...IGATIONS TO ASSESS INDUSTRIAL ...MPED AT UCIL, BHOPAL

UCIL (Union Carbide India Ltd.) had been producing pesticides and insecticides since the inception of its factory in 1969 in Bhopal (M.P.) India. After the MIC gas leakage in December 1984, the production had stopped and subsequently the factory has been closed. Some of the structures are lying in the premises, many buildings are demolished. The industrial wastes are dumped at different places. In order to assess the locations and dimensions of these dumps, geophysical investigations have been carried out. Geophysical investigations are used to identify buried industrial waste that cannot be easily identified by visual inspection. It is most economical and successful technique to assess the buried dump before a more detailed investigations or remedial measures can be adopted. The investigations have been financed by MP State Govt. namely BGRD (Bhopal Gas Relief Directorate) and Ministry of Chemical and Fertilizer (Govt. of India).

Introduction:

UCIL was established to produce pesticides at Bhopal and the factory is located in the north of Bhopal Railway Station, along the railway track as shown in Fig. 1. The production of pesticides continued till December 1984 when MIC (methylisocyanate) gas leaked and the factory was subsequently closed. There are some remains of plant, and building still lying in the factory premises (Fig. 2a, b, c, d, e, and f). There are heaps of industrial wastes lying at different places that can be easily seen at the ground surface (Fig. 3a, b, c, d, e, f, g, h, i, j and k). Many of these dumps give very pungent smell of pesticides even today, as one visits the dump sites. Although these heaps of dumps are seen at many places, it is not known how deep or extensive these dumps are? It is this gations have been carried out. The waste materials constitute mostly of solid waste (off specification products resulted from the manufacture of pesticides), terry residue from distillation unit, burnt and unburnt produce (NEERI, 1996). Apart from these, the Solar Evaporation Pond (SEP) situated in south eastern corner contains dried waste. These are described in detail by NEERI (1996) and Burmeier et al (2005).

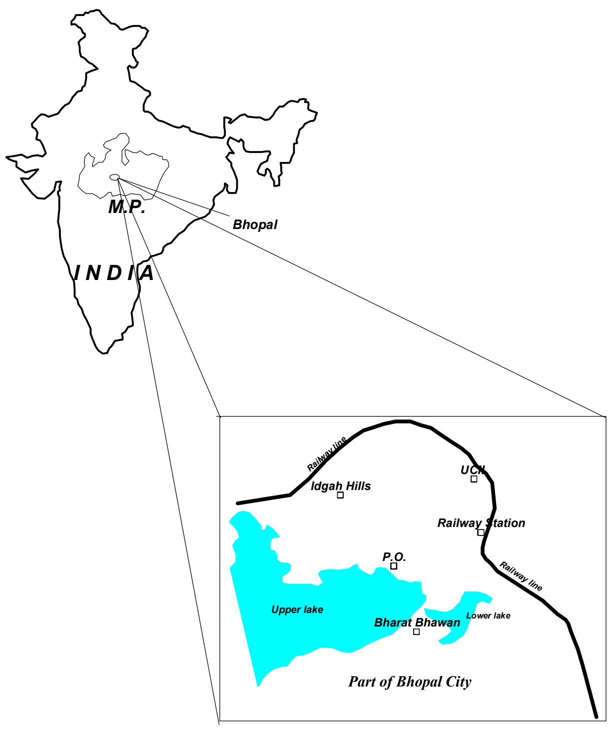

Fig. 1 Location map of study area


Fig. 2a Part of Plant


Fig. 2b Part of Plant


Fig. 2c Part of Plant


Fig. 2d Part of Plant


Fig. 2e Part of Plant


Fig. 2f Part of Plant

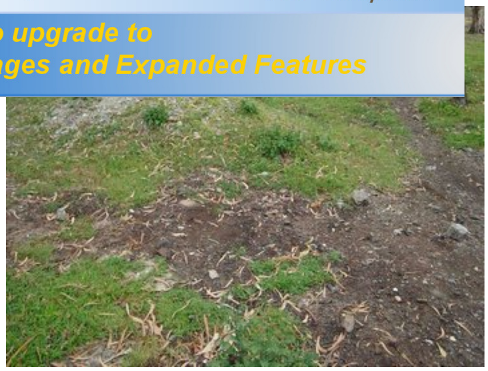

Fig. 3a Heap of dump near formulation plant

Fig. 3b Landfill site

Fig. 3c: Heap of dump east of Police post

Fig. 3d: Terry Dump north of Police post

Fig. 3e: Dumps in pit at southern part

Fig. 3f: Dump pit filled with water

Fig. 3g: Dump pit in southern part

Fig. 3h: SEP-II filled with water

Fig. 3i: SEP-I filled with water

Fig. 3j: SEP-I attracting domestic waste

Fig. 3k: Burned waste in eastern part

Geophysical Investigations : Geophysical investigation mainly comprises measurement and interpretation of signals from natural or induced physical phenomena generated as a result of spatial changes in subsurface lateral and depth wise inhomogenity. These signals measured repetitively at several points in space and time, are interpreted, on, in terms of sub-surface structures/features. Depending upon the scale of operations, geophysical survey can help to delineate regional hydrogeologic features. A reliable interpretation of geophysical survey data requires a good knowledge of sub-surface geology in the area. Geophysical investigations are the best tools for indirectly mapping the sub-surface rock formations and structures. Among all the surface geophysical techniques for shallow subsurface prospecting, Electrical Resistivity Method is the most widely applied method. This is because of its efficacy to delineate subsurface strata besides being simple and inexpensive to carry out the field operations.

The rock matrix of most of the geological formation is basically highly resistive and does not conduct electricity. There are, however, exceptions like clay, shale etc., which comprise conducting minerals. These formations have low electrical resistivities when compared to other rock formations. The resistivity of a rock formation reduces only when it contains moisture. The reduction in resistivity of a rock depends upon the relative quantity and quality of water it contains. Thus by measuring or determining the resistivities of earth layers at different depths, it is possible to infer the hydro-geological character of a particular subsurface layer.

In order to delineate subsurface stratigraphy, geophysical investigations are adopted. It is cost effective and easy to get subsurface lithological information. Earlier during 1994, NGRI carried out geo-electrical profilings and soundings to delineate dump site as well as subsurface strata in the premises of UCIL (Jain et al, 1994). Conventional four electrode resistivity meter was used. Schlumberger array and Wenner array were adopted to generate data. Fig. 4 shows the locations of soundings and profilings. The

...ut using Wenner array with 2, 5 and 10m electrode separations. The details of the profilings are described by Jain et al (1994). Based on the variations in the resistivities the probable dump sites are concluded as shown in Fig.5a. The top layer resistivity data also indicated higher resistivity in the southern part, north and northeastern parts as that could be location of dumps (Fig. 5b). A low resistivity between Storage Tanks and Neutralization Tanks indicated degradation of soil.

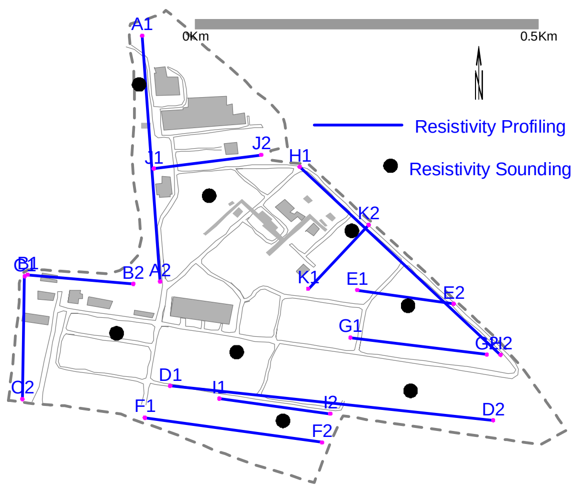

Fig. 4: Resistivity profiling & soundings during 1994

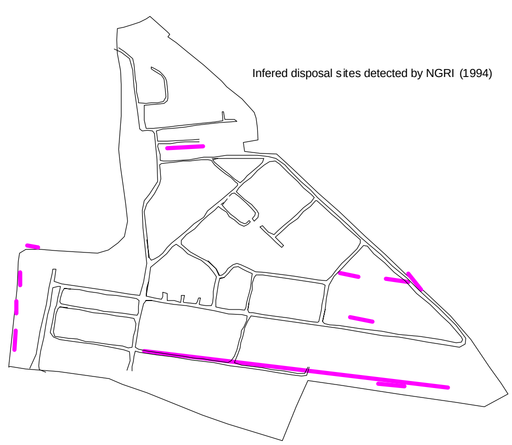

Fig. 5a The possible dump sites (after Jain et al, 1994.)

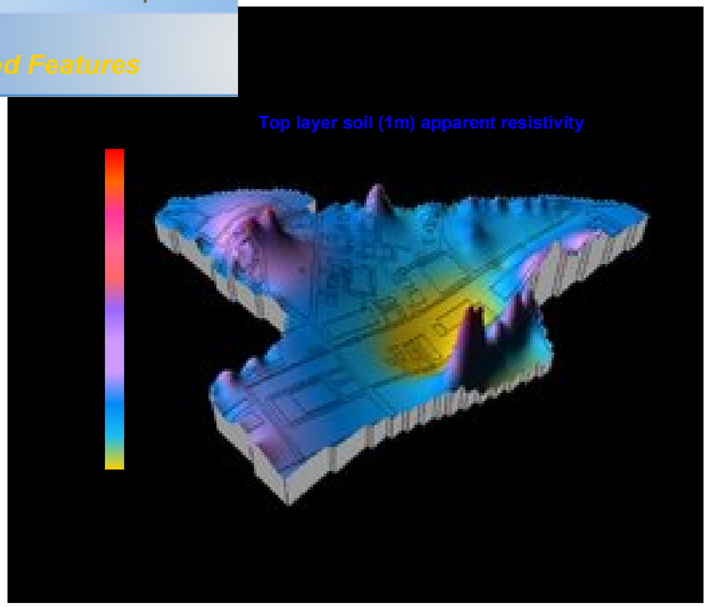

Fig. 5b Possible dump sites indicated by high resistivity (source of data: Jain et al, 1994)

The present study has taken advantage of latest technology of resistivity imaging and its application for detecting dump with the use of multi-electrode geo-electrical investigation. The High Resolution Electrical Resistivity Tomography (HERT) has been carried out to obtain 2D (two dimensional i.e. vertical profile) as well as 3D (three dimensional i.e. horizontal profile at different depth) distribution of resistivity of subsurface strata. An equipment SAS4000 (Fig. 6) from ABEM, Sweden has been used. The data were interpreted using RES2DINV (2005) software. Equipment SAS4000 consists of Terrameter, Junction box, multi core cables and electrodes as shown in Fig. 6. The four channel system allows selecting the array and then data is recorded on the terrameter. The data is then transferred to PC and software RES2DINV is used to process the data. Initially, data is converted to proper format then edited for any error. The 2D data is then inverted to layered resistivity model. The gradient array system was adopted to obtain data.

Fig 6 ABEM Terrameter with accessories (source: www.abem.se)

The various sequences of measurements to build up 2D profile are depicted in Fig. 7. With a particular electrode arrangement one gets a layer of information. Further, it can be seen from Fig. 7 that as one moves from station 1 to 2 the information depth also increases.

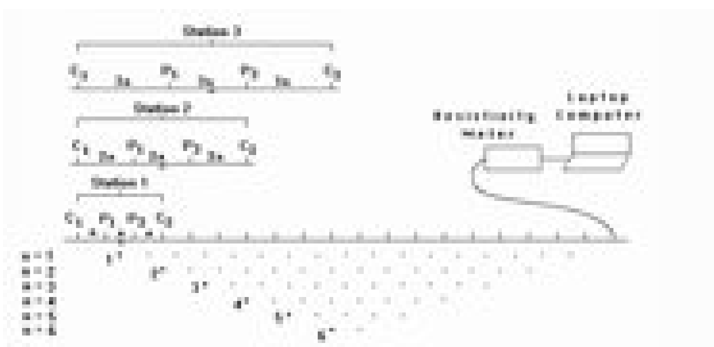

Fig. 7 : Sequence of measurements (Source: RES2DINV Manual)

The entire downloaded data were first checked for errors. Any error in the measured data was removed while processing through RES2DINV. An example of bad data record is shown in Fig. 8 . Such bad data records are removed before interpreting the profile.

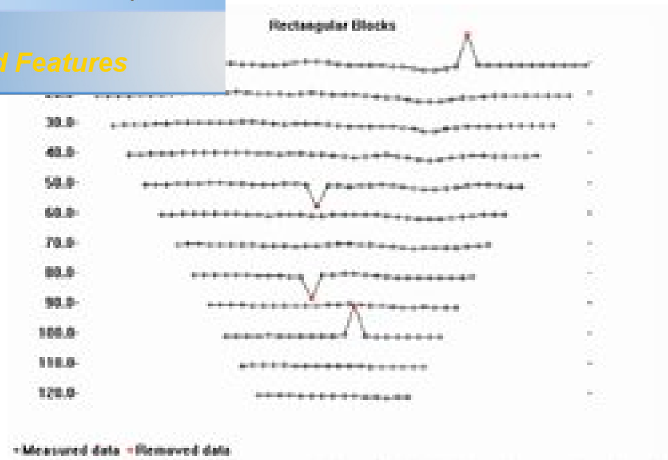

Fig. 8: Example of data set with few bad points (source: RES2DINV Manual)

The data obtained during field work were used to get subsurface resistivity distribution using RES2DINV window based software. A forward modeling technique is first used to calculate resistivities then non-linear least square optimization technique is used to invert the model. The optimization method basically deploys minimization of difference between calculated and observed resistivity and is reflected in terms of root mean squared (RMS) error. The low RMS or when RMS does not change significantly is considered as best model.

The data obtained during the field were processed for removal of error and then interpreted using RES2DINV and iterations were made till a low value of RMS and stable RMS was obtained.

The UCIL premises is occupied with concrete, demolished buildings, plant, sheds and metal road as shown in Fig 9.

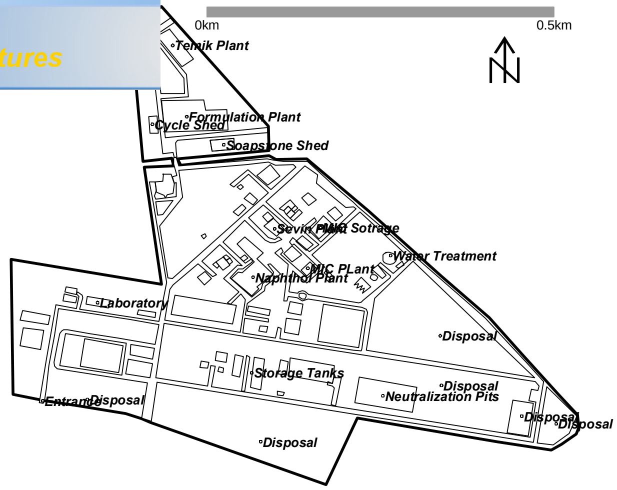

Fig.9 UCIL premises (source : Burmeier et al, 2005)

As it can be seen that most of the area is covered with construction, roads etc., and the soil covered area is the only place where we can perform HERT. Again many part of the open land area is covered with bushes (Fig.10) and it is difficult to penetrate these thorny bushes. There are ponds such as SEP in the southeastern part, pits filled with water and surrounded with bunds (in southern and eastern part) of premises. Such places cannot be scanned with geophysical method. A reconnaitory survey has been carried out to locate suitable places for HERT and effort has been to cover as much area as possible. The location of these profiles is shown in Fig.11.

Fig. 10 DenseBushes in UCIL premises

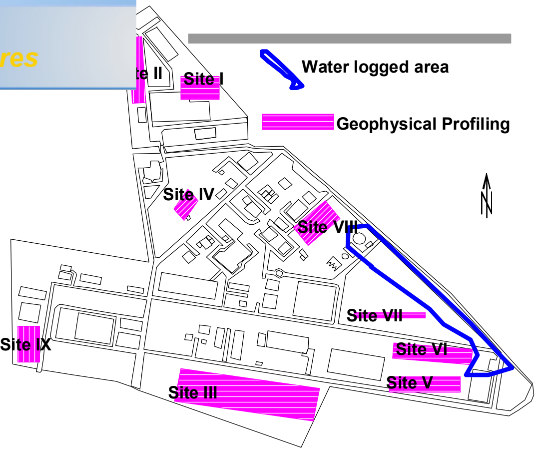

Fig. 11. Locations of Geophysical profiles

Site I : The site is situated in the northern part of the premises in the front of Formulation plant (Fig. 11). The heaps of dumps are visible at the open space. There is pungent smell of pesticides and it is intolerable. It is not known if the heap of dumps are in the pit or merely lying on the surface. Therefore the HERT profiles are laid across the dump in EW direction. The electrode separation was kept as 1m so that the dumps are adequately covered. Total 48 electrodes were used with profile length as 48m. The obtained data was edited for erroneous data and then interpreted using RES2DINV with enough iterations to get minimum root mean square error. The final profile showing resistivity distribution along the profile is depicted in Fig. 12 .

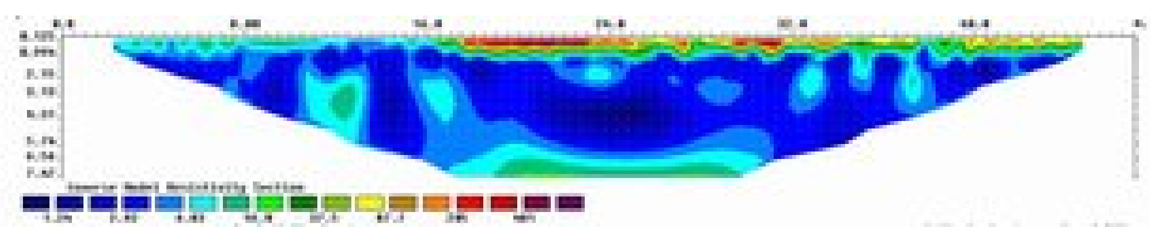

Fig. 12 : 2D geo-electrical profile

It can be seen that the dumps have higher resistivity of the order of 100 to 300 ohm m whereas the host black soil has about 5 to 8 ohm.m. The dumps are clearly demarcated in the profile having depth from few cm (between 38th to 48^{th} electrodes) to about 1m order to cover more area another four parallel profiles have been taken at the interval of 3m each. The profiles are shown in Fig 13a, b, and c.

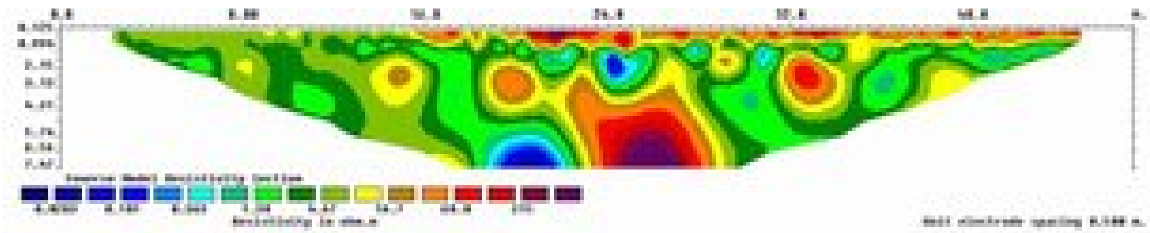

Fig. 13a : 2D geo-electrical profile

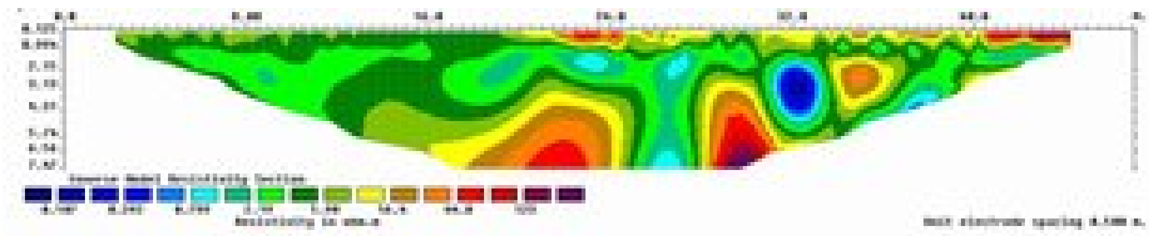

Fig. 13b : 2D geo-electrical profile

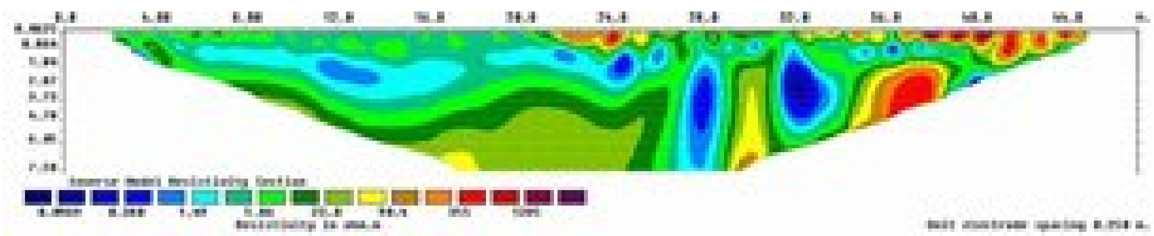

Fig. 13c : 2D geo-electrical profile

It can be seen that as we move northward the depth of eastern dumps decreases whereas the depth of western dump increases. Therefore an area of 9mx48m has been covered. Since there are demolished structures, we could not cover further area in this part of premises. The 2D data were used to infer 3D profile using software RES3DINV and the distribution of resistivity at different depths is shown in Fig. 14 . It can be easily seen that the dumps and their depths are clearly indicated. Further, it can be observed that the soil below the dumps have low resistivity of about 1 ohm.m. Could it be affected by leaching of dumps?

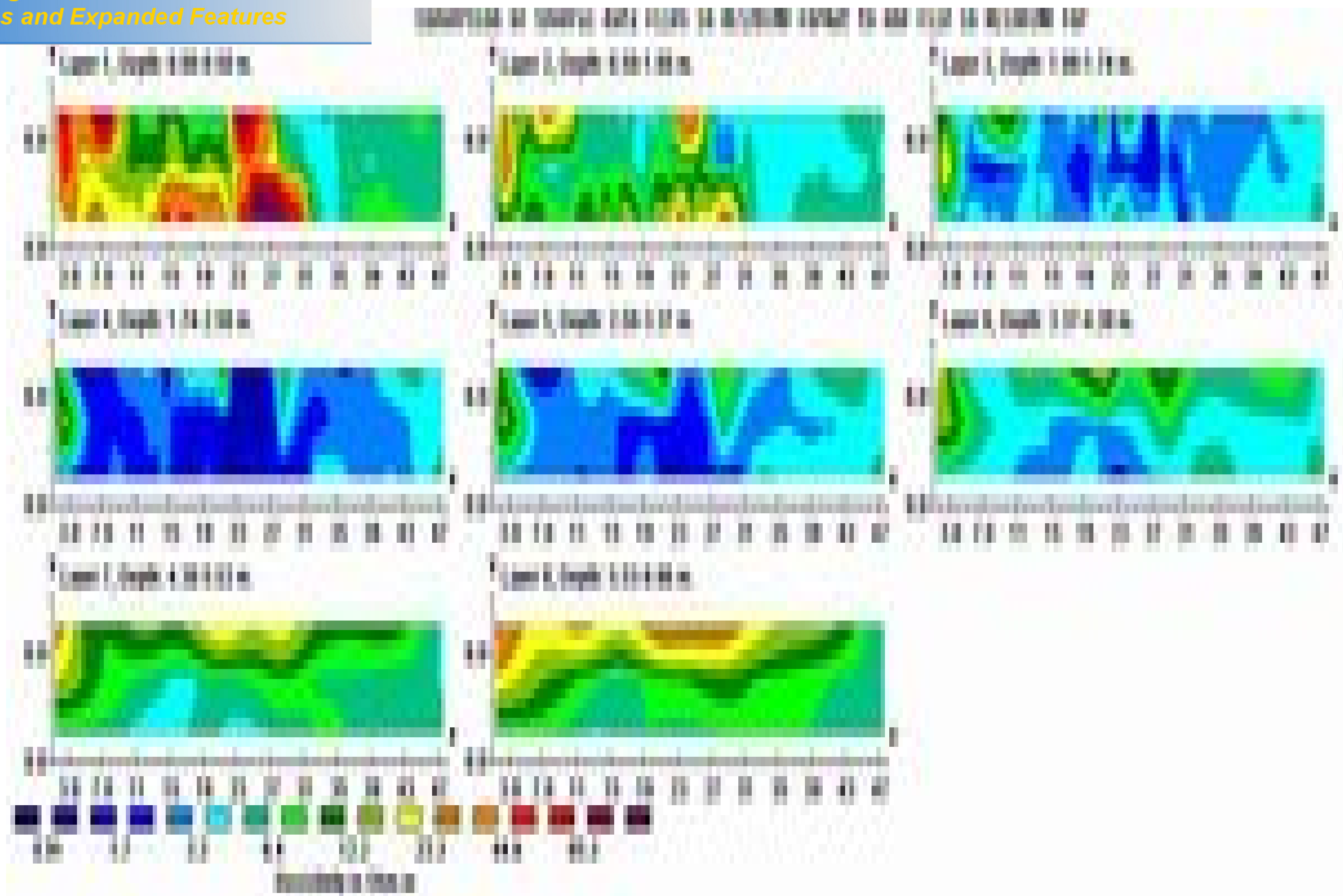

Fig. 14 : 3D geo-electrical profile at different depths

…ons has been selected in the open space close to Cycle shed of West of Formulation plant across the road (Fig. 11). The profile is laid in NS direction (close to western boundary) with 1st electrode in the south, close to cycle shed. The electrode separation was chosen as 2m so that entire area is covered. The subsequent profiles were laid at 3m separations which covered entire area. The 2D profiles are shown in Fig. 15a, b and c. It can be seen that there is no sign of any dump and the top layer resistivity is about 4 to 6 ohm.m. However, the low resistivity of 2 to 3ohm.m is found between 5 to 12m, which need further prob. Similar to previous exercise, in this case too we have converted 2D data into 3D as explained above. The 3D profile at different depth is shown in Fig. 16 , indicating no sign of near surface dump.

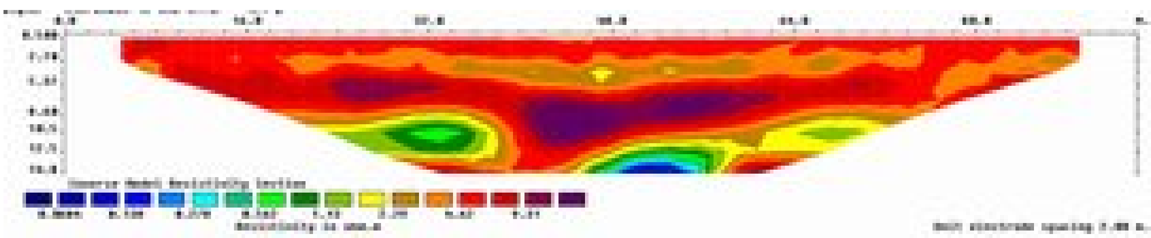

Fig. 15a : 2D geo-electrical profile

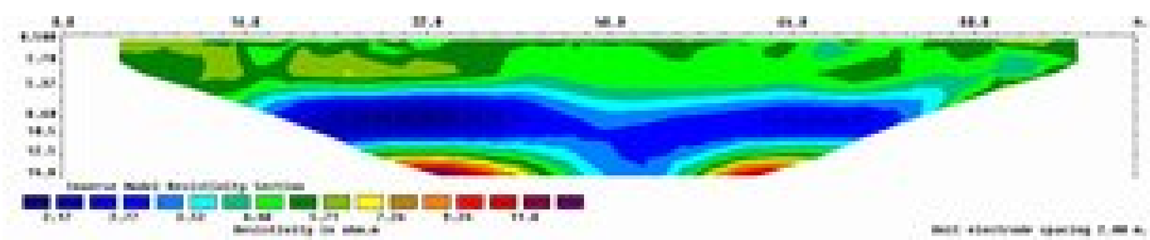

Fig. 15b : 2D geo-electrical profile

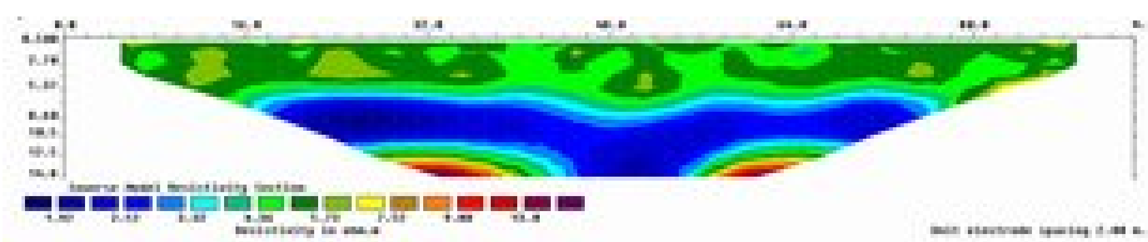

Fig. 15c : 2D geo-electrical profile

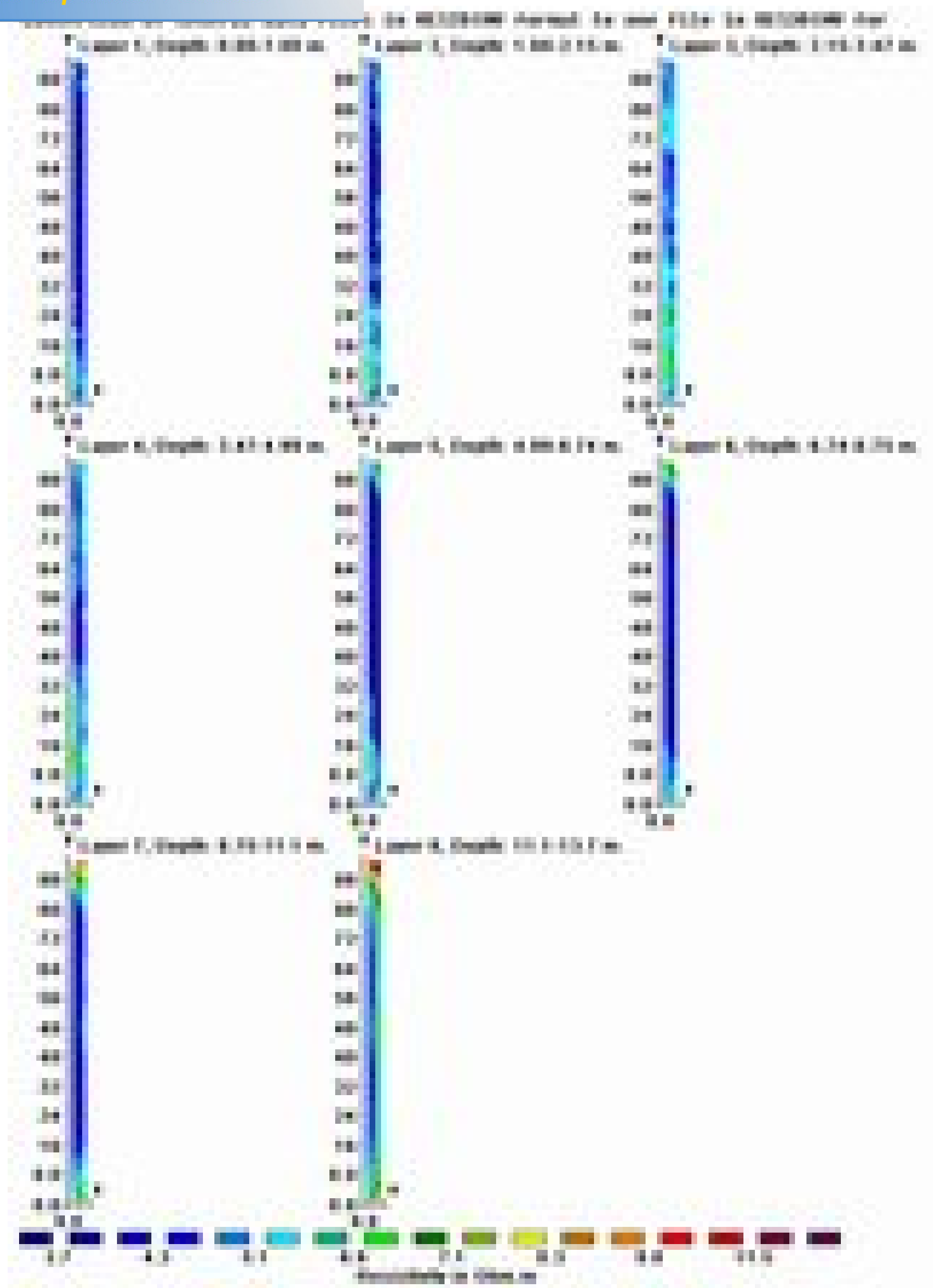

Fig. 16 : 3D geo-electrical profile at different depths

Site III: There are pits where burned materials and waste materials are reported (NEERI, 1999) to be dumped as shown in Fig. 3 e, f and g at this site which covers a vast open land (Fig. 11). Due to water logged in these pits and uneven topography we were wever these are known dump sites. Although there is no sign of any dump heap, we covered entire open area by selecting electrode separation of 3m in EW direction with 1st electrode in the area that is opposite Police post. The site is selected in the open area which is in the southern part of premises and south of road opposite to Storage tank or near Neutralization pit (Fig. 11). The western part of the area is occupied by metal road and demolished structures hence that part is not covered. The obtained data is interpreted as described above and the profile is shown in Fig. 17.

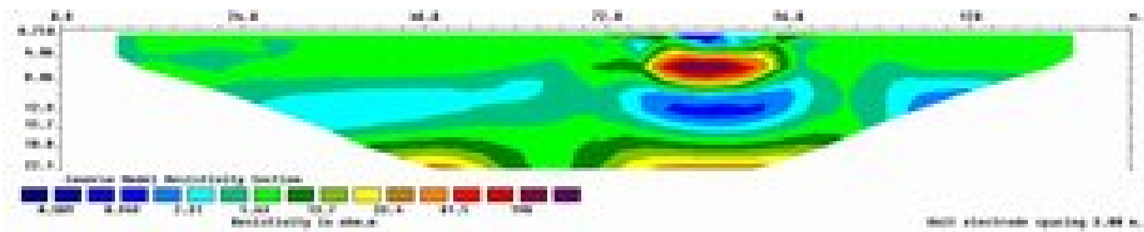

Fig. 17: 2D geo-electrical profile

It can be seen that about 78m along the profile there is anomaly of high resistivity (30 to 200 ohm.m) against low resistivity (4 to 8 ohm.m) of soil zone. The dump could be 4m deep and up to 8m that is not visible at ground surface. Further, there is low resistivity (less than 1 ohm.m) up to 16m and it may be leaching effect of dump. In order to map the lateral extent of this anomaly another five profiles had been laid at the intervals of 10m each covering an area of 141mx50m. The obtained profiles are shown in Fig. 18a, b, c, d and e. It can be seen that the shallow dump as seen in first profile is not found in remaining profiles indicating lateral limitation of this dump. The 3D profile generated from these 2D data is shown in Fig. 19 . It is clear that the dump may be up to 8m deep at a place only.

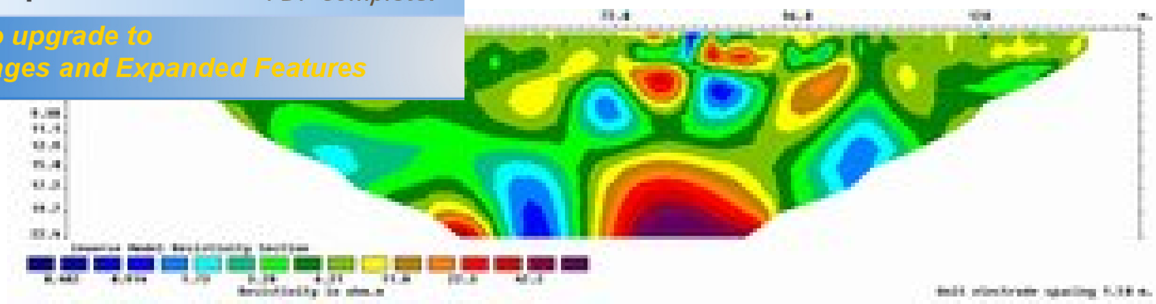

Fig. 18a : 2D geo-electrical profile

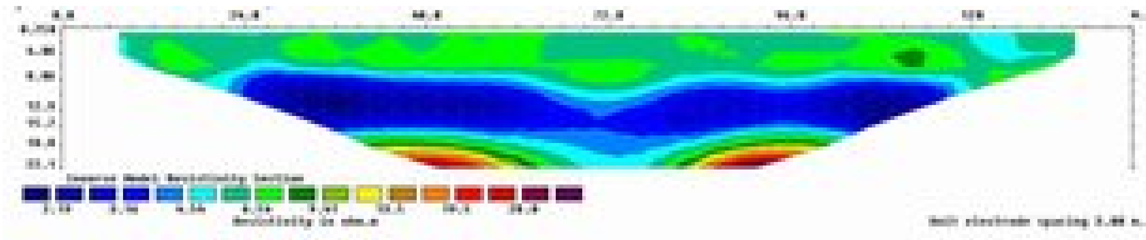

Fig. 18b : 2D geo-electrical profile

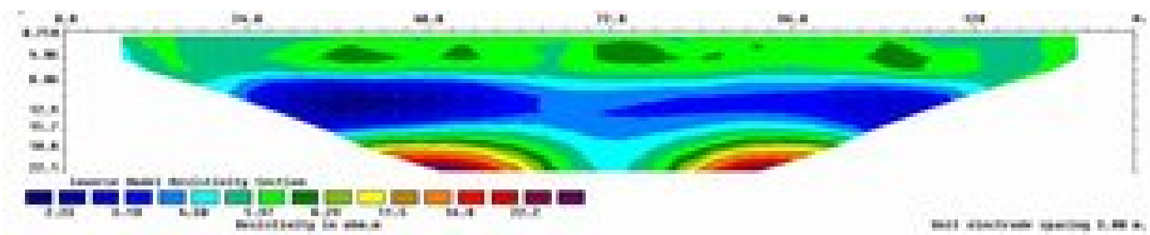

Fig. 18c : 2D geo-electrical profile

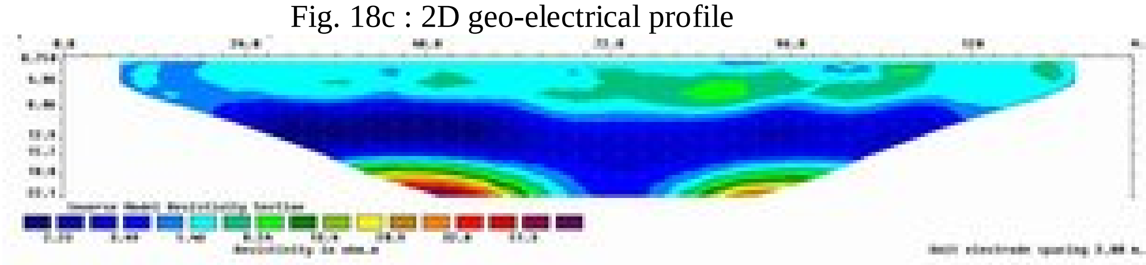

Fig. 18d : 2D geo-electrical profile

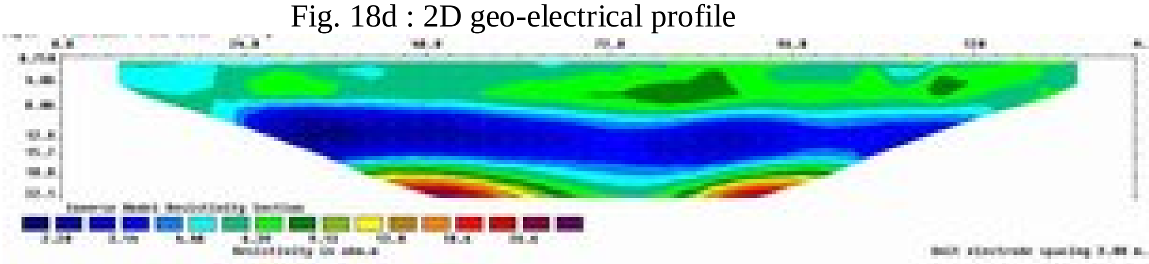

Fig. 18e : 2D geo-electrical profile

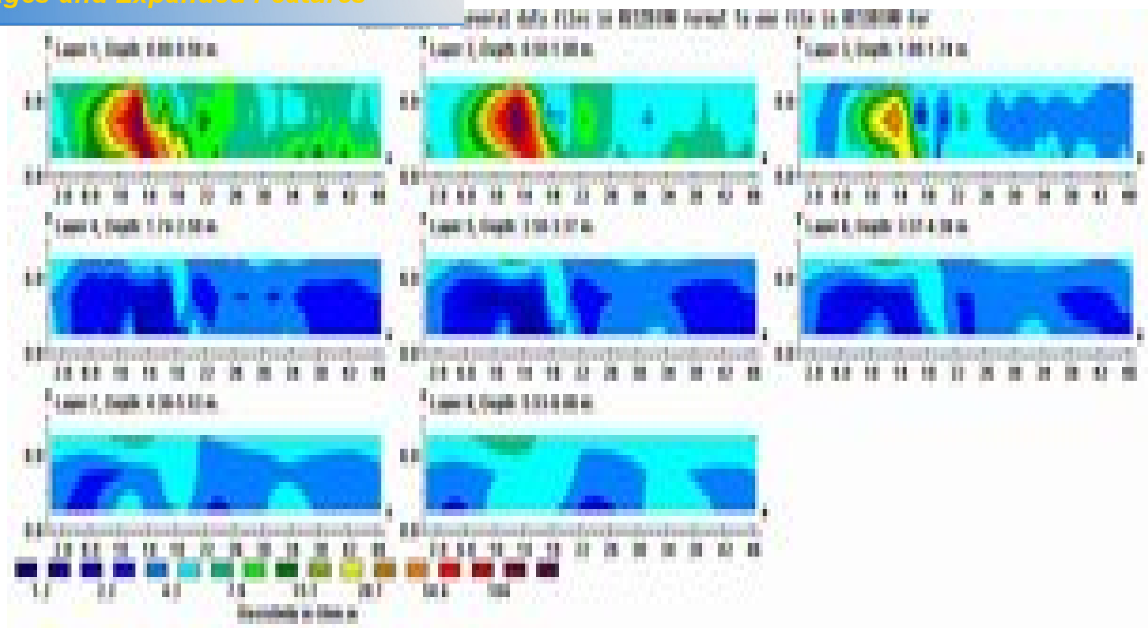

Fig. 19 : 3D geo-electrical profile at different depths

Another profile has been carried out at this open space to assess subsurface strata. The electrode spacing has been increased to 5m in EW direction with 1st electrode in the play ground of nearby school. The 2D profile thus obtained is shown in Fig. 20. It can be seen that top layers have low resistivity (3-6 ohm m) indication clay and below 22m the resistivity increases indication sandy layer of weathered Vindhyans. The profile indicates that up to 40m there is no indication of Vindhyan formation and perhaps it could be deeper in the area.

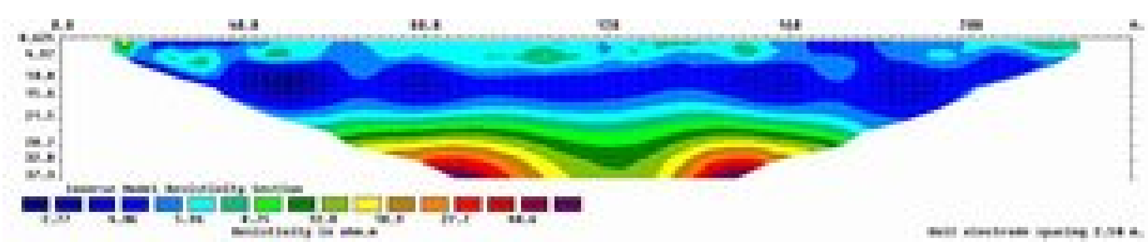

Fig. 20: 2D geo-electrical Profile

n the open space close to tower (Fig. 11). Due to limitation of space we restricted electrode spacing to 0.5m with total profile length as 23.5m in NS direction. The spacing between another two profiles was kept as 2m each. The obtained data was edited for error and interpreted using RES2DINV software. The final profile obtained after several iterations is shown in Fig. 21a, b and c.

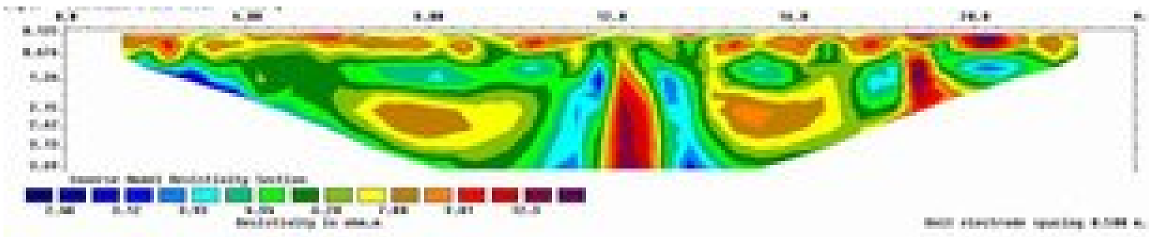

Fig. 21a: 2D geo-electrical Profile

A low resistivity profile indicates clay and no dump were inferred from this profile. However in the middle of profile slightly high resistivity is recorded and it is due to pot hole created in the ground along the cracks in the clayey soil. A 3D profile at various depth is shown in Fig. 22.

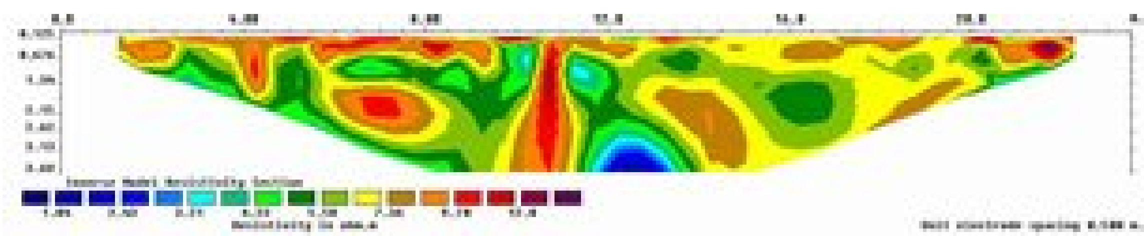

Fig. 21b: 2D geo-electrical Profile

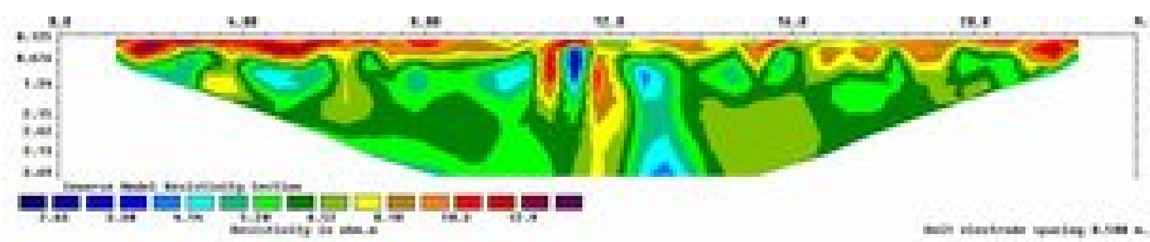

Fig. 21c: 2D geo-electrical Profile

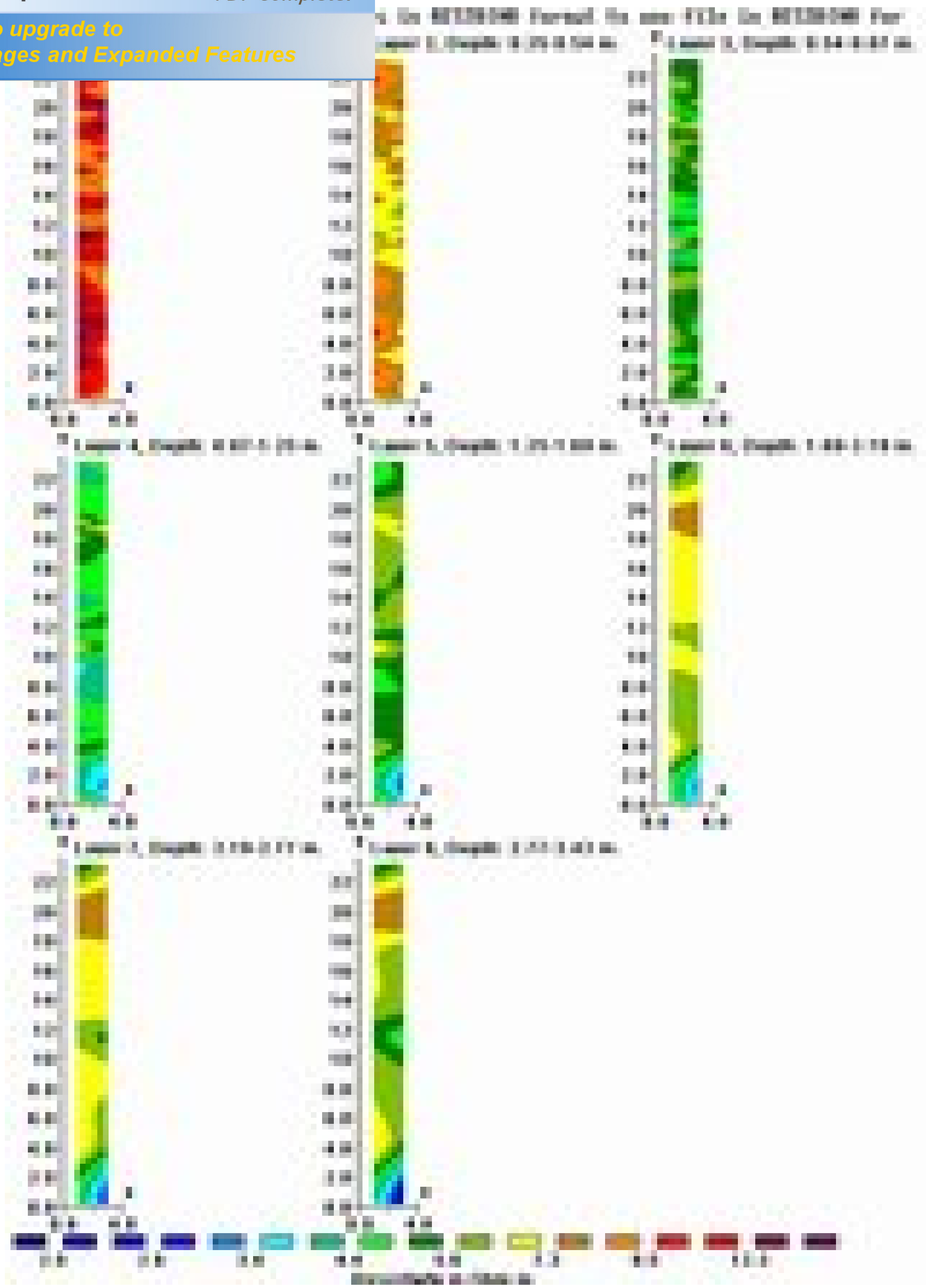

Fig. 22: 3D geo-electrical Profile

area east of Police Post and the open space between Neutralization tank and SEP (Fig. 11). The SEP I and II are water logged as shown in Fig. 3 h, I and j, hence could not be covered. The SEP-I is also made a dump site for domestic waste from nearby settlements. The heaps of dump are seen along the road leading to SEP. A strong smell of pesticides makes it difficult to work in the area. The first profile is selected along the road in EW direction across the dump as shown in Fig. 11. The electrode separation was kept as 1m so that maximum space available of 48m will be covered. The 1st electrode was kept in west near Police post. The data was obtained and processed for any error and interpreted using RES2DINV software. The final profile obtained after several iteration is shown in Fig. 23. It can be observed that the dumps are clearly depicted in the profile. The dump is shallow (0.7m) between 8 to 10m along the profile and deep (1.3m) between 10 to 16m along the profile. Again the dump becomes shallow all along the profile.

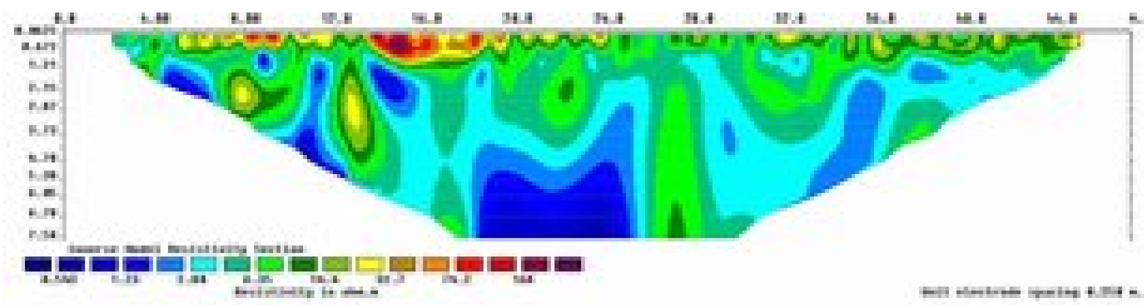

Fig. 23: 2D geo-electrical profile

In order to get northward lateral extension of dump another 3 profiles were taken at 3m, 3m and 5m interval. Hence the total area covered is 48mx14m. The profiles are shown in Fig. 24a, b, and c. It can be observed that the depth of dumps have increased as we is generated using all the 2D data and the inferred 3D profile at various depths is shown in Fig. 25.

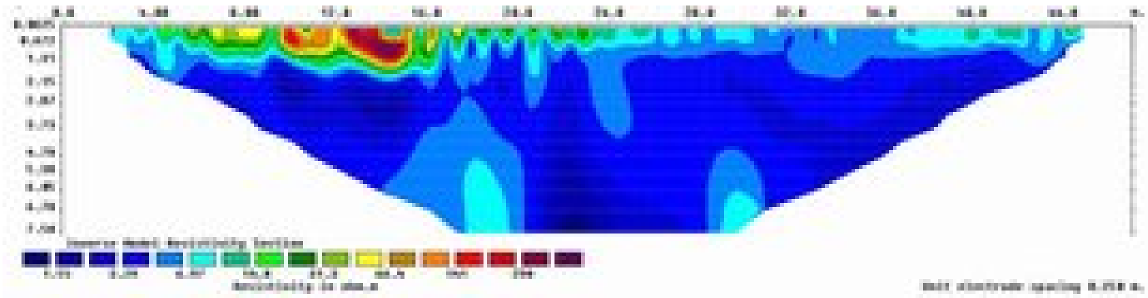

Fig. 24a: 2D geo-electrical profile

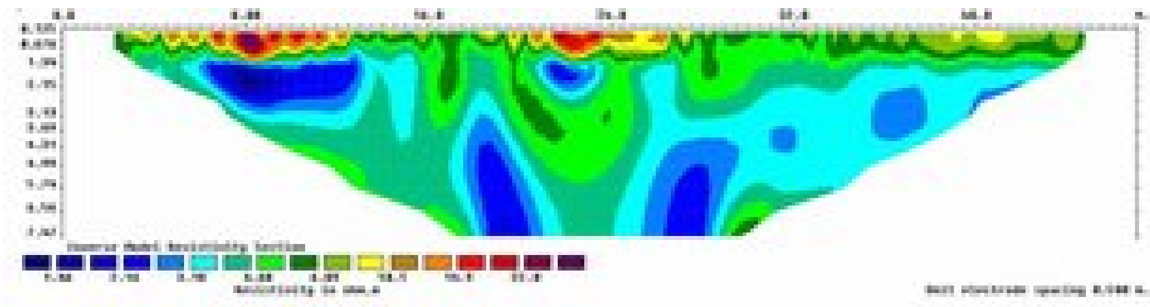

Fig. 24b: 2D geo-electrical profile

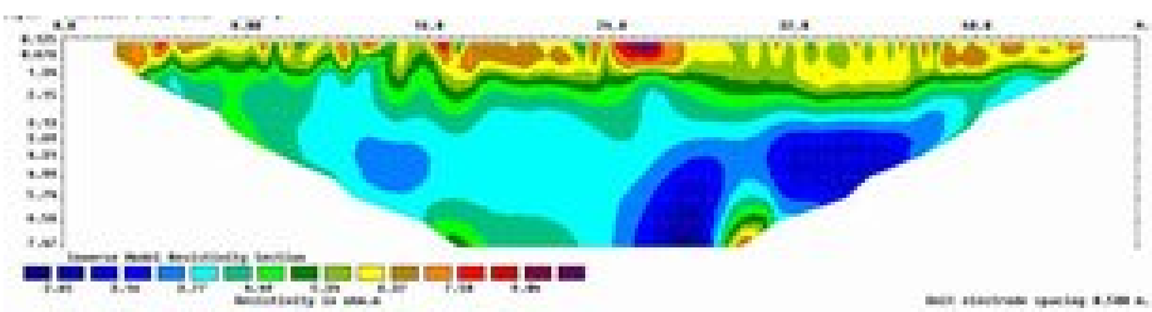

Fig. 24c: 2D geo-electrical profile

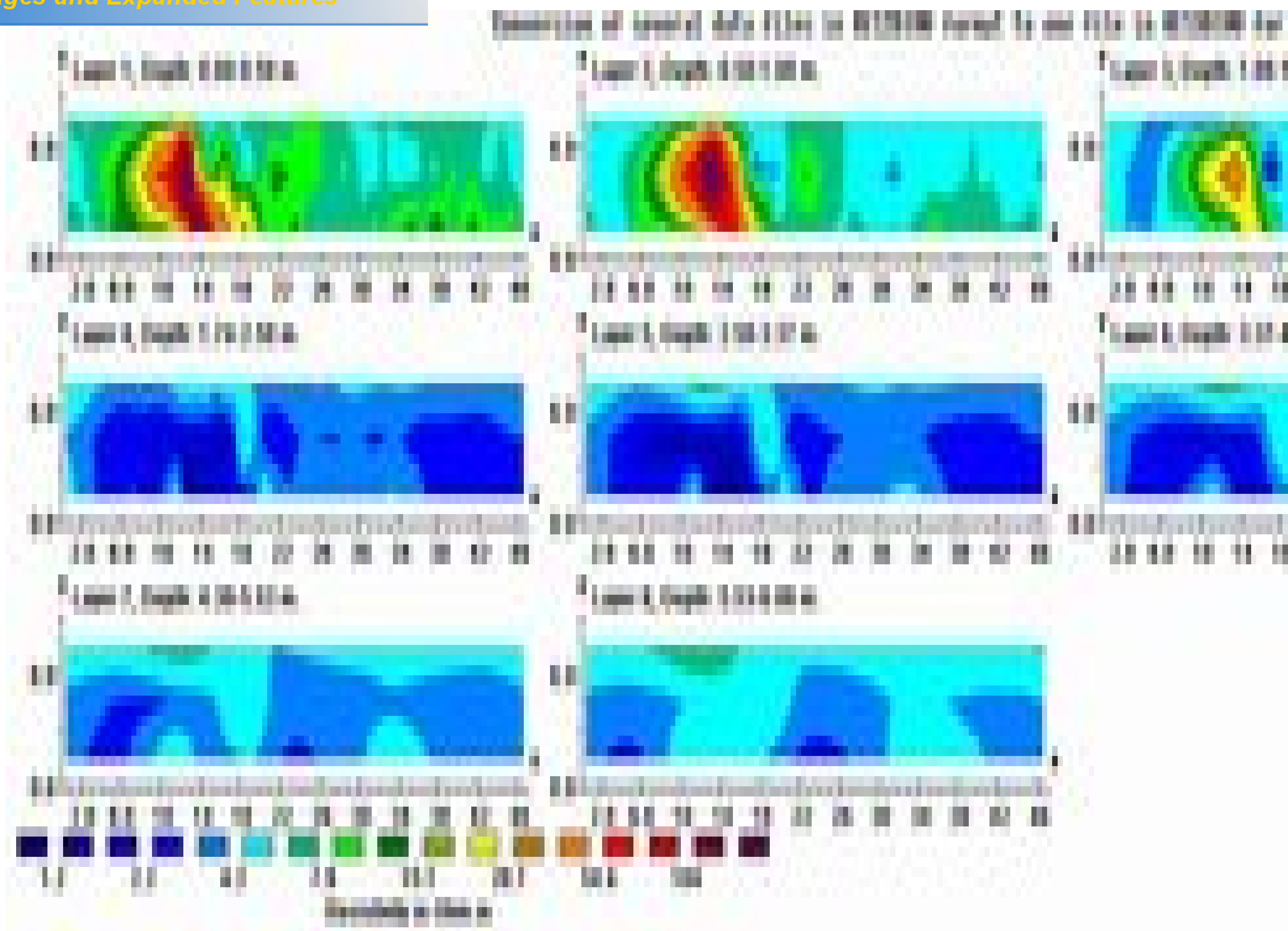

Fig. 25: 3D profile at various depth at site V

same area but in the northern most part along the road in EW direction (see Fig.11.). At the western end there is built up area and the eastern end is water logged, hence the space available had given us no choice but to select the electrode separation as 2m with total profile length as 48m in EW direction along the road. The bushes were cleared to get as close as possible to expected dump. The 2D data was corrected and interpreted to get geo-electrical distribution as shown in Fig. 26.

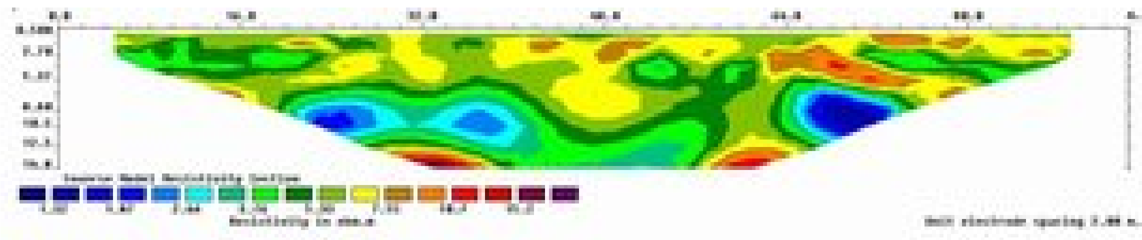

Fig. 26: 2d geo-electrical profile

There was no indication of any dump along this profile. Two more profiles were taken at 10m separation and the profile obtained is shown in Fig. 27a and b. These profiles have also indicated that there may not be any dump in this area. The 2D data is then converted into 3D and the depth wise profile is depicted in Fig. 28.

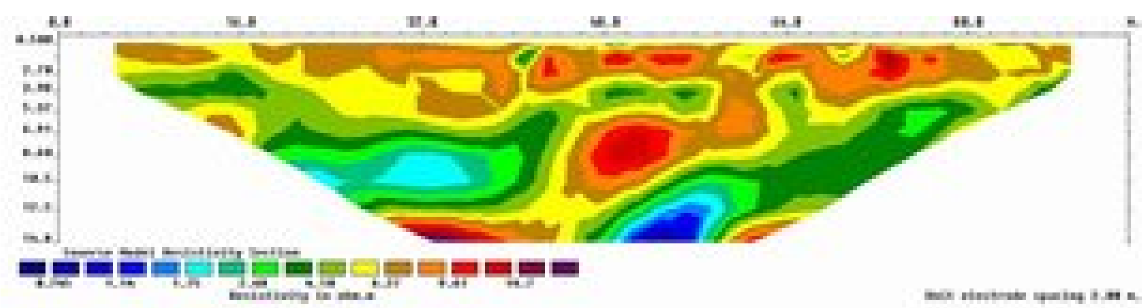

Fig. 27a: 2D geo-electrical profile

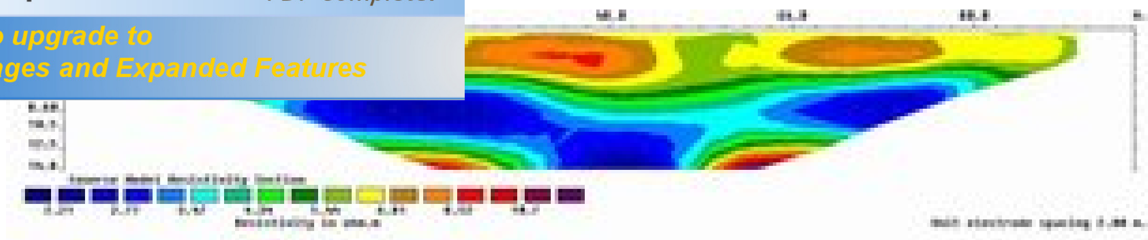

Fig. 27b: 2D geo-electrical profile

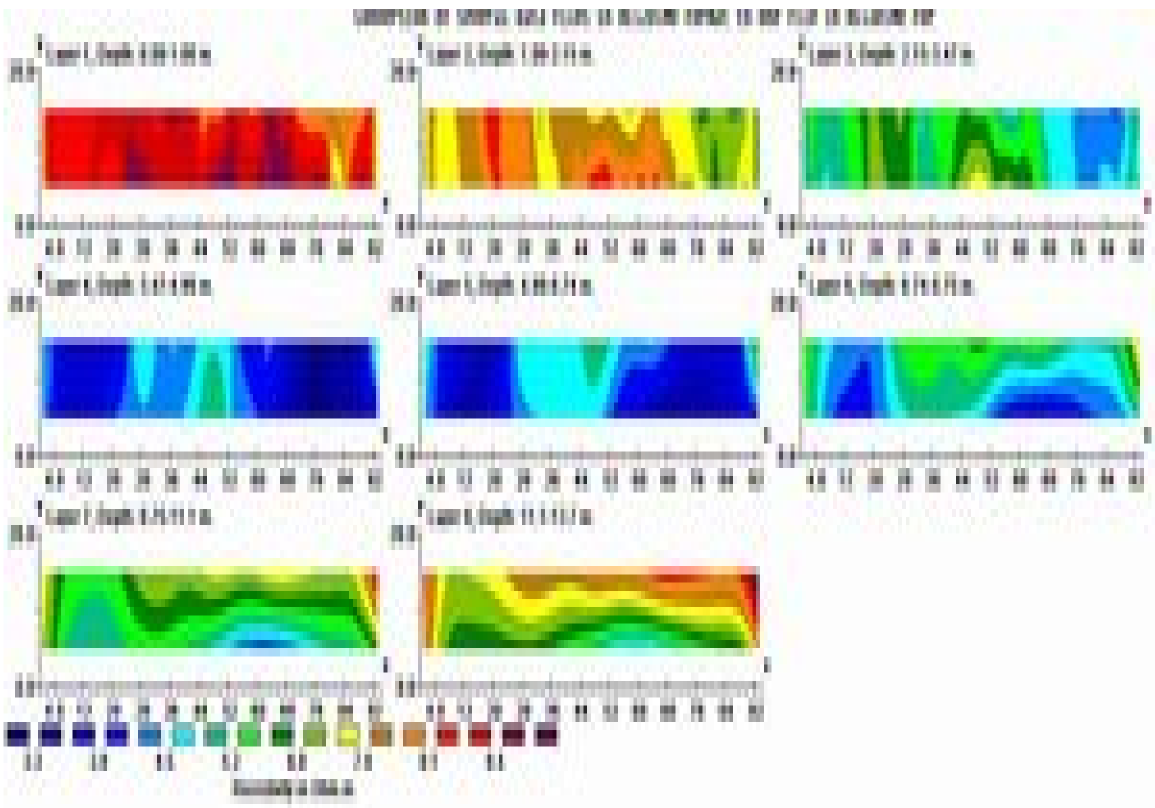

Fig. 28: 3D geo-electrical profile

Site VII : This site is selected in the eastern part of premises and north of SEP as shown in Fig. 11. The eastern part of this open land was waterlogged where as many parts are covered with bushes. After clearing some of the bushes we were able to take a profile in EW direction with 2m electrode spacing and keeping 1^{st} electrode in the E. The 2D data was corrected and interpreted with RES2DINV. The obtained result with minimum

. In this profile too the dump was not seen, although there are tarry dump in the south of this profile as shown in Fig 3f.

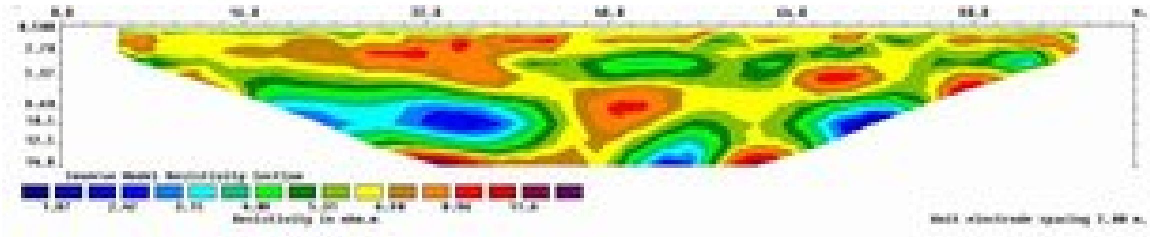

Fig. 29: 2D geo-electrical profile

Site VIII : The site is selected in the close vicinity of the plant in the eastern direction. Part of this area was also water logged and some are covered with bushes. The profile was taken in $N70^0E$ as shown in Fig. 11. A 2D profile was taken and the processed data was interpreted for resistivity profile which is shown in Fig. 30.

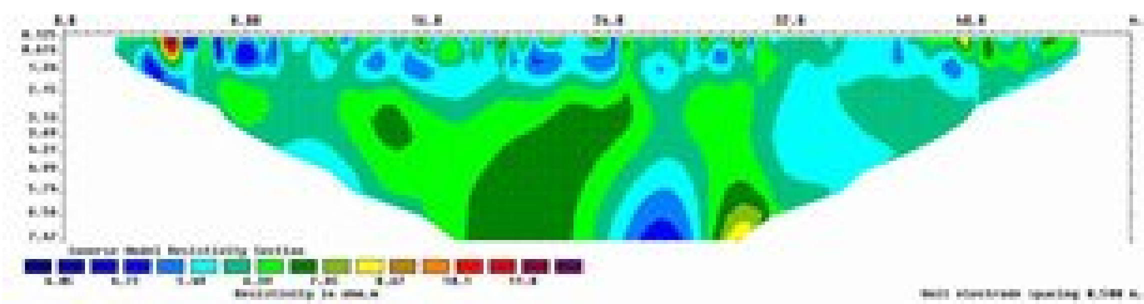

Fig. 30: 2D geo-electrical profile

There was no indication of any dump in this part of premises. Further three more profiles were taken parallel to it at the separation of 4m, 5m and 3m respectively. An area of 48mx12m was covered by these profiles. The interpreted data after correction is shown in Fig. 31a, b and c. There was no indication of any dump, although an anomaly was seen in one of the profile and it was found to be pot-hole. A 3D profile was also generated from s inferred that there was no dump in the area covered by the profiles.

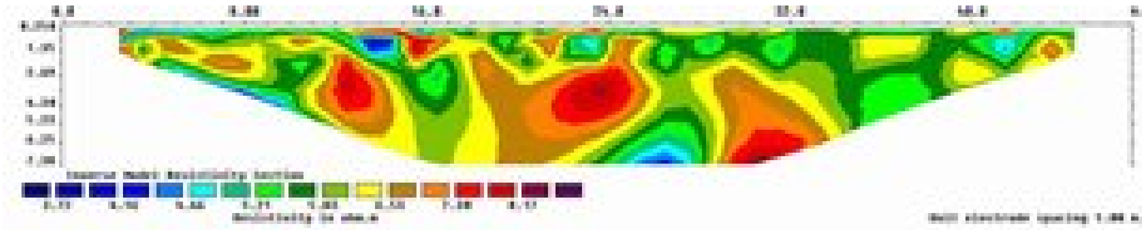

Fig. 31a: 2D geo-electrical profile

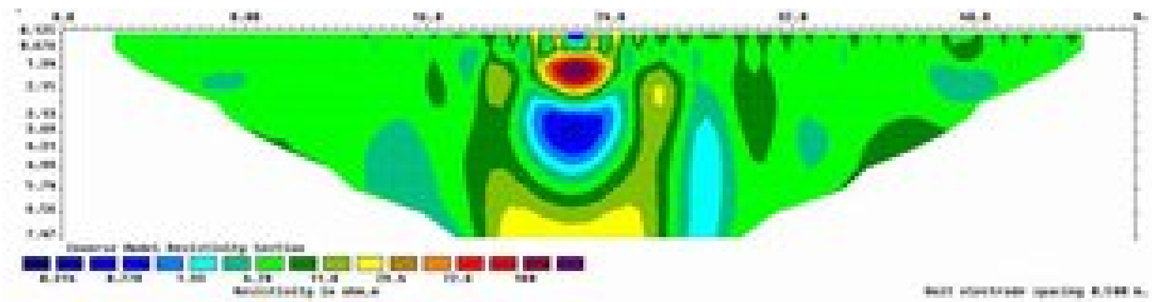

Fig. 31b: 2D geo-electrical profile

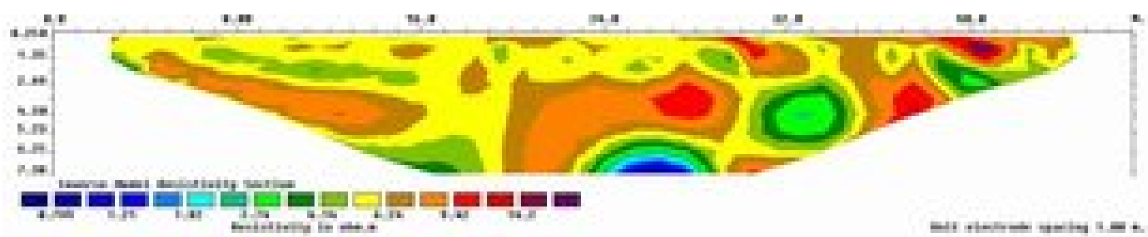

Fig. 31c: 2D geo-electrical profile

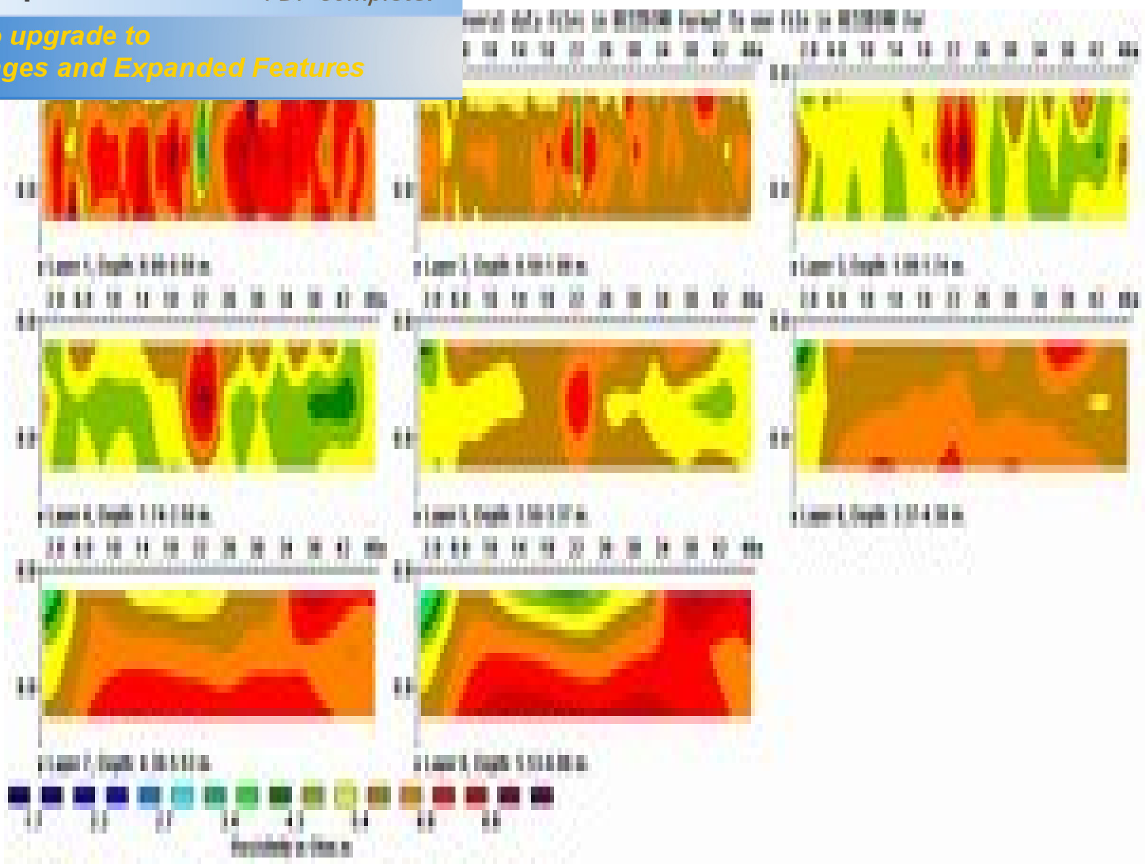

Fig. 32: 3D geo-electrical profile

Site IX : The site has been selected at the open space available at the main entrance, on the western side of road as shown in Fig. 11. The electrode separation was selected as 2m and 2D profile was obtained. The data was corrected and interpreted using RES2DINV. The obtained result is shown in Fig. 33.

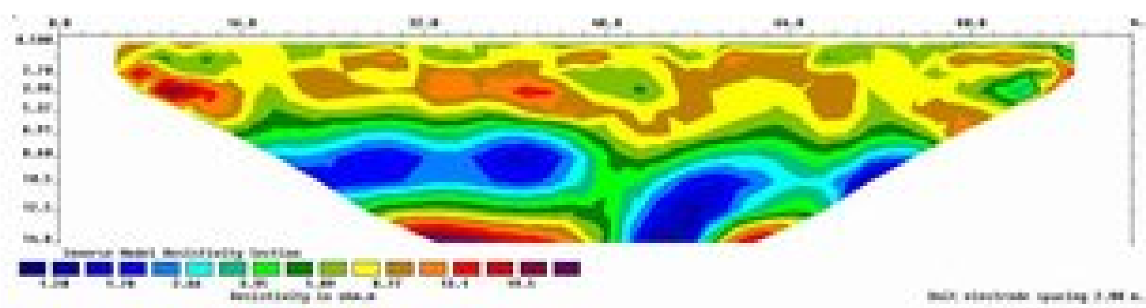

Fig. 33: 2D geo-electrical profile

cation of any dump. We took another two profiles parallel to it at the separation of 5m each. The geo-electrical profiles are shown in Fig. 34a and b.

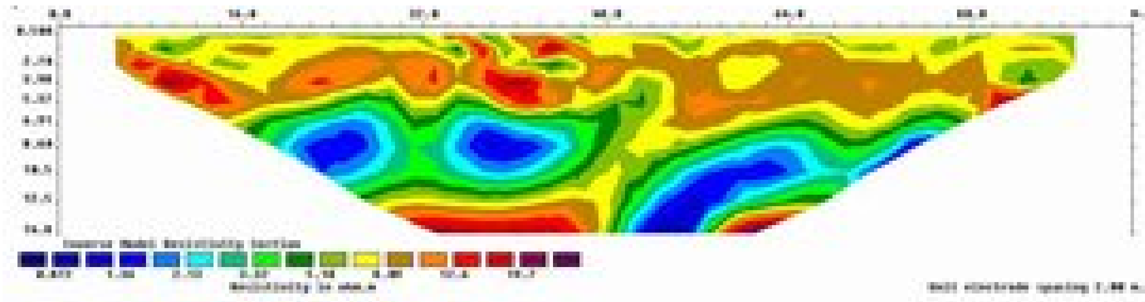

Fig. 34a: 2D geo-electrical profile

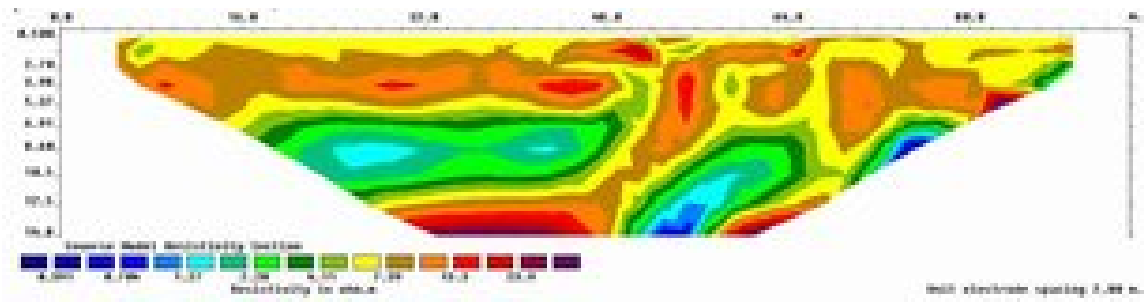

Fig. 34b: 2D geo-electrical profile

A 3D profile was generated with the software RES3DINV and using these 2D data to obtain a 3D picture at various depth. The profile is shown in Fig. 35. It does not appear that there is any dump in the patch covered by the profiles.

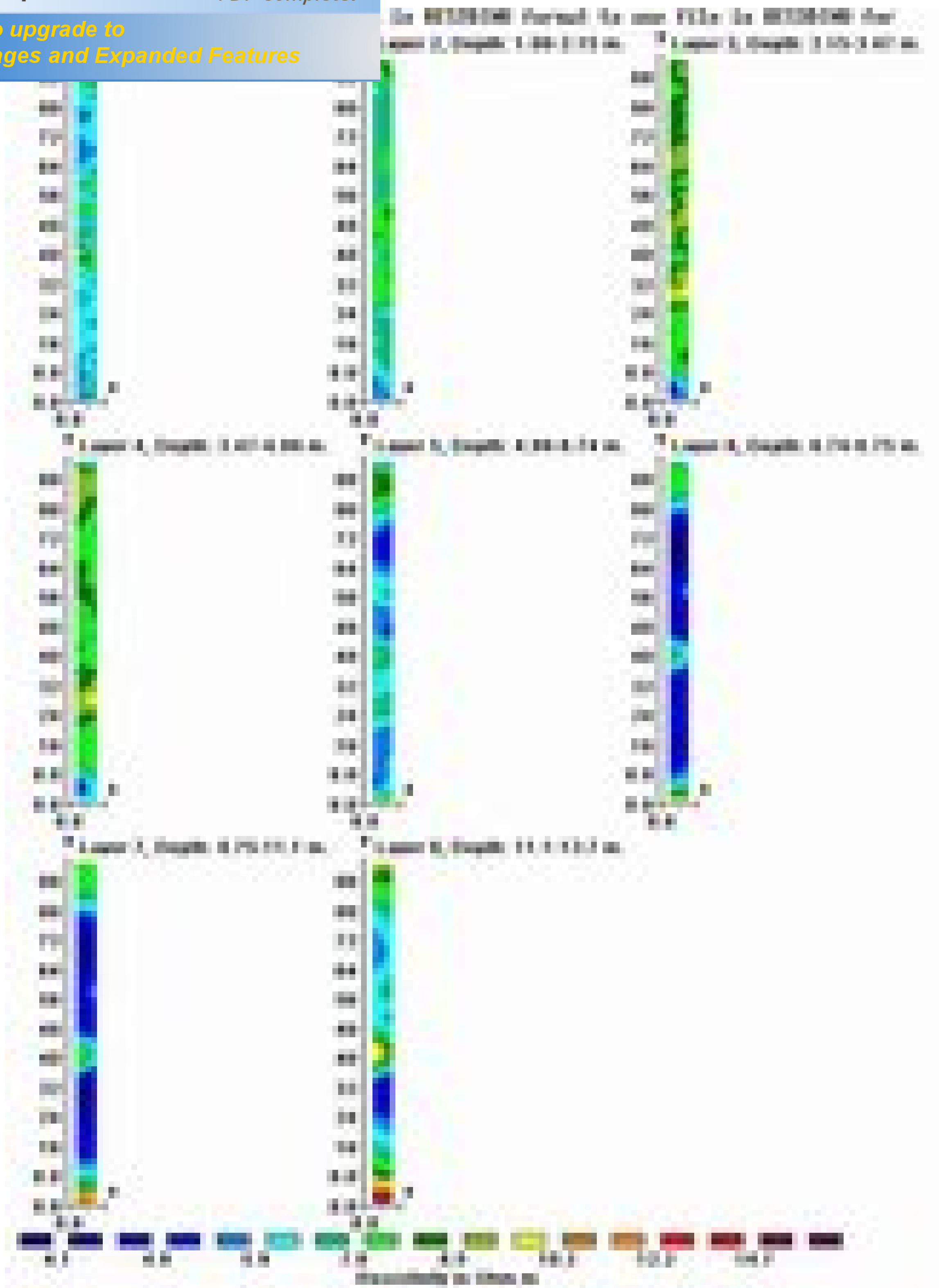

Fig. 35: 3D geo-electrical profile

HERT was carried out across the selected area based on the previous studies and reports to ascertain the extent and depth of dumps in the premises of UCIL. Total nine sites were covered as the technique requires continuous open space without concrete, bushes; waterlog (ponds) and roads which are very limited in the premises. Out of nine sites, dumps are located at three sites (Fig. 36) namely :

Site I : North of Formulation Plant

Site III : South of Storage tank and Police Post, and

Site V : Between Neutralization tank and SEP including Terry dump in northern part.

Most of the dumps are limited to about 2m in depth except one that may be deeper (4-8m). These dumps are limited to few spots. These high resistivity zones need to be ascertain through detailed chemical examination for their toxicity.

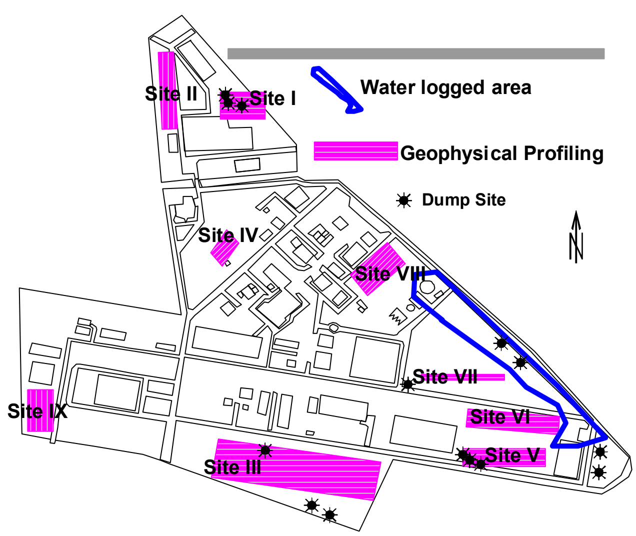

Fig. 36: Dump sites

anced the investigation and officials from BGRD have helped during the investigations. Director NGRI has encouraged carrying out investigations. Authors are thankful to them.

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Rapid 3D Resistivity & IP inversion using the least-squares method (For 3-D surveys using the pole-pole, pole-dipole, dipole-dipole, rectangular, Wenner, Wenner-Schlumberger and non-conventional arrays) On land, underwater and borehole surveys
Geoelectrical Imaging 2D & 3D, GEOTOMO SOFTWARE, MALAYSIA