Spatio-Temporal Trend Analysis of Groundwater Levels in Sharjah, UAE

Abdullah G. Yilmaz, Abdallah Shanableh, Rami I. Al-Ruzouq, Naseraldin Kayemah

Abstract—**United Arab Emirates (UAE) is a water stressed country due to limited rainfall. Moreover, rapid population growth, increase in agricultural and industrial activities are causing additional stress to the water resources in UAE. Groundwater is the most important fresh water source in UAE, and sustainable and efficient management of groundwater is vital for the country. Trend analysis of groundwater levels is an essential component of groundwater management, since it provides significant information about the direction and characteristics of the groundwater level trend, allowable discharge limit and the cause of groundwater decline. In this study, monthly groundwater level trends from eleven well fields were investigated over the period of 15 years in Sharjah, UAE. Groundwater spatiotemporal data analysis tool (GWSDAT) was used for the spatial and temporal trend analysis for groundwater levels. Mann-Kendall non-parametric test was used for the temporal trend analysis. Statistically significant decreasing trends were identified almost in all well fields in Sharjah. In parallel to decreasing groundwater levels, the groundwater production has fallen substantially (more than 90% decrease in some well fields over 15 years). It was found that the well fields close to the coastline experienced significant decrease in groundwater levels, which induces sea water intrusion and salinization of groundwater.**

Index Terms—**Groundwater levels, Sharjah, spatio-temporal trend analysis, United Arab Emirates.**

I. INTRODUCTION

Groundwater is an important fresh water source that can meet the domestic, agricultural and industrial water demand. Statistical assessment of groundwater quality and levels is an important task in sustainable management of groundwater, especially in the arid and semi-arid regions, where there is limited surface fresh water resources. The water demand in these regions are met mainly by groundwater and non-conventional water resources such as desalinated water.

Trend analysis of groundwater levels is an essential component of groundwater management, since it provides significant information about the direction and characteristics of the groundwater level trend, allowable discharge limit and the cause of groundwater decline ([1]; [2]). Several studies (e.g. [3]; [4]) showed that trend analysis is very powerful in planning management strategies for development and utilization of groundwater resources. As an example of groundwater level trend analysis studies, [5] studied

groundwater level trends by using non-parametric tests in Ardabil plain of Iran, and they found significant decreasing trends in groundwater levels in the study area. [6] used Mann-Kendall (MK) and Sen's slope tests to detect groundwater level trends in Bangladesh, decreasing trends in the maximum and minimum depths of groundwater levels (during 1991-2010) were reported. [7] investigated spatio-temporal trends in groundwater in Lake Umria region. [8] used regional Kendall method to analyze groundwater levels and their annual decline rates in Beijing, Tianjin and Hebei in China. This study showed a continuing declining regional trend in groundwater levels. [9] reported no significant trend in groundwater levels (with few exceptions) in Raipur city at 95% significance level by analyzing monthly groundwater level data using MK test and Sen's slope estimator.

United Arab Emirates (UAE) is a water stressed country due to limited rainfall. Moreover, rapid population growth, increase in agricultural and industrial activities are causing additional stress to the water resources in UAE [10]. There is very limited surface fresh water available in UAE due to rare rainfall events (about 110 mm/year) [11]. Groundwater is used to meet 70% of total water demand in UAE, and agriculture sector is the highest groundwater consumer with 83% of total groundwater use [12]. The over-extraction of groundwater and lack of recharge led to a serious decline in the groundwater level and caused sea water intrusion in UAE [13], [14]. In this study, spatio-temporal trends in monthly groundwater levels were investigated in Sharjah, UAE by analyzing data from eleven well fields. This study is expected to provide significant contribution to sustainable groundwater management in Sharjah, and to assist groundwater policymakers in the region for future planning.

II. STUDY AREA AND DATA

The study area, Emirate of Sharjah, is located in UAE with central coordinates of 25.3 ° N and 55.5 ° E approximately. Sharjah occupies around 2,590 km ? Fig. 1 shows location of Sharjah along with location of well fields used in this study. The climate in Sharjah is considered hot, dry and humid. Rainy season in Sharjah is from November to March. The available capacity of the groundwater wells is around 21.50 million gallons per day, and daily average water production from groundwater wells is around 15.46 million gallons. 70% of the total groundwater consumption is for irrigation purposes in Sharjah [15].

In this study, monthly groundwater level data from eleven well fields (i.e., Al Sadiyah, Aweed, Bedai, Filli, Ghuraifa, Hamdah, Madam, Mahafis, Sajaa, Seih Aqareb and Seih Hermal) are considered. As seen in Fig. 1, the well fields are

approximately evenly distributed between the west and the south parts of Sharjah. The data period ranges between 2004 and 2018 showing variation for different well fields as shown in Table I.
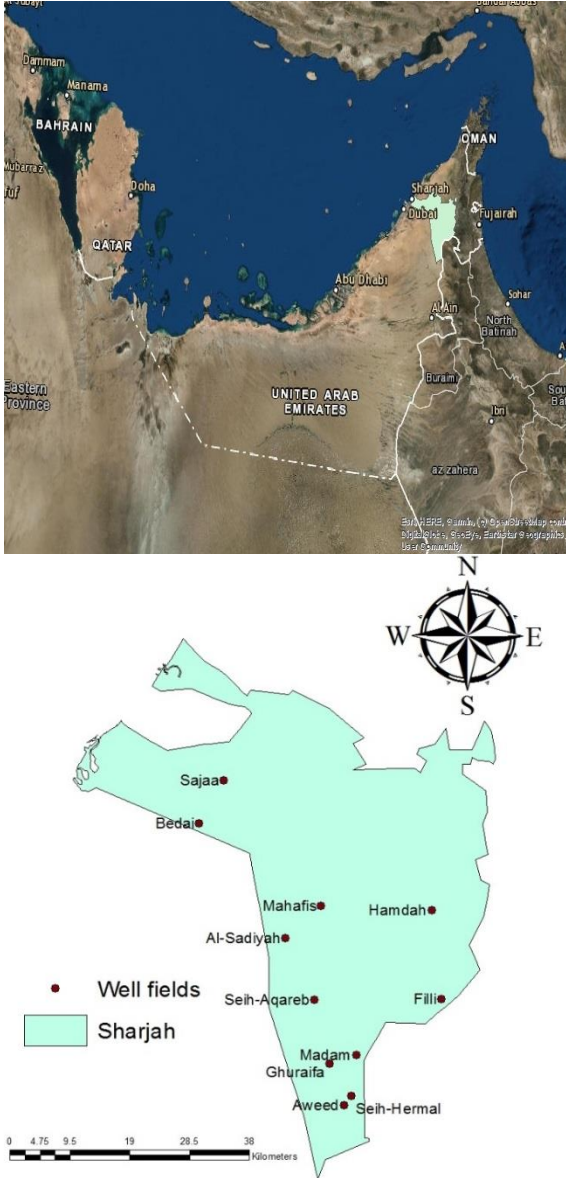

Fig. 1. Location of Sharjah and well fields.

TABLE I: AVAILABLE DATA TIME PERIOD

Well Field	Data period
Al Sadiyah	2008 – 2015
Aweed	2004 – 2018
Bedai	2006 – 2009
Filli	2010– 2016
Ghuraifa	2004 – 2018
Hamdah	2004 – 2016
Madam	2004 – 2018
Mahafis	2010 – 2015
Sajaa	2005 – 2010
Seih Aqareb	2004 – 2018
Seih Hermal	2004 – 2018

III. METHODOLOGY

Groundwater spatiotemporal data analysis tool (GWSDAT) was used for the spatial and temporal trend analysis for groundwater levels in this study. Since the groundwater level data is mostly non-normally distributed, MK non-parametric test was used for the temporal trend analysis, whereas penalized splines (P-Splines) smoothing was adopted for spatial trend analysis.

A. Mann-Kendall Test

The MK is a non-parametric rank-based test and used in several hydro-meteorological trend analysis studies (e.g. [16]-[24]). The z-statistics for this test can be calculated by:

$$z = \begin{cases} \frac{S-1}{Var(S)} & if \ S > 0 \\ 0 & if \ S = 0 \\ \frac{S+1}{Var(S)} & if \ S < 0 \end{cases} \quad (1)$$

The S value can be computed by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (2)$$

where $x_j - x_k$ are the sequential data values, n is the number of data

$$sgn(x_j - x_k) = \begin{cases} 1 & if \ x_j - x_k > 0 \\ 0 & if \ x_j - x_k = 0 \\ -1 & if \ x_j - x_k < 0 \end{cases} \quad (3)$$

The $Var(S)$ can be calculated using:

$$Var \ (S) = \frac{n(n-1)(2n+5)}{18} \quad (4)$$

Positive test statistics indicate increasing trend, whereas negative test statistic shows decreasing trend in MK test. After calculating z-statistics, normal distribution function is used to calculate the value p ($P(Z \geq z)$).

$$P(Z \geq z) = 1 - P(z) \quad (5)$$

$$P(Z \geq z) = P(-z) \quad (6)$$

p values equal or smaller than 0.1 indicate a significant trend at 90% significance level, whereas p values equal or smaller than 0.05 and 0.01 indicate a significant trend at 95% and 99% significance levels, respectively.

B. Spatial Analysis

Spatial analysis of the groundwater level was conducted to understand the variation of groundwater level over space. Non-parametric P-Splines method, which enables estimation of regression functions contrast with more traditional parametric models with greater flexibility in fitting data [25], was used for spatial analysis. More details of P-Splines method are explained in [26], [27].

IV. RESULTS AND DISCUSSION

A. Temporal Trend Analysis

Table II shows MK p-values and z statistics for eleven well fields.

TABLE II: P-VALUE AND Z STATISTICS OF MK TEST

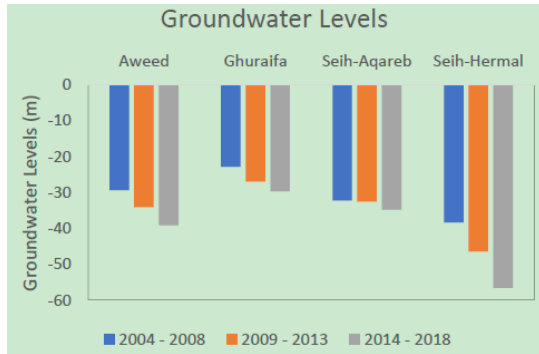| Well field	p value	z statistics
Al-Sadiyah	**< -0.01**	**-6.145**
Aweed	**< -0.01**	**-14.022**
Bedai	-0.0437	-2.017
Filli	**< -0.01**	**-7.489**
Ghuraifa	**< -0.01**	**-11.802**
Hamdah	**< -0.01**	**-13.192**
Madam	**< -0.01**	**-9.193**
Mahafis	**< -0.01**	**-8.665**
Sajaa	**< -0.01**	**-9.406**
Seih-Aqareb	**< -0.01**	**-11.056**
Seih-Hermal	**< -0.01**	**-12.756**

Fig. 2. Groundwater levels for selected well fields.

Fig. 2 shows average annual groundwater levels over three time periods (i.e., 2004-2008, 2009-2013 and 2014-2018) for selected well fields (Aweed, Ghuraifa, Seih-Aqareb and Seih-Hermal).

In Table II, bold numbers indicate statistically significant trends at 99% significance level. As shown in Table II, decreasing groundwater level trends were detected in all well fields. All detected trends were statistically significant at 99% significance level except the trends in Bedai well field. Supporting the results in Table II, Fig. 2 shows decreasing trend in groundwater levels over time. As can be seen in Table II, the strongest decreasing trend in groundwater level was detected in Aweed well field followed by Hamdah and Seih-Hermal well fields. The significant decreasing trends can be explained by large agricultural water demand around these three well fields. The groundwater production from these well fields were used to meet irrigation water demand in particular for date farms in the region.

Although the most significant decreasing trends (over time) was found at Aweed well field, the maximum groundwater level decrease occurred in Seih-Hermal well field. Fig. 3 shows the groundwater production values over the period of 2004 – 2018 in well fields including Aweed, Ghuraifa, Seih-Aqareb and Seih-Hermal.
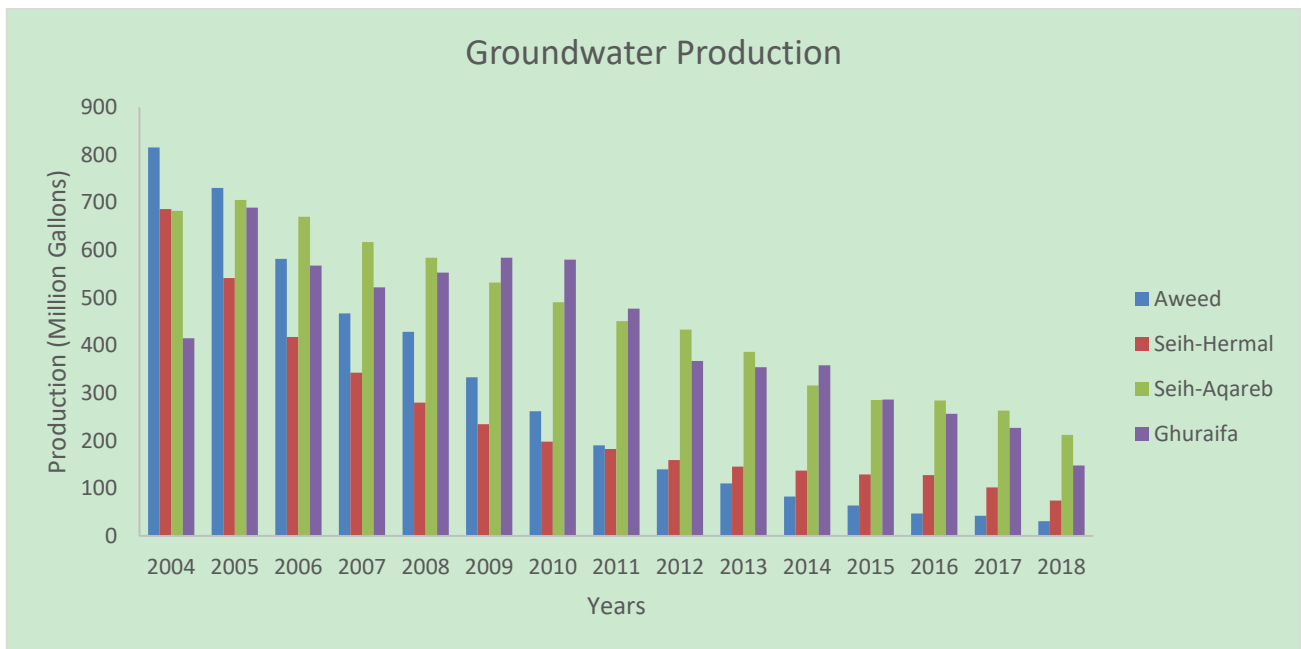

Fig. 3. Groundwater production for selected well fields.

It can be seen from Fig. 3 that the production at 2004 was very high for the selected well fields. The production in Aweed, Seih-Hermal, Seih-Aqareb and Ghuraifa well fields was approximately 815, 685, 682 and 415 million gallons respectively in 2004. The water level in 2004 was approximately 28, 32, 31, 21 m below the ground level for Aweed, Seih-Hermal, Seih Aqareb and Ghuraifa respectively. However, in 2018 the water levels decreased to around 40, 56, 33, and 32 m below the ground level in Aweed, Seih-Hermal, Seih Aqareb and Ghuraifa respectively. The decrease in the groundwater level resulted in decreases in groundwater productions (to be approximately 31, 74, 212, 148 million gallons in Aweed, Seih-Hermal, Seih Aqareb and Ghuraifa well fields respectively) in 2018. The significant decrease in

water level and production in Aweed and Seih-Hermal explains the high (negative) z-statistics values reached to -14.022 in Aweed and -12.756 in Seih-Hermal.

B. Spatial Analysis

Spatial analysis was conducted to understand the variation of groundwater levels over the study are. Fig. 4 shows an example of spatial analysis results for the years 2006 (Fig. 4 (a)) and 2009 (Fig. 4(b)). These years were selected, since almost all well fields had groundwater level data for these two years (which made spatial interpolation more reliable). Fig. 4 shows that highest groundwater levels were observed in southeast to east Sharjah, whereas lowest groundwater levels were detected in west to northwest Sharjah. It should be noted that scales in Fig. 4 represents the distance from

groundwater table to the ground surface. Therefore, lower values in the scale (represented by blue color) indicate higher groundwater level. It can be recognized from Fig. 4 that groundwater levels decreased in all well fields between the years 2006 and 2009. The groundwater level in the well fields close to the coastline (i.e., Bedai and Sajaa) are very low. Also, temporal trend analysis showed significant groundwater level decrease in Sajaa. If the groundwater levels keep decreasing around coastal region, the sea water will intrude to the groundwater aquifer and the groundwater will be saline. This will require advanced treatment of groundwater before using it to satisfy water demands.

Reference [28] studied on assessment of groundwater quality in Sharjah, and they reported that salinity related water quality parameters including Electrical Conductivity (EC), Chloride (Cl$^-$) and Total Dissolved Solids (TDS) are very high in well fields close to the coastal region. Fig. 5 illustrates well fields very close to sea cost (Bedia, Sajaa and Muhadhab).

Table III shows the average, minimum and maximum values of EC, Cl$^-$ and TDS in groundwater samples from Bedia and Muhadhab well fields along with permissible limits of these parameters according to Abu Dhabi Water Quality Regulations (ADWQR), standard deviation (std) and number of samples (count). It should be noted that groundwater quality data is not available for Sajaa well field.

TABLE III: ILLUSTRATIVE STATISTICS AND PERMISSIBLE LIMITS OF SALINITY RELATED PARAMETERS

		Cl$^-$ (mg/L)	EC (µS/cm)	TDS (mg/L)
Well fields	Limits	250	1600	1000
Bedai	Avg	711	3069	1960
	Max	1015	3982	2627
	Min	460	2340	1123
	Count	145	145	146

		Cl$^-$	EC	TDS
	Std	116	490	352
Muhadhab	Avg	951	3663	2376
	Max	1258	4269	2852
	Min	647	2960	1507
	Count	38	38	38
	Std	136	317	286

As shown in Table III, in Bedai well field, Cl$^-$ had values between 460 and 1015 mg/L with an average of 711 mg/L. The permissible limit of Cl$^-$ is 250 mg/L according to ADWQR. EC values ranged between 2340 and 3982 µS/cm with an average of 3069 µS/cm in Bedai well field. The permissible limit of Cl$^-$ is 1600 µS/cm according to ADWQR. TDS had values between 1123 and 2627 mg/L with an average of 1960 mg/L. The permissible limit of TDS is 1000 mg/L according to ADWQR. In Muhadhab well field, Cl$^-$ had values between 647 and 1258 mg/L with an average of 951 mg/L. EC values in Muhadhab well field ranged between 2960 and 4269 µS/cm with an average of 3663 µS/cm. TDS values in Muhadhab well field showed variation between 1507 and 2852 mg/L. The average of TDS values is 2852 mg/L. All salinity related water quality parameters (Cl$^-$, EC and TDS) in well fields close to sea had very high values, and these values are very well above the permissible limits. More importantly, there is a significant increasing trend (at 99% significance level) in Cl$^-$, EC and TDS according to trend analysis results shown in Table IV. Positive z statistics in Table IV shows that Cl$^-$, TDS and EC values in well fields close to sea are increasing, and these trends are statistically significant at 99% confidence level (as p values are smaller than 0.01).

This means that if groundwater levels keep decreasing in these well fields, the groundwater will be saltier, and groundwater will not be a fresh water resource.

TABLE IV: TREND RESULTS IN SALINITY RELATED PARAMETERS

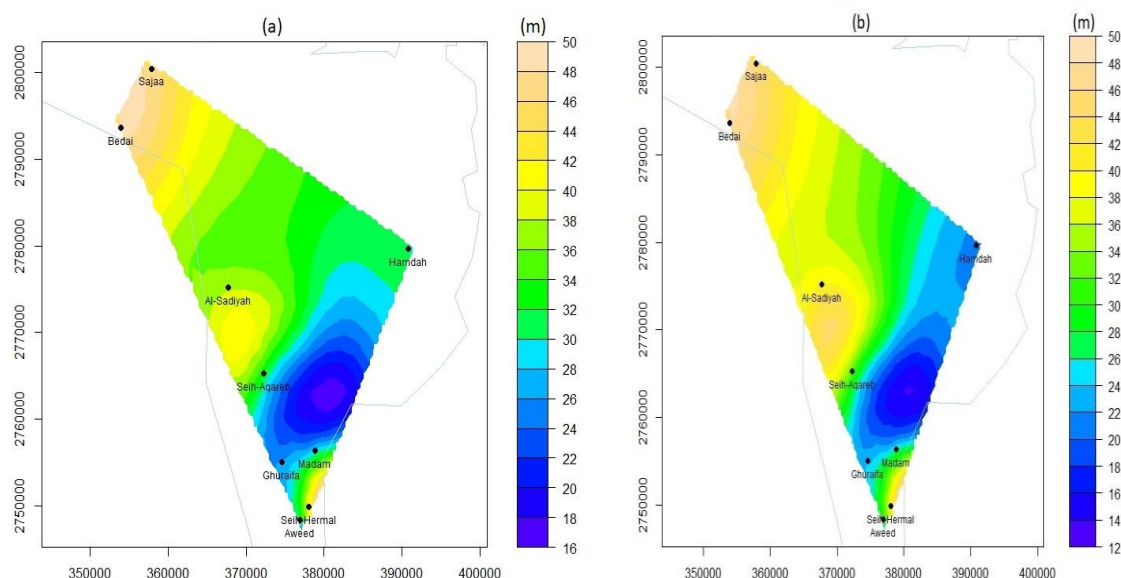| Well field	Cl$^-$(mg/L)		EC (µS/cm)		TDS (mg/L)	
	z statistics	p value	z statistics	p value	z statistics	p value
Bedai	11.41	<0.01	13.58	<0.01	11.79	<0.01
Muhadhab	4.48	<0.01	5.78	<0.01	5.13	<0.01

Fig. 4. Groundwater level map in 2006 (a) and 2009 (b).

Fig. 5. Location of the well fields close to sea coast.

V. CONCLUSIONS

In this study, monthly groundwater level data obtained from eleven well fields were used to conduct spatio-temporal trend analysis of groundwater levels in Sharjah, UAE. The spatial analysis of groundwater levels in Sharjah was conducted by P-spline method, whereas MK non-parametric test was used for the temporal trend analysis. Followings are the major conclusions from this study:

- Decreasing groundwater level trends were detected in all well fields in Sharjah.
- All detected trends were statistically significant at 99% significance level except the trend in Bedai well field.
- The highest decreasing trend was found in Aweed well field, and the highest decrease in groundwater level was detected in Seih-Hermal well field.
- In parallel to decreasing groundwater levels, the groundwater production has decreased significantly (more than 90% decrease in some well fields).
- It was found that groundwater levels in well fields close to coastline experienced a significant decrease over time leading seawater intrusion and salinization of groundwater.
- Analysis of salinity related water quality parameters including Cl$^-$, TDS and EC at well fields close to sea showed that these parameters have very high values (very well above the permissible limits).
- Statistically significant increasing trends were detected in Cl$^-$, TDS and EC parameters at well fields close to sea.
- Groundwater level decreases (and increased salinity) in particular at well fields close to sea require immediate action by groundwater managers to protect fresh groundwater.

Findings of this study provide significant input for groundwater management in Sharjah. As a next step, solutions to groundwater level decreases such as artificial recharge of the aquifers, or harvesting the limited rainfall in small dams and natural recharge of the aquifers will be investigated and discussed in further studies.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Abdullah G. Yilmaz supervised the analysis and wrote the paper, Abdallah Shanableh and Rami I. Al-Ruzouq contributed data collection and analysis, and reviewed the paper. Naseraldin Kayemah assisted data analysis.

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