Seasonal behaviour of spatial variability of groundwater level in a granitic aquifer in monsoon climate

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Groundwater flow in a small watershed in a hard rock region of Andhra Pradesh, India mainly exists in a coupled system of weathered and fractured rock aquifers. However, due to heavy extraction, groundwater level has declined and the weathered part has become unsaturated. In general, the water-table aquifer exists in the area under semi-confined or unconfined conditions. Monthly water-levels from 32 wells fairly evenly distributed over the area were collected to analyse the variability and finally to calibrate a groundwater flow model.

Universal kriging technique with a linear drift was applied to analyse the available groundwater levels during different periods for one cycle during the year 2000. The bounded variograms, i.e. without the effect of a drift, were calculated using the directional variogram in the direction perpendicular to the major mean flow. All the variograms were then cross-validated to get final acceptable models for each time period. Subsequently, two variograms, one for the monsoon period with the presence of recharge component and the other for the non-monsoon period without the presence of recharge component were evolved. A common variogram was also determined to represent the average over all time periods. Cross-validation tests were done to check that the variograms representing monsoon and non-monsoon periods were able to reproduce field values for the corresponding periods more satisfactorily than a single common variogram. Thus application of geostatistics could be simplified for time-varying parameters such as water level.

Although water level in an unconfined aquifer is a continuous variable showing spatial variability, variations in rate of change arise due to the heterogeneity of the aquifer. Geostatistical techniques using the theory of regionalized variables have been applied to study water level in aquifers by a number of workers. Both time and spatial variability of water level should be studied jointly to understand the dynamic behaviour of aquifer systems. Rouhani has attempted a multivariate geostatistical model jointly using the time and space variability of water level. However, practical application of analysing the time and space variability of water-level jointly has not been successful.

Since water level is time varying and is monitored using the same network of observation wells at desired intervals, estimating it for all the time periods following all the steps of geostatistical estimation becomes cumbersome. However, to account for the temporal variation in water level, it is possible to group water level for certain time periods having similar behaviour and analyse them geostatistically for spatial variability. Ahmed carried out such an exercise and showed that there could be a single variogram representing spatial variability for all the time periods in a year. LaVenue and Pickers have used transmissivity and water level jointly through groundwater flow equation and kriging to calibrate the aquifer model.

In the present study, monthly water-level data from a small watershed in a hard rock region of Southern India have been analysed geostatistically, and an attempt is made to evolve common variogram(s) for different time periods in a year, so that the frequently observed water level could be estimated on the grids of an aquifer model and used for calibration.

Major rainfall in India occurs during the monsoon season (July to October) and most of the water-related activities, either natural such as recharge or man-made such as agriculture with groundwater extraction for irrigation, is closely related to this period. It was therefore, hypothesized that a common variogram for the groundwater levels in monsoon or monsoon-affected period and another common variogram for the non-monsoon period could be determined. Also, an adequately derived common variogram for all the months of a year was used to analyse the

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spatial variability of water levels from various months in
the year, and the results of using the corresponding vario-
grams were compared.

Description of studied area

The Maheshwaran watershed situated in the Ranga
Reddy district of Andhra Pradesh, India about 30 km
south of Hyderabad, covering an area of 60 km², is a rep-
resentative watershed in hard rocks with geological out-
crops, structures and fracture system present (Figure 1).
The area consists of hard crystalline rock, mainly pink
and grey granites of Archaean age. The major part of the
basin is covered by a pediplain having shallow weather-
ing. Soil consisting of clayey loam, red loam and sandy
loam with variable thickness forms the top layer. The
host rock is intruded by dolerite dikes and at places,
quartz reefs. Detailed analysis of joints and fracture
pattern observed from the outcrops and the preparation of
rose diagram shows that the major orientations of frac-
ture pattern are in N-S direction. The area has a den-
dritic pattern of drainage.

A moderate thickness of rocks is weathered and thus a
two-tier coupled system, viz. weathered and fractured
aquifers exists almost over the entire area. Due to over-
exploitation, the groundwater levels have declined and
presently, groundwater flow is mainly in the fractured rock
aquifer under semi-confined to unconfined conditions.

The area being semi-arid in nature, subtropical climatic
conditions prevail with minimum and maximum tempera-
ture of 22 and 44°C respectively. The area receives more
than 80% of its rainfall from the SW monsoon, with an
average normal annual rainfall of 812 mm. Ninety per cent
of groundwater is withdrawn through bore wells. Paddy is
the main crop irrigated by wells and open tanks, with some
patches of vegetables, jowar and black gram grown in the
kharif season as rain-fed crops. About 600 bore wells,
ranging from a depth of 30 to 60 m fitted with submersible
pumps, exist in the area for irrigation purposes.

Description of available data

The water-level gradient largely depends on the order of
transmissivity and controls the flow direction and magni-

tude. In the area, past water-levels are available only
for the pre and post-monsoon time. However, with a spe-
cific project to model flow in this watershed, monthly
water levels have been collected from 32 wells fairly
distributed in the area (Figure 1). The monitoring wells
are all bore wells and water levels were monitored using
a graded tape that provides sound and light signals when
it touches water in the well, with an accuracy of 2 mm.
Care has been taken to collect the water levels in all the
wells in the minimum possible time and also when the
wells were not being pumped and the water level could
reach its natural condition. The ground and the measuring
points were connected to the permanent benchmarks with
an accuracy of a few metres. Due to certain constraints
the data could not be collected for each month during the
year 2000. Table 1 shows the water level data including
number of wells monitored for different months of the
year. Data collected from January 2000 to January 2001
could be considered as representative of the water cycle
for the whole year. The general flow direction of the
groundwater is from south to north (Figure 2), and
mostly follows the topography.

Statistical analysis of water-level data

The statistics of water-level data is shown in Table 1.
The reduced level of groundwater varies from 591 to
646 m in the area within a year. Although the mean is
more or less constant, there is some difference in the
water levels measured at different times of the year. The
lowest and the highest variance months have very close
mean. This shows that water levels have gone down in
some areas and at the same time, have risen in other
Table 1. Statistics of water level (amsl)

<table>
<thead>
<tr>
<th>Month and year</th>
<th>Number of wells monitored</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean (m)</th>
<th>Variance ($\sigma^2$)</th>
<th>Standard deviation ((\sigma))</th>
<th>(\sigma m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2000</td>
<td>26</td>
<td>595</td>
<td>639</td>
<td>616</td>
<td>134</td>
<td>11.6</td>
<td>0.01883</td>
</tr>
<tr>
<td>April 2000</td>
<td>27</td>
<td>593</td>
<td>636</td>
<td>613</td>
<td>124</td>
<td>11.2</td>
<td>0.01827</td>
</tr>
<tr>
<td>June 2000</td>
<td>18</td>
<td>592</td>
<td>637</td>
<td>615</td>
<td>158</td>
<td>12.6</td>
<td>0.02048</td>
</tr>
<tr>
<td>July 2000</td>
<td>21</td>
<td>591</td>
<td>639</td>
<td>614</td>
<td>130</td>
<td>11.4</td>
<td>0.01856</td>
</tr>
<tr>
<td>August 2000</td>
<td>24</td>
<td>593</td>
<td>642</td>
<td>616</td>
<td>141</td>
<td>11.9</td>
<td>0.01931</td>
</tr>
<tr>
<td>September 2000</td>
<td>28</td>
<td>596</td>
<td>646</td>
<td>618</td>
<td>147</td>
<td>12.1</td>
<td>0.01957</td>
</tr>
<tr>
<td>October 2000</td>
<td>29</td>
<td>595</td>
<td>646</td>
<td>617</td>
<td>140</td>
<td>11.8</td>
<td>0.01912</td>
</tr>
<tr>
<td>November 2000</td>
<td>29</td>
<td>593</td>
<td>642</td>
<td>616</td>
<td>136</td>
<td>11.6</td>
<td>0.01883</td>
</tr>
<tr>
<td>December 2000</td>
<td>29</td>
<td>593</td>
<td>640</td>
<td>615</td>
<td>130</td>
<td>11.4</td>
<td>0.01833</td>
</tr>
<tr>
<td>January 2001</td>
<td>29</td>
<td>593</td>
<td>640</td>
<td>615</td>
<td>129</td>
<td>11.3</td>
<td>0.01837</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>615.5</td>
<td>136.9</td>
<td>11.69</td>
<td>0.01898</td>
</tr>
</tbody>
</table>

All the above statistical parameters in m, while variance is in $m^2$.

**Figure 2.** Water level contour map, January 2000 (surfer without kriging).

areas. The variance increases during post-monsoon periods as the aquifer is hydrologically disturbed and the variability of rainfall recharge adds to the variability of the water levels, while the water level during pre-monsoon periods is less disturbed due to absence of recharge component and pumping is more or less uniform resulting in a decrease of the variance.

**Geostatistical analysis**

**Brief theory of geostatistical estimation**

Although details on the theory of regionalized variables are well documented, a brief account of the relevant methods used is presented here.

Water level, generally being a non-stationary variable, ordinary kriging technique is not applicable; the technique of universal kriging is thus applied. The water-level estimate at any point $p$ (say a well) using universal kriging is written as follows:

$$h_p^* = D_p^* + \sum_{i=1}^{N} \lambda_i (h_i - D_i),$$

(1)

where $h_p^*$ and $D_p^*$ are the estimated water level and the drift respectively, at any unmeasured well $p$; $h_i$ and $D_i$ are the values of water level and drift at well $i$, $\lambda_i$ the kriging weight. The water levels $h$ are split into a smoothly-varying deterministic part $D$, and the residual ($h-D$). A bounded variogram could be obtained for the residual, as this is a stationary random function.

Modelling the drift correctly is difficult as it is not possible to estimate parameters of the drift and those of the variogram of residuals from a single data set. Drift depends on the nature of water level variation, and could be linear, quadratic or of higher order. Usually a drift is approximated by polynomials of the space coordinates. For example, a linear drift can be written as:

$$D_i = a + bx_i + cy_i, \quad \forall i.$$  

(2)

A quadratic drift can be written as:

$$D_i = a + bx_i + cy_i + dx_i^2 + ey_i^2 + fx_iy_i,$$

(3)

where $a$, $b$, $c$, $d$, $e$ and $f$ are the drift coefficients and are constants.

It is possible to estimate a drift by ordinary kriging, but the indeterminacy problem requires a knowledge of the variogram of residuals.

The kriging weights and the drift coefficients can be determined as follows:

$$\sum_{i=1}^{N} \lambda_j \gamma_{ij} + a + bx_j + cy_j = \gamma_{jp}, \quad j = 1 \ldots N,$$

(4)
\[
\sum_{i=1}^{N} \lambda_i = 1, \quad (5)
\]
\[
\sum_{i=1}^{N} \lambda_i x_i = x_p, \quad (6)
\]
\[
\sum_{i=1}^{N} \lambda_i y_i = y_p, \quad (7)
\]

and the variance of the estimation error is given by:
\[
\sigma_p^2 = \sum_{i=1}^{N} \lambda_i^2 \gamma_{ip} + a + bx_p + cy_p, \quad (8)
\]

where \( \gamma \) are the variograms of residuals determined by the variographic analysis and \( i, j, p \) denote different points.

**Variographic analysis**

Calculation of experimental variograms and modelling with a theoretical variogram of the parameter is the first and primary step of the geostatistical estimation. However, only stationary random function can have bounded variograms. The expression for calculation of a variogram is written below:

\[
\gamma(d) = \frac{1}{2} \text{ var } [z(x+d) - z(x)], \quad (9)
\]

where \( z(x) \) is any random variable and \( d \) the distance between two points \( x \) and \( x+d \).

The presence of drift in a parameter produces an unbounded variogram and it is not possible to model it with a finite sill and range. Therefore, drift has to be removed directly or indirectly to obtain a bounded variogram.

During the geostatistical analyses of water-level data in the study area, initially unbounded variograms were obtained due to presence of a clear drift in water levels (Figure 2). Since a typical water-level map shown in Figure 2 depicts a single direction of major flow, it was decided to calculate directional variogram. The experimental variogram calculated in the direction of flow and perpendicular to the direction of flow is shown in Figure 3. It is clear that the major drift terms are present in the flow direction, and they have practically no contribution in the perpendicular direction. Thus calculation of experimental variogram in the perpendicular direction of major flow provides a bounded variogram that can be assumed as a variogram of residuals. Calculation of experimental variograms for all the time periods in a direction perpendicular to the main flow direction yielded bounded variograms.

Experimental variograms for all the time periods were calculated and modelled with theoretical models using an interactive program developed at NGR18,19. A theoretical variogram is fitted graphically by visual trial-and-error method. The parameters of theoretical variograms for different time periods are given in Table 2.

As shown in Table 2, all the variograms have zero nugget effect, confirming continuity of the parameter as well as low variability at the origin. A higher sill and lower range are found for the variograms calculated for the periods during monsoon, showing high variability of the phenomenon. Experimental and theoretical variograms for all the time periods are shown in Figure 4.

**Cross-validation test**

Due to the number of approximations made during calculation of the experimental variograms, the fitted models are bound to have ambiguities. Therefore, it is necessary to validate the variogram. A cross-validation test was performed by removing one observed value from the data

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**Figure 3.** Experimental variogram of water level in the aquifer in two directions.

**Table 2.** Parameters of theoretical variogram after graphical fitting

<table>
<thead>
<tr>
<th>Month and year</th>
<th>Model type</th>
<th>Nugget (m²)</th>
<th>Sill (m²)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2000</td>
<td>Spherical</td>
<td>0</td>
<td>155</td>
<td>4000</td>
</tr>
<tr>
<td>April 2000</td>
<td>Spherical</td>
<td>0</td>
<td>155</td>
<td>5000</td>
</tr>
<tr>
<td>June 2000</td>
<td>Spherical</td>
<td>0</td>
<td>175</td>
<td>4000</td>
</tr>
<tr>
<td>July 2000</td>
<td>Spherical</td>
<td>0</td>
<td>140</td>
<td>4500</td>
</tr>
<tr>
<td>August 2000</td>
<td>Spherical</td>
<td>0</td>
<td>175</td>
<td>3750</td>
</tr>
<tr>
<td>September 2000</td>
<td>Spherical</td>
<td>0</td>
<td>190</td>
<td>4200</td>
</tr>
<tr>
<td>October 2000</td>
<td>Spherical</td>
<td>0</td>
<td>150</td>
<td>3500</td>
</tr>
<tr>
<td>November 2000</td>
<td>Spherical</td>
<td>0</td>
<td>175</td>
<td>3500</td>
</tr>
<tr>
<td>December 2000</td>
<td>Spherical</td>
<td>0</td>
<td>165</td>
<td>3000</td>
</tr>
<tr>
<td>January 2001</td>
<td>Spherical</td>
<td>0</td>
<td>150</td>
<td>3500</td>
</tr>
</tbody>
</table>
Figure 4. Experimental and theoretical variograms for all time periods.

set and then estimating the value at that location using the remaining data. Following norms are calculated on the average basis to decide the best theoretical variogram representing a true variability of the parameters. The variograms are modified until satisfactory values of these norms are obtained.


where $h_i^{\text{obs}}$ and $h_i^{\text{est}}$ are the observed and estimated water level respectively, at any point $i$ and $\sigma$ is the kriging estimation error. The above equations determine if the estimated values are in good agreement with known values in the area. Satisfactory values of eqs (10) and (11) show that the estimates using the variograms on an average do not differ from the true value, whereas eqs (12) and (13) ensure the systematic bias. The numerator and denominator of eq. (12) represent the same magnitude, i.e. the variance of the estimation error obtained in different ways and therefore their ratio should approach 1. The value of eq. (12) guides the changes to be made in the variogram parameter. Equation (13) assumes that the difference in the true and estimated values, i.e. the error is normally distributed and with 95% confidence this equation should satisfy. Often for the outliers, eq. (13) is not satisfied. Cross validation was performed for all months starting from January 2000 to January 2001, and revised variograms for each time period were obtained (Table 3).

**Evolution of common variograms**

To avoid calculation of experimental and theoretical variograms for each time period, common variograms for the entire period and/or groups of periods were worked out. Four different types of common variograms were determined and cross-validated using observed values for all the months, and the results compared.

1. A common variogram estimated by taking resulting nugget effect, sill and range as the mean of the individual variograms called a mean variogram.
2. A variogram with a high sill value (the highest sill obtained) and a low range (lowest range obtained) to represent the type of aquifer present in a hard-rock area such as the one studied.
3. A common variogram by averaging the nugget, sill and range for the monsoon period was evolved, called monsoon variogram.
4. A common variogram was evolved in a similar way for the non-monsoon period, called non-monsoon variogram.

All four common variograms (Figure 5) were used for performing a cross-validation test with the observed value from the representative periods/months, and the results are compared in Table 4. In addition to the cross-validation test, values of water levels for the month of January 2000 were kriged using all the four considered variograms simultaneously. It is well established that kriging estimates are mostly affected by the particular field values and are less sensitive to the variograms; the kriged estimates for the four cases as depicted in Figure 6a-d provide interesting features, except a few lows that could be attributed to the local pumping. The water-level contours are different in the northern and southern parts of the area.

**Discussion**

A number of assumptions have to be made for the field application to a technique, e.g. continuity of the aquifer and flow of groundwater. In this area, less than four sets of joints are noticed. The most prominent set strikes N-S on an average basis. The strike varies between N10°E and N10°W. The joints are either vertical or dip

**Table 3.** Variogram obtained after cross-validation test

<table>
<thead>
<tr>
<th>Month and year</th>
<th>Model type</th>
<th>Nugget (m²)</th>
<th>Sill (m²)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2000</td>
<td>Spherical</td>
<td>0</td>
<td>140</td>
<td>4500</td>
</tr>
<tr>
<td>April 2000</td>
<td>Spherical</td>
<td>0</td>
<td>100</td>
<td>4000</td>
</tr>
<tr>
<td>June 2000</td>
<td>Spherical</td>
<td>0</td>
<td>160</td>
<td>4000</td>
</tr>
<tr>
<td>July 2000</td>
<td>Spherical</td>
<td>0</td>
<td>130</td>
<td>5000</td>
</tr>
<tr>
<td>August 2000</td>
<td>Spherical</td>
<td>0</td>
<td>140</td>
<td>3750</td>
</tr>
<tr>
<td>September 2000</td>
<td>Spherical</td>
<td>0</td>
<td>147</td>
<td>4200</td>
</tr>
<tr>
<td>October 2000</td>
<td>Spherical</td>
<td>0</td>
<td>140</td>
<td>5000</td>
</tr>
<tr>
<td>November 2000</td>
<td>Spherical</td>
<td>0</td>
<td>110</td>
<td>4500</td>
</tr>
<tr>
<td>December 2000</td>
<td>Spherical</td>
<td>0</td>
<td>105</td>
<td>4500</td>
</tr>
<tr>
<td>January 2001</td>
<td>Spherical</td>
<td>0</td>
<td>100</td>
<td>3000</td>
</tr>
</tbody>
</table>

**Figure 5.** Various types of common variograms studied.
very steeply towards west with angles 70–75° towards west. The second set of joints strikes E–W with steep dips. This strike of this joint set varies between N80°W and N80°E. The third set of joints strikes NE–SW direction with steep dips of 60°–75° towards SE. The fourth set of joints is more or less parallel to the surface of the topography. All these joints and the system help in the percolation of groundwater from the surface to the depths, in the otherwise impermeable granitic rocks. They also help to act as conduits for the transmission of groundwater. There are two sets of dykes and the strike of the first set is 90–110° and the second set strikes 50–60°. There are joints and fractures in the dykes also, but the surfaces are curved. These fractures also act as conduits for the transmission of surface water to the ground. The area is also traversed by lineaments, identified through the study of aerial photographs and landsat imageries. The high-yielding wells aligned in a particular direction on the ground, coincide with these lineaments. In Figure 1, only the dykes and lineaments, but not the joints, are shown as the joints are too small to be represented on the plan. The above fact ensures the continuity of the aquifer and allows us to calculate the variogram using water-level data from the entire area.
Table 4. Comparison of cross-validation with various common variograms

<table>
<thead>
<tr>
<th>Month and year</th>
<th>Month-wise</th>
<th>Yearly mean variogram (\gamma(d) = 0.0 + 127.2) sph (4245)</th>
<th>Considering hard rock variability (\gamma(d) = 0.0 + 160) sph (3000)</th>
<th>Non-monsoon (\gamma(d) = 0.0 + 110) sph (4100)</th>
<th>Monsoon (\gamma(d) = 0.0 + 128.4) sph (4390)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2000</td>
<td>38.45</td>
<td>1.03</td>
<td>38.10</td>
<td>1.07</td>
<td>43.28</td>
</tr>
<tr>
<td>April 2000</td>
<td>24.78</td>
<td>0.69</td>
<td>24.62</td>
<td>0.57</td>
<td>29.97</td>
</tr>
<tr>
<td>June 2000</td>
<td>63.49</td>
<td>1.02</td>
<td>65.06</td>
<td>1.38</td>
<td>60.58</td>
</tr>
<tr>
<td>July 2000</td>
<td>35.75</td>
<td>0.97</td>
<td>35.92</td>
<td>0.83</td>
<td>40.86</td>
</tr>
<tr>
<td>August 2000</td>
<td>44.67</td>
<td>0.72</td>
<td>47.34</td>
<td>0.95</td>
<td>45.16</td>
</tr>
<tr>
<td>September 2000</td>
<td>36.44</td>
<td>0.80</td>
<td>36.29</td>
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<tr>
<td>October 2000</td>
<td>29.62</td>
<td>0.84</td>
<td>29.73</td>
<td>0.78</td>
<td>33.49</td>
</tr>
<tr>
<td>November 2000</td>
<td>29.32</td>
<td>0.83</td>
<td>29.28</td>
<td>0.67</td>
<td>34.45</td>
</tr>
<tr>
<td>December 2000</td>
<td>27.91</td>
<td>0.86</td>
<td>27.82</td>
<td>0.66</td>
<td>32.84</td>
</tr>
<tr>
<td>January 2001</td>
<td>33.50</td>
<td>0.66</td>
<td>28.52</td>
<td>0.67</td>
<td>33.50</td>
</tr>
</tbody>
</table>

The calculation of variogram of the residuals of water levels has been possible as the groundwater flow conditions are simple and linear drift exists. In case the water levels are more disturbed and exhibit quadratic or higher order drifts, it becomes difficult to estimate the variogram of the residuals using directional variogram.

The averaging of the variograms is also allowed, as this is similar to the case of nested variogram or nested covariance\(^{1,21}\), where a variogram can be a weighted average of several independent variograms. However, according to Marsily and Ahmed\(^{22}\), the cross-validation tests are quite strong tools, and if a variogram is capable of reproducing the observed data to a satisfactory level, it is not important to worry as to how one has arrived at that variogram. We have extensively used this property of cross-validation in our present study. The cross-validation tests are much more important in this case, as obviously seen from Figure 4 that the fitting of the theoretical variograms through the respective experimental variograms is approximate and that the situation could not be improved due to limited observed data and the constraint of calculating the variogram in a particular direction.

The results are further compared in Figure 6 which shows dominance of the observed data over the variograms, and also that estimates using the hard-rock variogram are not acceptable.

Summary

The number of measurement points for hydrogeological studies is always less, resulting in a sparse data set compared to other fields such as mining, etc. Application of the theory of regionalized variable thus requires special efforts in analysing the variability of the parameter. The present study shows that by performing geostatistical analysis of a parameter for different time periods, it is not absolutely necessary to carry out variographic analysis separately for all the time periods, which at times, is quite cumbersome and ambiguous.

Although it is not always possible to evolve a single unique variogram for all time periods, the study with the help of cross-validation test has shown that if the year cycle is divided into two parts – monsoon and non-monsoon – it is possible to evolve a common variogram for each part. The common variograms during the validation test could satisfactorily reproduce the measured values of water level without losing much on the outcome (mean estimation error and mean reduced error) compared to cross-validation test using individual variograms. This was possible for water levels as both the input (rainfall recharge) and the output (groundwater withdrawal for irrigation) more or less follow a cyclic pattern each year. Even in the case of low or high rainfall years, the spatial variability of water levels could be assumed to remain the same.

The evolution of common variogram helps in analysing water levels for all the time periods that could be used, e.g. calibration of an aquifer model, etc. The study also helps in estimating water levels at any time period when all the wells could not be monitored. This would have otherwise been extremely difficult because variographic analysis in the absence of sufficient measurements becomes much more ambiguous.


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