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Evaluation of Spatiotemporal Variability of Groundwater Level Fluctuations in Zahrez basin, Algeria: Geostatistical Approach

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Abstract*: Groundwater level fluctuation in aquifer system plays the main role in quantitative water management especially in semi arid and arid areas. In practice, due to aspects of time and cost, data monitoring of water levels is conducted at a limited number of sites, and interpolation technique such as kriging is widely used for estimation of this variable in unsampled sites. The main objective of this study is to get a better understanding of the temporal and spatial variability of the groundwater level fluctuation in regular monitoring wells constructed by the ministry of water resources in zahrez basin, Algeria. In this study, seasonal groundwater level data for 57 wells were collected from 1994 to 2011 and analyzed using the geostatistical approach. The Kolomogorov–Semirnov test revealed that all data followed normal or log-normal distribution. Experimental variograms are fitted by variogram models and computed to be used in the kriging estimations. The results of variographic analysis indicate that experimental variograms are best fitted by the gaussian model and the exponential model. Nugget-sill ratio (<25%) revealed that the groundwater levels have strong spatial dependence in the area. Kriging interpolation techniques have indicated the groundwater flow directions remained almost constant over the years.

Index Terms: Geostatistics, Groundwater levels, Semivariogram, Universal kriging, Zahrez basin

I. INTRODUCTION

In Algeria, rapid growth in the population and economy has enhanced industrial and agricultural activities and has led to dramatic increases in water consumption and demand. Zahrez basin is a semi-arid region with irregular rainfall patterns. Where surface water availability is very limited, plays a very significant role in water supply for domestic and agricultural purposes. Sustainable management of groundwater resources is one of the essential objectives for the future development of a country, especially when the rising demand for clean drinking water is considered [1,2]. The water level in aquifer is an important parameter in groundwater hydrology and a careful and detailed analysis of its variation in time and space reveals useful information on the aquifer system behavior [3]. Spatial and temporal changes in groundwater levels are governed by natural factors (evapotranspiration, precipitation, climate changes, drainage pattern, etc.) and anthropogenic activities, such as land use, irrigation, pumping and induced infiltration [4].

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Monitoring of groundwater level of observation wells is the principal source of information on the effects of hydrologic stresses on groundwater systems.Both short and long-term records are invaluable in understanding the state of the groundwater system and in addressing problems that might develop in response to groundwater abstraction and changes in land use. In practice, due to aspects of time and cost, data monitoring of water levels is conducted at a limited number of sites.

Geostatistical approaches can provide more helpful, reliable and efficient tools to increase the number of measurement points at unsampled locations, and variogram analyses for examining structural relationship of data. The geostatistics has been used by several researchers to investigate the spatial-temporal variations of groundwater level. Ahmadi and Sedghamiz used ordinary and universal kriging methods in identifying the spatial and temporal analysis of monthly groundwater level fluctuations in the arid region, the Darab Plain, in the south of Iran [5]. Kumar and Ahmed monitored the groundwater level during 12 months of the year and used the kriging method to estimate groundwater level for unmeasured points and wells for each month [6]. Theodossiou and Latinopoulos worked on spatial analysis of groundwater level of 31 wells using kriging, but they did not do any temporal analysis [7]. Kumar and Remadevi applied several variogram models, i.e., spherical, exponential, and Gaussian semivariogram models to fit the experimental semivariograms for analyzing spatial variations of groundwater level fluctuations in small part of Rajasthan area, India.The results indicate that the kriged groundwater levels satisfactorily matched the observed groundwater levels [8]. In this present study, geostatistics are applied to analyze the spatial and temporal variations of groundwater level fluctuations in the Zahrez basin. Kriging techniques were used to interpolate the groundwater levels at unsampled locations. Kriging as an interpolation technique takes into consideration the spatial structure of groundwater levels.

II. STUDY AREA

The Zahrez basin (Fig.1) is one of the endorheic basins of the vast steppes region in the central The northern part of Algeria. The Zahrez hydrological basin covers approximately 8,989 km^2. Topography of the area is relatively flat with an elevation ranging from 900 to 1330 meters above mean sea level [9]. The catchment lies between longitudes 2° 15’ to 4° 08’E and latitudes 34° 35’ to 35° 30’N. The area is characterized by a semi-arid climate, typically Mediterranean, with an irregular annual rainfall.

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The mean annual rainfall and potential evapotranspiration are 250 and 1380 mm, respectively, exceeding rainfall for most of the year. The mean monthly temperature varies between 3°C and 25°C. The precipitation period in a typical year is between October and March and the dry period can extend from April to September [10]. The ephemeral rivers of the region, locally called ‘‘wadi’’, have an intermittent flow regime, because the dry season is typically very long (6–8 months) every year. The main wadis in this basin are the Melah and Hadjia rivers which receive many important flow tributaries. The drainage density of the area ranges between 1.4 and 1.8 km/km^2 [9].

III. HYDROGEOLOGY

The hydrogeology of the study area is subdivided into two hydrostratigraphic units on the basis of aquifer types. Aquifer system of Djelfa syncline consists of Mio-Plio-Quaternary, Turonian, Albian and Barremian formation [11]. The Mio-Plio-Quaternary shallow aquifer (0-50m) occurs in the continental detrital formations and consists of conglomerates and clays which are characterized by a direct contact with the Turonian and Albian aquifer in the northern side of Djelfa syncline. The confining bed of this aquifer consists of marly limestone and gypsum of Senonian age. The transmissivity values for this aquifer range from 2.17×10^{-5} to 8.3×10^{-4} m^2/s with a mean value of 3.17×10^{-4} m^2/s [10, 12]. The Turonian aquifer is confined and is in a direct contact with the Mio-Plio-Quaternary aquifer on the northern flank of Djelfa Syncline. The pumping tests on different wells showed high average transmissivity (1.2×10^{-2} m^2/s), indicating high yields. The hydraulic conductivity is 1×10^{-4} m/s.The Albian aquifer; this aquifer is confined characterized by an average transmissivity of about 0.5×10^{-2} m^2/s and a hydraulic conductivity of 1.2×10^{-4} m/s. The Barremian aquifer: this aquifer is more productive in downstream part of the Mellah-Djelfa wadi, the average transmissivity of the Barremian aquifer is 1.3×10^{-3} m^2/s [10]. The groundwater level contour map shown on (Fig. 2(a)) summarizes the distribution of piezometric head in the aquifer system within the study area. This map shows that the general flow directions are from the south to the north-east (from Dar El Chioukh to the chotts of Zahrez Chergui), following the topographic gradient. Another main flow direction appears in the western and central parts of the basin, from the south to the north (from Djelfa to the chotts of Zahrez Gharbi). The two flow directions highlight the importance of rainfall infiltration in Djelfa and Dar El Chioukh areas. The piezometric levels are high in the central and southeastern parts of the basin.

IV. MATERIALS AND METHODS

A. Data collection

Data for groundwater level analysis were provided by the National Agency for water Resources (ANRH), which included the longitude and latitude coordinates for each of 58 groundwater observation wells (Fig. 2 (b)) and groundwater level data during the period 1994–2011. The selected wells have complete data sets representing both wet and dry seasons (May–October data).

B. Data analysis

Descriptive statistics, including the mean, maximum, minimum, standard deviation and coefficient of variation (CV) were calculated using. Statistica 6 for Windows. For the variogram analysis and the definition of the theoretical model were performed with Variowin 2.21 software [13]. Interpolation and spatial distribution maps were performed using the software package Surfer 9 (Golden Software Inc., 1999).

C. Geostatistical approach

Geostatistics uses the technique of variography, i.e.,calculating variogram or semi-variogram, to measure the spatial variability and dependency of a regionalized variable. Variography provides the input parameters for the spatial interpolation of kriging [14,15].

Variogram analysis

The variogram γ(h) represents the average variance between observations separated by a distance h. The value plays an important role in the description and interpretation of the structure of the spatial variability of the investigated regionalized variable. It is estimated by Journel and Huijbregts [16]:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2 \qquad (1)$$

Where Z (xi) is the value of the variable Z at location of xi, and N (h) is the number of pairs of sample points separated by the lag distance h. The fitting of a theoretical variogram (curve) is an important step in the variogram analysis. The experimental semivariogram, γ(h) is fitted to a theoretical model such as Spherical, Exponential, Linear, or Gaussian to determine three parameters, such as the nugget (C0), the sill (C) and the range (a) [17].

Goodness-of fit Criteria for selecting best fit Semivariogram models

Selection of semivariogram models was made based on the indication of the goodness of fit (IGF), which is calculated using the following equation [13]:

$$IGF = \frac{1}{N} \sum_{k=1}^{N} \sum_{i=0}^{n(k)} \frac{P(i)}{\sum_{j=0}^{n(k)} P(j)} \frac{D(k)}{d(k)} \left[\left\{\frac{\gamma(i) - \hat{\gamma}(i)}{\sigma^2}\right\}^2\right] \qquad (2)$$

where N denotes the number of directional variograms, n(K) represents the number of lags relative to the variogram K, D(K) is the maximum distance relative to the variogram K, P(i) denotes the number of pairs for lag i of variogram K, d(i) represents the mean pair distance for lag i of variogram K, γ(i) is the experimental measure of spatial continuity for lag i, $\hat{\gamma}$ denotes the modeled measure of spatial continuity for d(i), and σ^2 represents the covariance of data. The IGF is a number of standardization without units; a value close to zero indicates a good fit [13].

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Interpolation with kriging

Kriging provides a means of interpolation to determine parameter values at non sampled locations, using knowledge about spatial relationships (the semivariogram) in the data set [18]. The general equation of the kriging method has the following form:

V. Results and Discussions

A. Descriptive statistical analysis

Data from observation wells in Zahrez basin during the period 1994–2011 were subjected to spatial and temporal analyses to address the problem of water level decline and rise that has been noticed in certain areas in the last decade (Fig. 2(b)).

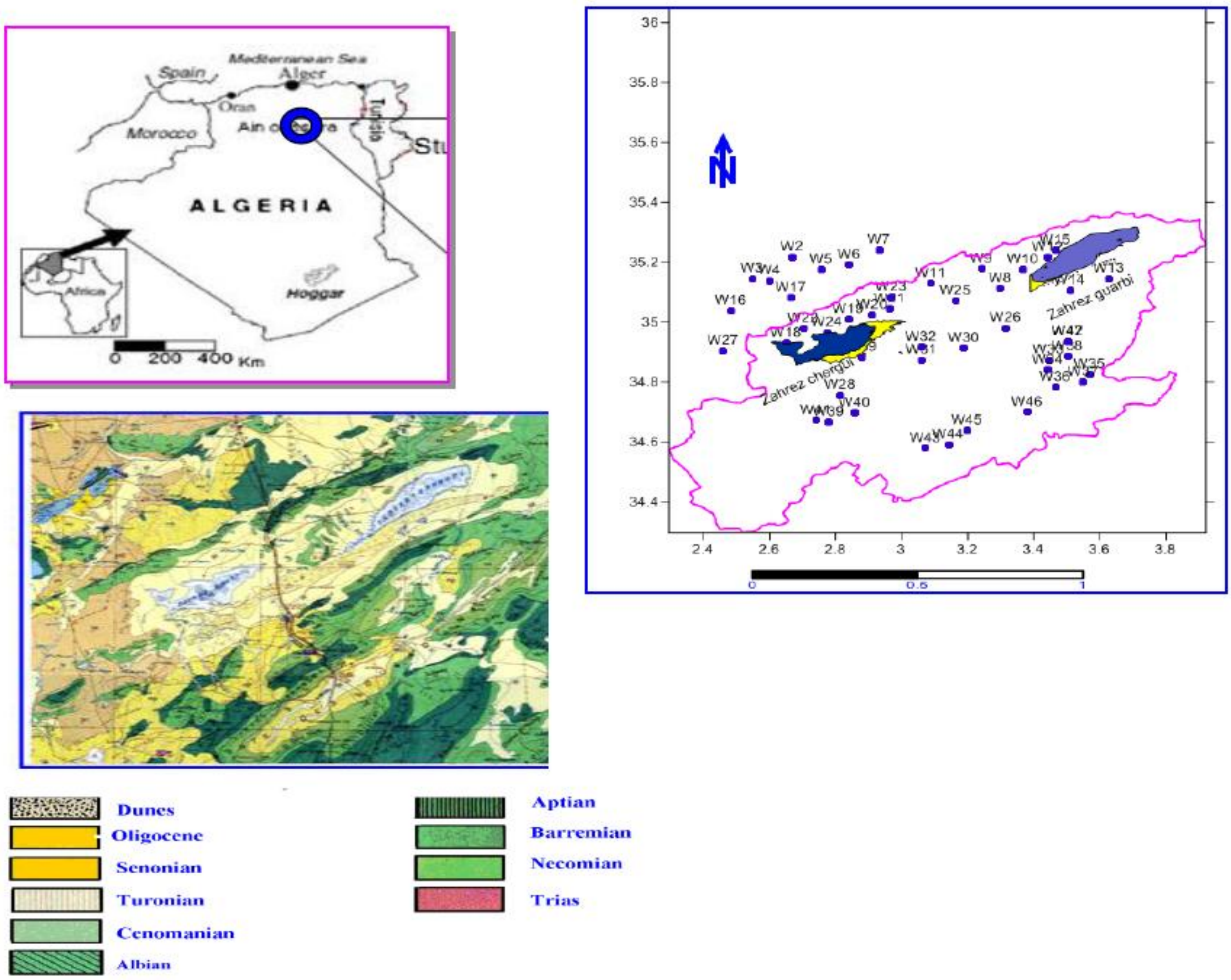

Fig.1. Location map and geological formations of the Zahrez

The first step in data statistical analysis involved the computation of basic summary statistic. The summary statistic, including mean, variation coefficient, minimum and maximum values are shown in Table 1 and 2. The ranges of groundwater level fluctuation (minimum-maximum) in observation wells are between 758.20 and 1226.30 m.

The mean values of groundwater levels fluctuations ranged between 860.79 and 963.06 m. The CV is the ratio of the SD to the mean values, which reflects the dispersion variation degrees of the samples. Usually, CV < 0.1 represents weak variability, $0.1 \leq CV \leq 1$ means moderate variability, and CV > 1 means strong variability. The CV values of groundwater levels data ranged from 0.03 to 0.15, indicated weak to means moderate variability.

The parameters of skewness, kurtosis, and the significance level of Kolmogorov–Smirnov test for normality (K-S p) are shown in Table 1 and 2. The coefficients of kurtosis and skewness of the series of groundwater levels in groundwater were close to zero revealing that these variables had near normal distributions.The Kolomogorov–Semirnov test confirmed that they all data followed a normal distribution or lognormal distribution (K-S $p < 0.05$). Although normality is not a prerequisite for kriging, it is only a desirable property. Kriging would only generate the best absolute estimate if the random function fits a normal distribution [19].

B. Temporal analysis of groundwater levels

The groundwater level dynamics reflects the response of the groundwater system to external factors such as climate and human activities.

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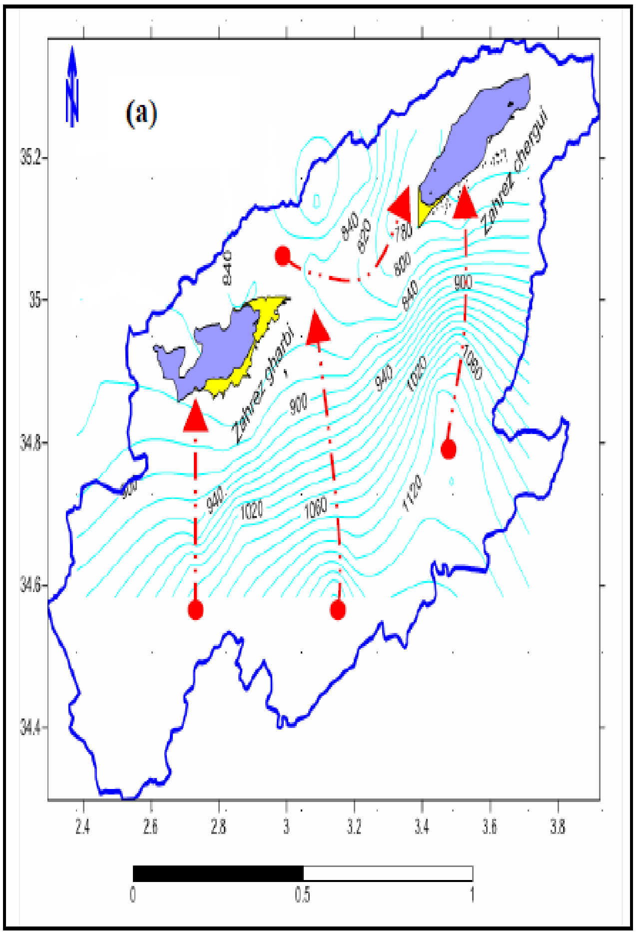
Regular monitoring of groundwater level fluctuations expresses the effect of these processes in an aquifer system and provides the knowledge for proper management. Thirteen years of groundwater level monitoring data were collected from the National Agency for water Resources (ANRH). Based on long-term water level fluctuations (Fig. 3), groundwater wells are classified into two groups. **Group 1** Wells in this group are located mostly in the south western and south eastern region (**1102-G7, 945-G7, 1003-G7, 1178-G8, 1783-G8**). In this group the water level, shows cyclic trend with a rapid yearly fluctuation throughout the study period. The greatest decline occurred in the period from 1994 to 2003. The maximum difference in water levels between the highest and lowest values is **9.02 m** for well **1778-G8.** The yearly cyclic trend observed in group1 appears to be due to evaporation and pumping activities of groundwater for agricultural and domestic. **Group 2** Groundwater level hydrograph of wells (**1962-G8, 1034-G7, 2119-G7, 1380-G7**) indicates that the piezometric level has remained almost stable for the years between 1994 and 2011. Most of the wells in this group are located in the central and east part of the zahrez basin.



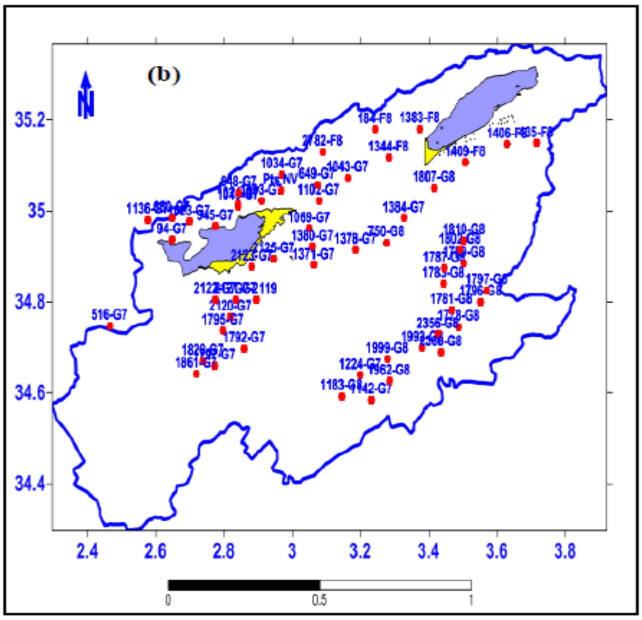
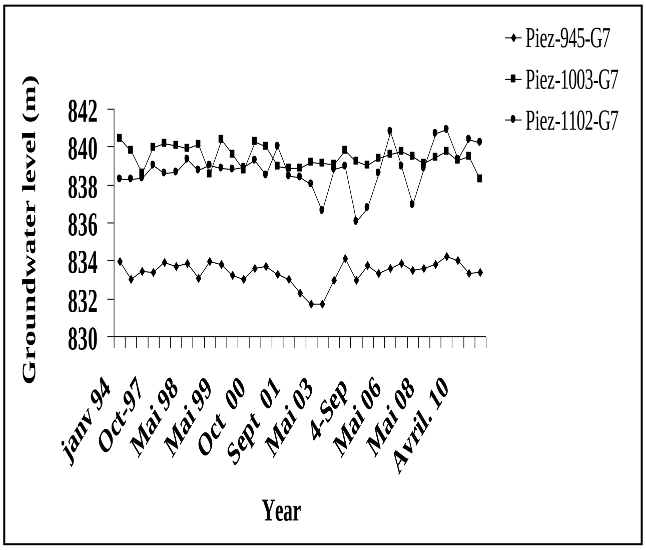


Fig. 2. Map showing the Piezometric map and location of monitoring wells in Zahrez basin

a



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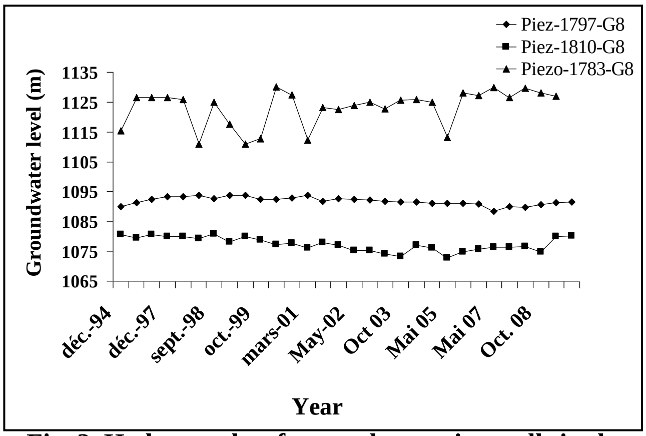

Fig. 3. Hydrographs of some observation wells in the study area

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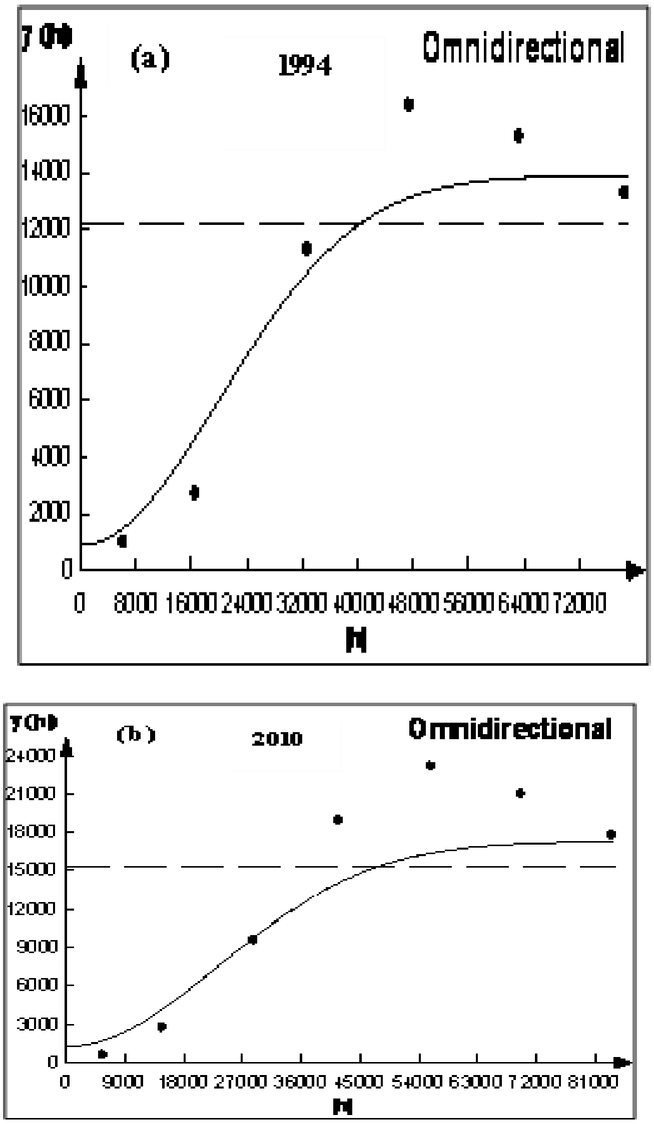

Fig. 4. Fitted experimental semivariograms for groundwater levels of (a) 1994 and (b) 2010

C. Variographic analysis

Variograms parameters of the best fitted semivariogram models for groundwater levels values, and the corresponding values of goodness of fit criteria are summarized in Table 3 and 4. It shows that two geostatistical models, viz., Gaussian and spherical are the best-fit models based on the indication of the goodness of fit (IGF) criteria. The range of influence is the distance within which the groundwater level values are spatially dependent. The minimum spatial dependence (40,800 m) was encountered in the wet season of the year 2011, and the maximum one (76,996 m) in the wet season of 2009. The presence of nugget effect (Co = variance at zero distance) implies inherited variability or variability over distances, shorter than the spacing between observation wells, and/or other unaccountable recording errors. The ratio of nugget variance to sill expressed in percentages has been used by Camberdella et al. (1994) to classify the spatial dependence variables. If this ratio is less than 25%, then the variable has strong spatial dependence; if the ratio is between 25 and 75%, the variable has moderate spatial dependence; and greather than 75%, the variables shows only weak spatial dependence. According to this classification, the values of this ratio for groundwater levels of the wet and dry seasons over the years 1994–2011 ranged from 0 to 20 (Table 3 , and 4), indicating the strong spatial dependency, which can be attributed to the intrinsic factors, such as climate, topography, hydrogeological condition, and groundwater runoff. The best fitted Gaussian model variograms for 1994 and 2010 wet and dry seasons were selected to analyze the spatial variations of groundwater level using kriging techniques.

Table 1: Summary statistic of groundwater levels during 1994/2010 (dry period)

Year	N0 of Wells	Minimum	Maximum	Mean	SD	CV	Skewness	Kurtosis	K–S p	Distribution
1994	44	759.95	1169.40	904.16	111.90	12.4	1.16	0.17	0.246	Lognormal
1996	36	770.14	1165.88	921.69	128.15	13.9	0.92	-0.91	0.285	Lognormal
2001	51	770.15	1226.30	948.40	132.94	14.0	0.55	-1.29	0.224	Normal
2002	44	770.00	1225.90	953.84	132.63	13.9	0.50	-1.33	0.217	Normal
2003	51	759.65	1224.85	935.00	129.08	13.8	0.69	-1.00	0.231	Lognormal
2004	58	758.78	1224.85	916.67	125.33	13.7	0.90	-0.49	0.243	Lognormal
2005	54	759.30	1224.55	926.87	129.73	14.0	0.73	-0.89	0.228	Lognormal
2007	46	758.70	1224.50	918.55	137.70	15.0	0.82	-0.90	0.264	Lognormal
2008	52	758.65	1224.35	920.46	127.92	13.9	0.84	-0.59	0.234	Lognormal
2010	54	758.20	1224.47	918.55	125.82	13.7	0.89	-0.48	0.242	Lognormal

Table 2: Summary statistic of groundwater levels during 2001/2011 (wet period)

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Year	N0 of Wells	Minimum	Maximum	Mean	SD	CV	Skewness	Kurtosis	K–S p	Distribution
2001	22	825.00	928.00	869.82	26.70	3.07	0.61	0.48	0.124	Lognormal
2002	51	768.50	1225.90	941.89	130.66	13.87	0.63	-1.15	0.229	Lognormal
2003	40	763.15	1224.95	963.06	133.04	13.81	0.24	-1.44	0.193	Lognormal
2004	52	759.90	1225.35	936.25	127.93	13.66	0.68	-0.95	0.212	Lognormal
2005	53	759.05	1225.40	936.34	123.92	13.23	0.80	-0.86	0.254	Normal
2006	45	769.00	1224.80	959.97	128.22	13.36	0.53	-1.32	0.229	Lognormal
2007	53	759.70	1224.90	930.74	124.67	13.40	0.81	-0.70	0.236	Normal
2008	56	758.75	1169.90	915.78	121.35	13.25	0.96	-0.27	0.229	Lognormal
2009	58	758.85	1224.70	916.49	122.62	13.38	0.95	-0.31	0.227	Lognormal
2010	58	758.75	1224.76	924.95	128.47	13.89	0.80	-0.72	0.231	Lognormal
2011	43	758.30	1027.90	860.79	61.24	7.11	0.69	1.26	0.139	Lognormal

Table 3 Fitted experimental semivariograms parameters for groundwater level (dry period)

Year	Best fit model	Nugget (m2) C0	Sill (m2) C0+C1	Range Km	IGF	(C0/C0+C1) %
2002	Gaussian	2210	17000	56.21	7.87E-02	13.0
2003	Gaussian	1080	18000	45.37	8.25E-02	6.0
2004	Gaussian	1760	16000	50.05	8.57E-02	11.0
2005	Gaussian	3200	16000	69.30	1.23E-01	20.0
2006	Spherical	2720	16320	69.30	1.08E-01	16.7
2007	Spherical	900	15000	64.73	1.37E-01	6.0
2008	Gaussian	520	13000	52.92	9.96E-02	4.0
2009	Spherical	0	19140	77	1.60E-01	0.0
2010	Gaussian	1359	17000	49.56	7.62E-02	8.0
2011	Gaussian	190	3800	40.80	9.64E-02	5.0

Table 4 Fitted experimental semivariograms parameters for groundwater level (wet period)

Year	Best fit model	Nugget (C0) (m^2)	Sill (C0+C1) (m^2)	Range Km	IGF	(C0/C0+C1) %
1994	Gaussian	910	13000	48980	6.07E-02	7
1996	Gaussian	1760	16000	47360	1.29E-01	11
2001	Gaussian	1190	17000	55.30	1.23E-01	7
2002	Gaussian	1700	17000	47.45	1.60E-01	10
2003	Gaussian	540	18000	48.98	8.57E-02	3
2004	Gaussian	1440	16000	45.36	6.47E-02	9
2005	Gaussian	850	17000	42.84	1.04E-01	5
2007	Gaussian	3420	19000	56.10	1.77E-01	18
2008	Gaussian	1440	16000	50.40	1.28E-01	0.9
2010	Gaussian	1280	16000	57.12	1.31E-01	8

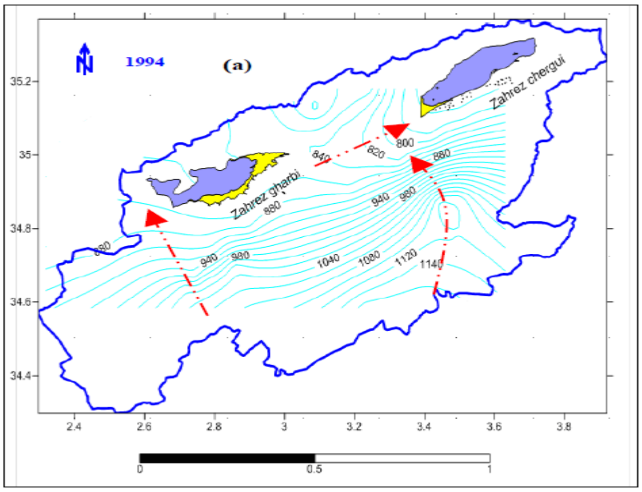
D. Ordinary kriging for groundwater elevation

To envisage the seasonal level variability over the years, contour maps of groundwater levels values in 1994 and 2010 (wet and dry seasons) were generated by kriging interpolations based on the best fitted semivariogram models.

The map of groundwater elevation determined by this method is shown in Fig. 4 and 5. These

Figures show that the highest groundwater elevation occurred in central to south-western part of the study area and the lowest groundwater elevation obtained in the north to north-eastern part of the study area.

The groundwater flows generally from south to north-east following the topographic gradient and in the western part occurs from south to north. The flow directions remained almost the same since 1994. However, Fig. 4 does not indicate exactly where in the basin parts the decline and rise phenomena took place. Therefore, to be more specific, the seasonal decline and rise level values for each well were calculated and mapped using kriging techniques (Fig. 6). The adopted model is a spherical one with nugget, sill and range of influence values 14.70 and 11,100 m, respectively. The calculated nugget to sill ratio is less than 25% (0.13%).



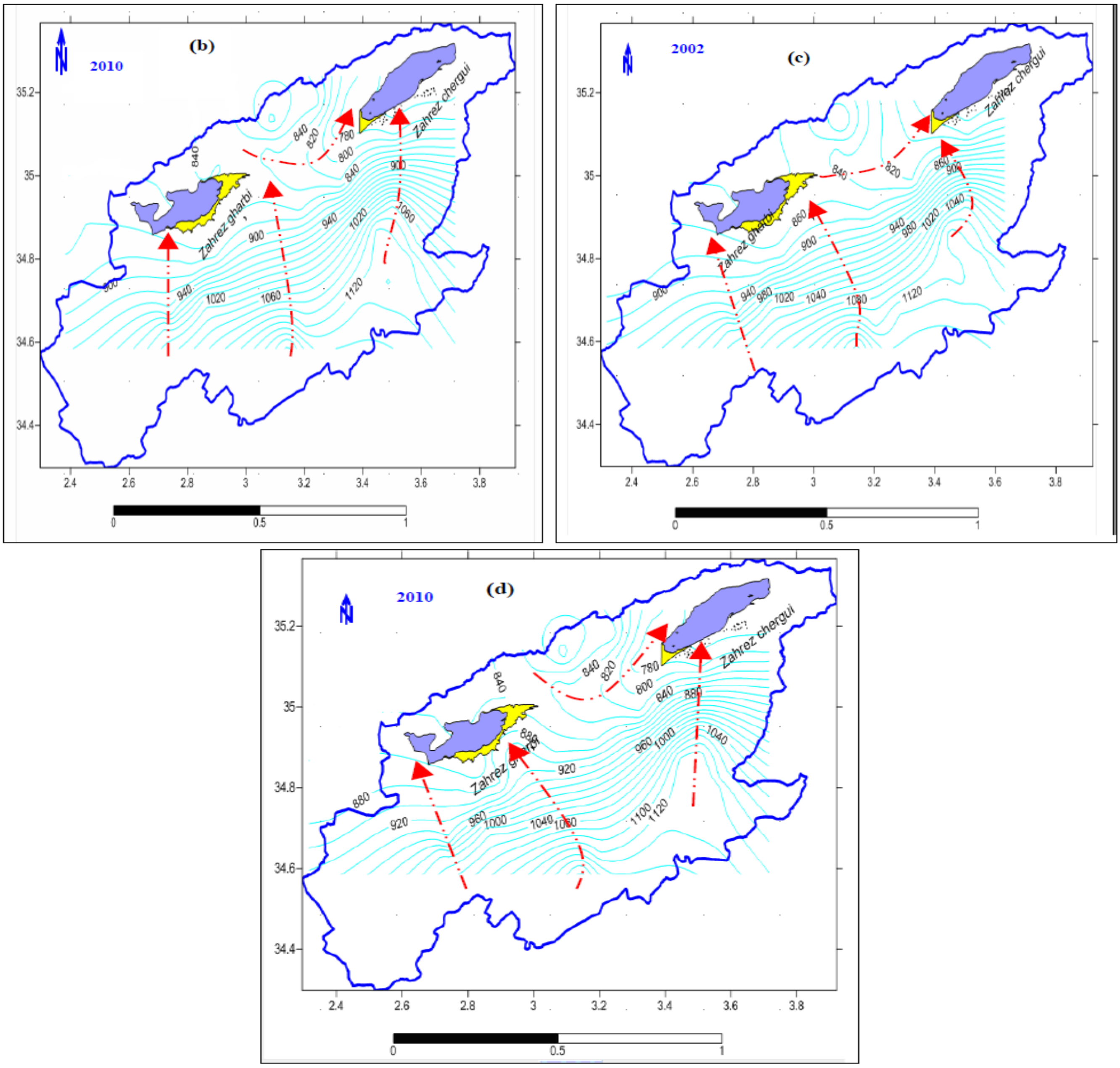


Fig. 5. Spatial distribution maps of groundwater level during (a) 1994 and (b) 2010 (dry seasons), (c) 2002 and (d) 2010 (wet seasons)

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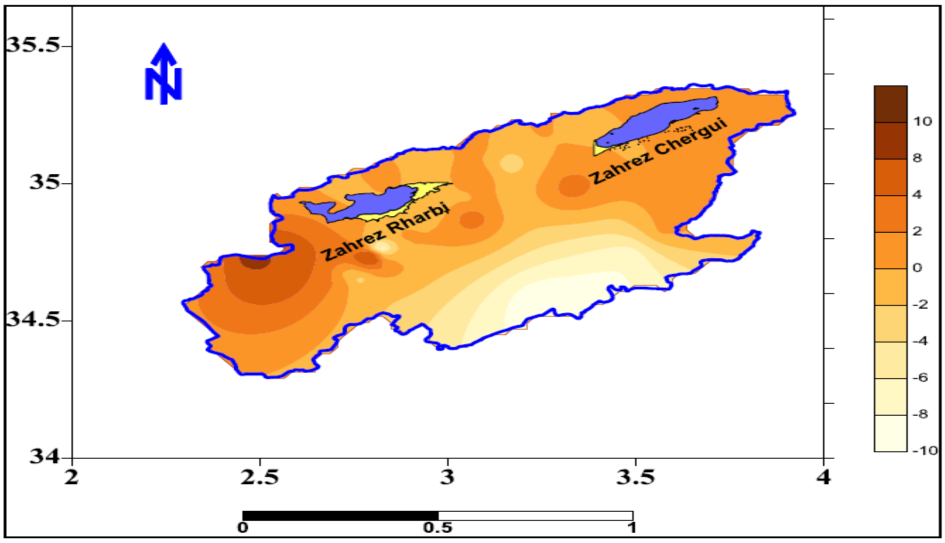

Fig. 6. Contoured kriged water level fluctuations over the years 1994–2010 (dry seasons) showing drop and rise sites

VI. CONCLUSIONS

The application of geostatistics and techniques in modeling spatial and temporal variations of groundwater levels in the Zahrez basin has been demonstrated in this study using seasonal groundwater-level data of 57 wells during the period 1994–2011. Variographic analysis results showed that the gaussian and exponential semivariogram models were found to be the best fitted model for groundwater level data. Furthermore, using the best fitted semivariogram, the spatial variability maps were generated using the kriging interpolation technique. The spatial variability maps showed that the groundwater levels tended to increase from north and north-east to south-western and south part of zahrez basin. Kriging interpolation techniques have indicated that the groundwater flow directions remain almost constant over the years. The generated spatial variability maps are very useful for groundwater resource management in terms of groundwater quantity assessments. Based on the long-term groundwater level pattern, groundwater wells are classified into three groups. In group 1, water level shows a long-term cyclic trend with a rapid annual fluctuation. In group 2, water level remains almost constant throughout the study period. The groundwater level rises in the south eastern part of the basin. The drop phenomenon is remarkable at two major sites in the central and western parts of the study area. Both drop and rise in groundwater level in the basin were attributed to human activities, evapotranspiration and rainfall recharge.

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REFERENCES

1. Kettab, "Water resources in Algeria : strategies, investments, and vision", Desalination, vol.136, no.1-3, pp.25-33, 2001.
2. Kettab, R. Mitiche, N. Bennaçar, "Water for a sustainable development: challenges and strategies", Revue des Sciences de l'Eau 21 (2): 247-256, 2008.
3. M. Aflatooni, M. Mardaneh, "Time series analysis of groundwater table fluctuations due to temperature and rainfall change in Shiraz plain", International Journal of Water Resources and Environmental Engineering 3 (9): 176– 188, 2011.
4. RW. Healy, PG. Cook, "Using groundwater levels to estimate recharge", Hydrogeology Journal 10: 91–109, 2002.
5. S. Ahmadi, A. Sedghamiz, "Geostatistical analysis of spatial and temporal variations of groundwater level", Environmental Monitoring Assessement 129(1–3):277–294, 2007.
6. D. Kumar, Sh. Ahmed, "Seasonal behaviour of spatial variability of groundwater level in a granitic aquifer in monsoon climate", Current Science 84: 188–196, 2003.
7. N.Theodossiou, P. Latinopoulos, "Evaluation and optimization of groundwater observation networks using the kriging methodology." Environmental Modelling and Software: 21: 991– 1000, 2006.
8. V. Kumar, Remadevi, "Kriging of groundwater levels—a case study." Journal of Spatial Hydrology 6 (1): 8 1–92, 2006.
9. ANRH, "Synthèse hydrogéologique du synclinal de Djelfa." Agency for Water Ressources, 1997, unpublished.
10. M. F. Sidi Moussa, " Ressources Hydrauliques de la zone du projet GTZ-HCDS." Coopération Algero-Allmande, 176 P, 2000, unpublished.
11. M. F. Sidi Moussa , M.Deramchi, "Synthèse des études et exploitation des données existantes sur le Synclinal de Djelfa", Agence Nationale des Ressources Hydrauliques (ANRH), Rapport Technique, 40P, 1993, unpublished.
12. B.Chibane, A. Boutaleb, "Geochemistry study and Isotopic Approach in Semi-Arid Region: Case of the Djelfa Syncline (Algeria)." European Journal of Scientific Research 45(2):270-290, 2010.
13. Y. Pannatier, "Variowin Software for Spatial Data Analysis in 2D", edited by Springer, New York,1996.
14. D.G. Krige, "A statistical approach to some basic mine valuation problems on the Witwatersrand", Journal of the Chemical, Metallurgy and Mining. Society. Southern. Africa 52 (6): 119–139, 1951.
15. G. Matheron, "Principles of geostatistics." Economic. Geology 58: 1246–1266, 1963.
16. A.G. Journel, C.J. Huijbregts, "Mining Geostatistics", edited by Academic Press Inc, London, UK, 1978, 600pp.
17. EH. Isaaks, RM. Srivastava, "An Introduction to Applied Geostatistics", edited by Oxford University Press: New York,1989, 322 pp.
18. M. David, "Geostatistical ore reserve estimation.", edited by Elsevier, Amsterdam, 1977.
19. P. Goovaerts, "Geostatistics for natural resources evaluation", edited by Oxford University Press, New York,1997.