A New Approach for Analyzing Continuous Groundwater Physicochemical Measurements Related to Earthquake Precursor Studies

Nimrod Inbar, Yuval Reuveni, Sharon Agibayev, Yaakov Anker and Josef Guttman*

Abstract

The relationship between changes in groundwater physicochemical parameters and earthquakes is well documented in the literature. Several methods were tested in order to extract pre-, co- and post seismic signals. Currently, successful attempts still result in anecdotal and fragmented conclusions. We suggest an alternative analysis approach using data collected in four monitoring wells in northern Israel. The dataset used in the current study includes groundwater levels, water conductivity and water temperatures at a resolution of 1/60 Hz (1 measurement/minute) collected throughout 2016. Relative changes of the different parameters were used in order to identify anomalies that are potentially related to earthquake occurrence. Preliminary data analysis includes noise reduction and interpolation techniques over data gaps. Our analyses reveal the daily and seasonal cycles of all the different parameters, which were measured, as well as an unexplained increase in pressure at confined parts of the Cenomanian-Turonian aquifer during summer, between July and September, while the water level was dropping in the phreatic section. Furthermore, we deduce that an anomaly detected in the electrical conductivity (EC) signal and possibly in the temperature signal as well, is strongly coupled with 4.9 Mw earthquake occurring more than 400 km away from the monitored area.

Key words: Earthquake precursor; Groundwater; Data analysis; Stacking analysis

Changes in groundwater physicochemical properties prior to seismic events are considered to be related to several aspects of crustal deformation. Both increases and decreases of groundwater, oil, or gas pressure and flow rate have been interpreted as earthquake precursors at distances up to several hundred kilometers from the epicenter (Roeloffs 1988). Aquifer breaching of various scales was considered as the mechanism leading to mixing of different water types from adjacent lateral (Cicerone et al. 2009) and vertical sources (Wang et al. 2016). Earthquake precursory electrical and/or electromagnetic signals were suggested to occur as a consequence of pre-seismic tectonic activity. Those signals may be generated by episodic flow of high pressure water between local compartments at the fault zone scale (Byerlee 1993). Using solid state theory and laboratory experiments the precursory magnetic field variations and low frequency EM emissions was suggested to result from a break of proxy links generating positive holes (h) which flow out of the stressed volume (Freund 2011). Chemical precursory changes were also attributed to exposure of
fresh rock surfaces to groundwater by expansion of the rock volume (dilation) and enhanced permeability (Skelton et al. 2014).

Data Acquisition

The current manuscript uses data collected in four wells in northern Israel (fig. 1; Table 1) between Jan 1st and Dec 23rd 2016. In the current research, four water wells in northern Israel were continuously monitored beginning January 2016 (fig. 1). The wells were drilled into the Cenomanian-Turonian carbonate aquifer. Two of the wells are located on the phreatic part of the aquifer (Carmel-13 and Hindaj-2) and in the other two are under confined conditions (Ta’anach-4 and Nurit-1). Three wells (Carmel-13, Ta’anach-4 and Nurit-1) are located along the Gilboa-Carmel Fault (GCF). Another well (Hindaj-2) is located north of the Hula Basin, close to the Dead Sea Transform (DST). All monitoring stations are located in observation wells with no adjacent pumping or injecting wells.

Figure 1: Location map of monitoring stations (black circles) on top of outcrops map (based on Sneh et al. 1998) and main fault locations (based on Andrews, 1992; Garfunkel, 1981; Shulman et al., 2004)
Table 1: Monitoring stations properties.

Coordinates converted from Israel CS 1923 to WGS84 using "The World Coordinate Converter"(online service). Faults: Gilboa-Carmel (GC); Dead Sea Transform (DST). Water Table Reference was measured at time of equipment installation (June 2015). Water level sensor was installed 5 m below water table and reading was set to 5.00 in the range of 0.00 – 10.00.

<table>
<thead>
<tr>
<th></th>
<th>Carmel 13</th>
<th>Ta’anach 4</th>
<th>Nurit 1</th>
<th>Hindaj 1</th>
</tr>
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<tr>
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<td>35.2620</td>
<td>35.3419</td>
<td>35.5450</td>
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<tr>
<td>Latitude</td>
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<td>32.5664</td>
<td>32.5519</td>
<td>33.0437</td>
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<td>Borehole Depth (m)</td>
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<td>713</td>
<td>718</td>
<td>163</td>
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<tr>
<td>Altitude (MSL)</td>
<td>50.16</td>
<td>62.53</td>
<td>14.34</td>
<td>190.10</td>
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<tr>
<td>Aquifer Type</td>
<td>Phreatic</td>
<td>Confined</td>
<td>Confined</td>
<td>Phreatic</td>
</tr>
<tr>
<td>Adjacent Fault</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>DST</td>
</tr>
<tr>
<td>Water Table reference (m below surface)</td>
<td>44.5</td>
<td>104</td>
<td>74</td>
<td>93.8</td>
</tr>
</tbody>
</table>

Water level, electrical conductivity and temperature measurements were collected using the following instrumentation.

- Water level - MSI Scantech 27w pressure transducer based on the Keller pressure capsule with ±0.1% accuracy. The sensor has a dynamic range of 10 meters and was installed 5 meters below water level to endure seasonal changes.
- Electrical conductivity - GLI 3422 1/2-inch sensor which measures from theoretically pure water (0.057 µS/cm or 18.2 MΩ) up to 200,000 µS/cm and also allows measurements in saline water wells.
- Temperature – the GLI 3422 sensor equipped with a Pt 1000 RTD temperature element built into its tip for exceptionally fast response to changes in temperature with ±0.1°C accuracy.
- Data loggers – GS828-N GPRS NET Data Loggers

Precipitation in the study area is limited to the rainy season (December to March). Main rain event occurrences are in January and February. The year 2016 did not deviate from that norm as shown by the data collected at Meggido rain measurement station operated by the Israeli Meteorological Service (fig. 2). Hence, aquifer recharge is limited to the rainy season and therefore the data obtained from that period could be influenced during that period by recharge of fresh meteoric water and dilution in its phreatic part. However, immediate change to the measured parameters as response to rain events is not expected under confined conditions.
Earthquakes information was obtained from the Geophysical Institute of Israel (http://seis.gii.co.il/heb/earthquake/searchEQS.php). The database includes all events above 2.4 Mw in the area defined by the rectangle 27.0 – 36.0 Latitude and 32.0 – 38.0 Longitude. Altogether 99 events were recorded between 1/1/2016 and 23/11/2016, the period of analyzed dataset (fig. 3). For each seismic event, the epicenter distance for each monitoring station was calculated.

Results

Stacking analysis was applied with all of the different parameters measured at each monitoring station (fig. 4). This approach provides a useful tool for comparing the measured parameter over different temporal resolutions and enables revealing periodicities and patterns over multiple time scales simultaneously. Once each pattern or cycle has been identified, it can be filtered out
Figure 4: Stacking analysis of relative groundwater level and EC at Nurit-1 well. The average of each minute of the day is presented on the left hand chart. Average of the entire day is presented below the stacking chart. Horizontal axis is compared with earthquakes events in Israel surroundings (fig. 3). Earthquakes bar height – magnitude. Earthquake bar color – epicenter distance from Nurit-1 station.
of the measured signal. Such filters can yield a cleaner signal that can be correlated to known pre, co, or post-seismic events.

Daily (in-day) water level fluctuation is observed only under confined conditions (fig. 5a). Two cycles are noticeable, one at night and another during daytime. Lows are computed to be at around 22:30 and 09:00 and highs are at 04:00 – 07:00 and 15:00 to 17:00. In-day temperature and EC (fig. 5b) seem connected to each other as those two values fluctuate simultaneously at each well. However, although all wells show similar patterns, the patterns shift. Values peaks at: Hindaj 14:00; Carmel 16:30; Nurit 18:00. Ta’anach may fluctuate within the noise range.

**Figure 5:** Average in-day fluctuation.
Water level (a): The Nurit-1 and Ta'anach-4 wells, which are under confined conditions, fluctuate with two peaks a day. Carmel-13, drilled to phreatic section, shows little daily change. Electrical conductivity (b): all wells show in-day fluctuation, regardless of the aquifer type (phreatic vs. confined)
During the rainy season water levels in the phreatic section respond to precipitation and show aquifer depletion towards the dry season. In the confined section pressure sharply increased from mid-July to mid-September, responding to an unknown source. Other prominent and hydrologically unexplained pressure changes are observed in the confined section as well. EC varies under both phreatic and confined conditions (as well as temperature). While seasonal trends may be observed, sharp changes seem to correlate with seismic events.

**Summary and Conclusions**

Groundwater physicochemical parameters, monitored during the year 2016 in four boreholes located in northern Israel adjacent to major faults in phreatic and confined aquifers, were analyzed using stacking analysis. The presented results reveal daily (in-day) and seasonal fluctuation that should be considered in future signal processing. Although some of the principals and mechanisms of such fluctuations are well documented in the literature, e.g. tidal effect, aquifer depletion, ground water dilution etc., some results are unexplainable with common hydrological mechanism e.g. abrupt changes in monitored parameters and pressure changes under confined conditions, which are entirely detached from the precipitation cycle.

Both under phreatic and confined conditions, daily cycles are more prominent for EC and temperature whereas water table cycles are noticeable only in the confined aquifer. It is suggested that daily cycles of EC and temperature are related to tidal effects as differential gravitational forces causes mixing of density stratified water in a well. It is suggested that daily pressure cycles occur due to the same tidal effect. However, under confined conditions those cycles are noticeable as the pressure increase over large area is concentrated to a well and measured in one point, whereas under phreatic conditions the increase in pressure spreads over a large area and the resulting pressure difference in a well is within the noise level.

Seasonally, EC and temperature, which seem to be related, rise in summer time. Water level in the phreatic aquifer seems to correlate with precipitation whereas pressure in the confined aquifer seems to be motivated by an unexplained cause. Those observations should be farther explored in the following years since the use of one year of data is insufficient for pattern analysis. This topic is brought forward in the current manuscript to invoke discussion within the scientific community. As shown by Skelton et al. (2014), a precursory signal may precede an earthquake by as much as six months prior to the actual event.

Finally, both in water level and EC charts (fig. 6), it seems that the analyzed signal can be correlated with the 4.9 Mw earthquake occurring at the Gulf of Eilat-Aqaba on the 16/05/2016 more than 400 km away from the monitoring array. Prior to that specific earthquake (tallest light blue bar on fig. 6), water level had risen under
confined conditions at the beginning of April and maintained a rather constant level between mid-April to early-May, then started to drop sharply about a week before the event. Studying the behavior of the EC processed signal around the same event show reveals a sharp anomaly around the time of the event. This anomaly lasts only a few days and peaks at the time of the event. These findings require further exploration and analysis of such signals. In such studies, stacking analysis proves itself a powerful tool for preliminary signal processing. It is especially useful for dealing with fragmented datasets.

*Figure 6: Seasonal variations of water level (a) and EC (b) compared with earthquakes events in Israel surroundings (fig. 3). Earthquakes bar height – magnitude. Earthquake bar color – epicenter distance from Ta'anach-4 station (color code – fig. 4).*
Acknowledgements

The authors thank the Mekorot Co. for the use of the company facilities and its field personal for their technical assistance. We would like to thank also the Ministry of National infrastructures, Energy and Water Resources (project No. 215-17-009), the mutual fund of the Eastern R&D and Ariel University for their financial support.

References


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