Comprehensive clues provided by popular free remote sensing imagery to interpretation of geophysical studies explained by example cases of magnetic surveys

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Received 21 December 2013; revised 30 December 2013; accepted 30 December 2013
Available online 6 February 2014

Keywords
Geophysics; Magnetic survey; Remote sensing

Abstract State-of-the-art remote sensing technologies for imaging the earth and its shallow subsurface are invaluable tools for sophisticated geophysical subsurface investigations. However, such type of remote sensing products remains inaccessible for most of geophysicists. On the other hand free simple satellite imagery has been commonly available since mid-last decade. Google Earth™ is a popular free Internet application through which users can view landscapes and maps.

In this work it is shown how easy and efficient it is to access the open-source of remote sensing in geophysical surveys to provide a quick overview for survey plans and comprehensive keys for interpretation based on cases of magnetic measurements.

A dry well that has been drilled in an aquifer few tens of meters away from a productive water well in Dahshour has been preliminary explained by considering Google Earth images. The images of the area show clear differentiation of surface lithology into 2 zones with a sharp interface.

Magnetic anomaly map of Dahshour fault raised two unclear features that might be interpreted by a curvature in Dahshour fault plane and an additional perpendicular fault trending N–S. The Google Earth imagery gives clues to basaltic intrusions to be the cause of the suspected gradients.

A continuous boat-born magnetic survey carried out in Nasser Lake, southern High Dam, reveals several characteristic anomalies. Visual inspection of Google-Earth images at various altitudes (zooms) indicates a relation between the anomalies and major faulting structures.

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1. Introduction

Remote sensing generally refers to the use of aerial sensor technologies to detect and classify objects on Earth by means of propagated signals. State-of-the-art geophysical and remote sensing technologies for imaging the earth and its shallow subsurface are invaluable tools; especially when direct measurements are sparse or even impossible and lack of knowledge...
will result in costly expenditures and long delays (Canada Centre for Remote Sensing, 2000, 2007). High tech remote imaging, conducted by terrestrial, airborne, or satellite based platforms has the ability to create high-resolution and spatially accurate images of the earth’s surface (Stow et al., 2008; De Santis et al., 2011). These images can be used for settlement and deformation monitoring, natural hazard alerts and engineering geology evaluations. Moreover, economical aspects like management of various resources as agriculture, forestry, mining, water, ocean...etc. have been a typical outcome of remote sensing (Groom et al., 2006; Kulkarni et al., 2007).

Spatial resolution, spectral resolution, temporal resolution, and radiometric sensitivity are key characteristics of any remote sensing product that decide about its applicability. This is considered by remote sensing specialists prior to utilization of the products. Some data must be subjected to manifestations such as radiometric, topographic and atmospheric corrections (Adler-Golden et al., 1999).

These types of remote sensing data need – in addition to its high costs – experience and curiosity in application otherwise it would lead to erroneous results when utilized (Schowengerdt, 2007).

On the other hand Google Earth™ acquires the best imagery available, most of which is approximately one to three years old. The information in Google Earth is collected over time and is not in ‘real time’. For example, it is not possible to see live changes in images.

Data are added to the primary database of Google Earth™ on a regular basis. Each month the newest additions to Google Earth imagery are highlighted in Google Earth’s newsletter named “The Sightseer”.

Google Earth is constantly working on gathering the highest resolution imagery possible. However, there are certain areas for which they do not currently provide high-resolution data. The user must be also aware that the imagery for some areas may contain cloud coverage or discoloration, so might appear blurry even at high resolution. This is very rare for Egypt and the middle-east countries in general.

The most advantage of this source of remote sensing imagery is that it is provided for free for any online browser together with a user friendly freeware. This enables a lot of very efficient tools that can be even utilized in the field to assess in survey planning. Images saved from the freeware of Google Earth can be simply enhanced using popular image processing that can be applied without any special experience (Loew and Mauser, 2007; Liu et al., 2009). Fig. 1 shows an example of an unprocessed Google-Earth image and its appearance after simple contrast and brightness enhancement.

2. Case A: Ground water inspection

A farm in Dahshour region covers its watering needs from a productive-well, that is known to provide water from a very good sandstone aquifer starting at a depth of about 70 m and extends to 170 m below the ground (upper image Fig. 2). As the need of water increased, one further water well has been planned to access more amount of water from the aquifer without exceeding the safe-yield limit of the existing well.

Although it has been expected that an area of 1 km diameter around the existing productive-well would have the same aquifer characteristics in the subsurface, geoelectrical investigations have been conducted before drilling, to explore the subsurface structure at this site.

Several vertical electrical soundings (VESs) have approved the existence of the aquifer at almost the same depth at a point lies about 350 meters far from the existing productive-well. Surprisingly, a drilling campaign at that point showed a succession of compact nonporous and impermeable sediments without any occurrence of the expected aquifer down to 140 m below the ground. Such lithology is referred to in hydrology as an “Aquitard” as it limits underground water flow and confines aquifers (Huang et al., 2009, 2010).

To overcome the problem of aquitard in the location further considerations are done to investigate its layout in the subsurface. A preliminary sightseeing indicates a sharp lithofacies interface that lies in-between the dry and productive well (bottom image Fig. 2). Hence, it has been suggested that the aquitard has a limited extension and by avoiding it the proposed well would reach the aquifer and provide water.

In order to verify the suggested sharp lithological Interface, two quick total field magnetic profiles have been measured from the PWW to the dry one (Fig. 3). As clear from Fig. 3, there is a sudden sharp change in the measured magnetic anomaly at about 300 m from the PWW that continues till the end of the profiles at the dry well.

![Fig. 1](image1.png) An unprocessed Google-Earth™ image (left) and its appearance after a simple contrast and brightness enhancement (right) using popular image processing software.
The indication above, leads to an extensive magnetic total field survey in the area under consideration, to decide about where to drill a new well for water production. The resultant magnetic anomaly map shows again 2 zones of different magnetic patterns (Fig. 4). Around the dry well a higher contour line density accompanied by intensive field variations and small spatial sized anomalies is evident. On the other side, away from the dry well – not only in the direction of the PWW but rather in all directions – the pattern of the magnetic anomaly turns to be of less contour lines density with smooth total field variations.

By referring to the available Google-Earth™ image of the study area (Fig. 1, left), one can easily notice a zone of a characteristic darker lithology that differs in appearance from its surroundings. The zone becomes clearer by simple brightness and contrast enhancement (Fig. 1, right). Further consideration of the image reveals that the dry well lays inside the darker zone, whereas, the PWW and the farm lie just outside this zone.

A projection of the magnetic contour lines of Fig. 4 on the image clearly shows that the pattern of intensive anomaly variations is limited to the dark zone (Fig. 5). On the other hand, outside the dark zone the anomalies tend to be smooth with low contour lines density.

The previous considerations suggested that there is a certain zone marked by darker appearance on the Google-Earth™ image that limits the ground water flow and hence can be referred to as an aquitard.

A final evaluation of the investigated area is represented in Fig. 6. The measured magnetic anomaly map together with the enhanced Google-Earth image determines an area surrounded by dashed yellow line and concluded to be a zone of aquitard. Outside this zone groundwater is available as at the productive wells.

3. Case B: North Lake Nasser

A boat-born magnetic survey has been carried out along Lake Nasser staring from Aswan Dam north down to Abu Simbel south in an almost S–N direction. The survey revealed various anomalies that are correlated with known structures on both banks of the lake and remain beyond the scope of this work.

However, at latitude about 23.8° N a very characteristic dipole anomaly started, formed a trough followed by a peak then stopped at about 23.74°N (Fig. 7). The amplitude of the anomaly reached the range of 500 nT over a distance of about 7 km.

As a first step the anomaly under consideration has been reduced to the pole (RTP) to cancel the effect of field inclination. Consequently, the RTP anomaly is projected as a color scaled band along the survey’s path along the northern part of Lake Nasser (Fig. 8).

From a general overview of Fig. 8 one can notice a linear sharp transition in surface lithology that occurs at latitude
near 23.8°N on the eastern bank of Lake Nasser. The dashed yellow line indicates that the trend of this transition line connects it spatially with the start of the characteristic anomaly under consideration. On the western bank the Google-Earth image does not indicate any evidence of a geological feature related to the observed anomaly.

Moreover, by in-zooming the linear sharp transition seen on the western bank of the Lake, one can gradually find out that the feature observed is related to faulting structures. Fig. 9 consists of three images of the feature with successive increasing zooming (Jensen, 2007). The uppermost image shows the linear feature marked with a dashed yellow line. The following middle image indicates that the geological feature has the appearance of fault trace. Further, the lower image gives a quite sure evidence of major faulting structure with an E–W strike. The faulting appears to be complicated...
and consists of a fault trace system rather than a single fault (Schott, 2007; Schowengerdt, 2007).

More curious inspection of the Google-Earth image reveals that the deduced faulting certainly affects the geomorphology of the region. Especially, drainage system of surface water seems to be reoriented in the post faulting time. By following the main drainage line from south to north in the lower image of Fig. 9 it can be observed that it shifts eastwards across the fault trace. This indicates a probable right-lateral strike slip faulting.

The ultimate contribution of the remote sensing image to the interpretation of the dipole anomaly can be summarized in the following points:

- A right-lateral faulting occurred in the eastern bank of the Lake.

Fig. 6  A final evaluation of the investigated area supported by the measured magnetic anomaly map and an enhanced Google-Earth image. The area surrounded by dashed yellow line is concluded to be a zone of aquitard. Outside this zone groundwater is available as at the productive wells.

Fig. 7  2-D representation of the total field magnetic anomaly resulted from the boat-born survey carried out along the Lake Nasser southern to Aswan dam. The sailing started behind the Dam southward. A characteristic dipole anomaly (bounded by 2 vertical lines) of amplitude 500 nT is measured for the first time at latitude 23.8°N.
As there is no evidence of the faulting on the western bank, then the fault trace stopped before reaching the western bank.

The horizontal slipping of rocks along the fault plane brought a block of certain magnetization and susceptibility under the lake in the latitude range from 23.74°N to 23.8°N.

**Fig. 8** The Google-Earth image of the Lake Nasser with the RTP magnetic anomaly projected in color scale on the path of the survey boat. The yellow dashed line points to the start of the characteristic anomaly and the corresponding lithological feature on the eastern bank of the Lake Nasser.

**Fig. 9** Google Earth image of the feature found on the eastern bank of Lake Nasser at the start of the dipole magnetic anomaly displayed with successively increasing zooming. The zooming clearly reveals the existence of a fault zone that causes the observed anomaly. The lower image (higher zooming) shows that the fault is a simple one but consists of a fault system. It can also be seen that the faulting affects the geomorphology of its zone. The drainage system of surface waters is seen to be reoriented post to faulting. The main drainage is shifted eastwards northern to the fault trace. This indicates a right-lateral strike slip faulting.
The moved block caused the magnetic anomaly measured in the boat-born survey.

4. Case C: Dahshour area

Dahshour fault is a geological structure that is of a great interest because of its seismic activity and its location is in the near south of greater Cairo. A famous moderate earthquake known as the 1992 earthquake originated at Dahshour fault and caused a widespread damage of civil and infra structures in Greater Cairo. Since that date the area has been subjected to intensive geological and geophysical investigations. Although the fault region has been magnetically surveyed before, a detailed magnetic survey has been repeated in Dahshour in the frame of an (STDF) project for land magnetic mapping of Egypt using accurate cesium vapor magnetometer with integrated GPS and with very small station intervals of about 1 m along N–S oriented profiles.

The resultant total field magnetic map of the survey revealed a pattern of anomalies that contradicts the previous knowledge about Dahshour fault and its surroundings (Fig. 10). As clear from Fig. 10 the RTP magnetic anomaly map indicates a curvilinear trace of Dahshour fault at latitude about 29° 28” instead of the known linear trace striking E–W. Moreover, an isolated anomaly in the south eastern part of the map leads to a preliminary interpretation of possible secondary faults of a regional scale. The secondary faults appear to trend NNE–SSW and have no geological reference.

After verifying the accuracy of field measurements and data reduction procedures the map has been correlated with the Google-Earth image of the study area (Fig. 11).

The Google-Earth image of Dahshour region shows surface lithofacies alterations that are well correlated with the anomalies of the RTP map (Fig. 11). The dashed lines on the image in Fig. 11 mark different lithofacies indicated from the image and correlated with the total field anomalies as shown by the arrows pointing to the RTP map on the right. The arrows show the correlation between the anomalies and the alterations in surface lithology as noticed from the Google-Earth image.

In order to confirm that the lithologies seen on the image contribute to the magnetic map a field inspection has been realized at locations where the alterations are obvious (Blaschke et al., 2008). The geological inspections resulted in the existence of outcropping igneous rocks in addition to surface occurrence of sandstone cemented with iron oxides. Fig. 12 shows images of a hand specimen from the iron rich sandstone as clear from its reddish color and high density. Consequently the pattern of magnetic anomalies can be explained as follows:

- The occurrence of lithology with high magnetic susceptibility at the surface is found to coincide with the lithofacies borders seen on the Google-Earth image.
As seen in Fig. 11 the lithofacies border marked with dashed line at the western end of Dahshour fault affected the measured field and interfered with the anomaly of the fault itself. This resulted in curvature in the contour lines of the map.

In the south eastern part of the map the lithological boarder forms a circular area with no surface occurrence of the highly magnetic rocks. This explains the isolated anomaly resulted there to be not of a structural source.

5. Discussion and conclusion

Three case studies are discussed in this work to show how remote sensing images support geophysical studies in a direct and rather simple way. In the first case a dry well has been drilled very near to a productive water well which needed to be explained. Site inspection shows a sharp interface in surface lithology between the locations of the productive well and the dry one. Magnetic surveys confirm the existence of such an interface in the subsurface of the location. A projection of magnetic-anomaly contour lines on the remote sensing image indicates that the zone of the dry well is characterized by certain magnetic anomaly pattern that is limited to a zone of definite appearance in the image. This zone is then interpreted as an aquitard that confines the ground water flow in the area. As a final result, the aquitard zone has been mapped on the image to be excluded from drilling in any further work.

In the second case a very characteristic magnetic anomaly known as “dipole anomaly” has been observed during a boat born survey. No previously known anomaly could be related to the clear anomaly. The Google-Earth image provided a linear feature that appeared to be of a right-lateral strike slip faulting on the eastern bank of the Lake Nasser.

In the last case, the well-known fault of Dahshour reveals a curvilinear anomaly that might be interpreted in terms of a curved fault trace. This contradicts the previously known fault of Dahshour. Moreover, an isolated anomaly has been interpreted in terms of secondary regional faults perpendicular to the fault of Dahshour. This has no support by the known geology of the area. The anomalies are then correlated with the Google-Earth image. This correlation unlocked the mysterious appearance of the anomalies in terms of surface lithological features that are not related to the structure of the fault but affected the measured anomalies as a result of its high magnetization and susceptibility.

Finally it is concluded that the availability of free remote sensing imagery such as Google-Earth is an effective support for geophysical studies. It is much recommended to curiously take the remote sensing images of an area into consideration.
prior to planning and execution of geophysical field campaigns. During the formulation of interpretation as a solution for field work data the remote sensing images would provide clues to unclear points or unexpected results that contradict previously confirmed information.

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