Integrated Use of Electrical Impedance Tomography Techniques in the Investigation of Dumpsite-Induced Groundwater Contamination

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Abstract: Electrical Impedance Tomography (EIT) is an imaging technique which calculates the electrical conductivity distribution within a medium. It allows estimation of the spatial distribution of the electrical conductivity within a medium from voltage measurements at its boundary, using non-invasive imaging technique. In this study, electrical measurements were made on the medium surface using circular electrode configuration patterns. The Opposite (Polar) and Cross (Diagonal) methods of current injection patterns and voltage measurement sequences were employed with a view to investigating dumpsite-induced groundwater contamination within an unconfined dumpsite, located at Solous 2, in Lagos State, Southwestern Nigeria. The inversion of the data was accomplished using Electrical Impedance and Diffuse Optical Reconstruction Software toolkits for MATLAB to obtain three – dimensional electrical conductivity profiles. The toolkits utilise a finite element model for forward calculations and a regularised nonlinear solver to obtain a unique and stable inverse solution. The scheme utilised is a forward solution, solved using a mesh of 768 finite elements with 205 nodes and 256 boundaries. The results depicted low and high conductivity responses on the dumpsite, ranging from less than 100 mS/m to 1500 mS/m, thus, the subsurface of the dumpsite reveals varying extent of waste decomposition. The high conductivity response of 1000 mS/m to 1500 mS/m is interpreted as conductive leachate contaminants, which are from the decomposing waste materials and have accumulated at several discrete localities within the dumpsite. It has been found that, the contaminants have migrated to depths exceeding 40 m, well below the aquifer, and over 25 m offsite distance from the dumpsite. The study showed that EIT can be used effectively to map areas of active decomposition that are characterised by varying conductivities, hence, a very adaptive tool to realise a systematic survey in dumpsites investigations.

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1. Introduction

Groundwater is of major importance to civilization since it is the largest reserve of potable water in regions where humans live. The health and well being of the population depend on abundance and adequate supply of this natural resource. Water forms an indispensable resource in economic activities like commerce, tourism and industry, and also for uses in domestic activities and agriculture. The result of some studies in Nigeria showed that water resources in many parts of the country, especially the southern part, are more than adequate to meet any demand and only need development (Egereonu and Ibe, 2003; Alile *et al*., 2011). Groundwater is less contaminated than surface water. Pollution of this major water supply has become an increasing concern in industrialized and industrializing nations due to contamination by toxic substances (Guter, 1981). Waste metal dumps and other waste materials which are either surface or buried are known to produce leachate that penetrate the aquifer and contaminate the groundwater (Becker, 2001).

Contaminant plumes usually have a sufficiently high contrast in physical properties against the host media due to an increase in dissolved salts in the groundwater and a resulting decrease in pore water resistivity; therefore they may be detected by geoelectrical techniques. Early studies have shown that the electrical resistivity method is one of the most efficient geophysical tools in detecting, delineating and monitoring underground contaminants (Greenhouse and Slaine, 1983; Olowofela and Akinyemi, 2001; Ayolabi, 2005).

Most geophysical responses from targets of environmental, hydrogeological and engineering interest are at shallow depths. The shallow subsurface of the earth is a very critical geological zone where complex interactions exist between processes in hydrogeology, geochemistry and geobiology (Slater *et al*., 2006). This critical geological zone is of utmost importance because it yields much of our water resources, supports our agriculture and ecosystems, influences our climate, and serves as a repository to most of our wastes. In addition to the shallowness of most targets, the subsurface geology encountered in some environmental and engineering investigations is heterogeneous, subtle, complex and multi-scale. Thus, the classical approach for resistivity surveys is not sufficient for environmental and engineering studies in such areas with complex and heterogeneous geology, such as dumpsites (Dahlin and Loke, 1998).

Electrical Impedance Tomography (EIT) is a relatively new imaging technique that produces images by computing electrical conductivity within an object or body (Barber and Brown, 1984; Webster, 1990). It is a technique that allows estimation of the spatial distribution of the electric conductivity within an object from voltage measurements at its boundary, using non-invasive imaging technique (Borsic, 2002). Normally, an array of electrodes is used to inject current, and the resulting voltage drops are measured with other electrodes within the array. The internal conductivity distribution of the object is reconstructed based on electrical measurements from electrodes attached around the boundary of the object or body under investigation.

EIT involves the injection of current into a body using circular electrode arrangements or configuration patterns to image the internals of the medium under investigation and has been principally used in the medical field to image organs of interest (Cook, 1992; Cheney and Isaacson, 1995; Cheney *et al.*, 1999; Broom, 2001; Olowofela *et al*, 2012a). It allows the generation of three - dimensional (3D) images of electrical conductivity for a given profile or volume of ground and is suitable for non-invasive investigation of dumpsites due to its sensitivity to high electrical contrasts as caused by changes in material types, fluid saturation and ion concentration levels (Daily and Ramirez, 1996; Pessel and Gilbert, 2003; Ruzairu *et al.*, 2003).

Lagos is a cosmopolitan city in Nigeria, characterized by a beehive of activities as a result of being the commercial nerve centre of the country. It has witnessed tremendous increase in population in the recent past, as such, huge masses of diverse wastes are generated far more than could be removed and dumped safely by the relevant government agencies. As a consequence, wastes are mostly dumped on open grounds, landfills and in water bodies, constituting serious environmental and health problems (Ball and Stove, 2002). Groundwater been the major source of potable water supply in the study area and Lagos in general, its contamination is a major environmental and health concern. This study was therefore, undertaken with the objective of investigating dumpsite-induced groundwater contamination at Solous 2 in Lagos State, Southwestern Nigeria.

2. Physics of the EIT Problem

An arbitrary medium, Ω undergoing electrical stimulation has electrical properties that vary as a function of position and time. These properties are represented by the electrical impedance, $\sigma(\vec{x},t) + j\omega(\vec{x},t)$, and relative permittivity $\epsilon\,(\vec{x},\, t)$, where $\vec{x} = (x_1, x_2)$ for 2D or $\vec{x} = (x_1,\, x_2,\, x_3)$ for 3D is the position vector. This work does not consider the temporal aspect of these functions. At high frequencies, magnetic effects cannot be ignored (Noor, 2007). However, under low frequency conditions the electrical properties are entirely described by the conductivity, σ(x).

A mathematical model of the problem is derived from Maxwell's equations. Outside the medium, Ω, there is no current flow because the conductivity is zero. Energy is applied to the medium in the form of current injection on the boundary, $\partial\Omega$, which sets up a distribution of voltage, $u(\vec{x})$, and a pattern of current flow, $J(\vec{x})$, in the medium. The electric potential, $u(\vec{x})$, can be expressed by an elliptic partial differential equation known as Laplace's equation or just the Laplacian:

$$\nabla.(\sigma\nabla u) = 0 \; in \; \Omega \qquad 1$$

Laplace's equation can be derived starting from the point form of Ohm's Law:

$$J = \sigma E \qquad 2$$

where the electric field vector, E, is obtained from the scalar potential function u(x) by taking the negative of the gradient of u :

$$E = -\nabla u \qquad 3$$

Applying the field equivalent of Kirchoff's current law, which states that the net current leaving a junction of several conductors is zero, yields:

$$\nabla J = 0 \qquad 4$$

Substituting 3 into 2 and taking the divergence of both sides in accordance with 4 gives Laplaces's equation 1 for the electric potential inside some medium. Cheney and Isaacson (1995) provide the following intuitive description of this equation:

"To understand where the equation comes from, it helps to read it from the inside out. The inside nabla takes the gradient of the potential, $u(\vec{x})$, computing the direction in which electrons will tend to flow, as well as the rate of change of voltage in that direction. In electric circuits, the conductance of a wire times the change in voltage gives the current passing through the wire. $\sigma(\vec{x})$ times the gradient of $u(\vec{x})$ represents the current at point $\vec{x}$. Finally, the outer nabla computes the divergence of the current, a measure of its tendency to flow into or out of one spot. As long as no charge is building up inside the body (a reasonable assumption), the divergence equals zero. The inverse electrical impedance problem is non-linear because the unknown conductivity and potential are multiplied together."

The boundary conditions on $\partial\Omega$, the boundary of Ω, are formed by fixing the normal current, $J_{\hat{n}}$, at every point of $\partial\Omega$. Representing the normal vector by $\hat{n}$, we have

$$J_{\hat{n}} = \sigma \frac{\partial u}{\partial \hat{n}} \; on \; \partial\Omega \qquad 5$$

The presence of the electrodes is taken into account via appropriate boundary conditions which will appear as modifications to the equation for normal current, 5, on $\partial\Omega$.

One possible model for EIT is (1) and (5) together with the conservation of charge condition (Graham, 2007)

$$\sum_{l=1}^{L} \mathrm{I}_l = 0 \qquad 6$$

And the condition

$$\sum_{l=1}^{L} V_l = 0 \qquad 7$$

This amounts to choosing a "ground" or reference voltage. The integral of the current density over the electrode is equal to the total current that flows to that electrode. Thus,

$$\int_{el}^{.} \sigma \frac{\partial u}{\partial \hat{n}} ds = I_l ,$$
$$l = 1,2,3, \dots \dots , L \qquad 8$$

where I_l is the current sent to the l^{th} electrode and e_l denotes the part of $\partial\Omega$ that corresponds to the l^{th} electrode. This is combined with

$$\sigma \frac{\partial u}{\partial \hat{n}} = 0 \text{ (in the gaps between electrodes)} \qquad 9$$

The conventional way to model the very high conductivity of the electrodes is to impose the constraint that u is constant on each of the electrodes (Graham, 2007). In practice, these constants which are denoted by U_l are the measured voltages on the electrodes. Therefore,

$$u = U_l \text{ on } e_l \qquad 10$$

Equation (10) fails to account for an electrochemical effect that takes place at the contact between the electrode and the body. This effect is the formation of a thin, highly resistive layer between the electrode and the body. The impedance of this layer is characterised by a number Z_l which is the effective contact impedance or surface impedance. The constraint (10) is therefore replaced by

$$u + Z_l \, \sigma \frac{\partial u}{\partial \hat{n}} = U_l \; on \; e_l \, ,$$
$$l = 1,2,3, \dots \dots , L \qquad 11$$

Equation (11) means that the measured voltages on the boundary consist of the voltage on the boundary plus the voltage dropped across the electrode impedance.

Equations (1), (8), (9) and (10), together with the conditions (6) and (7) give the complete electrode model for EIT.

These equations comprise the forward problem in EIT and are used to find the voltage distribution within the medium. However, solving the forward problem for models with arbitrary geometries requires numerical techniques such as the finite element method. With such methods, continuum problems of the equations are converted into discrete algebraic problems that can be solved with a computer.

3. Materials and Methods

Sites Description and Accessibility

Solous 2 dumpsite is located at Isheri, in Alimosho Local Government Area of Lagos State (Figure 1). Its geographical locations are 6.50°N, 3.31°E. The site is located along Lagos State University (LASU) - Isheri expressway and covers an area of about 9 hectares of land. It is surrounded by residential, commercial and industrial set-ups. The dumpsite has witnessed rehabilitation, such as reclamation of land, construction of accessible road for ease of tipping, spreading and compaction of waste since inception in 2007. It receives waste from entire Lagos metropolis. In its quarterly report, Lagos Waste Management Authority reported that a total of 469, 202.50 tonnes of municipal solid waste (MSW) was landfilled in the site in 2009 alone (LAWMA, 2009). It is accessible by tarred roads.

Figure 1: A section of Solous 2 dumpsite in Lagos, Nigeria

Geologic and Hydrogeologic Settings of the Study Area

Two principal climatic seasons can be easily distinguishable; the dry season which is usually from November to March and the wet season which starts from April and ends in October, with a short dry spell in August. Average annual precipitation is put at about 1,700 m^3 and serves as a major source of groundwater recharge (Jeje, 1983). Lagos is basically a sedimentary area located within the Western Nigeria coastal zone, a zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition. The subsurface geology reveals two basic lithologies; clay and sand deposits. These deposits may be interbedded in places with sandy clay or clayey sand and occasionally with vegetable remains and peat (Ayolabi and Peters, 2005). It is identified that the geology is made up of sedimentary rock mostly of alluvial deposits. These consist of loose and light grey sand mixed variously with varying proportion of vegetation matter on the lowland; while the reddish and brown loamy soil exists in the upland.

Field Investigations and Data Acquisition

Field investigations in the site were conducted using the Opposite (Polar) and Cross (Diagonal) methods of Electrical Impedance Tomography data acquisition technique to generate three - dimensional (3D) conductivity profiles of the dumpsite.

This requires providing a perfect circular layout for the electrode positions. This was achieved by using a thick white thread marked out at 10 m distance each for 16 electrodes. The circular layout showed where to plant electrodes on a circumference of 160 m. Electrodes were driven into the dump covered ground using the hammers till good contact was made with the ground. The current and voltage electrodes were connected to the terrameter via the reels of red and blue cables respectively, whose ends were connected to alligator clips to make good connection. Current was supplied to the current electrodes by the 12V battery and the corresponding values of the voltage and current were read off the PASI Terrameter and recorded. Two EIT models, each for the two acquisition methods, were taken on the dumpsite at locations 20 m apart.

Opposite (Polar) Method

Under the Opposite (Polar) method, current is injected through two diametrically opposed electrodes (Hua *et al*., 1987). Current was first applied through electrodes 16 and 8. The electrode adjacent to the current –injecting electrode (electrode 1) was used as the voltage reference. Voltage was then measured from all other electrodes except from the current electrode, yielding 13 voltage measurements. The next set of 13 voltage measurements was obtained by selecting electrodes 1 and 9 for current electrodes (Figure 2). This was followed by 2 and 10, 3 and 11,… ,8 and 9. With 16- electrode arrangement, this method yielded 8 x 13 = 104 data points.

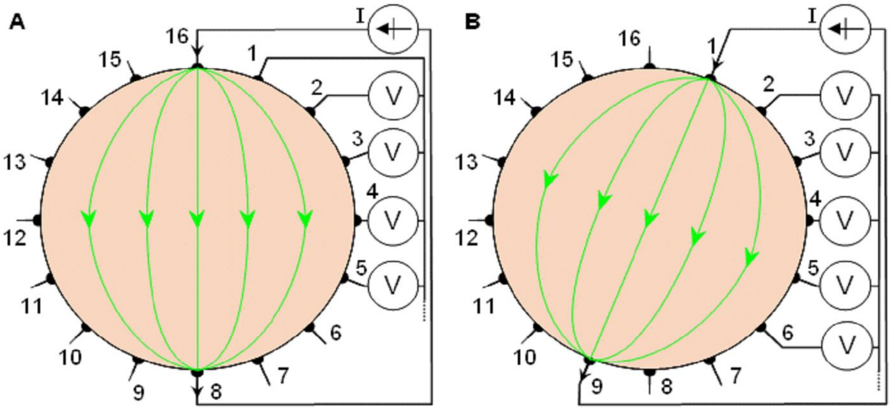

Figure 2: The Opposite method of impedance data collection

Cross (Diagonal) Method

In the Cross (Diagonal) method of Impedance measurement, (Figure 3) adjacent electrodes are first selected for current and voltage reference electrodes, respectively (Hua *et al*., 1987). Here, electrode numbers 16 and 1 were first selected for current and voltage reference electrodes respectively. The other current electrode, electrode number 2 was first used. The voltage was measured successively for all other 13 electrodes with electrode 1 as a reference. The current was then applied through electrode 4 and the voltage was again measured successively for all other 13 electrodes with electrodes 1 as a reference. The procedure was repeated using 6, 8, ----14; which gave 7 x 13 = 91 measurements. The measurement sequence was then repeated using electrodes 3 and 2 as current and voltage reference electrodes, respectively. I then applied current first to electrode 5 and then measured the voltage successively for all other 13 electrodes with electrode 2 as a reference. The procedure was again repeated by applying current to electrode 7, 9, 11 ----, 1 and measuring the voltage for all other 13 electrodes with 2 as a reference to obtain another 91 measurements. From the cross method, a total of 182 voltage measurements was obtained.

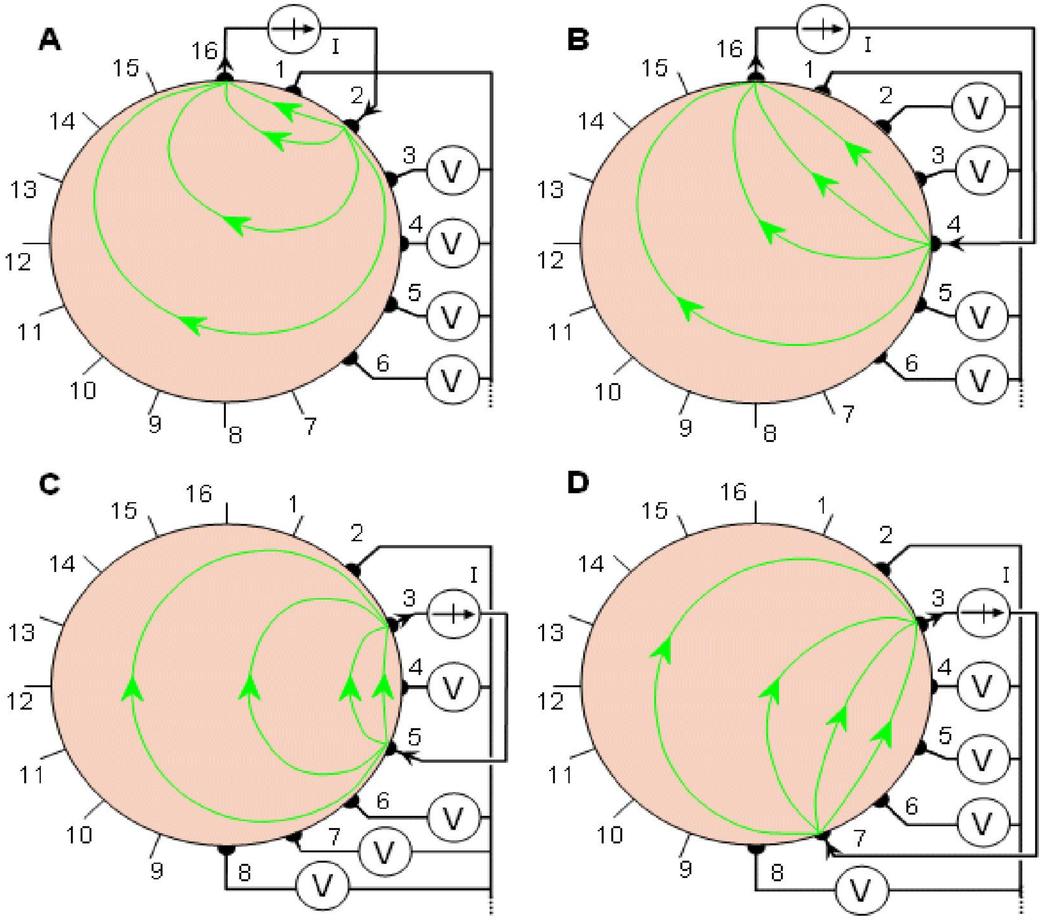

Figure 3: The Cross method of impedance data collection. The four different steps of this procedure are illustrated in A through D.

Figure 4 shows the Base map of the study area.

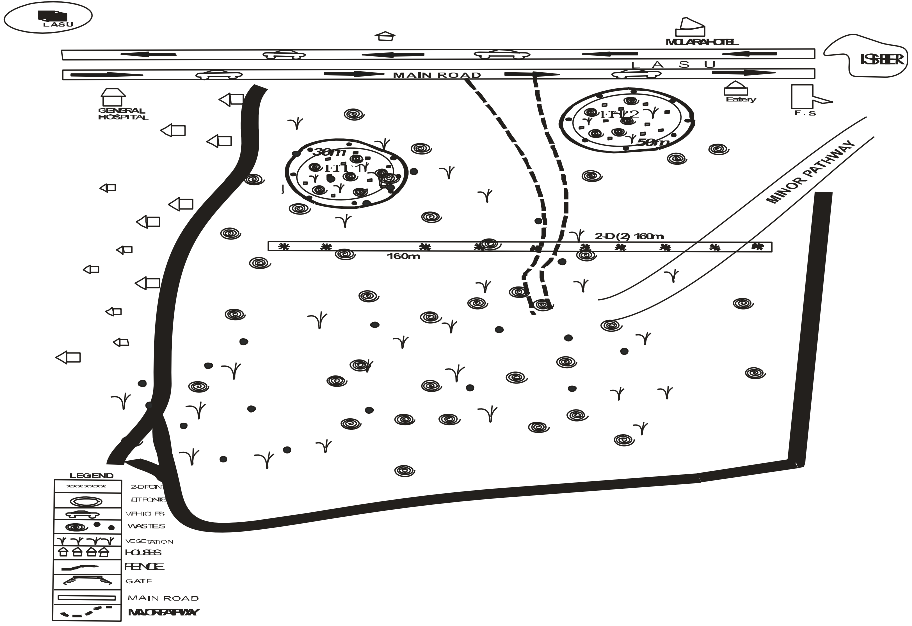

Figure 4: Base map of the study area

Data Processing and Inversion

The processing of the EIT voltage data was accomplished using the EIDORS toolkit for MATLAB. EIDORS is Electrical Impedance and Diffuse Optical Reconstruction Software. The work of Polydorides (2002) was of particular importance because he worked extensively in addressing the data processing issue of soft-field tomography, and eventually contributed to the development of the MATLAB toolkit. The toolkit was developed collaboratively by EIT research groups in order to help advance the field of EIT as a whole. It is essential because of the challenges in solving an EIT inversion problem which is nonlinear, ill-posed and is very intensive computationally. The package utilises a finite element model for forward calculations and a regularised nonlinear solver to obtain a unique and stable inverse solution. It is equipped with a mesh generator, a graphical output, and supports three-dimensional EIT systems. However, some modifications were made to the EIDORS package in order to use it in conjuction to the hardware used in this study. The scheme utilised is a forward solution solved using a mesh of 768 finite elements with 205 nodes and 256 boundaries (Figure 5). The programme then calculated the inverse solution iteratively.

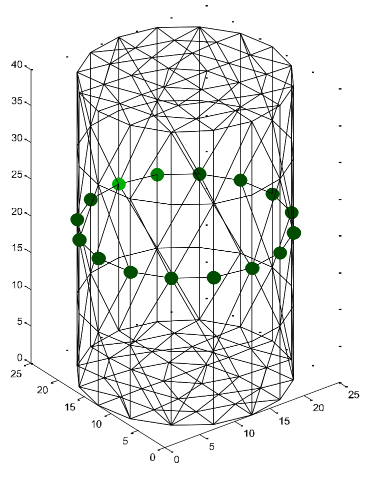

Figure 5: Mesh diagram with 768 elements, 205 nodes and 256 boundaries

4. Results

Figures 6-9 show the tomograms of the reconstructed electrical conductivity profiles of the Opposite (Polar) and Cross (Diagonal) methods of EIT on the dumpsite at location 20 m apart with sections from the inversion showing conductivity at different depths.

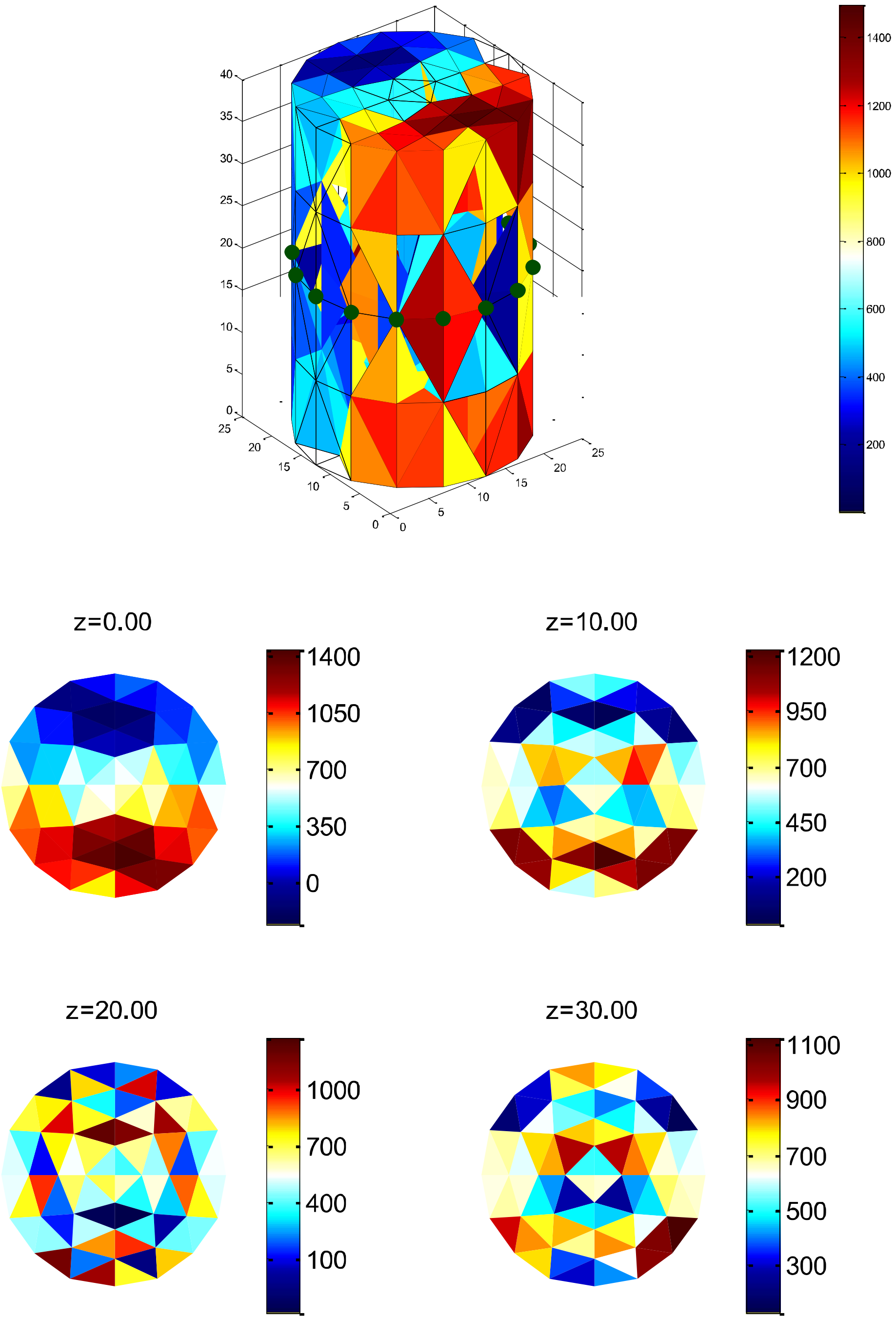

Figure 6: Opposite method reconstructed conductivity profile 1 (mS/m), where z is the depth downward (in metres).

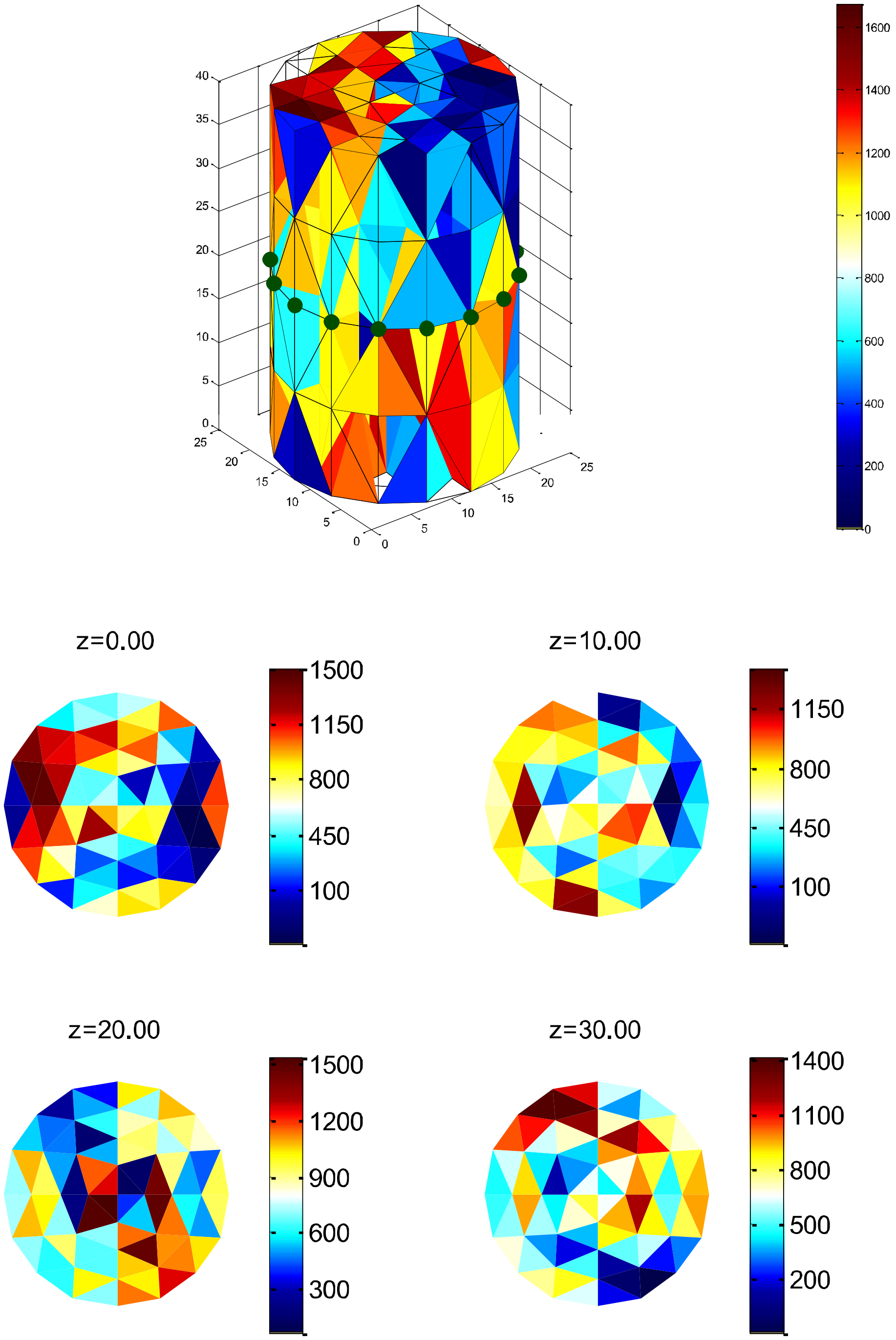

Figure 7: Opposite method reconstructed conductivity profile 2 (mS/m), where z is the depth downward (in metres).

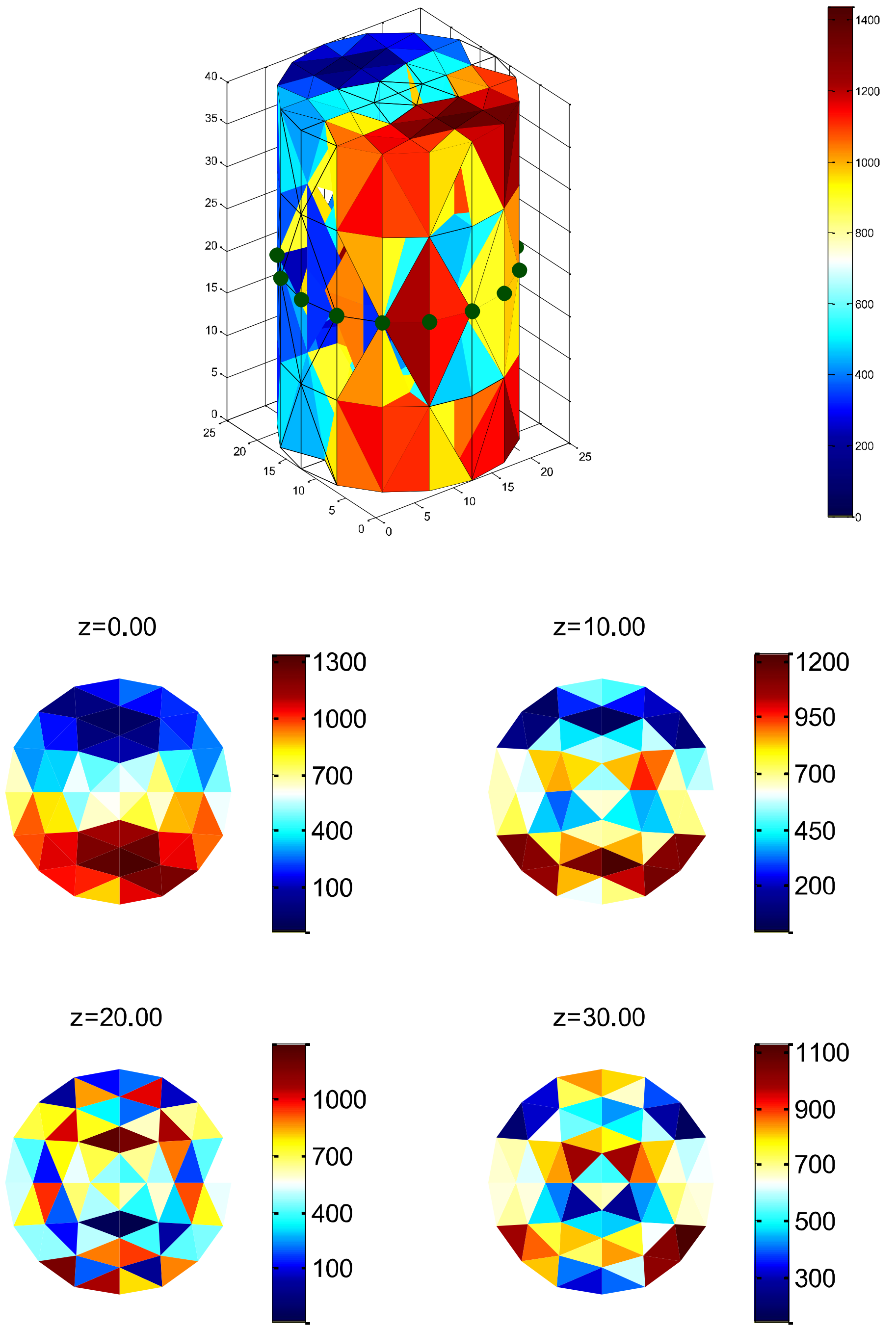

Figure 8: Cross method reconstructed conductivity profile 1 (mS/m), where z is the depth downward (in metres).

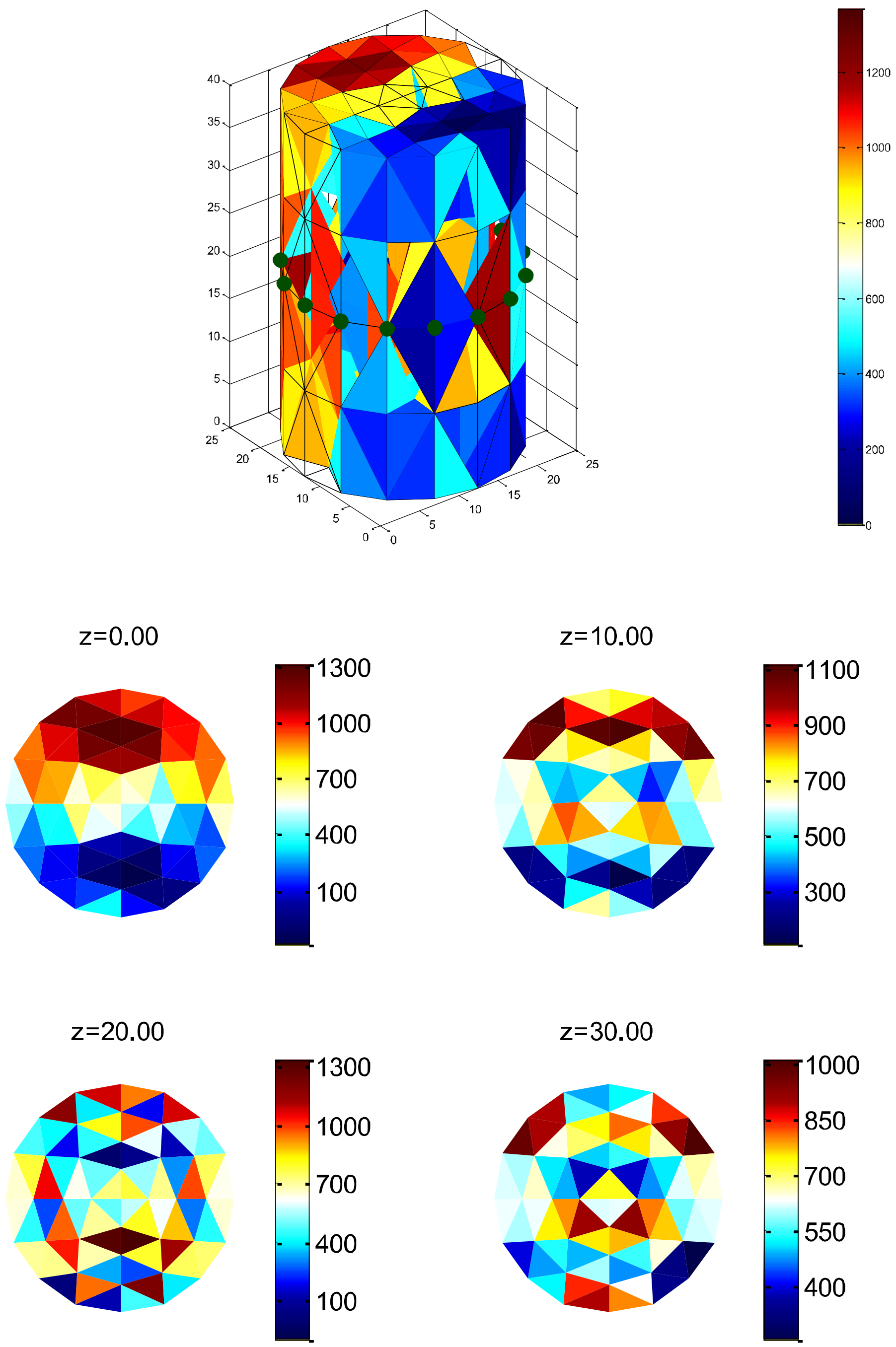

Figure 9: Cross method reconstructed conductivity profile 2 (mS/m), where z is the depth downward (in metres).

5. Discussion

The opposite profile 1 is shown in figure 6. Most section of this tomogram is characterised by high conductive zone, ranging from 900 mS/m to 1400 mS/m, from the surface up to 38 m depth, indicating leachate polluted soil. This is pronounced in the east, stretching to 25 m, with localised low conductive response within this zone. A section of the tomogram with low conductivity of less than 100 mS/m to 500 mS/m was mapped. This represents uncontaminated zone and stretches 10 m width in the north, to a depth of 40 m. A uniform conductivity value of 700 mS/m was also observed and interpreted as clay materials.

A similar trend of conductivity response was also observed on opposite profile 2 (figure 7), but with appreciable higher conductivity values when compared with profile 1. The substantial increase in conductivity is probably due to highly decomposing waste, saturated with highly conductive leachate and could also be attributed to the broken down of much of the biodegradable mass with time. The high conductive zones are characterised with conductivity in the range of 1100 mS/m to 1500 mS/m. This is an indication that this section of the dumpsite is polluted. It is from the surface up to 20 m depth and also in the north at depth 35 m to 40 m, which is an indication of the incursion of leachate into the subsurface. Some low conductive zones were observed at the surface, with conductivity value of less than 100 mS/m, which might be due to fresh dry waste within the dumpsite and from location 20 m depth, up to 40 m in the east of the tomogram. This is due to unpolluted sand.

The cross method reconstructed conductivity profile 1 is depicted in figure 8. Most section of this tomogram shows considerable high conductive zone, ranging from 900 mS/m to 1300 mS/m, from the surface up to 38 m depth, indicating leachate polluted soil. This is pronounced in the east, streching to 25 m, with localised low conductive response within this zone. A section of the tomogram with uniform conductivity value of 700 mS/m, was also mapped and interpreted as clay materials. Other part of the tomogram, indicating low conductivity was mapped, with value in the range of less than 100 mS/m to 500 mS/m. This represents uncontaminated zone and it stretches 10 m width in the north of the tomogram to a depth of 40 m.

Profile 2 is shown in figure 9. It depicts high conductive zone with conductivity ranging from 850 mS/m to 1300 mS/m in the north of the tomogram. The conductive plume is about 10 m width, stretching from the surface of the dumpsite, from west to east to 40 m depth. This is interpreted as conductive leachate contaminant plume and it has migrated from the surface downstream. The east of the profile is characterised by low conductivity, in the range of less than 100 mS/m to 550 mS/m. This is free from leachate contaminants and is as a result of waste saturated with water and unpolluted soil. But within this, there is a local high conductivity response. Some sections of the tomogram with uniform conductivity value of 700 mS/m were also observed within these zones and interpreted as clay materials.

6. Conclusion

Electrical Impedance Tomography has been presented and used to investigate dumpsite-induced groundwater contamination within an unconfined dumpsite, located at Solous 2, in Lagos State, Southwestern Nigeria. From this study, EIT has proved to be a useful technique in defining contaminants within the dumpsite, because the inverted conductivity models offered a matching distribution of the contaminant concentration and the technique has been effective in delineating leachate plumes emanating from the dumpsite. It has been found that the leachate contaminants have migrated to depths exceeding 40 m, well below the aquifer, and over 25 m offsite distance from the dumpsite. The study showed that EIT can be used effectively, to map areas of active decomposition that are characterised by varying conductivities, hence, a very adaptive tool to realise a systematic survey in dumpsites investigations.

The soil stratigraphy of Lagos metropolis or the existing sequence of soil types occurring in the metropolis makes land filling operation very risky especially when one considers the prevalent high water table in the state.

References

1. Alile, O.M., Ojuh, D.O., Iyoha, A. and Egereonu J.C. Geoelectrical investigation and hydrochemical analysis of groundwater in a waste dump environment, Isolo, Lagos. African Journal of Environmental science and Technology. 2011; 5(10); 795-806
2. Ayolabi, E. A. Geoelectric evaluation of Olushosun Landfill site southwest Nigeria and its implications on groundwater. Journal geological Society of India. 2005; 66; 318 – 322.
3. Ayolabi, E. A and Peters, D. Y. Hydrochemical and electrical resistivity assessment of the impact of solid waste on the groundwater at Okealfa refuse dumpsite, Lagos, Nigeria. Journal Science Eng. 2005; 12 (1); 5936 – 5946
4. Ball, J. M. and Stove, J. G. Pollution Plume migration. Coastal Park landfill. Proc. Waste Con. International Water management biennial. 2002; Durban South Africa.
5. Barber, D.C and Brown, B.H. Applied Potential Tomography. Journal of Physics E: Scientific Instrument. 1984; 17; 723-733.
6. Becker, C. J. Hydrogeology and leachate plume delineation at a closed municipal landfill, Norman, Oklahoma. Water Resources Investigations Report. 2001; 01-4168. U.S. Geological Survey.
7. Borsic, A. Regular Analyization Methods for Imaging from electrical measurements, Ph.D thesis 2002; Oxford Brooks University.
8. Broom, B. H. Medical impedance tomography and process impedance tomography. a brief

review. Measurement Science and Technology. 2001; 12(8): 991 – 996

9. Cheney, M. and Issacson, D. Issues in Electrical Impedance Imaging, IEEE Computational Science and Engineering. 1995; 2; 53 – 62
10. Cheney, M., Isaacson, D. and Newell, J. C. Electrical Impedance Tomography. Society for Industrial and Applied Mathematics. 1999; 41(1); 85 – 101.
11. Cook, R. D. Act 3. A High-speed, High Precision Electrical Impedance Tomography. Ph. D Thesis 1992, Rensselear Polytechnic Institute, Troy, New York.
12. Dahlin, T and Loke, M. H. Resolution of 2D Wenner Resistivity imaging as assessed by numerical modeling. J. Appl Geophysics. 1998; 38; 237 -249
13. Daily, W and Ramirez, A. Electrical Impedance Tomography of the 1995 OGI Perchloroethelyne Release. Lawrence Livermore National Laboratory. 1996; Livermore, CA 94550
14. Egereonu, U. U., Ibe, K. M. Investigation of nitrate Pollution in Groundwater of Owerri and Environs, South Eastern Nigeria, J. Assoc. Adv. Model. Simul. Techn. Enterprises. 2003; 65(1): 59-76.
15. Graham, B. M. Enhancements in Electrical Impedance Tomography (EIT) Imaging reconstruction for 3D lung imaging. P.hD Thesis 2007; University of Ottawa, Canada.
16. Greenhouse, J. P. and Slaine, D. D. The uses of reconnaissance electromagnetic methods to map contaminants migration. Ground water monitoring Rev. 1983; 3; 47 – 59.
17. Guter, G. A. Removal of Nitrate from Contaminated Water Supplies for Public Use, Environmental Protection Agency. 1981; Cincinnati; 41-42.
18. Hua, P., Webster, J. G., Tanpkins, W. J. Effect of the Measurement Method On Noise Handling and Image Quality of EIT Imaging. In Proc. Ninth Int. Conf. IEEE Eng. In Med. And Biol. Society. 1987; 2; 1429 – 1430
19. Jeje, L. K. Aspects of Geomorphology in Nigeria. In. Geography of Nigeria. Heinemann Educational Books, Nigeria. 1983; 17-44.
20. LAWMA. Waste Dumped on Landfills for the year. 2009 Retrieved from http://www.lawma.org/DataBank/Waste%20data%202009.pdf.
21. Noor, J. A. E. Electrical Impedance Tomography at Low Frequencies. Ph. D. Thesis 2007; University of New South Wales.
22. Olowofela, J. A and Akinyemi, O. D. A numerical model for the migration and fate of contaminants in Groundwater. Nigerian Journal of Science. 2001; 35; 87 – 93.
23. Olowofela, J. A, Akinyemi, O. D and Ogungbe, A.S. Imaging and Detecting Underground Contaminants in Landfill Sites using Electrical Impedance Tomography (EIT): A case study of Lagos, Southwestern, Nigeria. Research Journal of Environmental and Earth Sciences. 2012a; 4(3); 270-281.
24. Pessel, M and Gibert, D. Multi scale Impedance Tomography J. Geophys. Res. 2003; 108 (B1); 2054; 1 – 11.
25. Polydorides, N. Image reconstruction algorithms for soft – field tomography. Ph.D Thesis 2002; UMIST.
26. Ruzairu, A.R., Liew, Y.H, Chan, K.S, Pang, J.F and Leong, C.L. Initial result on Electrical Impedance Tomography. Jurnal Teknologi. 2003; 39(D) Dis.:105-113.
27. Slater, L., Knight, R., Shinga, K., Binley, A. and Atekwana, E. About AGU, Near Surface Geophysics. A New focus Group, EOS 2006; 87; 25.
28. Webster, J. G. Electrical Impedance Imaging in J. G. Webster, Editor, Electrical Impedance Tomography. 1990; Chapter 1; 1 – 7.

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