000	0.000	0.000
27	River Awumini, Ndiechi	0.031	0.025	0.000	0.052	0.003	0.000	0.016	0.000
28	Nwofe	0.064	0.003	0.024	0.000	0.003	0.000	0.000	0.043
29	Amachara abandoned mine site	0.054	0.209	0.046	0.583	0.014	0.000	0.016	0.000
30	Ndiugbala	0.016	0.008	0.001	0.042	0.008	0.000	0.000	0.054
31	Mkpuma Akpatakpa abandoned mine	0.244	0.045	0.221	1.715	0.033	0.000	0.208	0.000
32	Mkpuma Akpatakpa abandoned mine	0.218	0.034	0.087	0.871	0.027	0.000	0.065	0.000
33	Ndiagu-obovu Village	0.011	0.045	0.017	0.000	0.003	0.000	0.000	0.000
34	River Abe, Ndiagalegu	0.051	0.013	0.094	0.042	0.026	0.000	0.351	0.000
35	Agubata	0.005	0.026	0.046	0.000	0.003	0.000	0.005	0.000
36	Ngele Akpu Oyege	0.012	0.005	0.006	0.000	0.028	0.000	0.059	0.000
37	River Abe, Obeagu	0.052	0.004	0.045	0.007	0.034	1.408	0.003	0.000
38	River Abe, Odomoke	0.005	0.001	0.032	0.027	0.011	1.408	0.162	0.000
39	Ekebiligwe	0.0002	0.004	0.048	0.000	0.003	0.000	0.000	0.000
40	Ndiaguegbe	0.068	0.004	0.132	0.000	0.064	0.000	0.178	0.000
41	Eketabe	0.197	0.016	0.120	0.047	0.000	0.000	0.189	0.000

42	River Akpara, Enyigba	0.213	0.009	0.063	0.000	0.024	0.000	0.135	0.000
43	Agalegu	0.198	0.027	0.203	0.302	0.007	0.000	0.432	0.425
44	Mbabo	0.227	0.026	0.099	0.292	0.025	0.000	2.081	0.445
45	River Akpara, Agalegu	0.055	0.025	0.123	0.000	0.032	0.000	0.262	0.271
46	Alibaruhu	0.075	0.002	0.018	0.001	0.018	0.000	0.200	0.000
47	River Ogorube, Ngbo	0.017	0.004	0.023	0.000	0.001	0.000	0.005	0.000
48	River Ogbogbo, Izzi	0.110	0.107	0.156	0.011	0.022	0.000	0.000	0.014
49	River Atang Ndiokabi	0.089	0.026	0.128	0.000	0.011	0.000	0.205	0.287
50	Agbaja	0.024	0.021	0.007	0.000	0.031	0.000	0.057	0.000
51	Mgbabor	0.011	0.023	0.011	0.001	0.013	0.000	0.000	0.125
52	Otere Offie	0.023	0.007	0.009	0.002	0.014	0.000	0.000	0.357
53	Idembia	0.025	0.013	0.020	0.177	0.000	0.000	0.008	0.000
54	Umuoghara	0.052	0.011	0.014	0.000	0.000	0.000	0.351	0.000
55	Agharugha	0.069	0.011	0.023	0.000	0.028	0.000	0.124	0.000
56	Idembia	0.011	0.008	0.036	0.000	0.023	0.000	0.000	0.000
57	Ameka 3	0.346	0.023	0.296	0.617	0.000	0.000	1.1080.271	
58	Enyigba 3	0.454	0.012	0.255	0.239	0.001	0.000	0.081	0.271

Appendix 17a: Geoaccumulation index value for Stream Sediments/ Soil Sample Analysed in dry season.

S/N	Sample Location	Zn	Cu	Pb	Cd	Cr	As
1	Egwudigwu	0.0418	0.0005	0.0105	0.2943	0.0000	0.0000
2	Umueze – Okoha	0.0207	0.0000	0.0013	0.3813	0.0000	0.0018
3	Ikenyi	0.0232	0.0000	0.0352	0.3345	0.0000	0.0082
4	Ighohutom	0.0371	0.0045	0.0089	0.3478	0.0016	0.0000
5	Okaria Nkaliki	0.0147	0.0000	0.0000	0.3211	0.0000	0.0056
6	Mkpuma AkpataKpa	0.2689	0.8308	0.3911	4.3114	0.0000	0.0000
7	Aghamegu	0.2706	0.4263	0.2786	0.9310	0.0070	0.0000
8	Aboffia	0.1163	0.0169	0.0579	0.4145	0.0035	0.0421
9	Ohoke	0.0594	0.0048	0.0108	0.3344	0.0118	0.0000
10	Ebonyi River, Ndiegu	0.0485	0.0037	0.0026	0.3811	0.0000	0.0000
11	Ameka 1	0.2437	0.3749	0.2661	5.4524	0.0215	0.4193
12	Ameka 2	0.2410	0.1129	0.4319	0.9311	0.0192	1.0057
13	Enyigba 1	0.0954	0.329	0.2120	0.1469	0.6048	0.6448
14	Amegu 1	0.0334	0.0123	0.1684	0.0602	0.0000	0.0000
15	Amagu 2	0.0649	0.0163	0.0588	4.2077	0.0650	0.0000
16	Ameri salt lake	0.2317	0.2076	0.5681	0.1135	0.0000	0.0000
17	Akpara river Enyigba	0.0421	0.0099	0.0066	0.6153	0.00284	0.0018
18	Elinwobvu, Enyigba	0.0479	0.0117	0.0000	0.1337	0.0678	0.0040
19	Ameri	0.0505	0.0151	0.0267	0.2005	0.0287	0.0000
20	Amorie	0.0393	0.0111	0.0000	0.2207	0.0336	0.0000
21	Ndiefi	0.0214	0.0039	0.0196	0.2607	0.0183	0.0000
22	Ugbodo road, Egwudinagu	0.0284	0.0114	0.0797	0.0132	0.00336	0.0000
23	Egwudinagu	0.0522	0.0246	0.0238	0.0000	0.0298	0.0000
24	Ojiegbe	0.0336	0.0200	0.0547	0.0000	0.0529	0.0000
25	Amanchara	0.1092	0.0169	0.1291	0.0000	0.0189	0.0019
26	Nwofe road, Amanchara	0.0338	0.0147	0.0837	0.0066	0.0199	0.0000
27	River Awumini, Ndiechi	0.0396	0.0234	0.0012	0.0000	0.0301	0.0000
28	Nwofe	0.0781	0.0203	0.1648	0.0000	0.0149	0.1285
29	Amachara abandoned mine site	0.0660	0.0107	0.0959	0.0000	0.0196	0.3830
30	Ndiugbala	0.0300	0.0096	0.0990	0.0000	0.0154	0.0000
31	Mkpuma Akpatakpa abandoned mine	0.2259	0.0208	0.5108	2.5019	0.0139	0.2056
32	Mkpuma Akpatakpa abandoned mine	0.2157	0.0382	0.2299	0.4145	0.0249	0.0099
33	Ndiagu-obovu Village	0.0420	0.0170	0.1114	0.0000	0.0363	0.0000
34	River Abe, Ndiagalegu	0.0559	0.0180	0.1106	0.0000	0.0371	0.0000
35	Agubata	0.0527	0.0232	0.0108	0.0000	0.0437	0.2074
36	Ngele Akpu Oyege	0.0311	0.0181	0.0656	0.0000	0.0462	0.0843
37	River Abe, Obeagu	0.0597	0.0239	0.0573	0.0000	0.0441	0.0000
38	River Abe, Odomoke	0.0134	0.0076	0.0680	0.0264	0.0334	0.0482
39	Ekebiligwe	0.1924	0.0761	0.6223	0.2742	0.0208	0.1585
40	Ndiaguegbe	0.0152	0.0157	0.0630	0.0000	0.0344	0.0000
41	Eketabe	0.2144	0.0475	0.5848	0.3275	0.0407	0.5298
42	River Akpara, Enyigba	0.2012	0.0246	0.3248	0.3143	0.0136	0.7867
43	Agalegu	0.2297	0.0358	0.6649	2.8965	0.0169	0.6040
44	Mbabo	0.2309	0.0679	0.6597	5.2914	0.0350	0.6462

45	River Akpara, Agalegu	0.1274	0.0353	0.3370	0.0132	0.0403	0.9332
46	Alibaruhu	0.1355	0.0247	0.0983	0.0867	0.0209	0.3751
47	River Ogorube, Ngbo	0.0350	0.0183	0.1207	0.2673	0.0247	0.4455
48	River Ogbogbo, Izzi	0.1877	0.0435	0.6500	0.1806	0.0454	0.4013
49	River Atang Ndiokabi	0.1855	0.0352	0.3328	0.0400	0.0174	0.7987
50	Agbaja	0.0384	0.0283	0.0272	0.0000	0.0778	0.0000
51	Mgbabor	0.0432	0.0395	0.0374	0.0334	0.0322	0.4877
52	Otere Offie	0.0518	0.0310	0.0605	0.1069	0.0217	0.9272
53	Idembia	0.0471	0.0158	0.0578	0.0000	0.0196	0.7245
54	Umuoghara	0.1050	0.0320	0.0566	0.0000	0.0414	0.0000
55	Agharugha	0.0599	0.0269	0.0861	0.0000	0.0709	0.0401
56	Idembia	0.0323	0.0223	0.1024	0.0000	0.0360	0.0000
57	Ameka 3	0.4504	0.0670	0.7455	5.5191	0.0003	1.1237
58	Enyigba 3	0.4527	0.0160	0.6723	3.2182	0.0022	0.8429

Appendix 17b: Geoaccumulation index value for Stream Sediments/ Soil Samples Analysed in rainy season.

S/N	Sample Location	Zn	Cu	Pb	Cd	Cr	As
1	Egwudigwu	0.004	0.113	0.041	0.000	0.000	0.000
2	Umueze – Okoha	0.011	0.022	0.058	0.000	0.041	0.000
3	Ikenyi	0.051	0.005	0.237	4.415	0.104	0.000
4	Ighohutom	0.082	0.016	0.364	0.167	0.086	0.000
5	Okaria Nkaliki	0.239	0.017	0.494	4.730	0.022	0.000
6	Mkpuma AkpataKpa	0.240	0.412	0.657	5.131	0.038	0.000
7	Aghamegu	0.002	0.007	0.067	0.000	0.005	0.000
8	Aboffia	0.070	0.218	0.273	0.261	0.037	0.000
9	Ohoke	0.024	0.043	0.005	0.000	0.006	0.000
10	Ebonyi River, Ndiegu	0.075	0.019	0.000	0.134	0.002	0.002
11	Ameka 1	0.234	0.462	0.674	1.084	0.140	0.002
12	Ameka 2	0.216	0.412	0.562	1.003	0.135	0.002
13	Enyigba 1	0.189	0.386	0.280	1.077	0.000	0.042
14	Amegu 1	0.116	0.131	0.313	0.054	0.033	0.000
15	Amagu 2	0.116	0.131	0.201	0.007	0.022	0.000
16	Ameri salt lake	0.113	0.161	0.743	0.207	0.070	0.000
17	Akpara river Enyigba	0.006	0.128	0.603	6.830	0.005	0.020
18	Elinwobvu, Enyigba	0.034	0.017	0.297	0.000	0.004	0.000
19	Ameri	0.039	0.005	0.015	0.147	0.008	0.000
20	Amorie	0.022	0.004	0.100	0.000	0.004	0.000

21	Ndiefi	0.013	0.001	0.006	0.000	0.004	0.000
22	Ugbodo road, Egwudinagu	0.020	0.004	0.018	0.000	0.020	0.000
23	Egwudinagu	0.033	0.008	0.003	0.000	0.002	0.000
24	Ojiegbe	0.020	0.005	0.000	0.134	0.000	0.000
25	Amanchara	0.042	0.007	0.101	2.743	0.004	0.000
26	Nwofe road, Amanchara	0.025	0.007	0.052	0.000	0.004	0.000
27	River Awumini, Ndiechi	0.029	0.027	0.000	0.334	0.000	0.000
28	Nwofe	0.059	0.003	0.052	0.000	0.000	0.060
29	Amachara abandoned mine site	0.049	0.227	0.100	3.746	0.014	0.000
30	Ndiugbala	0.015	0.008	0.003	0.268	0.008	0.076
31	Mkpuma Akpatakpa abandoned mine	0.223	0.048	0.488	11.011	0.033	0.000
32	Mkpuma Akpatakpa abandoned mine	0.200	0.037	0.191	5.592	0.028	0.000
33	Ndiagu-obovu Village	0.010	0.049	0.038	0.000	0.003	0.000
34	River Abe, Ndiagalegu	0.047	0.014	0.208	0.268	0.026	0.000
35	Agubata	0.004	0.028	0.100	0.000	0.003	0.000
36	Ngele Akpu Oyege	0.011	0.005	0.014	0.000	0.028	0.000
37	River Abe, Obeagu	0.047	0.004	0.100	0.047	0.035	0.000
38	River Abe, Odomoke	0.005	0.001	0.071	0.174	0.011	0.000
39	Ekebiligwe	0.000	0.004	0.106	0.000	0.003	0.000
40	Ndiaguegbe	0.062	0.005	0.292	0.000	0.066	0.000
41	Eketabe	0.180	0.018	0.264	0.301	0.000	0.000
42	River Akpara, Enyigba	0.195	0.010	0.139	0.000	0.025	0.000
43	Agalegu	0.181	0.030	0.449	1.940	0.007	0.598
44	Mbabo	0.208	0.028	0.219	1.873	0.025	0.626
45	River Akpara, Agalegu	0.051	0.027	0.272	0.000	0.033	0.381
46	Alibaruhu	0.068	0.002	0.039	0.007	0.018	0.000
47	River Ogorube, Ngbo	0.016	0.004	0.051	0.000	0.001	0.000
48	River Ogbogbo, Izzi	0.101	0.116	0.345	0.074	0.022	0.020
49	River Atang Ndiokabi	0.082	0.028	0.283	0.000	0.011	0.403
50	Agbaja	0.022	0.023	0.015	0.000	0.031	0.000
51	Mgbabor	0.010	0.025	0.023	0.007	0.013	0.177
52	Otere Offie	0.021	0.007	0.020	0.013	0.014	0.502
53	Idembia	0.022	0.014	0.045	1.137	0.000	0.000
54	Umuoghara	0.048	0.012	0.031	0.000	0.000	0.000
55	Agharugha	0.063	0.012	0.052	0.000	0.028	0.000
56	Idembia	0.010	0.008	0.079	0.000	0.023	0.000
57	Ameka 3	0.317	0.024	0.654	3.960	0.000	0.381
58	Enyigba 3	0.415	0.013	0.564	1.539	0.001	0.381

Appendix 18a: Contamination factor of soil/ stream sediments of dry season samples analysed.

S/N	Sample Location	Zn	Cu	Pb	Cd	Cr	As
1	Egwudigwu	0.2099	0.0026	0.0525	1.4667	0.0000	0.0000
2	Umueze – Okoha	0.1032	0.0000	0.0065	1.9000	0.0000	0.0090
3	Ikenyi	0.1159	0.0000	0.1575	1.6667	0.0000	0.0410
4	Ighohutom	0.1847	0.0222	0.0445	1.7333	0.0082	0.0000
5	Okaria Nkaliki	0.0731	0.0000	0.0000	1.6000	0.0000	0.0280
6	Mkpuma AkpataKpa	1.3398	4.1398	1.9490	21.4833	0.0000	0.0000
7	Aghamegu	1.3483	2.1244	1.3885	4.6700	0.0351	0.0000
8	Aboffia	0.5796	0.0846	0.1156	2.0667	0.0177	0.2100
9	Ohoke	0.2961	0.0238	0.0540	1.6667	0.0588	0.0000
10	Ebonyi River, Ndiegu	0.2419	0.0186	0.0130	1.9000	0.0000	0.0000
11	Ameka 1	1.2146	1.8686	1.3260	27.1333	0.1071	2.0900
12	Ameka 2	1.2010	0.5626	2.1525	4.6400	0.0956	5.0120
13	Enyigba 1	0.4753	0.1640	1.0565	0.7333	0.0030	3.2130
14	Amegu 1	0.1662	0.0612	0.8395	0.3000	0.0000	0.0000
15	Amagu 2	0.3238	0.0812	0.2930	20.9667	0.3244	0.0000
16	Ameri salt lake	1.1544	1.0346	2.8310	0.5667	0.0000	0.0000
17	Akpara river Enyigba	0.2100	0.0492	0.0330	3.0667	0.1418	0.0010
18	Elinwobvu, Enyigba	0.2391	0.0586	0.0000	0.6667	0.3378	0.0201
19	Ameri	0.2516	0.0754	0.1330	1.0000	0.1432	0.0000
20	Amorie	0.1958	0.0554	0.0000	1.1000	0.1675	0.0000
21	Ndiefi	0.1067	0.0198	0.0975	1.3000	0.0914	0.0000
22	Ugbodo road, Egwudinagu	0.1414	0.0568	0.3970	0.0667	0.1674	0.0000
23	Egwudinagu	0.2603	0.1226	0.1185	0.0000	0.1484	0.0000
24	Ojiegbe	0.1676	0.0998	0.2725	0.0000	0.2640	0.0000
25	Amanchara	0.5441	0.0846	0.6435	0.0000	0.0945	0.0100
26	Nwofe road, Amanchara	0.1687	0.0732	0.4170	0.0333	0.0997	0.0000
27	River Awumini, Ndiechi	0.1976	0.1116	0.0060	0.0000	0.1503	0.0000
28	Nwofe	0.3804	0.1010	0.8215	0.0000	0.0742	0.6410
29	Amachara abandoned mine site	0.3292	0.0536	0.4780	0.0000	0.0979	1.9100
30	Ndiugbala	0.1497	0.0480	0.4935	0.0000	0.0767	0.0000
31	Mkpuma Akpatakpa abandoned mine	1.1258	0.1038	2.5455	12.4667	0.0697	1.0250
32	Mkpuma Akpatakpa abandoned mine	1.0749	0.1902	1.1460	2.0667	0.1242	0.0500
33	Ndiagu-obovu Village	0.2094	0.0848	0.5550	0.0000	0.1808	0.0000
34	River Abe, Ndiagalegu	0.2791	0.0898	0.5510	0.0000	0.1848	0.0000
35	Agubata	0.2624	0.1158	0.0540	0.0000	0.2177	1.0340
36	Ngele Akpu Oyege	0.1550	0.0904	0.3270	0.0000	0.2304	0.4200
37	River Abe, Obeagu	0.2974	0.1192	0.2855	0.0000	0.2197	0.0000
38	River Abe, Odomoke	0.0668	0.0378	0.3390	0.1333	0.1667	0.2400
39	Ekebiligwe	0.9589	0.3792	3.1035	1.3667	0.1038	0.7900
40	Ndiaguegbe	0.0759	0.0780	0.3140	0.0000	0.1715	0.0000
41	Eketabe	1.0684	0.2368	2.9140	1.6333	0.2032	2.6400
42	River Akpara, Enyigba	1.0031	0.1224	1.6185	1.5667	0.0680	3.9200

43	Agalegu	1.1444	0.1782	3.3130	14.4333	0.0845	3.0100
44	Mbabo	1.1506	0.3382	3.2875	26.3667	0.1745	3.2200
45	River Akpara, Agalegu	0.6348	0.1758	1.6795	0.0667	0.2010	4.6500
46	Alibaruhu	0.6751	0.1232	0.4900	0.4333	0.1041	1.8700
47	River Ogorube, Ngbo	0.1746	0.0912	0.6015	1.3333	0.1229	2.2200
48	River Ogbogbo, Izzi	0.9356	0.2166	3.2390	0.9000	0.2264	2.0000
49	River Atang Ndiokabi	0.9322	0.1752	1.6585	0.2000	0.0867	3.9800
50	Agbaja	0.1911	0.1412	0.1358	0.0000	0.3879	0.0000
51	Mgbabor	0.2151	0.1972	0.1865	0.1667	0.1608	2.4300
52	Otere Offie	0.2582	0.1546	0.3015	0.5333	0.1084	4.6200
53	Idembia	0.2348	0.0788	0.2885	0.0000	0.0979	3.6100
54	Umuoghara	0.5234	0.1600	0.2820	0.0000	0.2062	0.0000
55	Agharugha	0.2989	0.1344	0.4290	0.0000	0.3536	0.2000
56	Idembia	0.1612	0.1116	0.5105	0.0000	0.1796	0.0000
57	Ameka 3	2.2444	0.3340	3.7150	27.5000	0.0014	5.6000
58	Enyigba 3	2.2556	0.0800	3.3500	16.0333	0.0110	4.2000

Appendix 18b: Contamination factor of soil/ stream sediments of rainy season samples analysed.

S/N	Sample Location	Zn	Cu	Pb	Cd	Cr	As
1	Egwudigwu	0.02	0.564	0.206	0.000	0.000	0.000
2	Umueze–Okoha	0.057	0.110	0.291	0.000	0.207	0.000
3	Ikenyi	0.252	0.025	1.182	22.000	0.520	0.000
4	Ighohutom	0.407	0.082	1.814	0.833	0.426	0.000
5	OkariaNkaliki	1.189	0.085	2.492	23.567	0.109	0.000
6	MkpumaAkpataKpa	1.195	2.053	3.274	25.567	0.187	0.000
7	Aghamegu	0.009	0.033	0.332	0.000	0.027	0.000
8	Aboffia	0.348	1.084	1.362	1.300	0.184	0.000
9	Ohoke	0.121	0.212	0.026	0.000	0.029	0.000
10	Ebonyi River, Ndiegu	0.376	0.094	0.000	0.667	0.008	0.010
11	Ameka 1	1.167	2.303	3.360	5.400	0.699	0.010
12	Ameka 2	1.076	2.054	2.081	5.000	0.675	0.010
13	Enyigba 1	0.941	1.924	1.397	5.367	0.000	0.209
14	Amegu 1	0.579	0.652	1.561	0.267	16.493	0.000
15	Amagu 2	0.578	0.652	1.000	0.333	0.111	0.000
16	Ameri salt lake	0.563	0.802	3.703	1.033	0.351	0.000
17	Akpara river Enyigba	0.032	0.638	3.004	34.033	0.023	0.100
18	Elinwobvu, Enyigba	0.169	0.084	1.480	0.000	0.018	0.000
19	Ameri	0.196	0.025	0.075	0.733	0.040	0.000
20	Amorie	0.109	0.020	0.500	0.000	0.019	0.000
21	Ndiefi	0.063	0.003	0.030	0.000	0.019	0.000
22	Ugbodo road, Egwudinagu	0.101	0.022	0.090	0.000	0.097	0.000
23	Egwudinagu	0.166	0.042	0.014	0.000	0.012	0.000
24	Ojiegbe	0.100	0.027	0.000	0.060	0.000	0.000
25	Amanchara	0.210	0.036	0.503	13.667	0.019	0.000
26	Nwofe road, Amanchara	0.123	0.033	0.262	0.000	0.022	0.000
27	River Awumini, Ndiechi	0.133	0.134	0.001	1.667	0.001	0.000
28	Nwofe	0.292	0.014	0.216	0.000	1.507	0.300
29	Amachara abandoned mine site	0.244	1.134	0.501	18.667	0.070	0.000
30	Ndiugbala	0.075	0.014	0.015	1.333	0.038	0.380

31	MkpumaAkpatakpa abandoned mine	1.110	0.241	2.434	54.867	0.165	0.000
32	MkpumaAkpatakpa abandoned mine	0.995	0.185	0.952	27.867	0.139	0.000
33	Ndiagu-obovu Village	0.051	0.242	0.190	0.000	0.015	0.000
34	River Abe, Ndiagalegu	0.234	0.068	1.035	1.333	0.130	0.000
35	Agubata	0.022	0.140	0.501	0.000	0.015	0.000
36	NgeleAkpuOyege	0.056	0.025	0.071	0.000	0.141	0.000
37	River Abe, Obeagu	0.236	0.022	0.497	0.233	0.174	0.000
38	River Abe, Odomoke	0.025	0.004	0.356	0.867	0.057	0.000
39	Ekebiligwe	0.001	0.022	0.530	0.000	0.014	0.000
40	Ndiaguegbe	0.308	0.032	1.495	0.000	0.327	0.000
41	Eketabe	0.896	0.088	1.315	1.500	0.000	0.000
42	River Akpara, Enyigba	0.971	0.050	0.695	0.000	0.123	0.000
43	Agalegu	0.903	0.148	2.235	9.667	0.034	2.980
44	Mbabo	1.036	0.142	1.090	9.333	0.125	3.120
45	River Akpara, Agalegu	0.252	0.132	1.353	0.000	0.163	1.900
46	Alibaruhu	0.340	0.012	0.196	0.033	0.091	0.000
47	River Ogorube, Ngbo	0.078	0.022	0.253	0.000	0.007	0.000
48	River Ogbogbo, Izzi	0.501	0.576	1.721	0.367	0.111	0.100
49	River AtangNdiokabi	0.407	0.138	1.409	0.000	0.056	2.010
50	Agbaja	0.111	0.114	0.077	0.000	0.155	0.000
51	Mgbabor	0.052	0.122	0.116	0.033	0.066	0.088
52	OtereOffie	0.103	0.036	0.099	0.067	0.068	2.500
53	Idembia	0.112	0.040	0.222	5.667	0.000	0.000
54	Umuoghara	0.238	0.062	0.156	0.000	0.0004	0.000
55	Agharugha	0.312	0.060	0.257	0.000	0.140	0.000
56	Idembia	0.052	0.042	0.393	0.000	0.117	0.000
57	Ameka 3	1.578	0.122	3.260	19.733	0.0001	1.900
58	Enyigba 3	2.067	0.066	2.810	7.667	0.005	1.900

Appendix 19a: Contamination Degree for Soil/ Stream Sediment for dry season samples analysed

S/N	Sample Location	Zn	Cu	Pb	Cd	Cr	As	mCd	mCd index
1	Egwudigwu	0.209	0.002	0.052	1.466	0.000	0.000	1.729	0.288
2	Umueze–Okoha	0.103	0.000	0.006	1.900	0.000	0.009	2.018	0.336
3	Ikenyi	0.115	0.000	0.175	1.666	0.000	0.041	1.997	0.333
4	Ighohutom	0.184	0.022	0.044	1.733	0.008	0.000	1.991	0.331
5	OkariaNkaliki	0.073	0.000	0.000	1.600	0.000	0.028	1.701	0.284
6	MkpumaAkpataKpa	1.339	4.139	1.949	21.483	0.000	0.000	28.91	4.818
7	Aghamegu	1.348	2.124	1.388	4.67	0.035	0.000	9.565	1.594
8	Aboffia	0.579	0.084	0.289	2.066	0.017	0.210	3.245	0.540
9	Ohoke	0.296	0.023	0.054	1.666	0.058	0.000	2.097	0.349
10	Ebonyi River, Ndiegu	0.241	0.018	0.013	1.900	0.000	0.000	2.720	0.453
11	Ameka 1	1.214	1.868	1.326	27.13	0.107	2.090	33.74	5.623
12	Ameka 2	1.201	0.562	2.152	4.600	0.095	5.012	13.62	2.270
13	Enyigba 1	0.475	0.164	1.056	0.733	0.003	3.213	5.644	0.941
14	Amegu 1	0.166	0.061	0.839	0.300	0.000	0.000	1.366	0.228
15	Amagu 2	0.323	0.068	0.293	20.96	0.323	0.000	21.99	3.665
16	Ameri salt lake	1.154	1.034	2.831	0.566	0.000	0.000	5.585	0.931
17	Akpara river Enyigba	0.210	0.049	0.033	3.066	0.141	0.001	3.500	0.583
18	Elinwobvu, Enyigba	0.239	0.058	0.000	0.666	0.337	0.020	1.320	0.220
19	Ameri	0.251	0.075	0.133	1.000	0.143	0.000	1.602	0.267
20	Amorie	0.195	0.055	0.000	1.100	0.167	0.000	1.517	0.252
21	Ndiefi	0.106	0.019	0.097	1.300	0.091	0.000	1.613	0.268
22	Ugbodo road, Egwudinagu	0.141	0.056	0.397	0.066	0.167	0.000	0.827	0.137
23	Egwudinagu	0.260	0.122	0.118	0.000	0.148	0.000	0.648	0.108
24	Ojiegbe	0.167	0.099	0.272	0.000	0.263	0.000	0.801	0.134
25	Amanchara	0.544	0.084	0.643	0.000	0.094	0.010	1.375	0.229
26	Nwofe road, Amanchara	0.168	0.073	0.417	0.033	0.099	0.000	0.790	0.132
27	River Awumini, Ndiechi	0.197	0.116	0.006	0.000	0.150	0.000	0.469	0.078
28	Nwofe	0.389	0.101	0.821	0.000	0.074	0.641	2.026	0.338
29	Amachara abandoned mine site	0.329	0.053	0.478	0.000	0.097	1.910	2.867	0.478
30	Ndiugbala	0.149	0.048	0.493	0.000	0.076	0.000	0.768	0.128
31	MkpumaAkpatakpa abandoned mine	1.125	0.103	2.545	12.46	0.069	1.025	17.33	2.888
32	MkpumaAkpatakpa abandoned mine	1.074	0.190	1.146	2.066	0.124	0.050	4.650	0.775

33	Ndiagu-obovu Village	0.209	0.084	0.555	0.000	0.180	0.000	1.028	0.171
34	River Abe, Ndiagalegu	0.279	0.089	0.551	0.000	0.184	0.000	1.101	0.184
35	Agubata	0.262	0.115	0.054	0.000	0.217	1.034	1.682	0.280
36	NgeleAkpuOyege	0.155	0.090	0.327	0.000	0.230	0.420	1.222	0.203
37	River Abe, Obeagu	0.297	0.119	0.285	0.000	0.219	0.000	0.920	0.153
38	River Abe, Odomoke	0.066	0.037	0.339	0.133	0.166	0.240	0.981	0.164
39	Ekebiligwe	0.958	0.377	3.103	1.366	0.103	0.790	6.697	1.116
40	Ndiaguegbe	0.075	0.078	0.314	0.000	0.171	0.000	0.638	0.106
41	Eketabe	1.068	0.236	2.914	1.633	0.203	2.640	8.694	1.449
42	River Akpara, Enyigba	1.003	0.122	1.618	1.566	0.068	3.920	8.297	1.383
43	Agalegu	1.144	0.178	3.313	14.43	0.084	3.010	22.16	3.693
44	Mbabo	1.450	0.333	3.287	26.36	0.174	3.220	34.53	5.755
45	River Akpara, Agalegu	0.634	0.175	1.679	0.666	0.201	4.650	8.005	1.334
46	Alibaruhu	0.675	0.123	0.490	0.433	0.104	1.870	3.695	0.615
47	River Ogorube, Ngbo	0.174	0.091	0.601	1.333	0.122	2.220	4.541	0.756
48	River Ogbogbo, Izzi	0.935	0.216	3.239	0.900	0.226	2.000	7.516	1.252
49	River AtangNdiokabi	0.924	0.175	1.658	0.200	0.086	3.980	7.023	1.171
50	Agbaja	0.191	0.141	0.135	0.000	0.387	0.000	0.854	0.142
51	Mgbabor	0.215	0.197	0.186	0.166	0.160	2.430	3.354	0.559
52	OtereOffie	0.258	0.154	0.301	0.533	0.108	4.620	5.974	0.995
53	Idembia	0.234	0.078	0.288	0.000	0.097	3.610	4.307	0.717
54	Umuoghara	0.523	0.160	0.282	0.000	0.206	0.000	1.225	0.204
55	Agharugha	0.298	0.134	0.429	0.000	0.353	0.200	1.411	0.235
56	Idembia	0.161	0.111	0.510	0.000	0.179	0.000	0.961	0.160
57	Ameka 3	2.244	0.334	3.715	27.50	0.001	5.600	39.39	6.565
58	Enyigba 3	2.255	0.080	3.350	16.03	0.010	4.200	25.93	4.321

Appendix 19b: Contamination Degree for Soil/ Stream Sediment for rainy season samples analysed

S/N	Sample Location	Zn	Cu	Pb	Cd	Cr	As	mCd	mCd Index
1	Egwudigwu	0.02	0.564	0.206	0.000	0.000	0.000	0.79	0.132
2	Umueze–Okoha	0.057	0.110	0.291	0.000	0.207	0.000	0.665	0.111
3	Ikenyi	0.252	0.025	1.182	22.000	0.520	0.000	23.98	3.996
4	Ighohutom	0.407	0.082	1.814	0.833	0.426	0.000	3.562	0.594
5	OkariaNkaliki	1.189	0.085	2.492	23.567	0.109	0.000	27.44	4.574
6	MkpumaAkpataKpa	1.195	2.053	3.274	25.567	0.187	0.000	32.28	5.379
7	Aghamegu	0.009	0.033	0.332	0.000	0.027	0.000	0.401	0.067
8	Aboffia	0.348	1.084	1.362	1.300	0.184	0.000	4.278	0.713
9	Ohoke	0.121	0.212	0.026	0.000	0.029	0.000	0.649	0.108
10	Ebonyi River, Ndiegu	0.376	0.094	0.000	0.667	0.008	0.010	1.155	0.193
11	Ameka 1	1.167	2.303	3.360	5.400	0.699	0.010	12.94	2.156
12	Ameka 2	1.076	2.054	2.081	5.000	0.675	0.010	10.89	1.816
13	Enyigba 1	0.941	1.924	1.397	5.367	0.000	0.209	9.838	1.639
14	Amegu 1	0.579	0.652	1.561	0.267	16.493	0.000	19.55	3.258

15	Amagu 2	0.578	0.652	1.000	0.333	0.111	0.000	2.674	0.445
16	Ameri salt lake	0.563	0.802	3.703	1.033	0.351	0.000	6.452	1.075
17	Akpara river Enyigba	0.032	0.638	3.004	34.033	0.023	0.100	37.83	6.305
18	Elinwobvu, Enyigba	0.169	0.084	1.480	0.000	0.018	0.000	1.751	0.291
19	Ameri	0.196	0.025	0.075	0.733	0.040	0.000	1.069	0.178
20	Amorie	0.109	0.020	0.500	0.000	0.019	0.000	0.648	0.648
21	Ndiefi	0.063	0.003	0.030	0.000	0.019	0.000	0.115	0.019
22	Ugbodo road, Egwudinagu	0.101	0.022	0.090	0.000	0.097	0.000	0.310	0.051
23	Egwudinagu	0.166	0.042	0.014	0.000	0.012	0.000	0.234	0.039
24	Ojiegbe	0.100	0.027	0.000	0.060	0.000	0.000	0.187	0.031
25	Amanchara	0.210	0.036	0.503	13.667	0.019	0.000	14.44	2.405
26	Nwofe road, Amanchara	0.123	0.033	0.262	0.000	0.022	0.000	0.440	0.073
27	River Awumini, Ndiechi	0.133	0.134	0.001	1.667	0.001	0.000	1.936	0.322
28	Nwofe	0.292	0.014	0.216	0.000	1.507	0.300	2.329	0.388
29	Amachara abandoned mine site	0.244	1.134	0.501	18.667	0.070	0.000	20.61	3.436
30	Ndiugbala	0.075	0.014	0.015	1.333	0.038	0.380	1.855	0.309
31	MkpumaAkpatakpa abandoned mine	1.110	0.241	2.434	54.867	0.165	0.000	58.82	9.802
32	MkpumaAkpatakpa abandoned mine	0.995	0.185	0.952	27.867	0.139	0.000	30.14	5.023
33	Ndiagu-obovu Village	0.051	0.242	0.190	0.000	0.015	0.000	0.498	0.083
34	River Abe, Ndiagalegu	0.234	0.068	1.035	1.333	0.130	0.000	2.800	0.466
35	Agubata	0.022	0.140	0.501	0.000	0.015	0.000	0.678	0.113
36	NgeleAkpuOyege	0.056	0.025	0.071	0.000	0.141	0.000	0.293	0.048
37	River Abe, Obeagu	0.236	0.022	0.497	0.233	0.174	0.000	1.162	0.193
38	River Abe, Odomoke	0.025	0.004	0.356	0.867	0.057	0.000	1.309	0.218
39	Ekebiligwe	0.001	0.022	0.530	0.000	0.014	0.000	0.567	0.094
40	Ndiaguegbe	0.308	0.032	1.495	0.000	0.327	0.000	2.162	0.360
41	Eketabe	0.896	0.088	1.315	1.500	0.000	0.000	3.799	0.633
42	River Akpara, Enyigba	0.971	0.050	0.695	0.000	0.123	0.000	1.839	0.306
43	Agalegu	0.903	0.148	2.235	9.667	0.034	2.980	15.97	2.661
44	Mbabo	1.036	0.142	1.090	9.333	0.125	3.120	14.85	2.474
45	River Akpara, Agalegu	0.252	0.132	1.353	0.000	0.163	1.900	3.800	0.633
46	Alibaruhu	0.340	0.012	0.196	0.033	0.091	0.000	0.672	0.112
47	River Ogorube, Ngbo	0.078	0.022	0.253	0.000	0.007	0.000	0.360	0.060
48	River Ogbogbo, Izzi	0.501	0.576	1.721	0.367	0.111	0.100	3.376	0.562
49	River AtangNdiokabi	0.407	0.138	1.409	0.000	0.056	2.010	4.020	0.670
50	Agbaja	0.111	0.114	0.077	0.000	0.155	0.000	0.457	0.076
51	Mgbabor	0.052	0.122	0.116	0.033	0.066	0.088	0.477	0.079
52	OtereOffie	0.103	0.036	0.099	0.067	0.068	2.500	2.873	0.478
53	Idembia	0.112	0.040	0.222	5.667	0.000	0.000	6.041	1.006
54	Umuoghara	0.238	0.062	0.156	0.000	0.0004	0.000	0.457	0.076
55	Agharugha	0.312	0.060	0.257	0.000	0.140	0.000	0.769	0.128
56	Idembia	0.052	0.042	0.393	0.000	0.117	0.000	0.604	0.101
57	Ameka 3	1.578	0.122	3.260	19.733	0.0001	1.900	26.59	4.432
58	Enyigba 3	2.067	0.066	2.810	7.667	0.005	1.900	14.52	2.419