Arch. Min. Sci. **63** (2018), 2, 397-416

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.24425/122454

NGUYEN VAN GIANG*[#], NGUYEN TRONG VU**, NGUYEN BA DUAN**

ASSESSMENT OF CONTAMINATION IN NAMSON LANDFILL, HANOI, VIETNAM BY HYDROGEOPHYSICAL METHODS

OCENA STOPNIA SKAŻENIA TERENU NA OBSZARZE SKŁADOWISKA ODPADÓW NAMSON W HANOI (WIETNAM) Z WYKORZYSTANIEM METOD HYDRO-GEOFIZYCZNYCH

The main objective of this study was to assess the environmental impact of the subsurface geological structure in Nam Son landfill by hydrogeophysical method. The Electrical Resistivity Tomography (ERT), Self-Potential (SP) and Very Low Frequency (VLF) method was used for geological structure investigation. Three profiles (total 900 m long) of two-dimensional ERT, VLF density sections and 180 SP data points scattered within the study area near the disposal site were implemented. Surface water and groundwater samples were collected from 10 sites in the area for hydrochemical analysis. Interpretations of geophysical data show a low resistivity zone (<15 Ω m), which appears to be a fully saturated zone with leachate from an open dumpsite. There is a good correlation between the geophysical investigations and the results of hydrochemical analysis.

Keywords: Electrical resistivity tomography, Self-potential, Hydrogeophysics, NamSon waste site

Podstawowym celem pracy było określenie stopnia oddziaływania na środowisko w podpowierzchniowych warstwach geologicznych na obszarze składowiska odpadów Nam Son przy wykorzystaniu metod hydro-geofizycznych. W badaniach budowy geologicznej terenu wykorzystano metodę obrazowania elektrooporowego (*Electrical Resistivity Tomography* – ERT), metodę potencjałów własnych (*Self-Potential* – SP) oraz badania elektromagnetyczne bardzo niskich częstotliwości (*Very Low Frequency* – VLF). Wytypowano trzy profile (o całkowitej długości 900 m) do dwuwymiarowego obrazowanie ERT oraz siatki gęstości do badania elektromagnetycznego VLF oraz 180 rozproszonych punktów do badań metodą potencjałów własnych na badanym terenie. Próbki wód powierzchniowych i gruntowych do analizy chemicznej pobrano z 10 lokalizacji na terenie składowiska. Interpretacja danych geofizycznych wykazała istnienie strefy charakteryzującej się niskimi oporami (<15 Ω), w pełni nasyconej odpadami ciekłymi wypłukiwanymi z otwartego składowiska. Stwierdzono wysoki poziom korelacji pomiędzy rezultatami badań geofizycznych a wynikami analiz chemicznych.

Słowa kluczowe: obrazowanie elektrooporowe, metoda potencjałów własnych, badanie elektromagnetyczne bardzo niskich częstotliwości (VLF)

* GRADUATE UNIVERSITY OF SCIENCE AND TECHNOLOGY, VAST; A21, 18 HOANG QUOC VIET, CAUGIAY, HANOI, VIETNAM

** INSTITUTE OF GEOPHYSICS, VAST; A8, 18 HOANG QUOC VIET, CAUGIAY, HANOI, VIETNAM

[#] Corresponding author: giangnv@igp-vast.vn

1. Introduction

NamSon landfill is located in two communes: NamSon and BacSon; SocSon district, Hanoi City. Under phase 1 design, landfill operations since 1999 have a total land area of 83.5 ha with 10 sectors buried garbage and 2,000 tons of garbage a day. Although the landfill was too full but from second quarter of 2014 must still receive up to 5,200 tons per day, so the Hanoi city had to expand the landfill by phase 2 with an area of up to 75 ha.

In the process of dumping, natural humidity operating process, garbage disposal is due to the amount of rain present in the unprocessed spam building up in the burial box about 200,000 m^3, causing the risk of water leakage, affecting the surrounding environment. According to LaiSon village residents where it is considered most heavily affected, the people are miserable because of the stench from the landfill. The status of air pollution and water sources which they use for daily living in both the dry and rainy season is highly contaminated due to high concentration of sediments in surface and ground water. Before the landfill about this village no one had cancer but according to the villagers, 40 people have died in the past 3 years from cancer and about a dozen are suffering from end stage cancer just waiting to die.

Although water leak at the NamSon landfill garbage is built in the year 2000 with a combination of froth flotation and biological treatment but the system is still not functioning effectively. Currently, buried method is still a popular solution in urban solid waste treatment in Hanoi because of the simple techniques and low processing cost. However, in the garbage there are some garbage components capable of carrying toxic substances including heavy metals and organic components difficult to biodegradation. If not handled well, water can leak into the surface water, groundwater, causing serious environmental pollution.

A combination of geophysical methods in hydrology was chosen for the study area in the North of the NamSon landfill, where the lowest terrain around the landfill was applied to monitor the volatility of the environment, soil and water from time to time that may be caused by rubbish landfills. During the past 20 years, geophysical methods have proven to be an efficient and effective means for characterizing the subsurface geology and hydrology associated with landfills. As a result, geophysical characterization of landfills is now a routine practice. Even so, due to the inherent uniqueness of each site, it is necessary to carefully select the method and appropriately design the survey parameters in order to derive adequate benefit. In many cases, particularly when multiple objectives are desired, it is best to use complimentary geophysical methods. A variety of techniques can be applied to define landfill properties, leachate circulation, or regional contamination from offsite seepage (Giang et al., 2013). An integrated surface geophysical of 2-D electrical resistivity imaging complimented with measurement of some physical parameters was conducted at sanitary landfill site in Lagos metropolis, with the aim of investigating the lateral extent and depth of the possible subsurface leachate contamination plumes (electrically conductive anomalies) within the area (Ayolabi et al., 2015). Hydrogeophysical investigations have been conducted to determine the characteristics of groundwater. The main water-bearing formations by Pleistocene aquifer, Kom Hamada area, West Nile Delta, Egypt are composed of Quaternary deposits (El Maghraby et al., 2014). Impacts on groundwater regime associated with urbanization and industrialization can easily be assessed through the variation of resistivity in the inverse resistivity pseudo-section model of the ERT investigations in the assessment of groundwater contamination as well as groundwater potential (Rao et al., 2014). Hydrochemical analysis have been successfully used to explain the main factors and mechanisms controlling the distribution of major elements in groundwater for assessment of contamination sources in

Greece (Gamvroula et al., 2013). Abu-Zeid et al., (2004) used geochemical characterization of landfill leachates for Marozzo canal. Ayolabi et al., (2015) used physicochemical assessment for Olushosun sanitary landfill site in southwest Nigeria. Bhalla et al., (2011) assessed of groundwater pollution near municipal solid waste landfill in India. Ganiyu et al., (2016) used integrated electrical resistivity and hydrochemical methods for assessment of groundwater contamination around active dumpsite in Ibadan southwestern Nigeria. Kayabali et al., (1998) used hydrochemistry and resistivity methods in groundwater contamination caused by a recently closed solid waste site. Rapti-Caputo and Vaccaro, (2006) successfully used geochemical evidences of landfill leachate in groundwater. Thuy et al., (2015) used hydrogeochemical assessment of groundwater quality during dry and rainy seasons for the two main aquifers in Hanoi, Vietnam.

2. Geological setting of study area

The survey area has relatively flat terrain in the hilly terrain types (average 20 m) has a slightly inclined slope from the NW (24 m) to the SE (16 m) in the direction of flow of the LaiSon canal. The area is located in the tropical monsoon, rainy moist heat. Average annual rainfall is 1,670 mm and average air humidity is 84%. Underground water in the water layer vulnerabilities the Holocene deposits (qh) and Pleistocene deposits (qp) (Bui et al., 2012; Hida & Giang, 2012). The water layer deposits of Triassic rift (t) distribution of exposed in the North of Soc Son district has better water quality in the Quaternary sediments (Giang et al., 2013; Thuy et al., 2015). Research area with silver-colored soil developed on the ancient alluvial ferralitic products (Tanabe et al., 2003).

According to Fig. 1, the Geology-Mineral scale 1:50,000 by the Hanoi Institute of Geology and Environment of constructing published in 2015, the structure of Socson district featuring

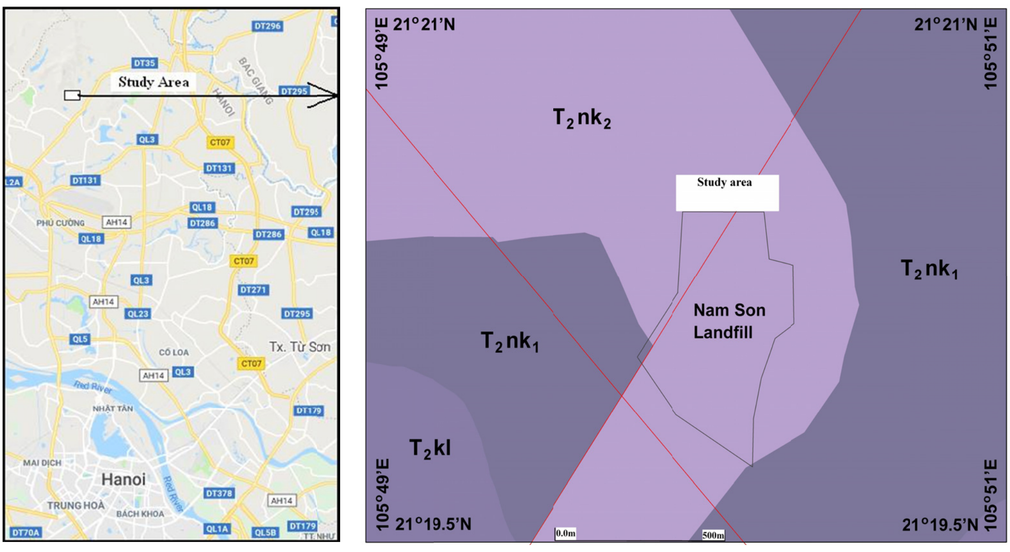

Fig. 1. Location of study area about 40 km in north of Hanoi city and Geological map of NamSon landfill and around (Sam, 2010)

mainly in the upper Triassic system, steps Carmi, level forms include the main lava is: clay schist, sandstone, and the Jura consists of conglomerate. This land was also created as ancient geology in the Quaternary age the youngest formation (Sam, 2010).

There are two stratigraphic formations. The formation before Quaternary is the KhonLang formation (T2a kl) and the NaKhuat formation (T2 nk); There are also two Quaternary stratigraphic units: The ThaiBinh formation (a albQ23, tb) and the Hanoi formation (a, dp, apQ12-3 hn) (Fig. 1).

According to the results of a number of holes drilled around the area to a depth of 25 m research shows stratigraphic column following (Giang et al., 2013):

– From surface to 1.5-2 m: the class covered ruins on the sepia-brown gold. The composition of clay and gravel. Half-hard State.
– From 1.5-2 m to 14-15 m: lightning weathered siltstone rock perfectly golden brown, half-hard hard status.
– From 14-15 m to 25 m: grey-black shale weathering to soft weathering, medium to hard State.

3. Methodology and results of geophysical investigation

The using of hydrogeophysical methods for landfill leachate assessment by shallow geological structure and water samples" is the goal of project. Then, a combination of geophysical methods in hydrology was chosen for the study area as well as Self Potential (SP), 2D Electrical Resistivity Tomography (ERT), Very Low Frequency (VLF) with groundwater and surface water samples for hydrochemical analysis to assess subsurface environmental contamination that may be caused by NamSon landfill (Fig. 2).

3.1. Methodology

Electric and electromagnetic geophysical methods, such as Electrical Resistivity Tomography (ERT) , Self-Potential (SP), Very Low Frequency (VLF) methods in the subsurface and are widely used for investigating groundwater (Hubbard et al., 1997; Ganiyu et al., 2016; Gupta et al., 2015), geological (Bernstone et al., 2000; Cardarelli & Fischanger, 2006; Chambers et al., 2006; Kumar, 2012) and environmental features (Guerin et al., 2004; Porsani et al., 2004; Maillet et al., 2005; Martinho & Almeida, 2006; Pantelis et al., 2010).

3.2. Self-Potential (SP)

More recently, the Self-Potential (SP) method has been adapted for hydrogeological and water engineering applications, with the use of more sensitive equipment and the careful application of data correction processes. The electrodes in contact with the ground surface were the non polarizing type, also called porous pots. A simple SP survey was adopted which consists of a base electrode position and a moving electrode to determine potential differences along profile line survey (Corwin, 1990; Frederico et al., 2013). The used equipment merely includes electrodes, wire, and a precise millivolt meter by Terrameter SAS 300C. Readings are normally taken with one electrode fixed at a base station and a second, mobile 'field' electrode that is

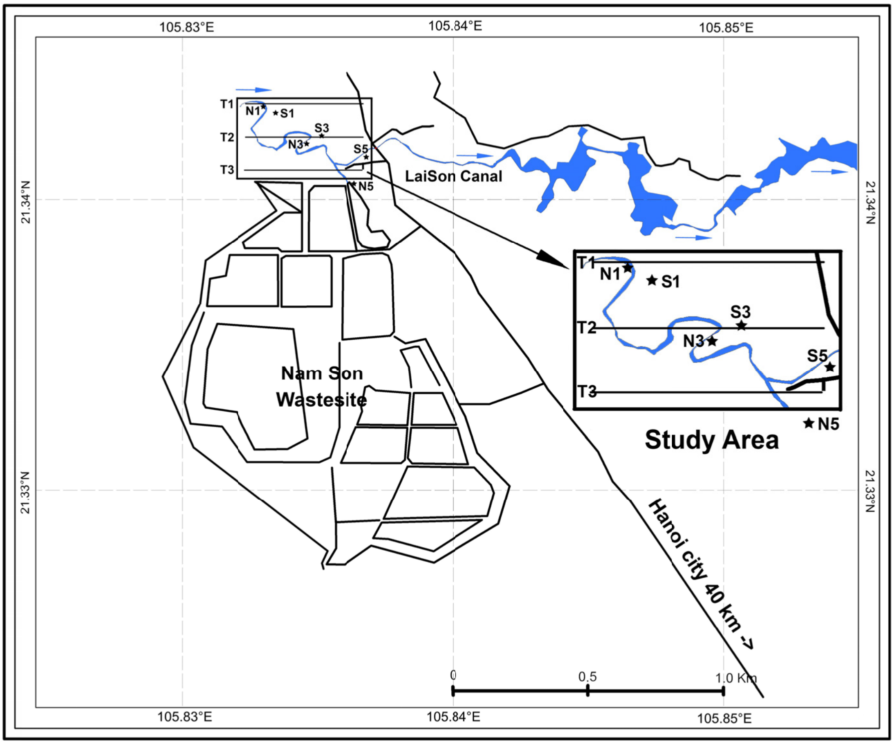

Fig. 2. Location NamSon waste site and geophysical profiles investigation (T1,T2,T3) with surface water samples sites (N1,N3,N5) and groundwater samples sites (S1,S3,S5). The study area (180×300 m) is in the North of the NamSon landfill, where the lowest terrain including upstream of LaiSon canal

moved along every profile and around the survey area. Various potentials are produced in the native ground or within the subsurface altered by our actions. Natural potentials occur about dissimilar materials, near varying concentrations of electrolytic solutions, and due to the flow of fluids. Other occurrences produce spontaneous potentials, which may be mapped to determine the information about the subsurface. Spontaneous potentials can be produced by mineralization differences, electro-chemical action, and bioelectric generation of vegetation. Four different electrical potentials are recognized. Electrokinetic, or streaming, potential is due to the flow of a fluid with certain electrical properties passing through a pipe or porous medium with different electrical properties (Matias et al., 1994; Sharma, 1997). Mineralization, or electrolytic contact, a potential is produced at the surface of a conductor with another medium. Telford et al., (1990) provide equations for differing potentials.

3.3. 2D Electrical Resistivity Tomography (ERT)

The Electrical Resistivity Tomograph **(**ERT**)** method applied in the study belongs to the group of geoelectrical methods used in geophysical engineering. It measures differences in the electrical resistivity of the ground (Keller & Frischknecht, 1966; Loke & Barker, 1996; Sharma, 1997; Smith & Sjogren, 2006). The 2D model is a more accurate model of the subsurface where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line (Loke, 2000). The measuring system used to automatically increase the spacing between electrodes. The increase in spacing caused an increase in the depth of the measurement. The electrodes are chosen from among the electrodes connected to the cable until there are no more programmed combinations left (Griffiths & Barker, 1993; Frid et al., 2008; Ustra et.al., 2012.

3.4. Very Low Frequency (VLF)

Very Low Frequency (VLF) is one of the geophysical methods commonly used in foundation investigation and environmental studies (Telford et al., 1990; Sharma, 1997, Benson et al.,1997; Gharibi & Pedersen, 1999; Karlik & Kaya, 2001). The principle is based on the induction of a secondary magnetic field Hs in the subsurface conductor of conductivity σ due to the effect of an artificially generated primary field Hp. If the source and receiver are brought near a more conductive zone, stronger eddy currents may be caused to circulate within it and an appreciable secondary magnetic field will thereby be created. Close to the conductor, this secondary or anomalous field may be compared in magnitude to the primary or normal field (which prevails in the absence of conductors), in which case it can be detected by the receiver. The secondary field strength, Hs, is usually measured as a proportion of the primary field strength, Hp, at the receiver in percent. ABEM WADI was used for VLF-EM measurements, it uses military transmitters as the source of primary electromagnetic waves Hp which is located several kilometers away at the high powered military communication transmission stations. The transmitter's antenna transmits signals continuously at low radio frequency range of 15-30 kHz.

3.5. Results of Geophysical Investigation

3.5.1. Results of SP

Reading stations of SP are spaced at regular intervals by 5 m along linear profiles T1, T2 and T3, closed grids measuring by 180 points (Fig. 2). Small potentials of the order of a few millivolts are produced by two electrolytic solutions of differing concentrations that are in direct contact, and by the flow of groundwater through porous materials. SP anomaly is positive (resurgence) where the hydrostatic pressure decreases (i.e. in the direction of the water flux) and SP anomaly is negative (infiltration). In this case, SP data collection process was done at each measuring point is measured according to the 3 reads and finally get the average value. In principle all 3 values read this near equal as they are almost in the same time, but there are some cases when it was measured, the garbage trucks have come close to that or a source of interference which has make one of 3 values read are different 2 values were read. In such cases should be excluded when the data processing SP. In the total score has measure of all three profiles measure SP also had 17 points to the need to process, although there have been measured repeat but in other times. Of cource, SP are usually caused by charge separation in clay or other minerals, due to presence of semi-permeable interface impeding the diffusion of ions through the pore space of rocks, or by natural flow of a conducting fluid through the rocks. Due to the nature of the electric current, SP can only be recorded in conductive mud. Then, at every measured point put electrode has been dug deep into the ground about 20 cm and used the mud poured into it before putting down the electrode to increase the exposure of the electrode with the surrounding environment.

After processing, SP data are in the range of +30 to –260 mV for area study of a tree measured line. Because the purpose of the study is the assessment of present near-surface geological formation relationship with environmental occurrences, then the processed SP data are used to map by contouring surficial voltages between base/reference electrode(s) and the mobile electrodes (Fig. 3a) and Fig. 3b)). On the map of equipotential based on SP data carried out on March 2015 (Fig. 3a)) are three positive anomalies (brown colour) and one negative anomaly (dark blue). The values of positive SP anomalies are ranging 10-25 mV and negative is –180 mV. But the values of SP distributed on study area are changed after one year measurement clearly (Fig. 3b))

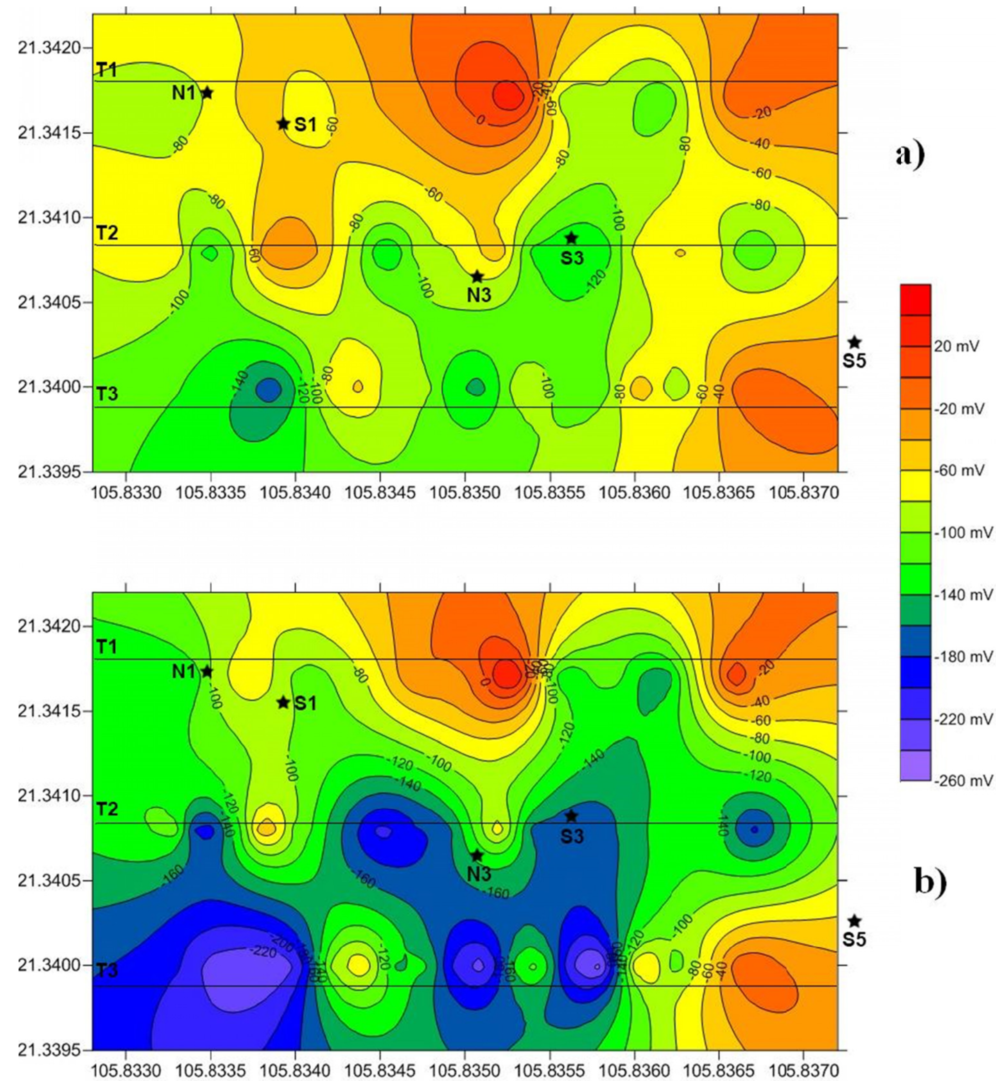

Fig. 3. Map of equipotential based on self potential data from profiles T1, T2, T3; a) carried out on March 2015; b) carried out on March 2016, and locations of water samples: N1,S1,N3,S3,S5

by six negative SP anomalies with amplitude range from –180 to –260 mV and three positive SP anomalies with amplitude similar range as well as in Fig. 3a). The flow of groundwater in geological media is a movement of ionic fluids to or within the groundwater. These potentials may exceed the background voltage variation of the study site.

3.5.2. Results of ERT

In this case, a SuperSting R1/IP equipment with 56 electrodes (AGI, 2003) was used for data acquisition along three profiles T1, T2 and T3 by Wenner array with 5 m electrode spacing in the study area (Fig. 2). Outcomes are presented in 2D sections showing electrical resistivity vs depth. Interpretation involved describing a given geoelectrical cross-section with reference to subsurface conditions by using EarthImager 2D software (AGI, 2003). The local picture in the area has been ascertained from the electrical resistivity image profile T1(A), T2(A) and T3(A) which are carried out in March 2015 (Fig. 4). The inter-electrode spacing of 5 m was maintained

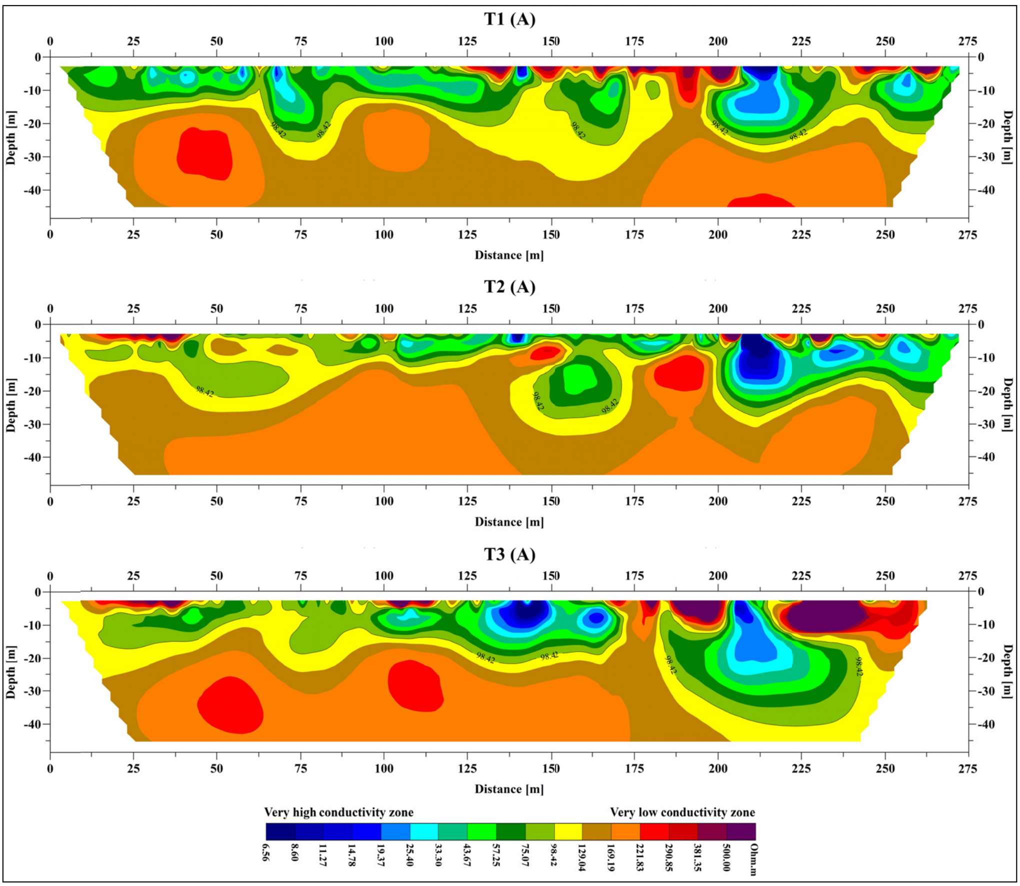

Fig. 4. Inverse model resistivity section of electrical resistivity tomography profile T1(A) by RMS = 12.78% and electrode spacing = 5 m; T2(A) by RMS = 9.46% and electrode spacing = 5 m, and T3(A) by RMS = 12.96% and electrode spacing = 5 m which were carried out in March 2015

throughout the profile of 275 m and the direction of profiles is W–E oriented performed and in electrical resistivity images, in general, the upper part was showing a resistivity value range of 10-20 Ωm (dark blue colour), 50-70 Ωm (green colour) and 100–130 Ωm (yellow colour) up to 26 m depth. There was a second level with resistivity values range 150-200 Ωm (brown colour) and 250-290 Ωm (red colour) between 20 and 50 m depth. High resistivity (>250 Ωm) was found in the top of the section of ERT extending up to the depth of 6 m in the second portion of the image, a slight increase in the resistivity up to the depth of 10 m indicates the presence of consolidated sand with sandstone, claystone (Fig. 2). Resistivity section T1(A), T2(A) and T3(A) represent adequate signal/noise ratio, an important parameter in low resistivity environments, while it also provides an adequate resolution (Telford et al., 1990). The RMS error computed for iterations of resistivity data has been found to vary by 12.78% from T1(A), 9.46% since T2(A) 12.96% and T3(A) in the inverse model resistivity sections. Delineation of various sub-surface lenses like clays as well as in situ saturated sand-clays of formations up to a depth of several m only has been inferred. In the study area, the principal aquifers have formed in the unconsolidated alluvial formations, deposited under various sedimentary environments. The geoelectrical profiles (Fig. 4) show resistivity values that varied laterally with depth, in the vertical aspect, two levels could be distinguished in accordance with the resistivity values obtained.

In the subsequent stage, 2D electrical resistivity method, using Wenner array, was carried out in this area after one year, the same date on March 2016. The survey was conducted using the same multi-electrode resistivity instrument and the measured resistivity profiles were interpreted using the same program. Electrical resistivity values were obtained from three parallel lines (Fig. 5). The RMS error computed for iterations of resistivity data has been found to vary by 11.68% for T1(B), 9.11% for T2(B) and 9.57% for T3(B) in the inverse model resistivity sections. The results of the resistivity survey show that the low resistivity lenses in the study area reach to depths of about –16-20 m by larger of area, with very low resistivity values less than 20 Ωm (dark blue colour) in resistivity sections T1(B), T2(B) and T3(B). According to the 2D inverted resistivity sections, low resistivities (<20 Ωm) at the depth correspond to areas that may be occupied by leachate. The high resistivity values (>150 Ωm) in profiles T1(B), T2(B) and T3(B) are associated with non-degradable waste materials. Because they are belong to consolidated formation by good condition (Hida and Giang, 2012; Giang et al., 2013; Sam, 2010). Also, very high resistivity zone (200-290 Ωm) in profiles T1(A), T(2), T3(A) and T1(B), T2(B), T3(B) are interpreted as consolidated formations as well as sandstone, siltstone, tuffite, clay shale (Fig. 2).

3.5.3. Results of VLF

The VLF measurements were accomplished along profiles T1, T2 and T3 (Fig. 2) that ranged in length of 900 m by a spacing point of 10 m. The selected sites in the field were good criteria for VLF signal which could be acquired from the transmitters of 18-22 kHz frequency. In our case, three VLF curves were very difficult to be interpreted, so, filtering techniques could be used to enhance data and make tilt-angle crossovers easier to identify by Karous-Hjelt filter (Karous and Hjelt, 1983). The real and imaginary parts are the ones presented in the graphical plots by using SECTOR software (VLF Wadi, 1995) and their interpretation can specify the different types of VLF data that can be acquired. The real part will always show a positive peak above a conductor, while the imaginary part can show a positive or negative peak, depending on the conditions of the overburden layer. An interpretation of in-phase (real part) anomaly of VLF-EM data was carried out using the analysis of the transform of the in-phase component and the amplitude of its

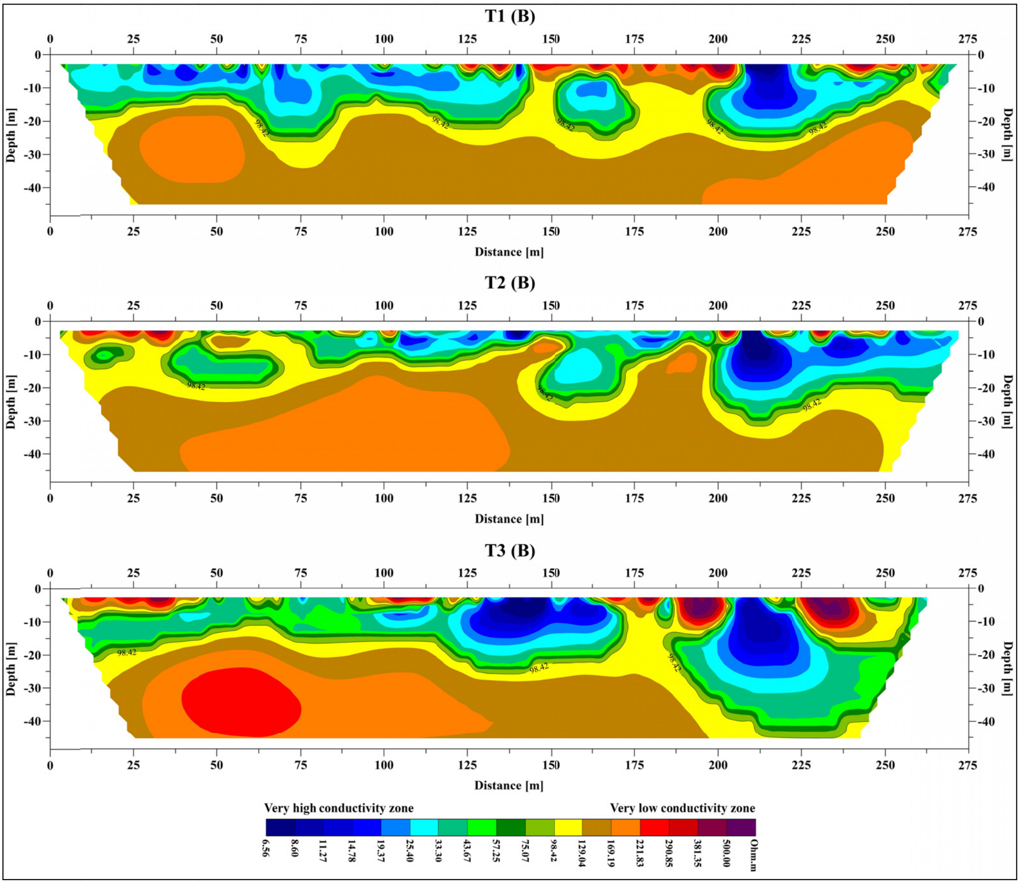

Fig. 5. Inverse model resistivity section of electrical resistivity tomography profiles T1(B) by RMS = 11.68% and electrode spacing = 5 m; T2(B) by RMS = 9.11% and electrode spacing = 5 m and T3(B) by RMS = 9.57% and electrode spacing = 5 which were carried out in March 2016

analytic signal. The analysis was used to delineate the source and depth to the top of a subsurface conductive body. The amplitude of the analytical signal of the data was observed to mimic the conventional Fraser-filtered operation and was used to locate the exact location of the anomalous body. Increasing the primary field strength increases the secondary field strength proportionally, but the anomaly measured in percent remains the same. The in-phase component of the transform yields an approximate depth of 20 m to the top of the conductor as shown in Fig. 6a and Fig. 6b. The color gradation indicates that the ratio Hs/Hp % is (the deeper the colour, the stronger the relationship Hs/Hp %): – red colour – positive Hs/Hp % relationship; – blue colour – negative Hs/Hp % relationship; – yellow/green colour – near zero Hs/Hp % relationship. All profiles were carried out at 18 kHz frequency (Fig. 6a, Fig. 6b). Very negative or very positive values (Hs/Hp < –160 % or Hs/Hp > 80 %) correspond to measurements taken under the influence of high tension power lines and so they must not be considered. Negative Hs/Hp % values usually relate to major resistivity layers, whereas positive Hs/Hp % values indicate major conductive layers (for instance, the presence of clay materials). Successive inflections of Hs / Hp % indicate fractured/saturated zones. McNeill, 1980 showed that the amplitude of these field Hp and Hs is a function of frequency, ground conductivity, and other factors. Where Hs at the receiver week, positive response indicate that the fault zone is a poor conductor. Major faults in this area appear to correlate with the stronger, positive VLF anomalies. If the ground consists of a conducting body, then the Hp induces a potential defference in the conducting body which produces a Hs. Then, the apparent conductivity of the ground can be determined by ratio Hs / Hp. VLF data permits detection of the presence of electricity-conducting body such as faults filled with clay materials exhibiting equally great sensitivity to other important hydrogeologic characteristics, such as lateral facies variation. Right after 1 year, 180 points measured by VLF Wadi is repeated

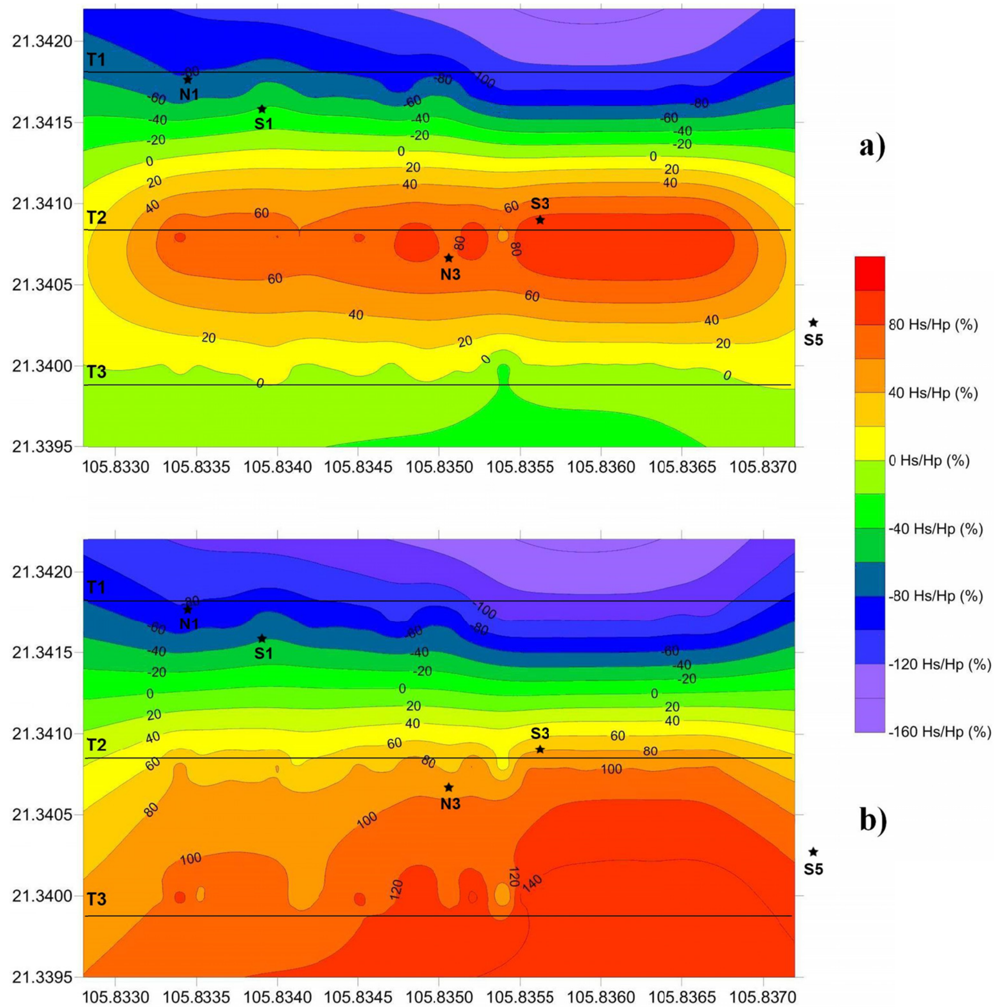

Fig. 6. Distribution of Fraser-filtered in-phase component (in %) based VLF data from profiles T1, T2, T3; a) carried out in March 2015; b) carried out in March 2016, and locations of water samples: N1,S1,N3,S3,S5

and the source of this data is also processed and interpreted as resource measurement in times ahead. Results are presented on Fig. 6b) is also the ratio of Hs/Hp but distributed picture changes very pronounced in the southern part, that is directly related to the T3 profile (profile adjacent landfill and almost parallel to the canal LaiSon). Thus, the density of the profiles through the VLF data has greatly increased with respect to the location of the profile T3. This proves the water leak junk has very strong influence to the quality of surface water and groundwater to a depth of 20 m in the area next to the landfill structure (Fig. 6b)). While in the area of structure related to T1 profile virtually very little influence, and even the profile between, T2 is also affected.

3.6. Hydrochemical analysis

Water enters a landfill from a number of sources, for example from precipitation, groundwater, surface run-off, and the disposal of liquids or sludges. The amount of water entering a landfill depends on many factors, such as the seasonal distribution of the water balance, the geology and hydrogeology of the site and the soil type and vegetation cover of the original and the completed site and the surrounding area (Ahmed & Sulaiman, 2001). Water provides three major functions in land filling: as a medium essential for bacterial activity in organic waste and for a chemical breakdown, as a medium for movement of contaminants, and as a medium for providing dilution. Landfill activities have the potential to change the quantity and quality of groundwater and change surface water in the locality (Abu-Zeid et al., 2004). The significance of the potential impacts will vary according to the phase of operation, the scale of the operations and the sensitivity of the local water resources. Potential impacts on surface water and groundwater level and quality which provide of low permeability ground surfaces, reducing inputs of water from the surface infiltration, leakage of leachate through the landfill liner. Leachate is produced when water or other liquid comes into contact with waste, particularly household waste, in a landfill. As water percolates through, it leaches material from the dissolved soluble inorganic waste components and organic wastes such as paper, cardboard and foodstuffs degrade by microbial action to simpler compounds which are soluble. As water percolates through the landfill, it generally deteriorates in quality, resulting in a polluted liquid which vanes in colour from light brown to black, and smells sweetish and sickly. Its polluting potential may be 10 to 100 times that of raw sewage. The main components of leachate are major ions – calcium, magnesium, potassium, iron, sodium, ammonium, bicarbonate, sulphate and chloride, trace metals such as manganese, zinc, copper, chromium, nickel, lead and cadmium, a wide variety of organic compounds which are usually measured as Total Organic Carbon (TOC), Chemical Oxygen Demand (COD) or Biochemical Oxygen Demand (BOD); individual compounds which are hazardous at very low concentrations may also be of concern, for example pesticides, benzene, phenol, microbiological components (Meju, 2000; 2006; Paul et al., 2007; Giang et al., 2014) .

As presented in the introduction, the landfill Nam Son has a large volume of garbage that is buried after a long time creating a mountain of garbage. So the infuse permeability and mobility of the waste water volume affecting the surrounding environment is inevitable. In the framework of this research project, we have conducted water, surface water sampling at the 3 locations (N1,N3,N5) on the LaiSon canal of the northern landfill and groundwater samples of 3 boreholes drilled in the area of research (S1,S3,S5) to analyze (see Fig. 2). The water samples were taken and analyzed in March 2015 and March 2016 to have a basis of comparison. The water sample analysis results are synthesized and presented in Tab. 1 and Tab. 2 for surface water and groundwater.

TABLE 1

Result of surface water analysis by Institute of Chemistry and Institute of Geophysics, VAST

No.	**Parameters**	**Units**	**Name of samples and content for date**						**Standard QCVN-08-MT(B1) 2015**
			N1		**N3**		**N5**		
			Mar. 24 2015	**Mar. 26 2016**	**Mar. 24 2015**	**Mar. 26 2016**	**Mar. 24 2015**	**Mar. 26 2016**	
1	pH	mg/l	7.95	7.68	7.78	7.89	7.72	7.75	5.5-9.0
2	TSS	mg/l	98	87	32	30	26	37	50
3	COD	mg/l	233	278	401	444	540	556	30
4	BOD_5	mg/l	196	202	312	337	341	356	15
5	NH_4^+	mg/l	11.5	18.7	21.0	22.7	19.4	20.3	0.9
6	NO_2^-	mg/l	0.12	0.20	0.46	0.53	1.02	0.96	0.05
7	NO_3^-	mg/l	3.6	5.2	8.7	9.4	15.6	16.8	10
8	Cyanide (CN^-)	mg/l	0.04	0.05	0.08	0.10	0.12	0.13	0.05
9	Arsenic (As)	mg/l	0.08	0.08	0.15	0.15	0.14	0.17	0.05
10	Cadimium (Cd)	mg/l	0.03	0.06	0.09	0.08	0.12	0.13	0.01
11	Lead (Pb)	mg/l	0.05	0.06	0.16	0.17	0.22	0.24	0.05
12	Copper (Cu)	mg/l	0.8	0.9	1.2	1.3	1.6	1.9	0.5
13	PO_4^{3-}	mg/l	0.27	0.56	1.00	1.12	1.12	1.24	0.3
14	Iron (Fe)	mg/l	1.77	1.90	1.45	1.88	1.89	2.03	1.5
15	Total N	mg/l	23.6	25.7	39.8	43.3	42.7	55.8	—
16	Total P	mg/l	2.05	2.06	3.56	3.89	4.07	5.55	—
17	Coliform	MPN/100 ml	9800	10500	10700	11000	11600	12800	7500
18	E-coli	MPN/100 ml	400	500	500	600	500	600	100
19	EC	mS/m	25.8	33.7	117.8	130.2	102.6	136.5	
20	Temperature	^oC	23.4	22.7	22.7	23.1	23.3	22.8	
21	TDS	ppm	234	267	389	390	443	456	

Legend: QCVN-08-MT (B1)2015: Vietnam Technical Regulation on surface water quality by Ministry of Natural Resources and Environment (MONRE)

As we know that environmental indicators are essential tools for water quality assessment which consist of physical indicators as well as water temperature, EC, TDS and TSS; chemical indicators as well as pH, BOD, COD, nitrate and heavy metals; and biological indicators as well as E-coli and coliform. Because direct measurements of water quality can be expensive, then tools available to the study include on-site test kits and water samples analyzed at laboratories by real-time monitoring.

Surface water quality monitoring has been carried out by establishing 3 observation sites on the LaiSon canal for March 2015 and March 2016 for providing input to the integrated data interpretation. The values of the parameters during one year by two times measured were presented

TABLE 2

Result of groundwater analysis by Institute of Chemistry and Institute of Geophysics, VAST

No.	Parameters	Units	Name of samples and content for date						Standard QCVN-09-MT 2015
			S1		S3		S5		
			Mar. 24 2015	Mar. 26 2016	Mar. 24 2015	Mar. 26 2016	Mar. 24 2015	Mar. 26 2016	
1	pH	—	7.67	7.25	7.72	7.49	7.23	7.18	5.5-8.5
2	TSS	mg/l	39	44	53	55	67	69	—
3	COD	mg/l	10	19	16	23	24	31	4
4	BOD_5	mg/l	5	10	11	22	16	40	—
5	NH_4^+	mg/l	0.22	0.31	0.26	0.42	0.30	0.44	1
6	NO_2^-	mg/l	0.03	0.07	0.06	0.11	0.09	0.25	1
7	NO_3^-	mg/l	0.12	0.23	0.14	0.33	0.12	0.38	15
8	Cyanide (CN^-)	mg/l	0.01	0.017	0.02	0.023	0.028	0.03	0.01
9	Arsenic (As)	mg/l	0.03	0.05	0.04	0.06	0.05	0.07	0.05
10	Cadimium (Cd)	mg/l	0.004	0.005	0.005	0.006	0.006	0.007	0.005
11	Lead (Pb)	mg/l	0.02	0.03	0.03	0.03	0.03	0.04	0.01
12	Copper (Cu)	mg/l	0.9	1.1	1.1	1.2	0.9	1.3	1
13	PO_4^{3-}	mg/l	0.12	0.15	0.13	0.14	0.15	0.18	—
14	Iron (Fe)	mg/l	0.07	0.12	0.08	0.12	0.12	0.15	5
15	Total N	mg/l	0.99	1.00	1.22	1.53	1.24	1.36	—
16	Total P	mg/l	0.12	0.15	0.15	0.19	0.18	0.22	—
17	Water level	m	4.33	5.15	4.50	5.21	4.44	5.37	
18	EC	mS/m	45.6	58.7	56.3	77.4	69.8	87.6	
19	Temperature	^oC	25.6	25.8	24.9	25.0	25.2	25.6	
20	TDS	ppm	115	167	190	232	295	308	500

Legend: QCVN-09-MT2015: VietnamTechnical Regulation on groundwater quality by Ministry of Natural Resources and Environment (MONRE)

(Tab. 1). The data presented shows that 2016 values of most parameters elevated concentration as compared with the 2015 values. Most of the surface water samples indicated a slightly alkaline nature with pH varying from 7.56 to 7.95. The values of COD, BOD_5, NH_4^+, NO_2^-, Arsenic, Cadimium, Lead, Copper and Iron are exceeding permissible limits. Elevated TDS concentration levels noticed around N3 and N5 (downstream of LaiSon canal). Very high values of Coliform and E-coli is also reported in the samples.

Groundwater level and quality monitoring have been carried out by establishing 3 observation wells for March 2015 and March 2016 for providing input to the integrated data interpretation. The values of the parameters during one year by two times measured were presented (Tab. 2). The data presented shows that 2016 values of most parameters elevated concentration as compared with the 2015 values. Most of the groundwater samples indicated a slightly alkaline nature with pH varying from 7.07 to 7.80. Elevated TDS concentration levels noticed around S3 and

S5 (downstream of LaiSon canal). High values of COD, Cadimium, Lead, Copper and Coliform are also reported in the samples. Furthermore, all the groundwater samples indicated Cyanide concentration exceeding permissible limits. High concentration of TDS and EC has been observed in all wells and by those contents can be attributed to possible poor groundwater quality in the area. In the area where LaiSon canal is dominant, considerable leaching of clay minerals has taken place in the shallow aquifers (Giang et al., 2013).

4. Discussions and remarks

The objectives of the subject is to assess the transformation of the environment near-surface geological structure in the area next to the landfill NamSon with time, through which can clarify the effects of the operation of the landfill Nam Son to the surface water environment, groundwater, sediment, by involving the formation contains water near the ground in the area of research, which have included near-surface geological formation. To accomplish the above goals, the survey measured by the methods of sampling and analysis of water power is concentrated in the period March 2015 and March 2016 may have similar climatic conditions and in the dry season to produce the results bring objectivity. The chosen method to survey the geological structure under measure three profiles as SP and ERT are both out for the results that are object based on the basis of the value of the conductivity, resistivity and dielectric constant of magnitude environment. Particularly noteworthy is the value after 2 times measurement showed the changes in both the substance and the amount of which is indicated by the ability of the conductivity as well as the range of highly conductive structure related to the lens contains water with unconsolidated sediments by stamping. This trend can be seen very clearly by the widened place in the peculiar position (including the lens) of dark blue color for negative anomalies on the Fig. 3b) and Fig. 5 – measuring results repeat after exactly one year of time compare with Fig. 3a) and Fig. 4.

Generally, the SP method is qualitative and does not attempt to quantify the anomalous volume size, owing to the unknown volumetric shapes, concentration/density of various masses, and electrical properties of the sought causative media. ERT is a particularly useful survey method in the clay ground. The method to measure variations in the electrical resistivity of the ground and can also help to identify transitional boundaries in subsurface layers that can be difficult to detect using other geophysical methods and the resistivity sections are correlated with ground interfaces such as soil and fill layers or soil-bedrock interfaces, to provide detailed information on subsurface ground conditions that is useful in hydrogeologic study.

When comparing the map of equipotential based on self potential (SP) data carried out on March 2015 (Fig. 3a)) and the map of equipotential based on self potential (SP) data carried out on March 2016 (Fig. 3b)) showed the differences very clearly about the quantity, magnitude as well as overarching scope related to the location of the SP anomalies brought negative sign. In March 2016, the scope of the SP anomaly carries negative sign extends significantly and has much larger amplitude versus time of March 2015. This demonstrates the direction of the amount of water charged down the bottom carries much higher conductivity when compared with March 2015. Meanwhile, the number and position of the amplitude, anomalies SP positive is almost unchanged in both time of measurement. This shows that the direction of the country from the bottom up in the two times measuring period is almost constant. Through comparison of the results and the mobilization of field value SP also showed the conductivity additional source of water for aquifer in this changing trend is affected by water leaking from a landfill Nam Son flowing out as in the dry season, rain water is not diluted out. This would be evidenced by the results of the analysis of samples of surface water and groundwater.

On the inverse model resistivity section of electrical resistivity tomographic profiles T1(A), T2(A) and T3(A) carried out in March 2015 (Fig. 4) and profiles T1(B), T2(B) and T3(B) carried out in March 2016 (Fig. 5) showed a clear difference on the resistivity values by some interfaces in every section. Although the survey depth is also limited to about 50 m, but the most inhomogenous very high structure is shown vertically than horizontally. So the class structure here has created favorable conditions for the formation of the lens contains water as well as the tropical disruption by the blocks by sediments, including surface layer. With such a structure, the dry season surface water flows under the LaiSon canal had charged easily to the aquifer makes resistivity values change over time. In particular, the sections carried out in March 2016 appears the tropical high conductivity structure up and broadened over time, especially with regard to section T3(B) is located right next to the canal LaiSon. This can be explained by the dry season, the water in the canal has always been complementary to the aquifer, that water quality in the canal LaiSon affected again directly from the seepage of effluent deposited from landfill Nam Son trend of pollution.

The VLF-EM result mapped shallow linear conductors that are suspected fractured/saturated zones of varying length in the area which is of significant hydrogeologic importance for groundwater bearing. Interpretations were done normally by considering the high amplitude signal, which is diagnostic of weathered or fractured zones. The double plot of the new reality and filtered qualitative identification of the top linear features, i.e. points of coincident of crossovers and positive peaks of the real and filtered anomaly. The analysis of VLF data by in-phase component was used to delineate the source and depth to the top of a subsurface conductive body. The amplitude of the analytical signal of the data showed the location of the anomalous body. The anomaly observed in VLF survey is also associated with the deviation of the measured signal from the normal level, and this deviation is a result of the response of the subsurface geological objects of interest. The integration of these results shows a main conductive anomalous zone in the northern part of the landfill that increases in thickness towards the middle and with a depth up to 20-30 m. Correlation with natural surface runoff enables to infer that the conductive anomalous body indicates the presence of leachates. Measurement of VLF repeat results affirm the increasing environmental impact the structure of the soil/rock and water in the area north of the landfill water leaks caused by garbage from time to time. This result also reflected as surface water sample analysis results N1, N3, N5 and underground water S1, S3, S5 of two times the sampling and sample analysis within 1 year. Both VLF and SP methods provided a good response in fractured zones.

In a sedimentary formation the sand, clay and a fine-grained sand formation in the sub-surface have shown a minimum resistivity among all the aquifer materials. Thus, fine-grained sand formation may contain high TDS (> hundred mg/l) water may be responsible for lower resistivity value of the aquifer in the area, and any formation having less than this optimum resistivity value may represent either clay or sand formation, containing groundwater of elevated TDS (> hundred mg/l), which is unsuitable for human consumption. High TDS, EC, Arsenic, Cadimium, Lead, Copper and Iron are reported at S3, S5 and N3, N5 (Tab. 1 and Tab. 2). The higher concentrations may be due to infiltration of seepage water from the landfill, which recharges in the aquifer and canal. The lowering of resistivity may be due to the encroachment of polluted water into the aquifer zones in the study area. ERT profiles and negative regional groundwater level contour during 2015 and 2016 seasons and elevated heavy metal concentration confirm the contaminated condition. This was confirmed in the ERT profiles interpretations.

The results of the hydrochemical analysis showed the values of pH for almost samples ranged from 7.4 to 7.8 indicate slightly alkaline water (Abudeif, 2015). The TDS value of surface water samples, as well as samples of groundwater is very high. Although TDS is not generally considered a primary pollutant, but it is used as an indication of aesthetic characteristics of domestic water as an aggregate indicator of the presence of a broad array of chemical contaminants (Abu-Zeid et al., 2004). Primary sources for TDS in receiving waters are leached of soil contamination and point source water pollution discharge from the landfill. The most common chemical constituents are found in nutrient runoff (Bhalla et al., 2011). The chemicals may be cations, anions, molecules or agglomerations on the order of one thousand or fewer molecules, so long as a soluble micro-granule is formed. Certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils (Rapti-Caputo and Vaccaro, 2006). The COD test is commonly used to indirectly measure a number of organic compounds in water. Most applications of COD determine a number of organic pollutants found in surface water making COD a useful measure of water quality, which indicates the mass of oxygen consumed per litre of solution. E. coli and Coliform bacteria are very high for surface water, mean surface water quality in this heavily contaminated. Eutrophication is one of the most widespread environmental problems in inland waters, and is their unnatural enrichment with two plant nutrients, phosphorus and nitrogen. Growth results from the process of photosynthesis which is how the plants generate organic compounds and biomass through the uptake of nutrients (nitrogen, phosphorus and others) from the water and soil (WHO, 2007). The result of water samples analysis showed a high value of P and N for surface water and groundwater (Tab. 1 and Tab. 2). In the process, light acts as the energy source and carbon dioxide dissolved in water as the carbon source. As a result of the photosynthetic process, oxygen is also produced and eutrophication is a serious pollution problem in this case study. The remarkable thing here is that the values of total P and N was high, but it also increased after 1 year. There is also the need to associate the environment, soil and water polluted in the area.

5. Conclusions

Integrated, geophysical survey and hydrochemical analysis methods were employed to assess the subsurface geologic formations, aquifer location/changing and seepage water intrusion, if any in the area. The area generally has an inhomogenous formation at shallow depth, which largely is responsible for the transfer of contaminated water intrusion into the underlying aquifer. Major ionic compositions effectively indicated the effect of the seepage water intrusion and particularly TDS, COD, EC, Arsenic, Cadimium, Lead, Copper and Iron concentrations are the simplest indicators for the assessment of pollution process. In this study, values of TDS and some heavy metals concentrations are found to be highly indicated that the seepage water intrusion is due to in situ contamination of groundwater in the buried soil and soft sediments. The lowering of resistivity was due to the encroachment of very high conductivity, surface water into the aquifer zones and also infiltration of contaminated water from the landfill seepage water intruding into the lens and fractured sediments. The equipotential map based on SP data demonstrates the direction of the water amount charged down by much higher conductivity.

ERT surveys indicated the differences very clearly about the resistivity values by interfaces in the inverse model resistivity section. The subsurface geological structure has created favorable conditions for the formation of the lens contains water as well as the tropical disruption by the blocks by sediments. With such a structure, the dry season surface water flows under the Lai Son canal had charged easily to the aquifer makes resistivity values change over time. In particular, the sections carried out in March 2016 appears the tropical high conductivity structure up and broadened over time, especially with regard to section T3(B) is located right next to the canal LaiSon. This can be explained by the dry season, the water in the canal has always been complementary to the aquifer, that water quality in the canal LaiSon affected again directly from the seepage of effluent deposited from the landfill NamSon trend of pollution.

Regular monitoring of groundwater and surface water quality for compliance, as well as waste water treatment by landfill NamSon infuse a thoroughly and follow the right process technique before discharge out LaiSon canal and environmental protection of groundwater resources to remove the public apprehensions of groundwater pumping from domestic wells in the area is recommended.

Acknowledgment

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 105.05-2014.28.

References

Abudeif A.M., 2015. *Integrated electrical tomography and hydro-chemical analysis for environmental assessment of El-Dair waste disposal site, west of Sohag city, Egypt*. Environmental Earth Sciences **74** (7), 5859-5874; DOI: 10.1007/s12665-015-4610-5.

Abu-Zeid N., Bianchini G., Santarato G., Vaccaro C., 2004. *Geochemical characterization and geophysical mapping of Landfill leachates: the Marozzo canal case study (NE Italy).* Environ. Geol. **45** 439-447.

AGI, 2003. *The SuperSting with Swift automatic resistivity and IP system instruction manual*. Advanced Geosciences, Inc., Austin, Texas.

Ahmed A., Sulaiman W., 2001. *Evaluation of groundwater and soil pollution in a landfill area using electrical resistivity imaging survey*. Environ. Manag. **28** (5), 655-663.

Ayolabi E.A., Oluwatosin L.B., Ifekwuna C.D., 2015. *Integrated geophysical and physicochemical assessment of Olushosun sanitary landfill site, southwest Nigeria*. Arabian Journal of Geosciences **8** (6), 4101-4115, doi:10.1007/s12517-014-1486-8.

Benson A.K., Payne K.L., Stubben M.A., 1997. *Mapping groundwater contamination using dc resistivity and VLF geophysical methods – A case study*. Geophysics **62**/1; 80-86. – USA: Society of Exploration Geophysicists.

Bernstone C., Dahlin T., Ohlsson T., Hogland W., 2000. *DC-resistivity mapping of internal landfill structures: two pre-excavation surveys*. Environ. Geol. **39** (3-4), 360-368.

Bhalla G., Kumar A., Bansal A., 2011. *Assessment of groundwater pollution near municipal solid waste landfill*. Asian J. Water Environ. Pollut. **8** (1), 41-51.

Bui D.D., Kawamura A., Tong T.N., Amaguchi H., Naoko N., 2012. *Spatio-temporal analysis of recent groundwater-level trends in the Red River Delta, Vietnam*. Hydrogeol. J. **20**, 1635-1650.

Cardarelli E., Fischanger F., 2006. *2D data modelling by electrical resistivity tomography for complex subsurface geology*. Geophys. Prospect. **54**, 121-133.

Chambers J.C., Kuras O., Meldrum P.I., Ogilvy R.D., Hollands J., 2006. *Electrical resistivity tomography applied to geologic, hydrogeologic, and engineering investigations at a former waste-disposal site*. Geophysics **71** (6), B231-B239.

Corwin R.F., 1990. *The self-potential method for environmental and engineering applications*. Geotech. Environ. Geophys. **1**, 127-145.

El Maghraby M.M.S., El Fiky A.A., Nawar A.F., 2014. *Hydrogeophysical investigations on the Pleistocene aquifer, Kom Hamada area, West Nile Delta, Egypt*. Arab. J. Geosci. 7 (9), 3839-3853, doi:10.1007/s12517-013-1047-6.

Fraser D.C., 1969. *Contouring of VLF-EM data*. Geophysics **34**, 958-967.

Frederico R., Phygeo W., Márcio M., Guilherme M., Paulo K.N.A., 2013. *The self-potential (SP) method applied for investigating the contamination in the vicinity of the Estrutural city landfill, in Brasilia-DF*. In: 13th international congress of the Brazilian Geophysical Society, Rio de Janeiro, Brazil, p. 1-4.

Frid V., Liskevich G., Doudkinski D., Korostishevsky N., 2008. *Evaluation of landfill disposal boundary by means of electrical resistivity imaging*. Environ. Geol. **53**, 1503-1508. doi:10.1007/s00254-007-0761-3.

Gamvroula D., Alexakis D., Stamatis G., 2013. *Diagnosis of groundwater quality and assessment of contamination sources in the Megara basin (Attica, Greece).* Arab. J. Geosci. 6 (7), 2367-2381, doi:10.1007/s12517-012-0533-6

Ganiyu S.A., Badmus B.S., Oladunjoye M.A., Aizebeokhai A.P., Ozebo V.C., Idowu O.A., Olurin O.T., 2016. *Assessment of groundwater contamination around active dumpsite in Ibadan southwestern Nigeria using integrated electrical resistivity and hydrochemical methods*. Environmental Earth Sciences, First online: 11 April 2016; DOI: 10.1007/s12665-016-5463-2.

Giang N.V., Duan N.B., Thanh L.N., Hida N., 2013. *Geophysical techniques to aquifer locating and monitoring for industrial zones in North Hanoi, Vietnam*. Acta Geophysica **61**, 6, 1573-1597. DOI. 10.2478/s11600-013-0147-8.

Giang N.V., Thanh L.N., Hiep V.Q., Hida N., 2014. *Hydrological and hydrogeological characterization of groundwater and river water in the North Hanoi industrial area, Vietnam*. Environmental Earth Sciences **71**, 11, 4915-4924. DOI 10.1007/s12665-014.3086-z.

Gharibi M., Pedersen L.B., 1999. *Transformation of VLF data into apparent resistivities and phases*. Geophysics **64**, 5, 1393-1402.

Griffiths D.H., Barker R.D., 1993. *Two-dimensional resistivity imaging and modeling in areas of complex geology*. J. Appl. Geophys. 29, 211-226.

Guerin R., Begassat Ph., Benderitter Y., David J., Tabbagh A., Thiry M., 2004. *Geophysical study of the industrial waste land in Mortagne-du-Nord (France) using electrical resistivity*. Near Surf. Geophys. 3, 137-143.

Gupta G., Patil J., Maiti S., Erram V.C., Pawar N., Mahajan S., Suryawanshi R., 2015. *Electrical resistivity imaging for aquifer mapping over Chikotra basin, Kolhapur district, Maharashtra*. Environ. Earth Sci. **73**, 8125-8143.

Hida N., Giang N.V., 2012. *Decline in groundwater levels in Thang Long industrial park within the area of Northwest Hanoi, Vietnam*. J. Japan Assoc. Hydrol. Sci. **42**, 4, 167-172 (in Japanese).

Hubbard S.S., Peterson J.E. et al., 1997. *Estimation of permeable pathways and water content using tomographic radar data*. The leading EDGE **16** (11), 1623-1630.

Karlik G., Kaya M.A., 2001. *Investigation of groundwater contamination using electric and electromagnetic methods at an open waste-disposal site. A case study from Isparta, Turkey*. Environ. Geol. **40** (6), 725-731.

Karous M., Hjelt S.E., 1983. *Linear filtering of VLF dip-angle measurements*. Geophys. Prosp. **31**, 782-794.

Kayabali K., Yuksel F.A., Yeken T., 1998 *Integrated use of hydrochemistry and resistivity methods in groundwater contamination caused by a recently closed solid waste site*. Environ. Geol. **36** (3-4), 227-234.

Keller G.V., Frischknecht F.C., 1966. *Electrical methods in geophysical prospecting*. Pergamon Press Inc., Oxford.

Kumar D., 2012. *Efficacy of ERT technique in mapping shallow subsurface anomaly*. J. Geol. Soc. India **80**, 304-307.

Loke M.H., Barker R.D., 1996. *Rapid least squares inversion of apparent resistivity pseudosections by a quasi-Newton method*. Geophys. Prospect **44**, 131-152.

Loke M.H., 2000. *RES2DINV version 3.44 for windows 95/98 and NT: rapid 2D resistivity and IP inversion using the least squares method*. Advanced Geosciences Inc., Austin.

Maillet G.M., Rizzo E., Revil A., Vella C., 2005. *High resolution electrical resistivity tomography (ERT) in a transition zone environment: application for detailed internal architecture and infilling processes study of a Rhône River paleo-channel*. Mar. Geophys. Res. **6**, 317-328. DOI:10.1007/s11001-005-3726-5.

Martinho E., Almeida F., 2006. *3D behaviour of contamination in landfill sites using 2D resistivity/IP imaging: case studies in Portugal*. Environ. Geol. **49**, 1071-1078.

Matias M.S., Marques da Silva M., Ferreira P., Ramalho E., 1994. *A geophysical and hydrogeological study of aquifers contamination by a landfill*. J. Appl. Geophys. **32**, 155-162.

McNeill J.D., 1980. *Use of electromagnetic methods for groundwater studies*. In: Ward S.H. (ed) Geotechnical and environmental geophysics. Soc. Expl. Geophys. p. 194-198.

Meju M.A., 2000. *Geoelectrical investigation of old/abandoned landfill sites in urban areas: model development with a genetic diagnosis approach*. J. Appl. Geophys. **44**, 115-150.

Meju M.A., 2006. *Geoelectrical characterization of covered landfill*. In: Vereecken H et al. (eds) Applied hydrogeophysics, p. 319-339.

Pantelis S., Nikos P., Ilias P., Maria K., Filippos V., Apostolos S., Thrassyvoulos M., 2010. *Application of integrated methods in mapping waste disposal areas*. Environ. Geol. **53**, 661-675. doi:10.1007/s00254-007-0681-2.

Paul T.I., Debra R.R,, Marja E., Roger G., Nitin G.B.H., Sreeram J., Timothy G.T., Ramin Y., 2007. *Review of state of the art methods for measuring water in landfills*. Waste. Manag. **27**, 729-745.

Porsani J.L., Filhob W.M., Vagner R.E., Shimelesa F., Douradob J.C., Moura H.P., 2004. *The use of GPR and VES in delineating a contamination plume in a landfill site: a case study in SE Brazil*. J. Appl. Geophys. 55, 199-209.

Rao G.T., Rao V.V.S.G., Padalu G. et al., 2014. *Application of electrical resistivity tomography methods for delineation of groundwater contamination and potential zones*. Arab. J. Geosci. **7** (4), 1373-13847, doi:10.1007/s12517-013-0835-3.

Rapti-Caputo D., Vaccaro C., 2006. *Geochemical evidences of landfill leachate in groundwater*. Eng. Geol. **85**, 111-121.

Sam D.X., (eds.), 2010. *The natural conditions of the natural resources and the environment in the development of space-oriented Hanoi capital*. Hanoi Published House, p. 590 (in Vietnamese).

Sharma P.V., 1997. *Environmental and engineering geophysics*. Cambridge University Press, Cambridge.

Smith R.C., Sjogren D.B., 2006. *An evaluation of electrical resistivity imaging (ERI) in Quaternary sediments, southern Alberta, Canada*. Geosphere **2** (6), 287-298.

Tanabe S., Hori K., Saito Y., Haruyama S., Vu P.V., Kitamura A., 2003. *Song Hong (Red River) delta evolution related to millennium-scale Holocene sea-level changes*. Quaternary Sci. Rev. **22**, 2345-2361.

Telford W.M., Geldart L.P., Sheriff R.E., 1990. *Applied Geophysics*. 2nd edition, Cambridge University Press, 792 p.

Thuy N.T., Kawamura A., Thanh T.N., Nakagawa N., AmaguchiH., Gilbuena R. Jr., 2015. *Hydrogeochemical assessment of groundwater quality during dry and rainy seasons for the two main aquifers in Hanoi, Vietnam*. Environmental Earth Sciences **73**, 8, 4287-4303, DOI: 10.1007/s12665-014-3713-8.

Ustra A.T., Elis V.R., Mondelli G., Zuquette L.V., Giacheti H.L., 2012. *Case study: a 3D resistivity and induced polarization imaging from downstream a waste disposal site in Brazil*. Environ. Earth Sci. **66**, 763-772.

VLF WADI instrument manual introduction, 1995. ABEM Sweden.

WHO, 2007. *Water for pharmaceutical use in quality assurance of pharmaceuticals A compendium of Guidelines and Related materials*. 2nd ed. World Health Organization, Geneva, p. 170-187.