AJ ACADEMIC JOURNALS
expand your knowledge

International Journal of Physical Sciences

Full Length Research Paper

Application of integrated geophysical methods in environmental studies: A case study of oil spillage in Thange Area Makueni County, Kenya

K'orowe Maurice O.[1], Mwanzia Dorothy K.[1]*, Obonyo Evance O.[1], Kitavi Stephen M.[1], Masila Karen N.[2] and Machimbo Evans W.[2]

[1]Department of Physics, Jomo Kenyatta University of Agriculture and Technology Nairobi, Kenya.
[2]Department of Geology, School of Physical Sciences, College of Physical and Biological Sciences, University of Nairobi, Kenya.

This research was conducted with the aim of mapping the extent of soil and ground water hydrocarbon contamination from an oil pipeline leak point within the area. An integrated geophysical survey approach involving horizontal electrical profiling (HEP), vertical electrical sounding (VES) and Gravity Survey was applied. Resistivity and gravity lows were identified as aquifer zones confined within basalts and potential migration zones of Light Non-Aqueous Phase Liquids (LNAPL's). An integration of the geophysical findings showed two potential migration paths: one trending (SW-NE) and the other (NE-SW) both influenced by geologic factors.

Key words: Resistivity, horizontal electrical profiling (HEP), vertical electrical sounding (VES), hydrocarbons, gravity, light non-aqueous phase liquids (LNAPL's).

INTRODUCTION

Oil pollution is widespread and arises at all stages of the petroleum industry: extraction, transportation, refining and distribution (Shevnin et al., 2003). A serious environmental concern is the movement of pollutants to the water table and subsequent contamination of drinking water resources (Okezie and Elijah, 2014).

When oil leakages and spill happen, both surface and underground water is affected negatively resulting in the need to ascertain the extent to which subsurface water has been affected by hydrocarbon leakage (Nwankwo and Emujakporue, 2012). Hydrocarbons move through unsaturated zone as discrete accumulations of the contaminants due to their non-uniform dispersion in the medium, which can be attributed to changes in the permeability of the soils in the unsaturated zone (Domenico and Schwartz, 1990).

Hydrocarbons such as NAPLs exist as a separate, immiscible phase when in contact with water and/or air.

Spilled hydrocarbons from underground oil punctured pipes are observed as LNAPL above the water table and in Dense Non-Aqueous Phase Liquids (DNAPL) below the water table (Newell et al., 1995; Alekwana et al.,

---
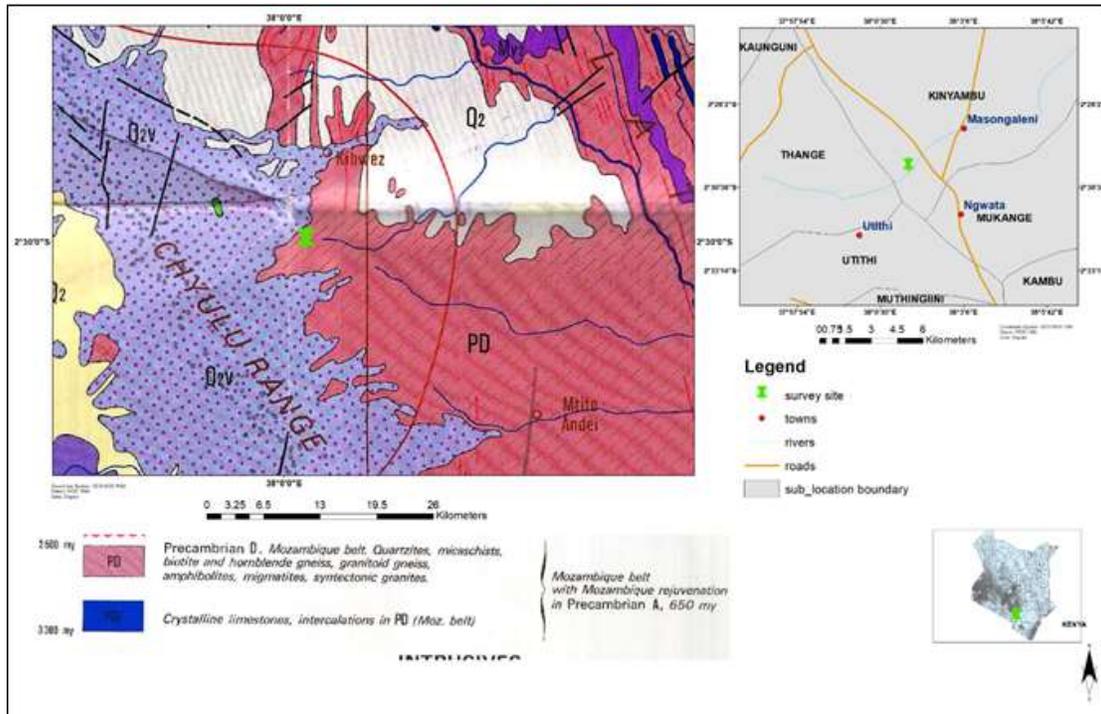
Figure 1. Location and regional geology of the study area.

2000; Win et al., 2011).

The LNAPLs on the water table do not necessarily stay in one place. They can migrate, exist as a partially dissolved phase and even be temporarily submerged below the water table during times of high rainfall. Migration of LNAPL's in the subsurface appears to be associated with seasonal variations in rainfall, and the hydrologic gradient in an area. LNAPL's above the water table can be concentrated by changes in the permeability of the subsurface materials in the unsaturated zone (Zaw Win et al., 2011).

This project is the first phase in delineating the extent of soil and ground water pollution using geophysical techniques in the area.

Background of the study area

The research was conducted at Thange, Kibwezi area, Makueni County. It is an area characterized by a typically semi-arid climate, defined by an average rainfall and temperature of 600 mm and 23°C respectively (Mwangombe et al., 2011). The rainfall is bimodal with long rains from March to May and short rains from November to December to early January

The study area is covered with reddish brown soils derived from weathering of the volcanic deposits. However, the soils are darker on basement exposures due to weathering of basement rocks. Fine sands dominate the dry river bed.

Baobab trees and thick shrubs cover sections of the area with deep soils. There is little or no vegetation within basement exposures while there is an artificially controlled ecosystem as part of the remediation measures within the affected sections consisting of planted mango trees and Legumes. The river within this area is a major SW-NE trending seasonal tributary that flows into Thange River.

Site geology and structural setting

The area is mainly occupied by exposed rocks of the Basement System, though lavas and sediments of much younger age are also present. The approximate ages of the various groups are as follows:

a) Recent - Soils, gravels alluvial deposits etc.
b) Pleistocene - Basalt.
c) Miocene - Kapitian phonolite.
d) Archaean - basement System.

The hydrogeology consists of shallow aquifers confined within the basalts and possible deeper aquifers within fractured basement rocks- (Dodson, 1953).Contamination of ground water in these aquifers is therefore influenced by hydrologic gradient (surface runoff), lithologic control, and structural control by faults and fractures within the basement system. Figure 1 gives an overview of the geology of the study area.
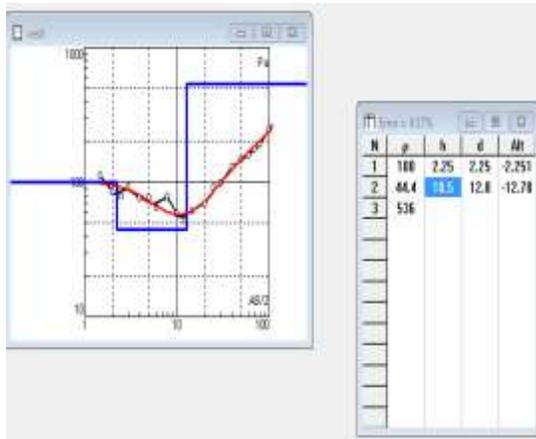
Figure 2. VES 6 resistivity curve.
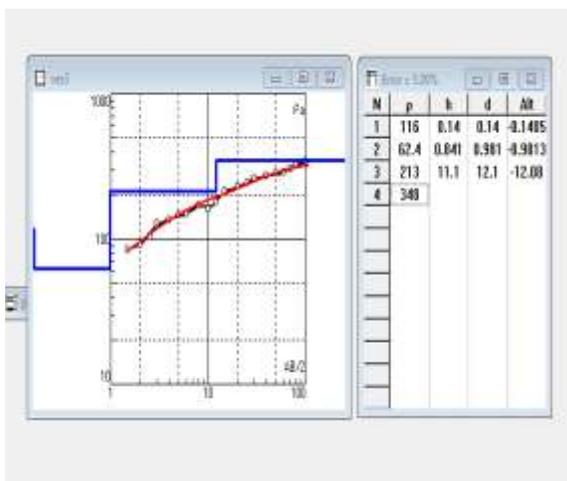
Figure 3. VES 3 resistivity curve.

Geophysical properties of hydrocarbon contaminants

Hydrocarbons typically have high resistivities relative to water, and low resistivity if inorganic compounds are added to contaminated water to stimulate bioremediation, thus increasing the Total Dissolved Solids (TDS) in the water (Benson et al., (1997)). Therefore, recent oil pollution shows a high –resistivity anomaly while mature oil pollution produces a low resistivity anomaly (Sauck, 1998).

Fresh organic compounds in the water saturated soils usually have high electrical resistivity values (Okezie and Elijah, 2014).

The initial free product accumulation may show up as high resistivity in the area only until biodegradation becomes established. With time the mixed zone and underlying aquifer may show anomalously low resistivity. This suggests that LNAPL sites should be treated as individual cases with change dependent on site composition, time and many other variables specific to

the location (Alekwana et al., 2000).

MATERIALS AND METHODS

Electrical resistivity survey

Under this method, two Direct current DC electric methods were deployed, HEP and VES. The VES was used to determine the variations of resistivity with depth, while HEP was used to determine lateral resistivity variation. Schlumberger and Wenner electrode arrays were adopted respectively.

8-VES stations(selected at interpreted resistivity lows) and 17-HEP profiles were established (7-HEP Profiles done in the SE-NW orientation and 10-profies in NE-SW orientation).The maximum current electrode spread for the Schlumberger electrode array (AB/2) was 200 m, while the potential electrode separation (MN/2) maximum was 10 m.The current electrode spread (AB/2) for Wenner electrode array was 20 and 10 m for the potential electrode spread (MN/2).

Gravity method

Worden gravimeter was used in data collection .Ten transects were established across the study area with a separation distance of 50 m along east-west direction. One hundred and eighty gravity stations with a separation distance of 20 m, the base stations and control station were established using a handheld Global Positioning System (GPS). A base station was established in the beginning of the survey and was re-occupied after every one hour. Obtained data from the base station was used during data processing to account for the instrumental drift. During the gravity survey period, base station reading was taken as the first and the last reading of each day.

RESULTS AND DISCUSSION

Electrical resistivity

Resistivity data were audited and subjected to various data processing techniques. Data obtained from HEP were analyzed using SURFER 10 software and a resistivity contour map was generated (Figure 4).Using the generated contour map, it was possible to denote regions of anomalous resistivity lows which are potential contamination pathways. These also defined our choice of VES stations.

VES data collected from 8 established stations along these anomalous regions were analyzed using IP2WIN software. Using the software subsurface formation, corresponding resistivity and thickness for each station were clearly mapped. Figures 2 and 3 show the digital inversion results for (VES) 6 and 3 respectively.

VES 3, 4 and 5 were done at the suspected initial leakage point while VES 1,2,6,8 and 7 was done at the regions of anomalous resistivity lows. VES 3 and 6 have been selected as representative stations of the two regions mentioned, to discuss the lithologic units and possible contamination migration paths.

The results show a subsurface sequence consisting of
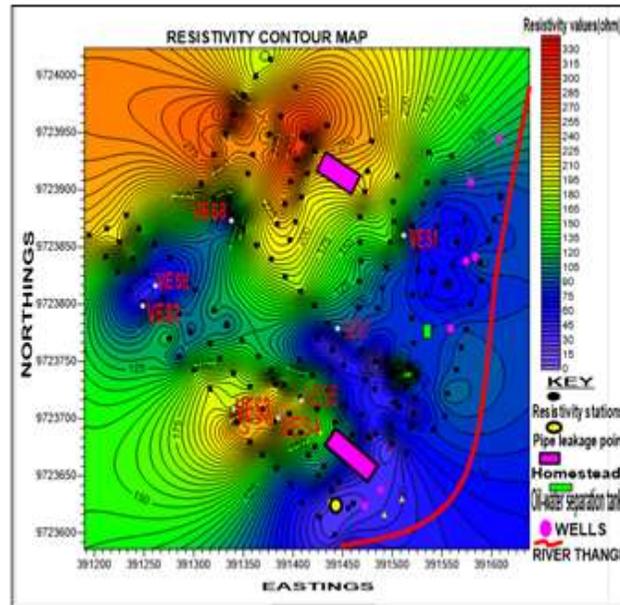
Figure 4. HEP contour map.

Table 1. Lithologic units with reference to VES 6.

Value	Rock
2 –3.2	Basalts
3.2– 16	Basement rocks (highly weathered/fractured)
16–40	Basement rocks(compact/fresh)
40-63	Basement rocks (weathered/fractured)
63-100	Basement rocks (compact/fresh rock)

Table 2. Lithologic units with reference to VES 3.

Value	Rock
0 – 3.2	Red soils
3.2-10	Basalts(highly weathered)
10-32	Basalts(Aquifer zone)
32-100	Basement rocks

4 geoelectric layers. 3-layers were identified at VES 6 and interpreted as three lithologic units namely red soils, basalts and basement rocks (Tables 1 and 2).

The overburden overlying the basement at VES 6 is to a depth of 32 m while that at VES 3 is to a depth of about 3 m. This is attributed to the orientation of dip and strike of the basement rocks. Therefore we can say that the overburden, that comprises volcanic sediments, thins towards basement exposures.

At VES 6, the aquifer is confined within the basalt with a thickness of about 22 m while at VES 3, there is an aspect of weathering and fracturing within the basement rocks at depth intervals of (3.2 -16 m) and (40-63 m) that are possible aquifer zones. These regions are the

hydrocarbon contamination paths.

Gravity data

Gravity raw data were subjected to corrections that included, drift, latitude, free air, and slab bouguer. Using SURFER 10, corrected gravity data were utilized in generating a gravity contour map shown in Figure 5.

Qualitative interpretation

A gravity low was evident, trending in the NW-SE
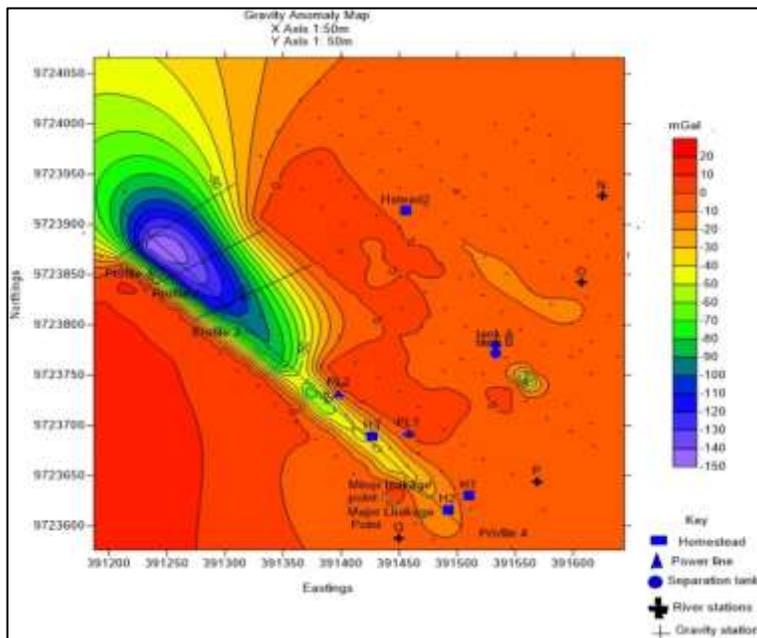
Figure 5. Gravity contour map.
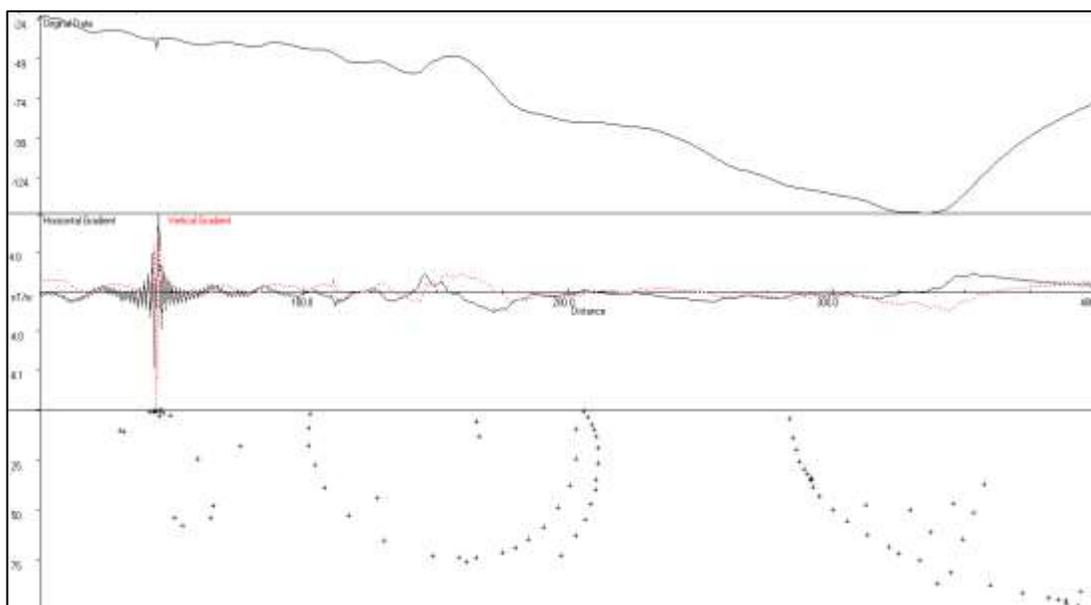
Figure 6. Profile 4 Euler curve.

direction and was suspected to be a burried fault with volcanic deposits (possible aquifer). Three gravity crossections were cut across the anomaly and one along it. These were modelled to provide information on the depth and thickness of the anomalous gravity low.

Euler deconvolution was perfomed on profile 4 (Figure 6) and the results showed evidence of a fault zone occurring from a depth of 13 m.

Forward modelling using Grav2Dc

Grav2dc software was also utilized to model the density of anomalous structures and their depths using two-dimensional models.

The results confirmed the presence of a fault structure occurring from a depth of about 13 m and extending through the basement system by a depth of about 100 m
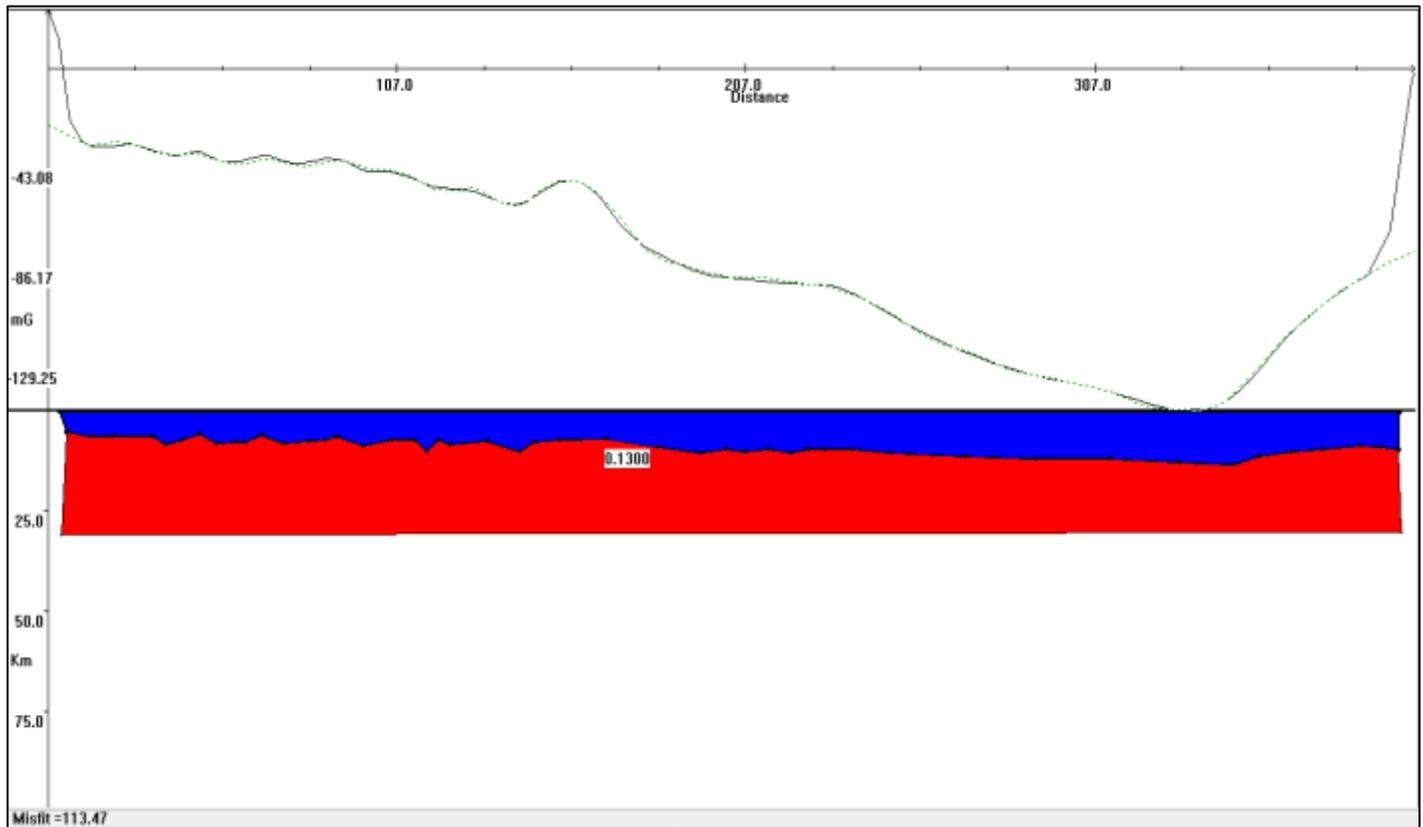
Figure 7. Profile 4 2D Model.

along the western side of the study area as shown in (Figures 6 and 7). The overburden and the bedrock present in the region showed to have a density contrast of 0.1300.

Gravity and resistivity data Integration

It was observed that results from both the resistivity and the gravity methods were helpful in delineating the contamination migration paths, extent and possible contaminated zones. The Euler deconvolution performedon profile 4 and HEP and VES 6 confirm the existence of thick sediments NW of the area that would have probably gone unnoticed by surface geological mapping.

In each contour map, this anomalous area was delineated and a region of intersection was observed and denoted as the zone of interest as shown in Figures 8 and 9.

Conclusion

The objective of the research was to delineate the extent of soil and ground water pollution from the leakage point.

HEP resistivity lows were interpreted as ground water aquifer zones confined within basalts and potential contaminant migration zones while resistivity highs, as regions of basement exposures.

Observations in hand dug wells within the region of low resistivity from the HEP map, that runs from the leakage point in the direction of the river regime, show evidence of soil and ground water contamination to depths of up to 10m.It therefore confirms this zone as a SW-NE contaminant migration path.

The area of interest as stated from the integration can be deduced as a NW-dipping fault (aquifer-bearing volcanic deposits) and therefore a potential contaminant migration path, since it acts as a structural control for soil and ground water contamination

RECOMMENDATION

Despite the remediation measures being executed within the eastern part of the study area, much attention also needs to be directed in the region NW of the area identified as a fault zone.

As a follow-up test a 2D-tomography should be conducted along the region identified as a SW-NE contaminant migration path and the region identified as a
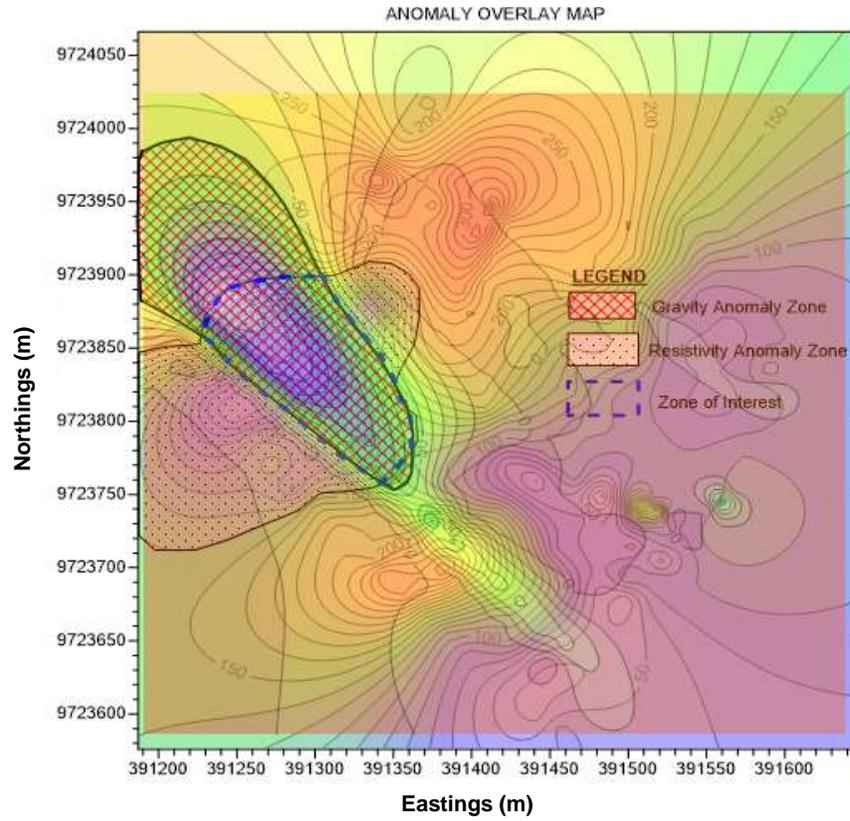
Figure 8. Resistivity and Gravity contour overlay.
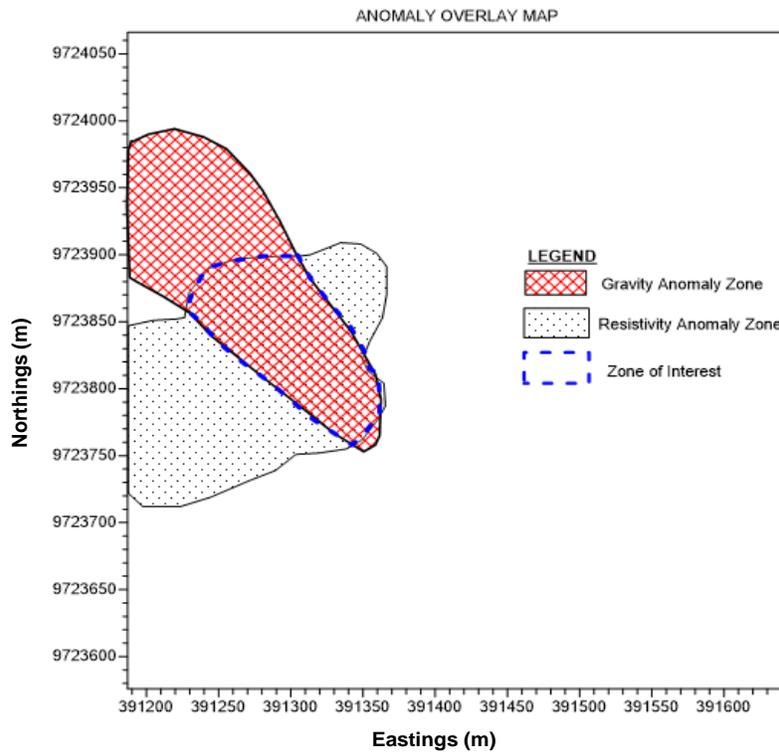
Figure 9. Merged contour denoting the area of interest.

NW dipping fault.

A borehole should be subsequently drilled to ascertain the geophysical findings and improve our understanding of the area's lithology, and ground water chemistry.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Dodson RG (1953). *Geology of the south-east Machakos area: degree sheet 52, SE quadrant (with coloured map)* (No. 25). Geological Survey of Kenya.

Domenico PA, Schwartz FW (1990). Physical and chemical hydrogeology.

Mwangombe AW Mongare N, Chege W (2011). Livelihoods under Climate Variability and change: An Analysis of the Adaptive Capacity of Rural Poor to Water Scarcity in Kenya's Drylands. Journal of Environmental Science and Technology 4(4), pp. 403-410.

Nwankwo C, Emujakporue G (2012). Geophysical method of investigating groundwater and sub-soil contamination–A case study.

Okezie U, Elijah AA (2014) Application of Electrical Resistivity Imaging in Investigating Groundwater Pollution in Sapele Area, Nigeria Journal of Water Resource and Protection 6:1369-1379

Shevnin V, Delgado O, Mousatov A, Nakamura E, Mejía A (2003). Oil pollution detection using resistivity sounding. Geofísica Internacional 42(4):613-622.

Win Z, Hamzah U, Ismail MA, Samsudin AR (2011). Geophysical investigation using resistivity and GPR: A case study of an oil spill site at Seberang Prai, Penang.

Zohdy A, Eaton G, Mabey D (1990). *Application of surface geophysics to ground-water investigations.*U.S. Geological Survey, Dallas.