Hydrogeology Journal (2018) 26:1875–1885
https://doi.org/10.1007/s10040-018-1739-9

PAPER

Time series analyses of hydrological parameter variations and their correlations at a coastal area in Busan, South Korea

Sang Yong Chung[1] · Venkatramanan Senapathi[2,3] · Selvam Sekar[4] · Tae Hyung Kim[5]

Received: 29 May 2017 / Accepted: 25 January 2018 / Published online: 23 February 2018

Abstract

Monitoring and time-series analysis of the hydrological parameters electrical conductivity (EC), water pressure, precipitation and tide were carried out, to understand the characteristics of the parameter variations and their correlations at a coastal area in Busan, South Korea. The monitoring data were collected at a sharp interface between freshwater and saline water at the depth of 25 m below ground. Two well-logging profiles showed that seawater intrusion has largely expanded (progressed inland), and has greatly affected the groundwater quality in a coastal aquifer of tuffaceous sedimentary rock over a 9-year period. According to the time series analyses, the periodograms of the hydrological parameters present very similar trends to the power spectral densities (PSD) of the hydrological parameters. Autocorrelation functions (ACF) and partial autocorrelation functions (PACF) of the hydrological parameters were produced to evaluate their self-correlations. The ACFs of all hydrologic parameters showed very good correlation over the entire time lag, but the PACF revealed that the correlations were good only at time lag 1. Crosscorrelation functions (CCF) were used to evaluate the correlations between the hydrological parameters and the characteristics of seawater intrusion in the coastal aquifer system. The CCFs showed that EC had a close relationship with water pressure and precipitation rather than tide. The CCFs of water pressure with tide and precipitation were in inverse proportion, and the CCF of water pressure with precipitation was larger than that with tide.

Keywords Periodogram · Power spectral density · Auto and cross-correlation function · Groundwater statistics · South Korea

Introduction

Effective management of freshwater reservoirs is very important for the sustainability of natural resources. Freshwater stored in coastal aquifers is particularly vulnerable in terms of water quality degradation due to its proximity to seawater, in combination with the intensive water demands that accompany the higher population densities of coastal zones. The water level in an 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 (Aflatooni and Mardaneh 2011). Various factors affecting the groundwater level are groundwater pumping, recharge, precipitation, water pressure, evapo-transpiration, interaction with surface-water bodies, and the tidal oscillation of the sea level in coastal aquifers (Ataie-Ashtiani et al. 1999; Maréchal et al. 2002). The pressure of tidal waves causes periodic fluctuation of the groundwater level in the coastal aquifer. This damping effect progressively diminishes the amplitude of groundwater head in the inland direction (Maréchal et al. 2002). The monitoring of primary hydrological parameters (water pressure, precipitation, electrical conductivity and tide) takes into account the principal sources of information on the seawater intrusion against the coastal aquifer groundwater system. (Winter et al. 2000; Moon et al. 2004; Ahmadi and Sedghamiz 2007; Christophe et al. 2016).

✉ Venkatramanan Senapathi
venkatramanan@tdt.edu.vn

[1] Department of Earth & Environmental Sciences, Pukyong National University, 45 Yongso-ro Nam-gu, Busan 48513, South Korea

[2] Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam

[3] Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Vietnam

[4] Department of Geology, V. O Chidambaram College, Tuticorin, Tamil Nadu 628008, India

[5] Local Values Research Team, Jeju Province Development Corporation, Jeju 63345, South Korea

Hydrological processes are usually nonlinear, complex, dynamic, and widely scattered due to the influence of physical processes involving variability in space and time. Further complexity is added when such processes are observed at small spatiotemporal scales, but estimates are needed for very large ones; therefore, it is vital to evaluate whether these processes have different behaviors at different scales. These processes and properties vary at different spatiotemporal scales, and their variations essentially affect groundwater level and quality fluctuations in coastal aquifer systems. Time series of groundwater parameters usually exhibit complex fluctuations owing to the interactions of many factors, and time series analysis has been widely used in the evaluation and forecast of groundwater monitoring data, because it elucidates the characteristics of these complicated features. Many research projects decompose groundwater-level variations into trend, periodicity and random components, and combine the components together as a model to forecast the future variations (Hu et al. 2001; Kim et al. 2005, 2007; Zhao et al. 2007; Zhou et al. 2007; Yang et al. 2009; Chung et al. 2015).

The permeation of seawater through coastal shores and eventual intrusion into coastal aquifers affects the salinity levels of the groundwater. The degree of seawater intrusion varies with the water pressure, precipitation and tidal fluctuations. Time series analysis can gain insight into the relationship between seawater intrusion and groundwater parameters. In this study, the freshwater–saltwater interface was considered as a sharp interface, and a TLC meter was installed at 25-m depth in a monitoring well to observe the interface (Fig. 1). The TLC device measured temperature (T), groundwater level (L) and electrical conductivity (C) of the groundwater. Spectral analysis methods outlined by Shumway and Stoffer (2011) were used to understand the fluctuation behavior of selected hydrological parameters.

The purpose of this study is to understand the variation of the hydrological parameters EC, water pressure, precipitation and tide, and their correlations at a coastal area in Busan, South Korea, using monitoring techniques and time series analysis of these hydrological parameters. Prediction of the extent and influence of seawater intrusion is possible for the long period covered through this study.

Materials and methods

Study area and field measurements

The study area (Fig. 2) is in the Nam-gu District in Busan City, and includes Pukyong National University Campus and the surrounding coastal area. The geology of the study area is mainly composed of tuffaceous sedimentary rocks and andesitic volcanic breccia. The geological time of the rocks is the Cretaceous Period of the Mesozoic Era. Groundwater in the study area is relatively vulnerable to seawater intrusion, because the coast is composed of a sandy beach and reclaimed land.

The study area has four climatological seasons, and received 1,222 and 1,773 mm of precipitation in 2000 and 2009, respectively. The precipitation of 2000 was much smaller than that of 2009 because of drought. Most of the precipitation falls from May to September, with averages 963.5 and 1,352.2 mm in 2000 and 2009, respectively (Fig. 3a,b). During summer, a typhoon usually comes to the Korean Peninsula, accompanied by heavy rain.

Water level and EC were measured at a monitoring well at Pukyong National University from August 2009 to October 2009, using an automatic TLC sensor with a time interval of 5 min. The monitoring period covered a short dry season (see

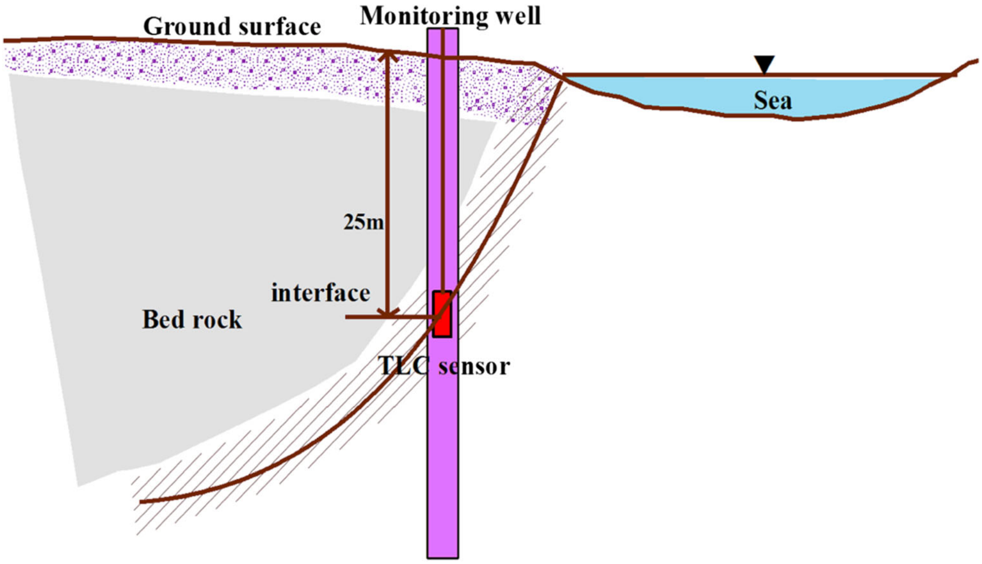


Fig. 1 Schematic diagram of the interface between freshwater and saline water and the monitoring design in the study area

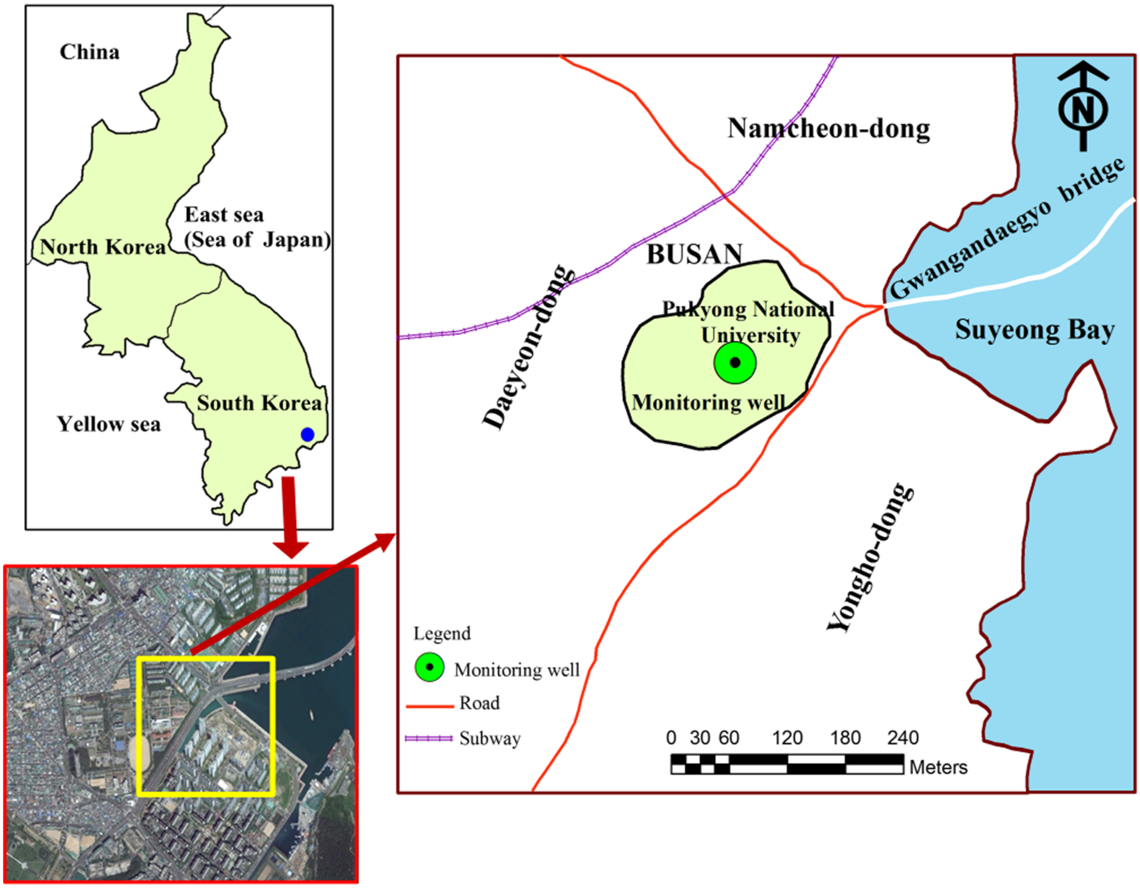
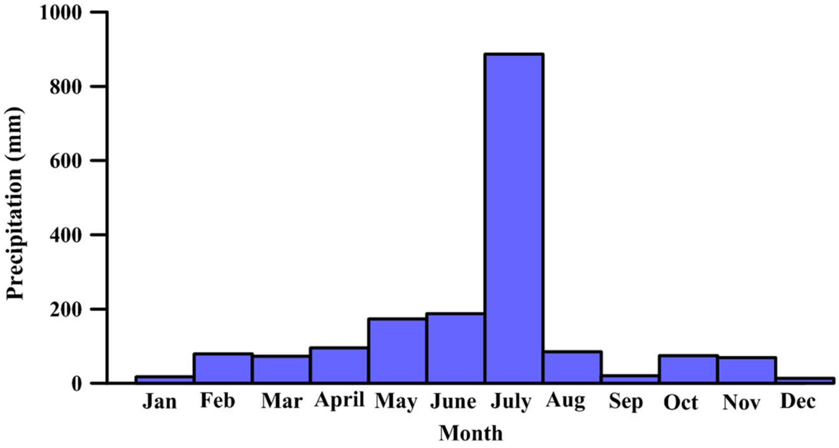


Fig. 2 Location map of the study area

Fig. 3 precipitation data). The reason for gathering hydrogeological data in the dry season is to reduce the rainfall effect on the groundwater level and quality data. The hydrological data in the dry season was monitored because groundwater quality was not much influenced by rainfall. This well is developed in an unconfined aquifer, and is located 650 m from the coastline. It is 120 m in depth, and its topographic elevation is 4.1 m above mean sea level. The early water level was about 3.9 m below the ground surface in 2009. In this area, the aquifer is almost homogeneous and consists of tuffaceous sedimentary rocks.

The freshwater–saline water interface was measured at the depth of about 25 m below ground surface (−GL). The interface between the freshwater and saline water was considered as a sharp interface. The TLC meter (model 107) made by Solinst Canada Ltd. was used to collect data and was installed

Fig. 3 Precipitation data of the study area in 2009



at 25 m (−GL). Tide was monitored by the Korea Hydrographic and Oceanographic Administration, and precipitation was measured by the Korea Metrological Administration.

Time series analyses

Time series models have been developed for various hydrologic and environmental applications for effectively forecasting risk (Li et al. 2009; Xu et al. 2009; Erdogan and Gulal 2009). A time series can be composed of a case observed at discrete times, averaged over a time interval, or recorded continuously with time. A sequence of observations made in a time series can be influenced by three components: (1) a trend or long-term component, (2) a cyclical or oscillating component and (3) a random or irregular component. Several techniques are available for separating the trend component from the oscillating fluctuations and random variations in a time series. An important aspect of hydrogeological studies is the determination of long- and short-term trends, which can show the effect of all processes that influence the aquifer over a long and short period (Box and Jenkins 1976).

A short overview of periodogram, spectral density function, auto and partial auto correlation analysis (ACF and PACF) and cross correlation functions (CCF) is presented. The mathematical expressions of the functions are shown in detail by Jenkins and Watts (1968), Mangin (1984), Box et al. (1994), Padilla et al. (1994) and Laroque et al. (1998). The simple auto-correlation analysis quantifies the linear dependency of successive values over a time period. The auto-correlation function, $\rho(k)$ is expressed as

$$\rho(k) = {}^{C(k)}\!/_{C}(0) \tag{1}$$

$$C(k) = \frac{1}{n-k-1}\sum_{t=1}^{n-k}\left(x_t - \overline{X}\right)\left(x_{t+k} - \overline{X}\right) \tag{2}$$

where k is the time lag ($k = 0$ to m) for which m is the cut point, n is the number of events, x_t is a single event at time t, and $\overline{X}$ is the mean of events. $C(k)$ is an auto-covariance of time series data, $x(t)$. The cutting point is usually determined based on the interval of the analysis and the given circumstance. If the time series has strong interdependency and a long memory effect, the auto-correlation function shows a gently decreasing slope and nonzero values over a long time lag. However, if the time series is uncorrelated such as for rainfall, the auto-correlation function decreases very quickly and reaches a zero value in a short time (Lee and Lee 2000; Liang 2011; Chung et al. 2015).

The partial autocorrelation function (PACF) of a stationary process, x_t, denoted $\O_{hh}$, for $h = 1, 2, \ldots$, (where h is the separation between x_{t+h} and x_t) is

$$\O_{11} = \mathrm{corr}(x_{t+1}, x_t) = \rho(1) \tag{3}$$

and

$$\O_{hh} = \mathrm{corr}\left(x_{t+h} - \hat{x}_{t+h}, x_t - \hat{x}_t\right), \quad h \geq 2 \tag{4}$$

Both $\left(x_{t+h} - \hat{x}_{t+h}\right)$ and $\left(x_t - \hat{x}_t\right)$ are uncorrelated with $\{x_{t+1}, \ldots, x_{t+h-1}\}$. The PACF, $\O_{hh}$, is the correlation between x_{t+h} and x_t with the linear dependence of $\{x_{t+1}, \ldots, x_{t+h-1}\}$ on each, removed (Shumway and Stoffer 2011). If the process x_t is Gaussian, then $\O_{hh} = \mathrm{corr}(x_{t+h}, x_t\ x_{t+1}, \ldots, x_{t+h-1})$; that is, $\O_{hh}$ is the correlation coefficient between x_{t+h} and x_t in the bivariate distribution of (x_{t+h}, x_t) conditional on $\{x_{t+1}, \ldots, x_{t+h-1}\}$.

ACF is not as useful in the identification of the order of an auto-regressive process (AR) for which it will most likely have a mixture of exponential decay and damped sinusoidal expressions. PACF is useful for the analysis of the time series with the AR structure (Montgomery et al. 2008). The simple spectral density analysis is complementary to the auto-correlation analysis. The spectral density function corresponds to change from a time mode to a frequency mode through a Fourier transformation of the auto-correlation function. The Blackman and Turkey (1958) method was used for the power spectral density (PSD) in this study. The method corresponds to change from a time mode to a frequency mode through a complex Fourier transformation of the auto-correlation function. The actual computation of the power spectrum can only be performed at a finite number of different frequencies by employing the Fast Fourier Transformation (FFT; Trauth 2015). The FFT is a method of computing a discrete Fourier transform with reduced execution time.

$$X_{\mathrm{x}}(f) = \sum_{k=0}^{M} \gamma_{\mathrm{k}}(k) e^{-i2\pi fk/f_{\mathrm{s}}} \tag{5}$$

$$\mathrm{PSD}_{\mathrm{x}}(f) = \frac{|X_{\mathrm{x}}(f)|^2}{f_{\mathrm{s}}} \tag{6}$$

where f_{s} is sampling frequency, M is maximum lag, $X_{\mathrm{x}}(f)$ is a complex Fourier transformation of the auto-correlation function, and $\mathrm{PSD}_{\mathrm{x}}(f)$ is power spectral density.

The cross-correlation analysis is used to establish a link between the input time series and the output time series. If the input time series is random, the cross-correlation function, $r_{xy}(k)$, corresponds to the impulse response of the system. In other cases, the cross-correlation function provides information on the interrelationship between the input and the output time series data as well as the importance of these relationships. The definition of a cross-correlation coefficient is as follows:

$$\rho_{xy(k)} = \frac{C_{xy}\ (k)}{\sigma_x \sigma_y} \tag{7}$$

$$C_{xy}\ (k) = \frac{1}{n-k-1}\sum_{t=1}^{n-k}\left(x_t - \overline{X}\right)\left(y_{t+k} - \overline{Y}\right) \tag{8}$$

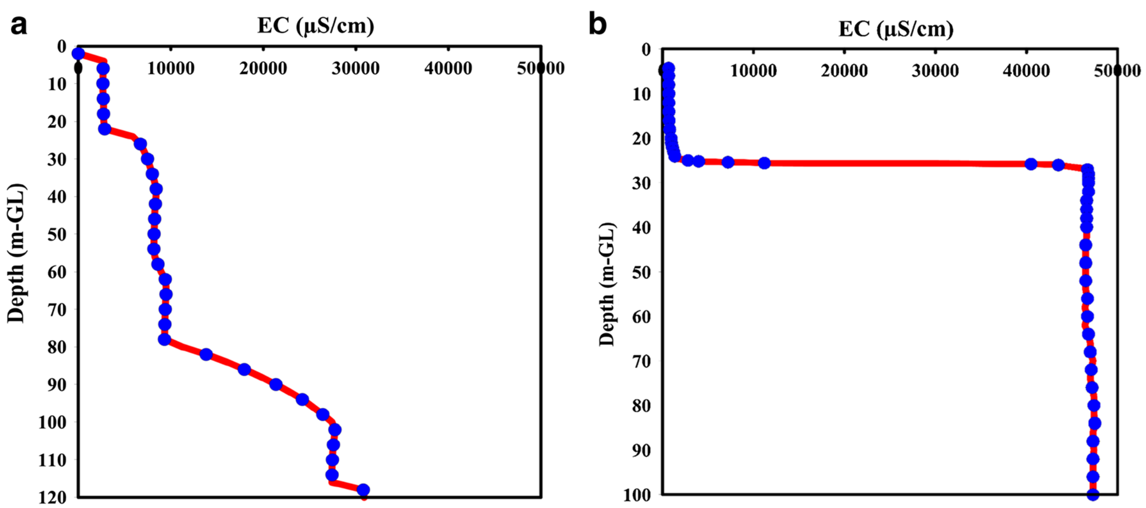


Fig. 4 Electrical conductivity (EC) logs of groundwater with depth in **a** June 2000 and **b** August 2009

where $C_{xy}(k)$ is the cross-covariance of $x(t)$ and $y(t)$ time series, and σ_x, σ_y are the standard deviations of two time-series, respectively. The time series analyses were performed by SPSS (Ver. 21).

Results and discussion

Variations of water pressure and EC at the interface between freshwater and saline water

Figure 4a,b illustrate the EC variations with depth in the monitoring well in June 2000 and August 2009, respectively. At the beginning of the well development in June 2000, EC increased with depth at three intervals, i.e., from 22 to 79 m, from 79 to 101 m, and from 117 to 120 m (Fig. 4a). Thus, three transition zones were formed by seawater intrusion at that time. However, the transition zones changed into a saline water zone due to the complete mixing of groundwater with seawater in August 2009 (Fig. 4b). The EC value was 47,000 µS/cm below the interface in 2009, and it was nearly seawater quality. Then, the interface between freshwater and sea water was located only at 25 m depth (−GL).

Figure 5a,b show the variation of water pressure and EC with precipitation and tide at the interface at 25 m (−GL). The minimum, maximum and average values of measured

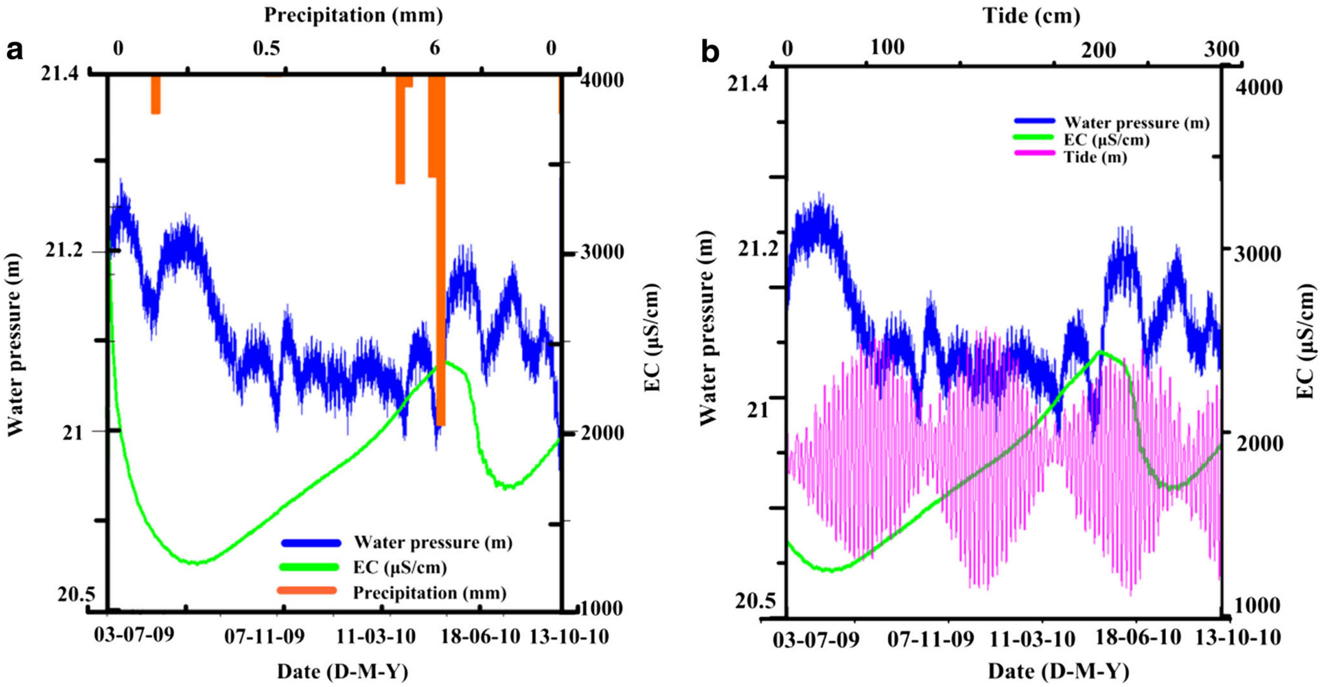


Fig. 5 Relation of water pressure and EC with **a** precipitation and **b** tide

Table 1 Minimum, maximum and average values of measured parameters in the study area

	EC (µS/cm)	Water pressure (m)	Tide (cm)	Precipitation (mm)
Minimum	1,257.6	20.96	6	0
Maximum	3,148.8	21.28	145	52.5
Average	1,768.0	21.11	71.5	1.76

parameters are presented in Table 1. The water pressure varied from 20.96 to 21.28 m at the fresh–saline water interface, and formed a quite complex shape due to the several kinds of influences such as tide, air pressure and precipitation. EC varied from 1,258 to 3,149 µS/cm, and showed a very smooth variation. EC was largely affected by precipitation rather than by tide. This was examined by the relation of precipitation with EC from 22 August 2009 to 17 October 2009 (Fig. 5a,b). EC began to decrease due to the increase of precipitation at the beginning of October 2009.

If the water pressure at the fresh-saline water interface was increased, EC decreased due to the increase of freshwater, and vice versa. When water pressure was increased at the end of August 2009, EC decreased due to the increase of freshwater. When water pressure decreased during September 2009, EC increased due to the decrease of freshwater. Figure 5b shows the relation of water pressure and EC with tide. Water pressure was influenced by tidal variation. Water pressure generally increased according to the rise of tide, and in case of the fall of tide, water pressure decreased. EC is decreased by the

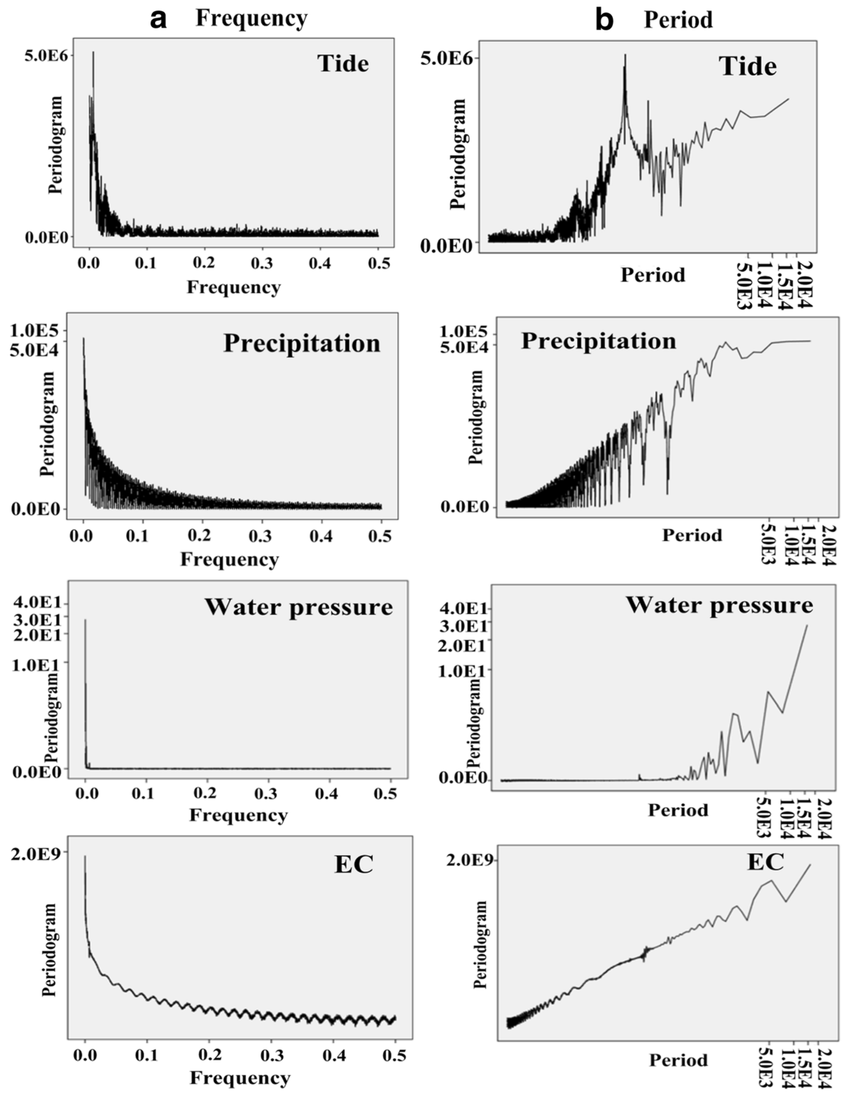


Fig. 6 Periodograms of hydrological parameters with respect to **a** frequency and **b** period

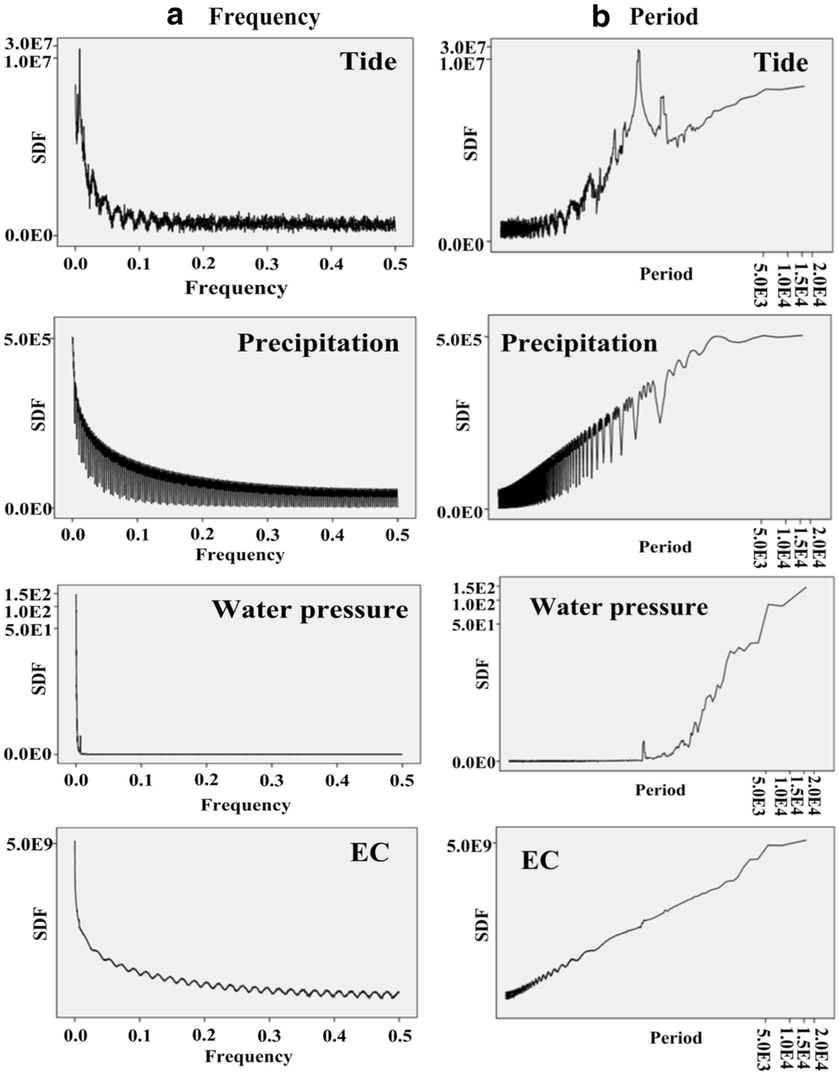


Fig. 7 Power spectral density of hydrological parameters with respect to **a** frequency and **b** period

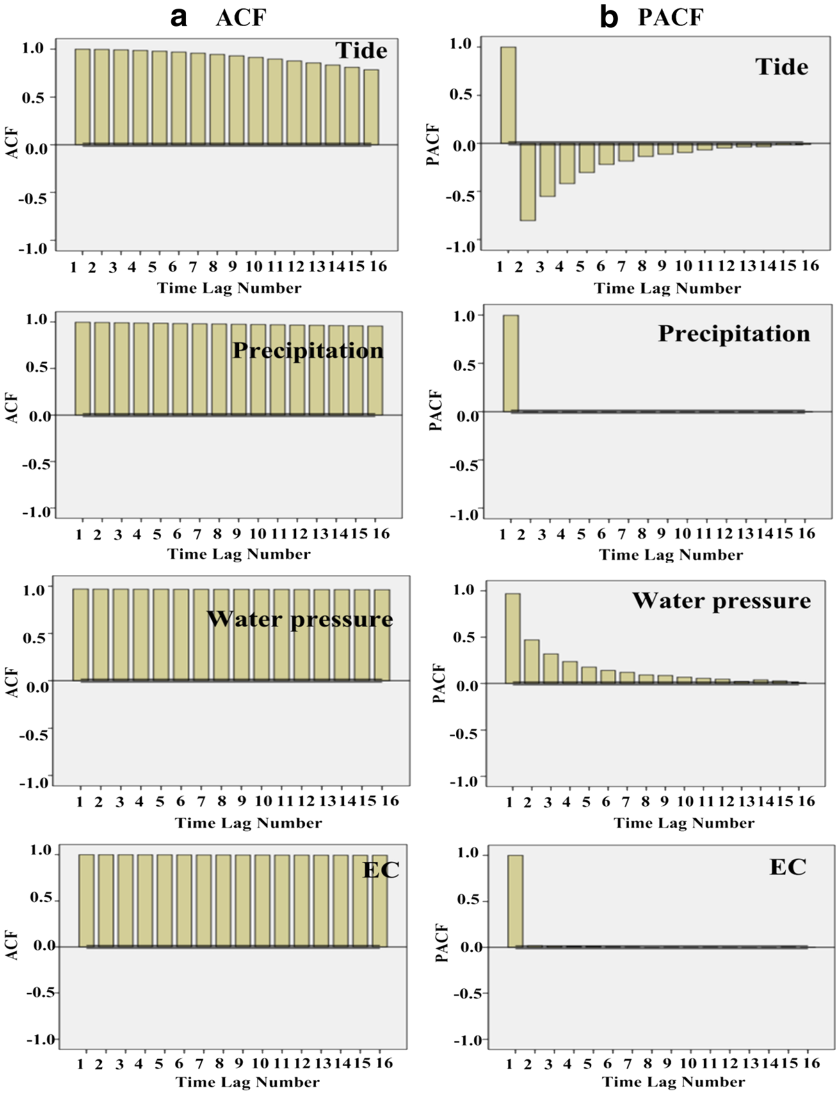
increase of water pressure, and vice versa; thus, the level and quality of groundwater were affected by seawater intrusion in the study area.

Periodograms and spectral density functions (SDF)

The periodograms of hydrological parameters according to frequency and period are given in Fig. 6. All periodograms of the frequency domain are in inverse proportion to those of the period domain, because frequency is inversely proportional to period. The periodogram of tide is similar to that of precipitation on the basis of frequency, but the periodogram of tide is different from that of precipitation on the basis of period. Tide has a big periodogram value on the very low frequency, and many small periodogram values on the higher frequencies. Tide has a big periodogram value at the period of less than 5×10^3. Precipitation also has a big periodogram value on the very low frequency; however, its periodogram value on the period domain continuously increases and ends as a big value. Water pressure and EC also have high periodogram values at the very low frequency, but their periodogram values are different on the period domain. Water pressure has very low periodogram values until the period of 5×10^3, and it increases after that period value. The periodogram value of EC increases continuously.

Spectral density functions (SDF) of selected hydrological parameters such as EC, water pressure, precipitation and tide are shown in Fig. 7. The SDF was calculated using the Blackman-Turkey method. This method used the complex Fourier transformation for the autocorrelation functions of time series data. The spectral density functions of hydrologic parameters are quite similar to the periodograms of hydrologic parameters in this study. The behaviors of spectral density functions of hydrologic parameters are also similar to each other, and their highest peaks have a single point on the very small frequency. The spectral density function of EC shows the similar trend as those of tide, precipitation and water pressure on both the frequency and period domains. This suggests

Fig. 8 **a** Auto correlation functions (ACF) and **b** partial auto correlation functions (PACF) of hydrological parameters



that EC fluctuations were affected by tide, water pressure and precipitation (Diggle 1992; Lu et al. 2014). All hydrological parameters show quite similar spectra with an initial break in slope and gradual fall-off until the increased asymptotic frequency. To explain the variation in frequency and period, additional factors must play controlling roles. This behavior suggests the preponderance of long memory in the interaction between groundwater and seawater. The results of these analyses show that hydrological parameters are useful for predicting the seawater intrusion in the monitoring well.

Autocorrelation and partial autocorrelation functions (ACF and PACF)

Figure 8 shows the ACF and PACF of the hydrological parameters EC, water pressure, precipitation and tide. The ACFs and PACFs of precipitation and EC present nearly the same pattern. The ACFs almost approach 1.0 regardless of the number of the time lag; however, the PACFs are 1.0 only at the time lag 1, and almost 0 at more than the time lag 1. The ACF of tide gradually goes down according to the increase of the time lag, and approaches 0.75. The PACF of tide is 1.0 only at the time lag 1, and its absolute value is decreased to 0 with the increasing time lag number. The ACF of water pressure is 1.0 regardless of the number of time lag, but the PACF of water pressure is gradually decreased to 0 with the increasing time lag number. The ACFs of all the hydrological parameters show very good correlations over the entire time lag; however, the PACFs of precipitation and EC reveal good correlations only at time lag 1, and they are almost 0 over the rest of the time lags. The PACFs of tide and water pressure show good correlations only at time lag 1, and their correlations decrease with the increasing time lag number; thus, the PACF cuts off after the first time lag, and the only significant sample PACF value is at time lag 1, suggesting that for the first-order autoregressive process, the AR(1) model is indeed

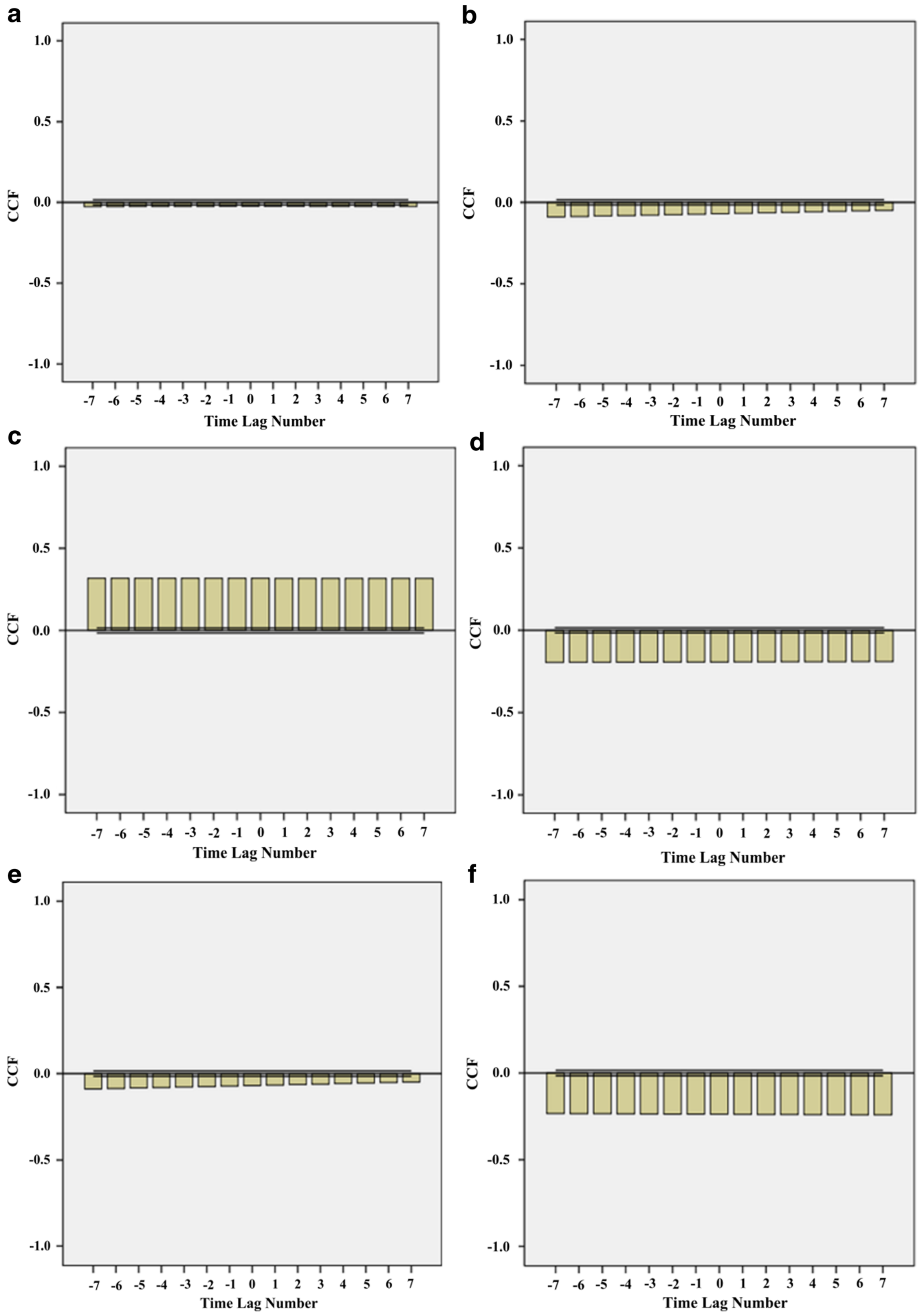


Fig. 9 Cross correlation functions (CCF) of hydrological parameters: **a** EC and tide, **b** EC and natural log-transformed Tide, **c** EC and precipitation, **d** EC and water pressure, **e** water pressure and tide, and **f** water pressure and precipitation

appropriate to the hydrologic data (Montgomery et al. 2008). The ACF and PACF of hydrological data are effective analyses for forecasting seawater intrusion against groundwater in the coastal area (Tularam and Keeler 2006).

Cross correlation functions (CCF)

The CCF was used to evaluate the correlations between the hydrological parameters EC, water pressure, precipitation and tide, and the characteristics of seawater intrusion in a coastal aquifer system. In this analysis, EC and water pressure were the objects of cross correlation using tide, precipitation and water pressure. Figure 9 presents the graphs of CCFs for these hydrological parameters.

The cross correlation between EC and tide was −0.024 to −0.026 (Fig. 9a), and the correlation was largely increased to −0.063 to −0.065 after the natural log transformation of tide data (Fig. 9b). The cross correlation between EC and precipitation was 0.316 to 0.317 (Fig. 9c) and it suggests that EC was largely affected by precipitation rather than tide. The cross correlation between EC and water pressure was −0.190 to −0.195 (Fig. 9d), and their relation was in inverse proportion. This means that the increase of water pressure decreased the EC, because the increase of water pressure resulted from the increase of freshwater. EC generally has a close relationship with water pressure or precipitation; however, their cross correlation coefficients were not large in this study, because the amount of data was not enough for the definite identification of their relations. The cross correlation between water pressure and tide was −0.049 to −0.089 (Fig. 9e), and that between water pressure and precipitation was −0.234 to −0.241 (Fig. 9f); thus, water pressure was much more influenced by precipitation than tide. The variation of water pressure was partially caused by precipitation events acting as a recharge source (Namdar Ghanbari and Bravo 2011). From the cross correlations between the hydrologic parameters, it is understood that EC was much more influenced by precipitation, and water pressure was also much affected by precipitation in the study area.

Conclusions

The transition zone between fresh and saline water was changed into a saline water zone due to the complete mixing of groundwater with seawater in the monitoring well after 9 years of well development. The interface existed only at 25 m depth in August 2009, although it was located at 22, 79, 101 and 117 depths at the time of well development in 2000. Moreover, EC greatly increased from 30,000 to 47,000 μS/cm over the 9-year period; thus, seawater intrusion expanded widely during the 9 years of study and greatly affected the groundwater quality in this coastal aquifer of tuffaceous sedimentary rock.

EC and water pressure were compared to the variations of precipitation and tide. EC was largely affected by water pressure and precipitation, rather than tide. Water pressure was influenced by precipitation as well as tide. The periodograms of hydrological parameters were produced on the basis of frequency and period. All periodograms on the frequency domain were in inverse proportion to those on the period domain. The periodograms of all hydrological parameters were quite similar to each other, and had a big periodogram value on the very low frequency. The power spectral density (PSD) of selected hydrological parameters such as EC, water pressure, precipitation and tide were produced by the Blackman-Turkey method, and were nearly the same as the periodograms of the hydrologic parameters used in this study. This behavior highlights the significance of long-term behavior in the interaction between groundwater and seawater.

The ACF and PACF of the hydrological parameters were produced to understand their self-correlations. The ACFs of all hydrologic parameters showed very good correlation over the entire time lag, but the PACFs revealed that their correlations were good only at time lag 1. The CCF was used to evaluate the correlations between the hydrological parameters and the characteristics of seawater intrusion in the coastal aquifer system. The large cross correlation between EC and precipitation suggests that EC was largely affected by precipitation rather than tide. The inverse cross correlation between EC and water pressure means that the increase of water pressure decreased the EC, because the increase of water pressure resulted from the increase of freshwater. From the CCFs between hydrologic parameters, it is understood that EC was much influenced by precipitation, and water pressure was also much affected by precipitation in the study area. The monitoring and time series analysis of hydrological parameters such as water pressure, EC, precipitation and tide have been found to be very useful to understand the characteristics of the parameter variations and their correlations, and the extent and influence of seawater intrusion. The continuous monitoring of hydrological parameters will be very useful for preventing the further deterioration of groundwater quality in the coastal regions.

Acknowledgements We express a deep gratitude to the fruitful comments of an anonymous reviewer.

Funding Information This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2016R1D1A3B03934558).

References

Aflatooni M, Mardaneh M (2011) Time series analysis of groundwater table fluctuations due to temperature and rainfall change in Shiraz plain. Int J Water Res Environ Eng 3(9):176–188

Ahmadi SH, Sedghamiz A (2007) Geostatistical analysis of spatial and temporal variations of groundwater level. Environ Monit Assess 129:277–294

Ataie-Ashtiani B, Volker RE, Lockington DA (1999) Tidal effects on sea water intrusion in unconfined aquifers. J Hydrol 216:17–31

Blackman RB, Turkey JW (1958) The measurement of power spectra. Dover, New York

Box GEP, Jenkins GM (1976) Time series analysis: forecasting and control. Holden-Day, San Francisco

Box GEP, Jenkins GM, Reinsel GC (1994) Time series analysis: forecasting and control, 3rd edn. Prentice-Hall, Englewood Cliffs, NJ, 598 pp

Christophe O, Mark B, Kees M (2016) A time-series analysis framework for the flood-wave method to estimate groundwater model parameters. Hydrogeol J 24:1807–1819

Chung SY, Venkatramanan S, Park N, Rajesh R, Ramkumar T, Kim BW (2015) An assessment of selected hydrochemical parameter trend of the Nakdong River water in South Korea, using time series analyses and PCA. Environ Monit Assess 187:4192

Diggle PJ (1992) Time series: a bio-statistical introduction. London, Oxford, 257 pp

Erdogan H, Gulal E (2009) The application of time series analysis to describe the dynamic movements of suspension bridges. Nonlin Anal RWA 10:910–927

Hu KZ, Zhang JZ, Xing LT (2001) Study on dynamic characteristics of groundwater based on the time series analysis method. Water Sci Eng Tech 5:32–34

Jenkins GM, Watts DG (1968) Spectral analysis and its applications. San Francisco: Holden-Day, 514 pp

Kim K, Chon C, Park K (2007) A simple method for locating the fresh water–salt water interface using pressure data. Ground Water 45: 723–728

Kim JH, Lee J, Cheong TJ, Kim RH, Koh DC, Ryu JS, Chang HW (2005) Use of time series analysis for the identification of tidal effect on groundwater in the coastal area of Kimje, Korea. J Hydrol 300: 188–198

Laroque M, Mangin A, Razack M, Banton O (1998) Contribution of correlation and spectral analysis to the regional study of a large karst aquifer (Charente, France). J Hydrol 205:217–231

Lee JY, Lee KK (2000) Use of hydrologic time series data for identification of recharge mechanism in a fractured bedrock aquifer system. J Hydrol 229:190–201

Li N, Liang X, Li X, Wang C, Wu DD (2009) Network environment and financial risk using machine learning and sentiment analysis. Hum Ecol Risk Assess 15(2):227–252

Liang YH (2011) Analyzing and forecasting the reliability for repairable systems using the time series decomposition method. Int J Qual Reliab Manag 28:317–327

Lu WX, Zhao Y, Chu HB, Yang LL (2014) The analysis of groundwater levels influenced by dual factors in western Jilin Province by using time series analysis method. Appl Water Sci 4(3):251–260

Mangin A (1984) Pour une meilleure connaissance des systemes hydrologiques a partir des analyses correlatoire et sepctrale [For a better knowledge of the hydrological systems from correlation and spectral analyses]. J Hydrol 67:25–43

Maréchal C, Sarma MP, Ahmed S, Lachassagne P (2002) Establishment of earth tides effect on water level fluctuations in an unconfined hard rock aquifer using spectral analysis. Curr Sci 83:61–64

Montgomery DC, Jennings CL, Kulahci M (2008) Introduction to time series analysis and forecasting. Wiley, London, 441 pp

Moon SK, Woo NC, Lee KS (2004) Statistical analysis of hydrographs and water-table fluctuation to estimate groundwater recharge. J Hydrol 292:198–209

Namdar Ghanbari R, Bravo HR (2011) Evaluation of correlations between precipitation, groundwater fluctuations, and lake level fluctuations using spectral methods (Wisconsin, USA). Hydrogeol J 19(4):801–810

Padilla A, Pulido-Bosch A, Mangin A (1994) Relative importance of base flow and quick flow from hydrographs of karst springs. Groundwater 32:267–277

Shumway RH, Stoffer DS (2011) Time series analysis and its applications. Springer, Heidelberg, Germany, 596 pp

Trauth MH (2015) MATLAB recipes for earth sciences. Springer, Heidelberg, Germany, 427 pp

Tularam GA, Keeler HP (2006) The study of coastal groundwater depth and salinity variation using time-series analysis. Environ Impact Assess Rev 26(7):633–642

Winter TC, Mallory SE, Allen TR, Rosenberry DO (2000) The use of principal component analysis for interpreting ground water hydrographs. Groundwater 38(2):234–246

Xu J, Li X, Wu DD (2009) Optimizing circular economy planning and risk analysis using system dynamics. Hum Ecol Risk Assess 15(2): 316–331

Yang ZP, Lu WX, Long YQ (2009) Application and comparison of two prediction models for groundwater levels: a case study in western Jilin Province, China. J Arid Environ 73:487–492

Zhao J, Bian YM, Zhou XJ (2007) Application of time series analysis method in groundwater level dynamic forecast of Shenyang City. Water Resour Hydropower Northeast China 8:31–34

Zhou XJ, Lan SS, Wang B (2007) Application of time series analysis in groundwater level forecast of Siping region. Water Sci Eng Technol 8:35–37