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Heavy metal contamination of groundwater resources in a Nigerian urban settlement

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The aim of the study was to create awareness on the effect of dumpsite on groundwater in developing countries, especially Nigeria. In order to achieve this, water samples were obtained from 20 randomly selected hand dug wells and boreholes in the area, in February and August, 2006. 10 leachates samples were also obtained from the dumpsite. From these samples, pH and conductivity were determined using a pH/conductivity meter (Jenway model), while the concentrations of the heavy metals (Co, Fe, Pb and Cu) were determined using atomic absorption spectrophotometer (AAS). The trend of dispersion of each variable was demonstrated on Landsat ETM+ (2006) imagery using Erdas Imagine and ArcView GIS software. The study showed that the groundwater in the study area were generally alkaline (8.3 ± 2.77) and contained Cu (0.02 ± 0.04 mg/l), Fe (4.23 ± 6.4 mg/l), Pb (2.4 ± 3.3 mg/l) and Co (1.03 ± 1.1 mg/l) concentrations that are higher than the permissible limits recommended by the World Health Organization (0.5, 0.1, 0.01 and 0.0002 mg/l, respectively; $p > 0.05$). The study concluded that the groundwater sources within 2 km radius of a major landfill will be vulnerable to the effect of landfill, if they are not adequately protected.

Key words: Groundwater, landfill, Landsat imageries, heavy metals contamination.

INTRODUCTION

Pollution of groundwater sources by leachate from landfills have been recognized for a long time (Hem, 1989; Butow et al., 1989; Alloway and Ayres, 1997). Clark (2006) described landfill practices as the disposal of solid wastes by infilling depressions on land. The depressions into which solid wastes are often dumped include valleys, (abandoned) sites of quarries, excavations, or sometimes a selected portion within the residential and commercial areas in many urban settlements where the capacity to collect, process, dispose of, or re-use solid waste in a cost-efficient, safe manner is often limited (www.makingcitieswork.org, 2009) by available technological and managerial capacities. In most developing countries such as Nigeria, several tons of garbage are left uncollected on the streets each day, acting as a feeding ground for pests that spread disease, clogging drains and creating a myriad of related health and infrastructural problems.

The practice of landfill system as a method of waste disposal in many developing countries is usually far from standard recommendations (Mull, 2005; Adewole, 2009). A standardised landfill system involves carefully selected location, and are usually constructed and maintained by means of engineering techniques, ensuring minimized pollution of air, water and soil and risks to man and animals. Landfilling involves ‘placing’ wastes in lined pit or a mound (sanitary landfills) with appropriate means of leachate and landfill gas control (Alloway and Ayres, 1997). In most cases however, ‘landfill’ in developing countries’ context is usually an unlined shallow hollow (often not deeper than 50 cm). Zurbrugg et al. (2003) referred to it as ‘dumps’ which receive solid wastes in a more or less uncontrolled manner, making a very uneconomical use of the available space and that which allows free access to waste pickers, animals and flies, and often produce unpleasant and hazardous smoke from slow-burning fires. Besides, instances have been

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shown that revealed that even the lined (protected) landfills have been inadequate in the prevention of groundwater contamination (Lee and Lee, 2005).

In Nigeria, open dump is almost the verily available option for solid waste disposal, even in the capital cities. Sanitary landfill, however, is rare and unpopular, except perhaps among few institutions and few affluent people. Financial and institutional constraints are the immediate identifiable reasons for this in Nigeria and some other developing countries, especially where local governments are weak or underfinanced and rapid population growth continues (Nnuan, 2000; Elaigwu et al., 2007). Other reasons include the issue of inappropriate guidelines for siting, design and operation of new landfills as well as missing recommendations for possible upgrading options of existing open dumps (Zurbrugg et al., 2003). Often the available guidelines for landfills available are those from high-income countries, and they are based on technological standards and practices suited to the conditions and regulations of the source countries, they often do not take into account for the different technical, economical, social and institutional aspects of developing countries. In another case, many of the municipal officials think that uncontrolled waste disposal is the best that is possible (www.makingcitieswork.org, 2009). In the case of Lagos State, Nigeria, Adewole (2009), exemplifies the unacceptable view that dumpsite has been adopted for use in the State because more refined methods are technically and financially expensive. This equally revealed a general ignorance of the deleterious effects of dumpsites on the groundwater sources on which a number of city dwellers depend (Foster, 1986; Ako et al., 1990). According to Zurbrugg et al. (2003), one out of four people in cities, in developing countries, lives in ‘absolute poverty’ while another one in four is classified as ‘relatively poor’ (see also, Human Development Report, 2009). It has also been revealed that municipal authorities in these countries tend to allocate their limited financial resources to the richer areas of higher tax yields where citizens with more political pressure reside (Onakerhoraye and Omuta, 1994; Akinbode et al., 2008).

Furthermore, acidification and nitrification of groundwater have been linked to dumpsite around their outlets (Bacud et al., 1994) while a number of dumpsites have been implicated for bacterial contamination of drinking water (Torres et al, 1991) in some cases, causing poisoning, cancer, heart diseases and teratogenic abnormalities (Sia Su, 2008). Although there have been no in-depth studies yet concerning groundwater quality around the Olusosun or Lagos State Waste Management Authority (LAWMA) dumpsite in Nigeria, it will be in interest of the future of Lagos State, Nigeria and development agencies in other developing cities to be aware of the environmental impact of uncontrolled and improper waste disposal in the society. It is therefore the aim of this study to provide benchmark information on the extent of pollution brought about by the open dumpsite on groundwater sources of those selected areas. The objectives are to map and describe the distribution of some selected heavy metals like cobalt (Co), cadmium (Cd), lead (Pb) and copper (Cu)) in the groundwater around the Olusosun landfill in Ojota area of Lagos State, Nigeria.

STUDY AREA

The study was carried out in Ojota area of Lagos State in Nigeria. The area covers Ikosi Ketu, Oregun industrial estates, the commercial area of Kudirat Abiola way, Ojota residential area and LAWMA dumpsite (Figure 1), known as Olusosun landfill (Bello, 2002). The landfill is located between 6°23’N; 2°42’E and 6°41’N; 3°42’E. It is the largest of all the landfills in Lagos area; it has received more than 50% of the total refuse in Lagos area since 1989. As at the period when the dumpsite was created, the area (Ojota) was almost a vacant land (Bello, 2002). The area is however a flourishing commercial central district in Lagos State. Figure 2 shows some views of the landfill as at 2007.

The site of the landfill is about 10 km South East of Ikeja Local Government Area (LGA). Ikeja is the capital city of Lagos State. The state is the most flourishing Nigerian commercial arena, with a population of more than 9, 013, 534 and an annual growth rate of 3.2% (NPC, 2006).

The depths of hand dug wells in this region vary from 3.81 to 30.37 m above the mean sea level (a.s.l), and boreholes are generally between 21 and 58.86 m deep. Most of the hand dug wells are neither lined nor have properly constructed base or covers. Some are simply covered with planks and rusted metal sheets. The geology of the area is generally characterized by coastal plain sands which form the low lying, gently sloping uplands, and the coastal deposits forming extensive red earths, and loose poorly sorted sands that are mixed with an abundance of clays (World Bank, 2002). The topography is generally low, ranging from 18 to 52 m above the mean sea level (Figure 3)

The climate of Lagos area is characterized by two main seasons: wet (April - October) and dry (November - March) seasons. The peaks of rainfall occur in July and September/October, and they are often characterized by floods, which effects are usually aggravated by the poor surface drainage systems. Mean annual rainfall in Lagos area varies from 1567.2 mm at the North West to 1750 mm at the mainland (Oyeku, 2007).

MATERIALS AND METHODS

20 groundwater points (10 each of boreholes and hand dug wells) were randomly selected for this study. Water samples were collected between February, 2006 and August, 2007 in the selected groundwater points. The locations of the groundwater points were obtained with a hand held Global Positioning System (GPS, Germin 72 model) with position accuracy of less than 10 m (Table 1).

The choice of the sampling stations considered location, accessibility, proximity to residential areas and the topography of the study area. 12 sample stations were within the 2 residential areas (in the 2 km radius), 5 in the commercial area and 3 in the industrial section of the study area. Water samples were obtained for both dry and wet seasons in February and August 2006, respectively. In all, about 40% of the groundwater sources within 2 km radius of the landfill were sampled. Water samples, in the hand dug wells were obtained using same material that is used to fetch water from each well. This is usually a rubber container made from motorbike or car wheel tube, attached to a long chord. Using this, about 4 L bulk sample was collected in a large plastic bowl, after a

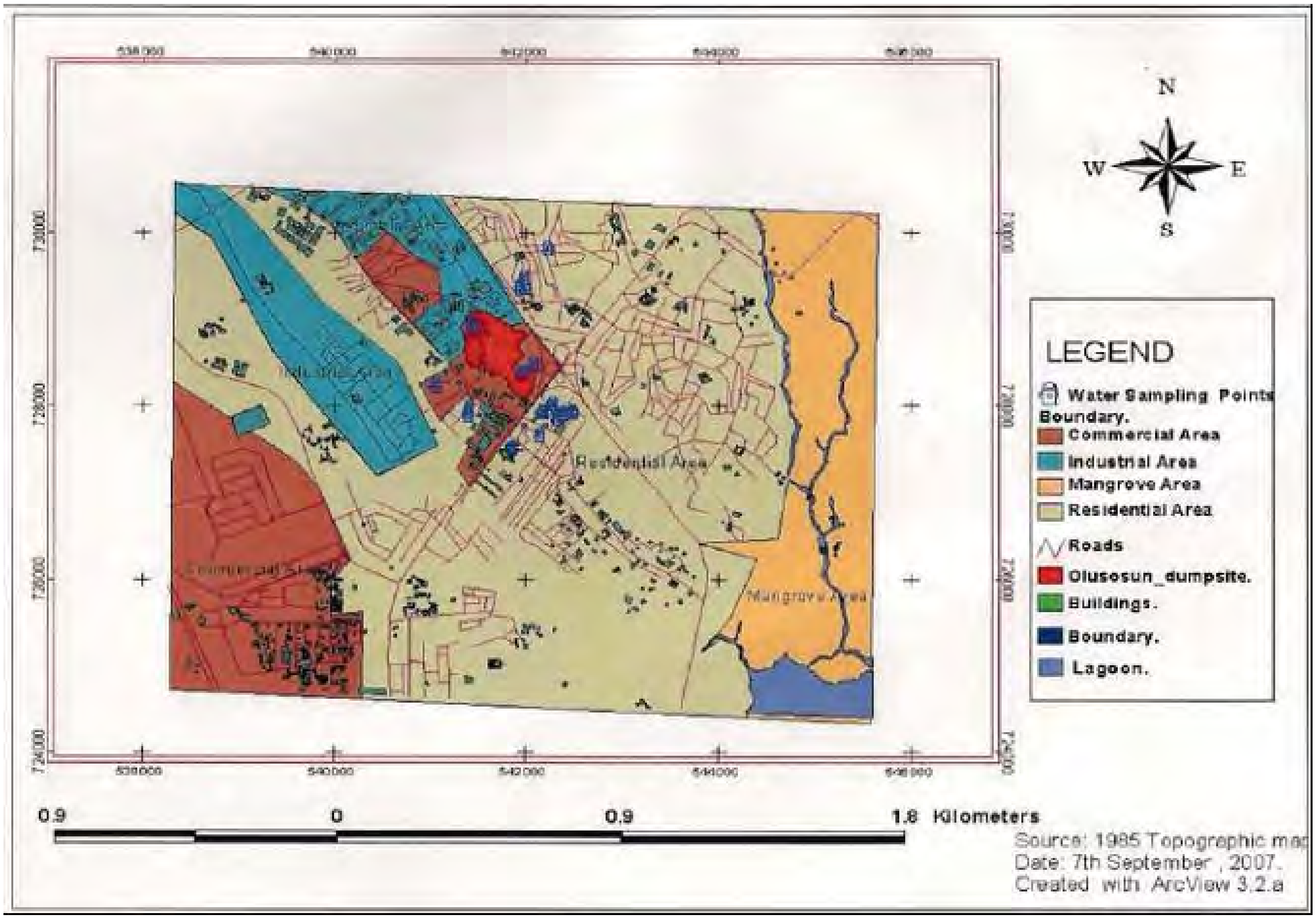


Figure 1. The landuse of the study area as shown on Landsat ETM+ of 2006 imageries.

Figure 2. Some perspectives of Olusosun landfill (dumpsite) in Ojota area, Lagos, as at October, 2007.

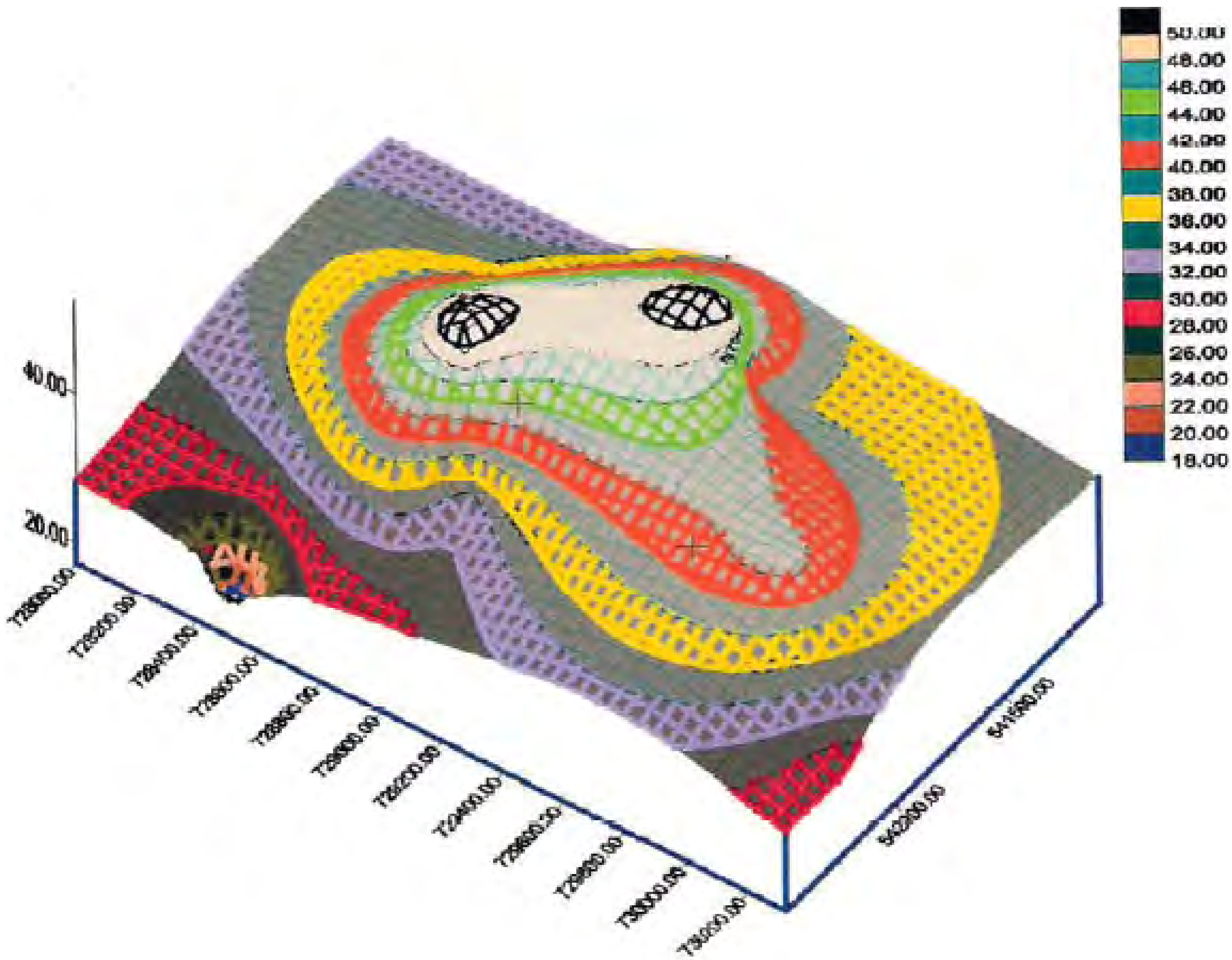


Figure 3. Digital elevation model showing the topography (in meters a.s.l.) of Ojota area in Lagos State, Nigeria.

Table 1. Site description of the sampled stations.

Sample code	Locations	Longitude (East)	Latitude (North)	Average water level (m a.s.l)	Distance from the landfill (m)
[4]WL01	No. 55, Hazzan street, Ikosi Ketu, Ojota	3022.791'	6036.202'	17.3	730
WL02	No. 6, Biola Fadayomi street, Ojota-Lagos	3022.950'	6035.417'	15.4	863
WL03	No. 18, Niyi Ogunleye street, Ojota – Lagos	3023.008'	6035.383'	9.4	974
WL04	No. 442 Ikorodu road, Ojota-Lagos	3022.920'	6036.446'	30.4	730
WL05	No. 20, Araromi street, Ikosi – Ketu, Ojota	3022.786'	6036.260'	16.6	830
WL06	No. 24 Araromi street	3022.760'	6036.199'	18.0	712
WL07	Plot 27, Ojota mechanic village (Jolly – Ventures) Lagos	3022.837'	6035.725'	23.3	930

Table 1. Continued.

WL08	No. 8, Niyi Ogunleye street, Ojota	3023.977’	6036.356’	11.0	992
WL09	No. 26, Niyi Ogunleye, Ojota	3023.033’	6035.402’	8.3	974
WL10	No. 6, Alake street, Ikosi – Ketu	3022.055’	6035.392’	3.8	1014
[5]BHO1	Muwazan Hotel, Ikorodu Rd	3022.807’	6035.297’	54.9	969
BH02	No. 20, Kudirat Abiola way, Total filling station, Ojota	3022.888’	6035.417’	20.1	810
BH03	No 1A, Oregun Rd., Ojota	3022.469’	6035.403’	40.2	861
BH04	No. 24, Akinwale street, Ikosi- Ketu	3022.716’	6035.185’	48.8	1153
BH05	No. 19, Fadayomi street, Ikorodu Rd, Lagos	3022.945’	6035.425’	45.7	1100
BH06	Bennet Industries, Plot D, Ikosi – Ketu, Oregun Industrial Estate	3022.460’	6036.104’	41.3	683
BH07	Goddis Garden, 98B, Oregun Rd.	3022.276’	6035.561’	21.3	900
BH08	Total filling station, Ikorodu road, Ojota	3022.452’	6035.479’	38.4	761
BH09	Total Consult, Plot G, Ikosi – Ketu, Oregun Lagos	3022.503’	6035.925’	40.0	408
BH10	Plot 11, ELOHIM Ezedia Mechanized Limited, Ojota, Lagos	3022.775’	6035.665’	45.7	310

[4]WL = Hand dug well.
[5]BH = Borehole well.

Table 2. Mean concentrations of the investigated physiochemical variables in Ojota area of Lagos State, Nigeria.

Variables	Mean ± standard deviation (range)	Dry season values	Wet season values	WHO maximum permissible limit in water for domestic purposes
pH	8.3 ± 2.77 (3.2 – 12.4)	5.4 ± 1.1 (3.2 – 7.2)	6.7 ± 1.9 (3.8 – 12.4)	6.5 – 8.5
Electrical conductivity (μScm^{-1})	584 ± 745.68 (68.0 – 3030.0)	551.4±653.6 (68.0 – 2820.0)	617.9±843.7 (69.0 – 3030.0)	1000
Cu (mg/L)	0.02 ± 0.04 (0 - 33)	1.05 ± 0.99 (0 – 2.8)	1.01 ± 1.3 (0 – 3.3)	0.5
Fe (mg/L)	4.23 ± 6.4 (0 – 21.4)	2.7 ± 6.0 (0 – 21.4)	5.8 ± 6.6 (0 – 18.5)	0.1
Pb (mg/L)	2.4 ± 3.3 (0 – 14.8)	3.2 ± 4.0 (0 – 14.8)	1.5 ± 2.2 (0 – 5.9)	0.01
Zn (mg/L)	0.04 ± 0.06 (0 – 0.23)	0.04 ± 0.05 (0 – 0.2)	0.05 ±0.06 (0 – 0.23)	3.0
Co (mg/L)	1.03 ± 1.1 (0 – 3.3)	0.02 ± 0.03(0 –0.11)	0.03 ±0.04 (0 – 0.11)	0.0002

thorough agitation of the water in the well; so as to derive a homogeneous and representative sample. 2 L was subsequently taken from the bulk sample and stored in well labeled, clean polyethylene bottles for laboratory analyses. Separate water samples were however collected for dissolved oxygen (DO) and five day-biochemical oxygen demand (BOD5) in clean 250 ml reagent bottles. The DO was fixed on the field and the bottled lids were replaced to preserve the absolute oxygen content in the water samples and minimize oxygen contamination and the escape of dissolved gases. The other water samples were analyzed for electrical conductivity (EC), potential hydrogen (pH), lead (Pb), iron (Fe), zinc (Zn), cobalt (Co) and copper (Cu); solute properties that have generated concerns in water development, globally (GEMS/WHO, 1996), especially in terms of their toxicity. pH and EC were determined using pH/conductivity meters (Jenway model) while Co, Cu, Fe, Pb and Zn were determined with the aid of the Atomic Absorption Spectrophotometer (AAS), respectively at 240.7, 324.7, 248, 283 and 213.9 nm wavelengths (APHA et al, 1992).

In addition, the American Landsat ETM+ imagery (2006) of the study area was sourced and processed using the Erdas Imagine software, and presentations were made in ArcView 3.2a. The Digital Elevation Model to show the topography of the area was generated with Surfer 32. The value of each point source was interpolated using the nearest neighbour interpolation (see ArcView Helpfile for details on how this is generated).

RESULTS AND DISCUSSION

The summary of the results of laboratory analyses conducted on the samples are in Table 2. Table 2 shows that the groundwater resource is not suitable for domestic purposes for which it is presently used in some of the residential areas in the study area. The waters are generally alkaline (8.3 ± 2.77), and generally contain the investigated heavy metals at an amount that is above the maximum recommended (WHO, 1998) limits, except perhaps Zn. Specifically, the pH of the groundwater samples showed that the water sources around the landfill were within a wide range of 3.8 and 12.4. Samples from the residential area (Ikosi – Ketu) were between slightly acid to highly alkaline while those from the industrial area (Oregun) were acid. The lowest pH (3.2) in the investigated groundwater sources was recorded in a borehole within the industrial area; in a firm that shares a wall boundary with the landfill (Bennet Industries, Plot D, Ikosi – Ketu, Oregun Industrial Estate). The borehole was 41.3 m deep, in the dry season.

The most alkaline was a 16.6 m hand dug well in the residential area in Ikosi Ketu, northeast of the landfill (No. 20, Araromi Street, Ikosi – Ketu, Ojota) From Figure 4a (i and ii), a number of groundwater in the study area was acid in the wet season, and are not suitable for domestic use, especially drinking, when compared with the Standard Limits (FEPA, 1991; WHO, 1998). The effects of acidic waters on human health and the environment have been widely reported. For example, acidic waters have been known to be aggressive and enhance the dissolution of iron and manganese causes unpleasant taste in water (Edwards et al*.,* 1983).

The overall EC values varied between 68.0 and 3030.0 μcm^{-1}. The solute concentration in the wet season (617.9 ± 843.7μcm^{-1}) was higher than the dry season's (551.4 ± 653.62 μcm^{-1}). EC was lowest for a sample collected from a borehole sited at about 810 m away from the landfill (No. 20, Kudirat Abiola way, Total filling station, Ojota) while the highest occurred in a sample from a borehole closer to the landfill (310 m) (Plot 11, ELOHIM Ezedia Mechanized Limited, Ojota, Lagos) (Table 1). Another instance of serious concern is a hand dug well in the Ojota mechanic village (Plot 27, Ojota mechanic village (Jolly – Ventures) Lagos), where mean conductivity was 2940 μcm^{-1}. On the whole, water sampled within 310 m radius of the landfill is characterised by high conductivity, quite above the World Health Organisation's standard limits of 1000 μcm^{-1}, although the instances of lower conductivity in some groundwater sources have reduced the average conductivity to appear normal. A number of groundwater sources within the residential area also contain high conductance value in the wet season (Figure 4b (i and ii), probably as a result of increased volume of water and runoff in the wet season. According to Jackson (1989), the wetter, a landfill or dumpsite is, the greater the seepage runoff and chemical enrichment of the groundwater resource. High conductivity will in most cases affect the taste of water (Langenegger, 1990).

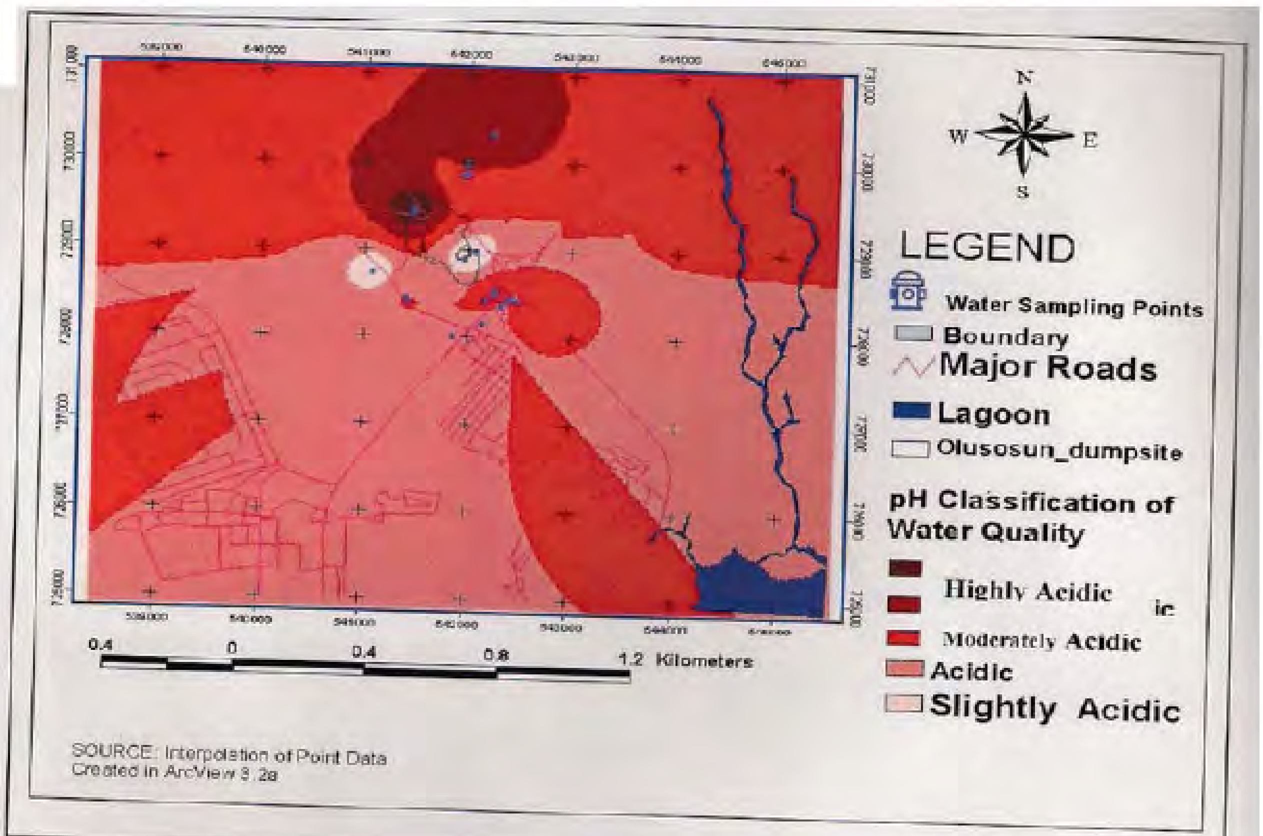
Figure 5 shows the spatial and seasonal variations in the distribution of the investigated heavy metals (Co, Cu, Fe, Pb, and Zn) in the study area. Each heavy metal is classified into portable, above permissible limits, hazardous, toxic and highly toxic. Except for zinc whose concentration in the water samples was detected to be within the maximum permissible range, all other heavy metals are abnormally high (Table 2) (FEPA, 1991; WHO, 1993). Concentrations of ions above permissible limits are generally not suitable for consumption.

For example, water containing cobalt ions (≥ 0.0002 mg/L) can have an erythropoietic effect such as increased incidence of goitre among most mammals, including humans. In addition, toxic concentration of lead (≥ 0.01mg/L) in human beings has been implicated for causing anaemia, kidney damage and cerebral oedema (Townsend, 1991; Egborge, 1991).

In this study, 0.11 mg/L of Co was detected in a hand dug well in a residential house (No. 18, Niyi Ogunleye Street, Ojota). Figure 5e shows that the groundwater sources in the whole of the northeast and southeast had cobalt in high concentration, covering a total of about 426.1 Ha. Cu similarly varied from 0.0 to 3.32 mg/l. Higher concentrations were obtained in the wet season than in dry season, and in hand dug wells than in boreholes. Figure 5a showed that water quality around the southeast of the study area is toxic. Areas with toxic groundwater are represented as bright reddish and dark turquoise coloured areas, covers Ketu, Mile – 12 residential areas, and towards Oregun industrial estate. The iron concentration in the study area is higher than the desirable limit. The ferrous level is toxic in the southeast of the landfill, where mechanical repairs of vehicles and use of engine oils are on a daily basis. Similarly, lead was observed in abnormally high concentrations in most groundwater sources in dry season. It is particularly toxic in the borehole within 310 m of the landfill.

Conclusion

The study has shown that the groundwater sources within 2 km radius of the Olusosun landfill in Ojota area of Lagos State, Nigeria, are contaminated by heavy metals. This very large extent is associated with the dispersion of chemical constituents from leacheates produced at the landfill. The seepage of chemical constituents in the leachate formed as a consequence of continuous disposal of municipal and industrial wastes at the landfill have been shown to constitute serious threat to the environment and human health (Abu-Rukah and Al-Kofahi, 2001; Lee et al., 2005). The uncontrolled disposal of lead acid batteries and spent petroleum products probably caused the relative high levels of Pb, Cu and Fe found in groundwater. The spatial and seasonal variations in most of the investigated variables suggest point source contamination in hand dug wells and boreholes. Field observations have shown that some of these wells and boreholes were covered with rusty metal sheets and planks. The study has also provided some relevant baseline information for accessing the public health risks, which could arise from the intake of groundwater from Ojota area of Lagos State. It is therefore recommended that the dumpsite condition be improved to minimise the effects on the environment or that it be relocated to another area, outside the ai



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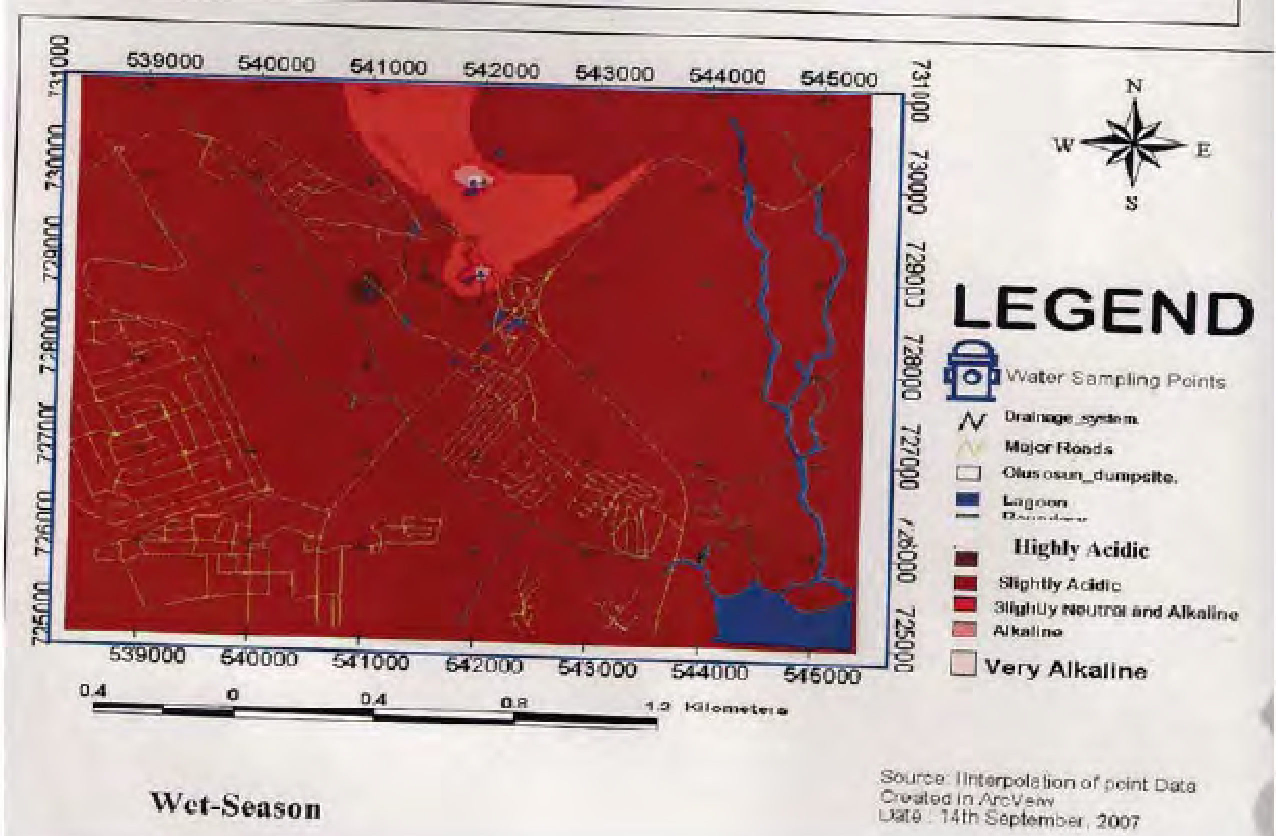

Figure 4a. Spatial and temporal variations in the pH (ai and aii) in groundwater in Ojota area, Lagos State.

bi

bi

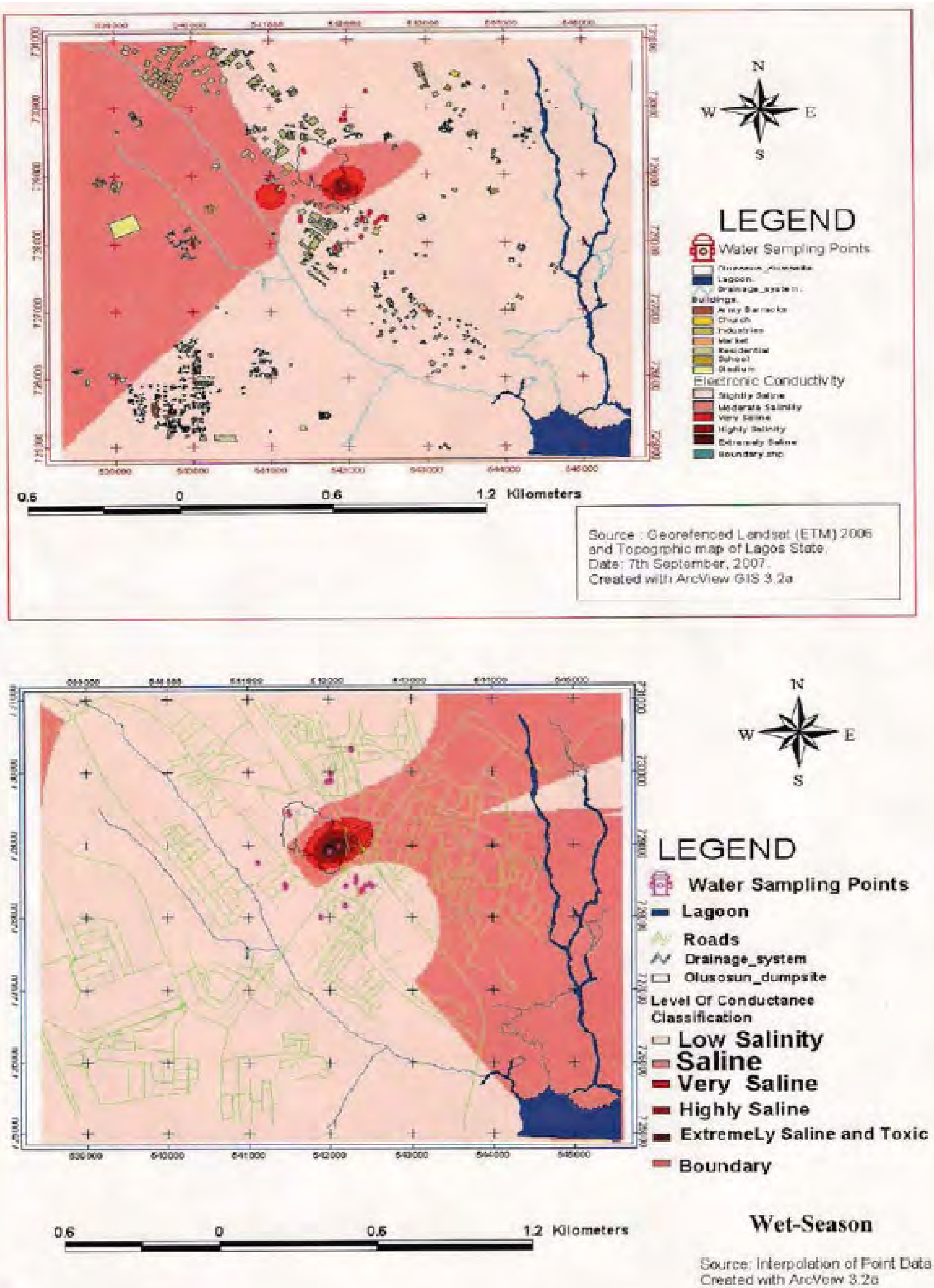

Figure 4b. Spatial and temporal variations in the conductivity (bi and bii) in groundwater in Ojota area, Lagos State.

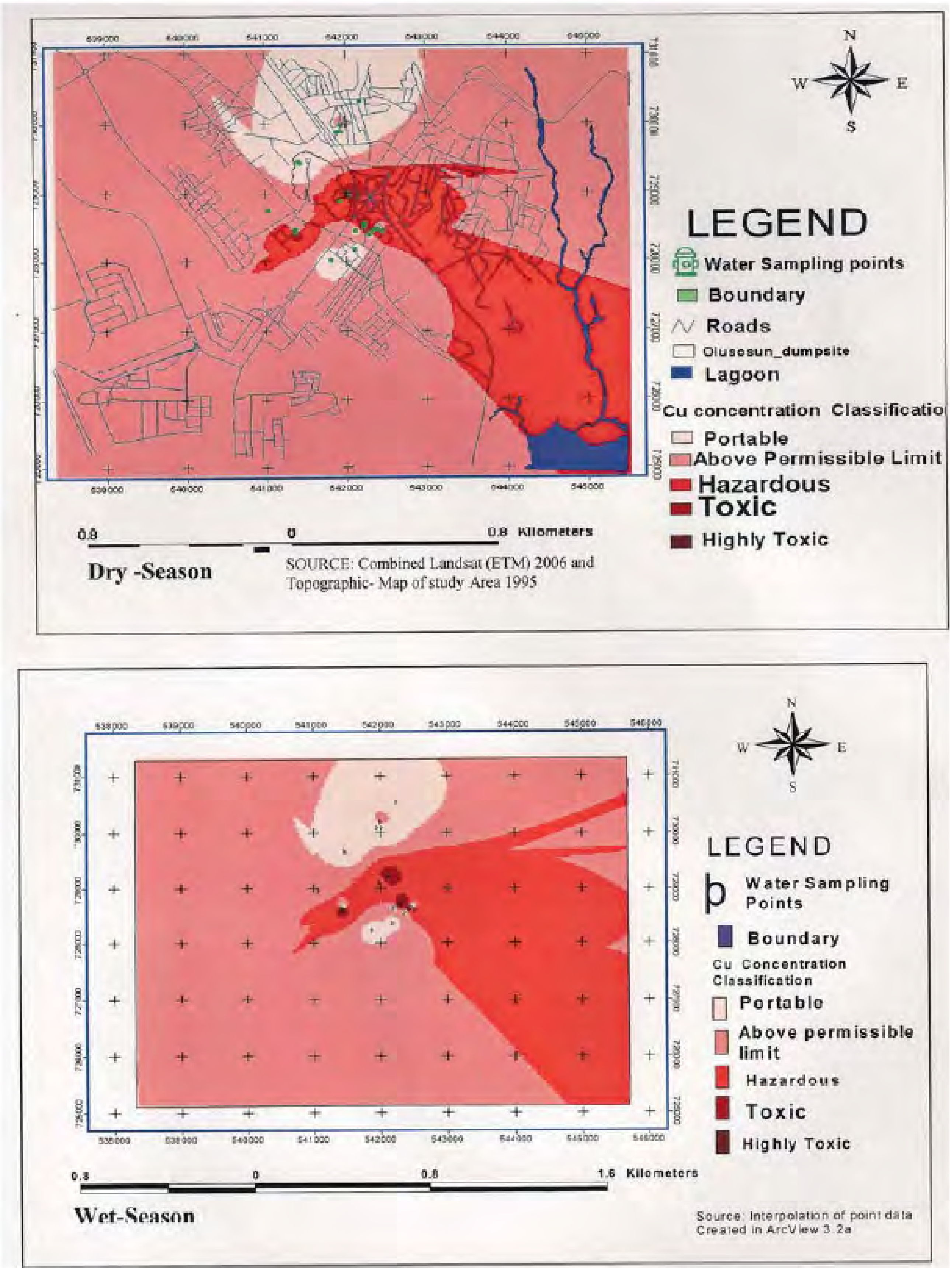

Figure 5a. Spatial and temporal distribution of Copper (Cu) in groundwater in Ojota, Lagos.

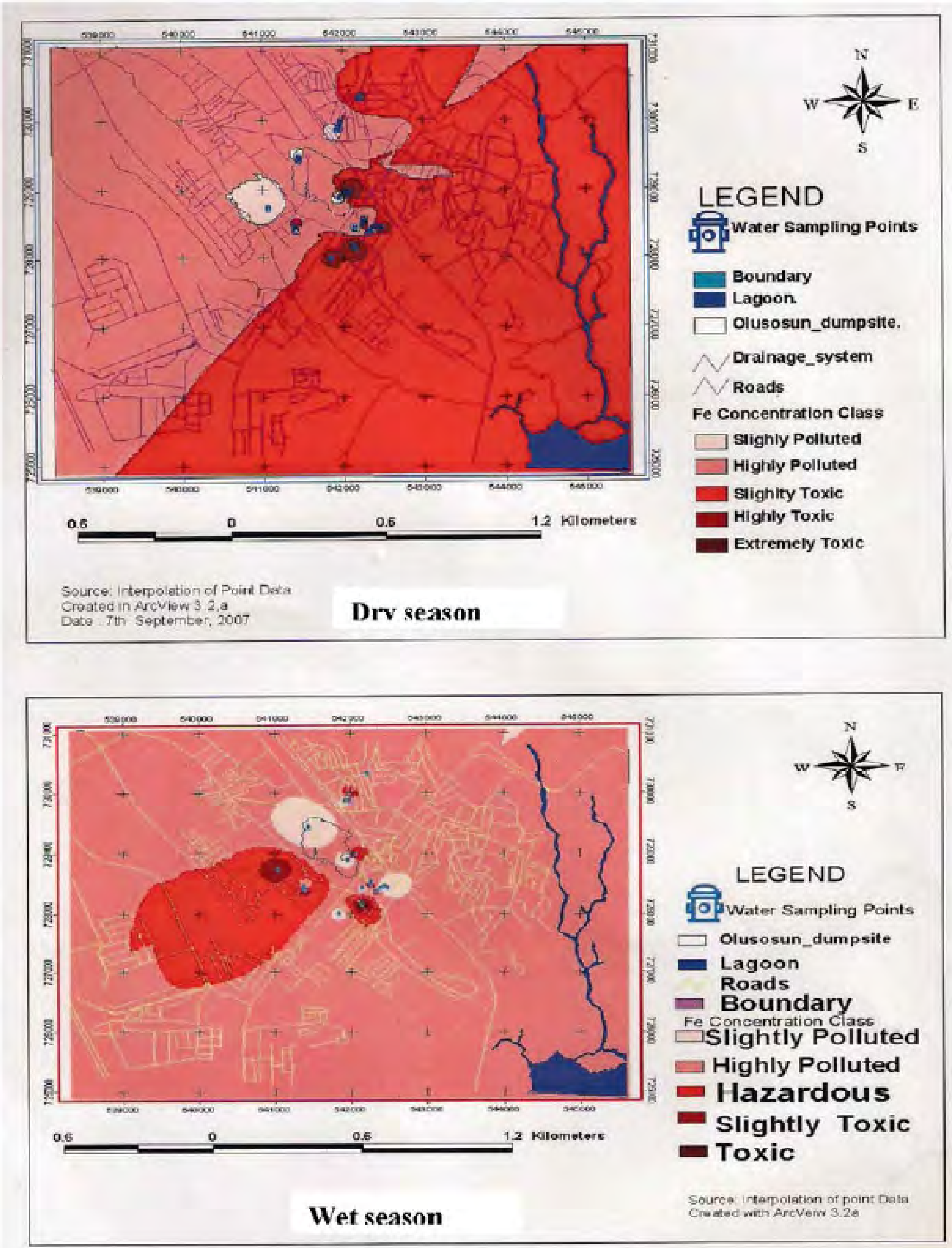

Figure 5b. Spatial and temporal distribution of Iron (Fe) in groundwater in Ojota, Lagos.

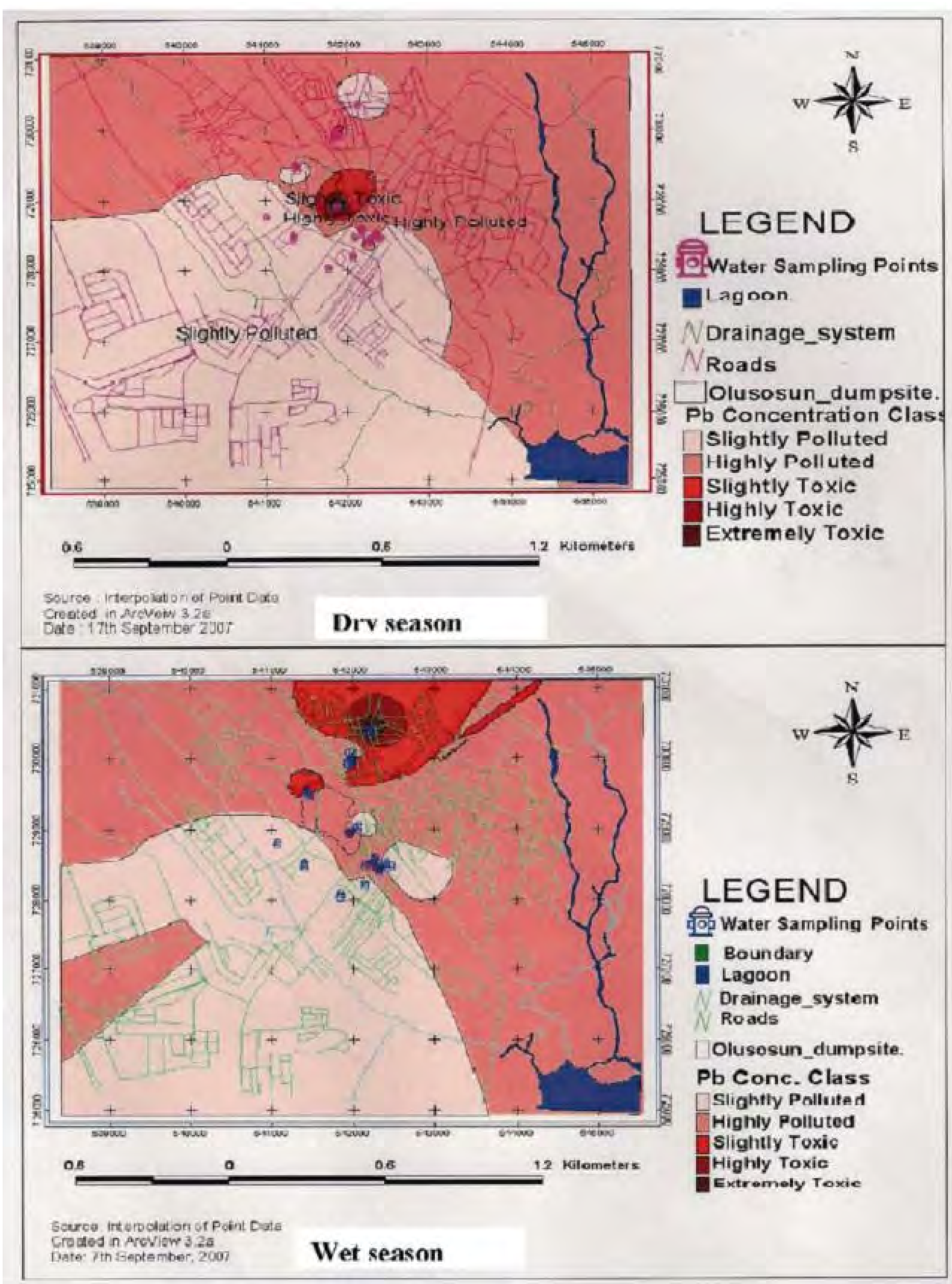

Figure 5c. Spatial and temporal distribution of Lead (Pb) in groundwater in Ojota, Lagos.

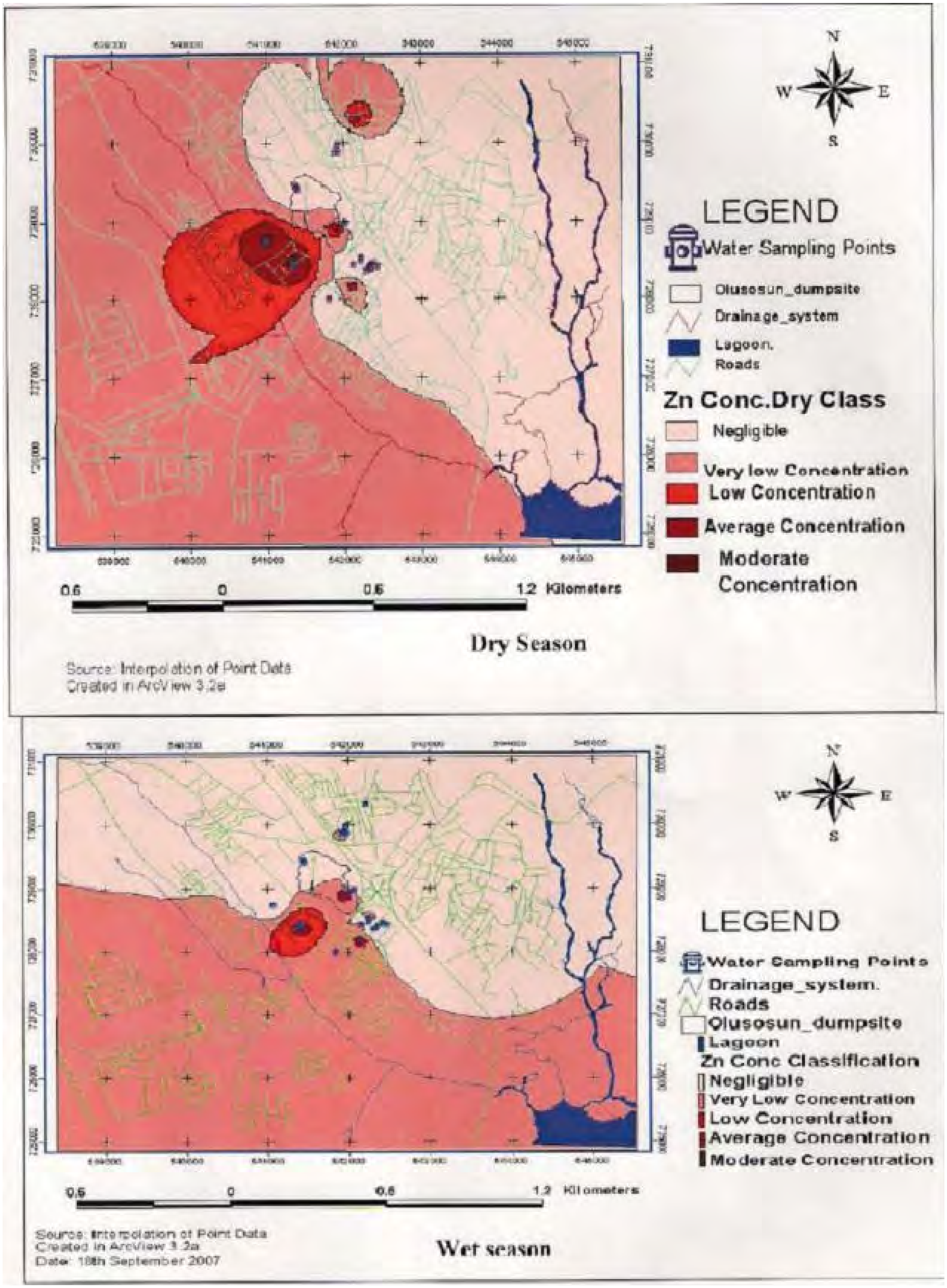

Figure 5d. Spatial and temporal distribution of Zinc (Zn) in groundwater in Ojota, Lagos.

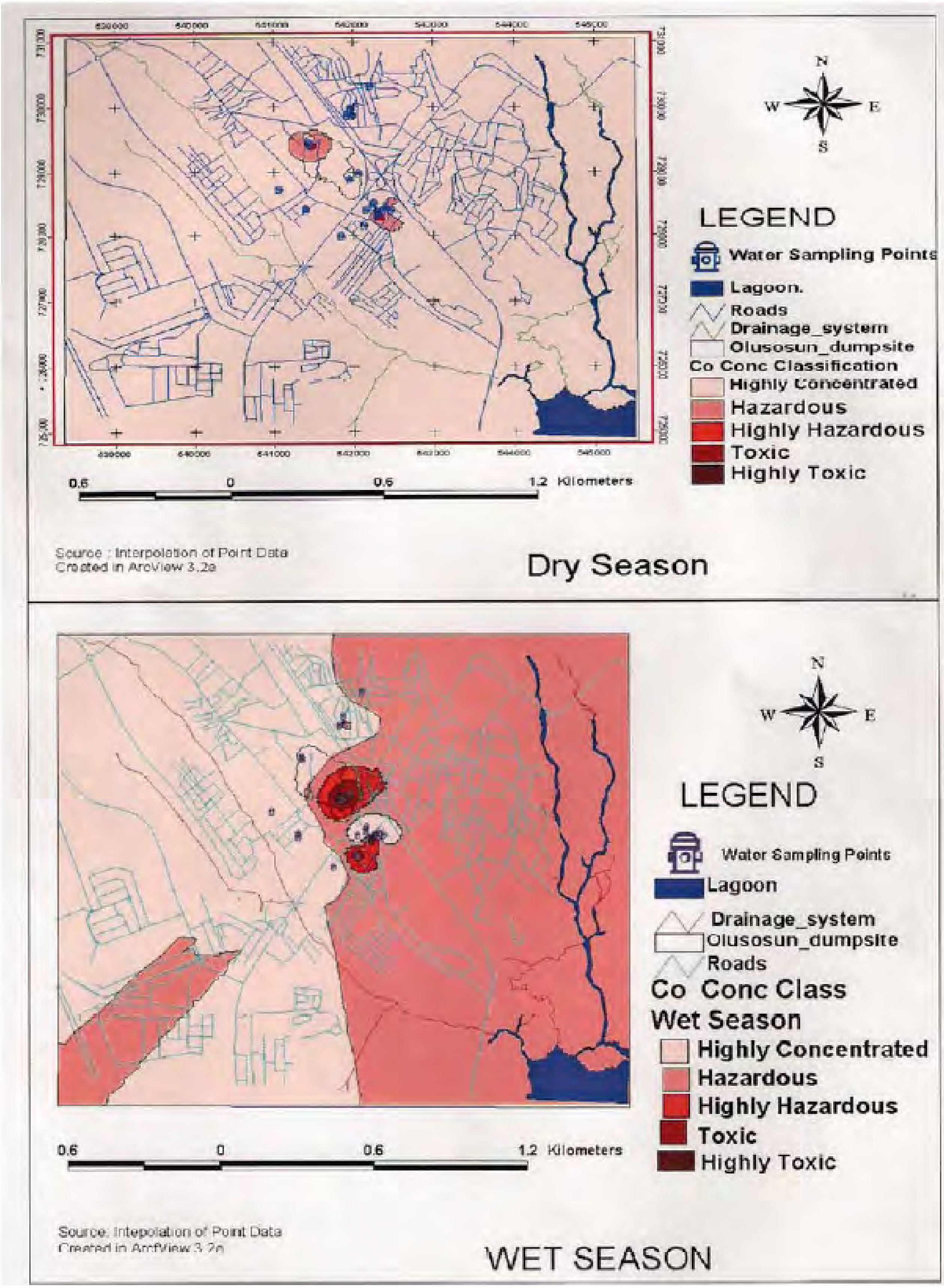

Figure 5e. Spatial and temporal distribution of Colbalt (Co) in groundwater in Ojota, Lagos.

residential area.

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