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Evaluation of the Parameters of Water Quality with Wavelet Techniques

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Abstract Generally, wavelets are purposefully crafted to have specific properties that make them useful for signal processing. In recent years, wavelet analysis have commonly been used instead of Fourier analysis. This is a new approach for evaluation of water quality parameters. This study determined water quality parameters and effects on water quality in Gölcük, Turkey. A 13-month data series was compared with results from laboratory analysis by using wavelet model techniques. The study investigated eight surface water sources, located in rural areas (five different villages) in the vicinity of Gölcük. Water samples were obtained during spring and analyzed for contaminants. The samples were analyzed for Cl^- (chlorine), NO_3-N (nitrate) and pH values. Wavelet analysis of extreme events showed the role of seasonal oscillations, and small-, meso- and large-scale effects on some water quality parameters. In addition, the Cl^-, NO_3-N and pH contents were determined for their suitability for irrigation, drinking and other domestic uses.

Keywords Image processes · Signal analysis · Quality of irrigation water · Wavelet

1 Introduction

Wavelet analysis (meaning small waves) was first proposed in the early 1980s, by Grossman and Morlet (1984; for a comprehensive review, see Furati et al. 2005). An interesting introduction to wavelet theory was published by Hubbard (1996). Wavelet theory has since been applied to various physical phenomena, ranging from climatic analysis to analysis of physics, medicine, biology, image processing, financial problems, time series analysis, engineering and technological problems (Siddiqi 2010; Can et al. 2005).

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Water quality modeling is the basis of water pollution control. It predicts the tendency of water quality variability according to present water quality, transfer and transformation of the pollutants in the river basin (Najah et al. 2010). Nevertheless, few of these studies were applied to water quality management systems, where water quality monitoring data were used for parameter prediction (Dohan & Whitfield 1997). Najah et al. 2010 studied the accuracy of training, validation and prediction of monthly water quality parameters utilizing an Adaptive Neuro-Fuzzy Inference System (ANFIS). The primary objective of that study was to develop a technique that could enhance the accuracy of water quality prediction. Whitfield & Dohan (1997) studied wavelet transform techniques in relation to water quality. They successfully identified the location, duration and magnitude of transient events in water quality parameters.

The role of water quality in vexing technical, economic, social, environmental, and political issues was discussed at the 2011 World Environmental and Water Resources Congress. The congress aimed to encourage the environmental and engineering community to integrate the notion of sustainability, including: (1) Arid Lands; (2) Climate Change; (3) Sustainability; (4) North American Regional Event; (5) Urban Watershed Management; (6) Groundwater, Hydrology, Quality, and Management; (7) Water Distribution Systems; and (8) GV Loganathan Memorial Operations Management (Beighley et al. 2011).

Studies using wavelet transform show that this model had good performance, higher precision, simple operation, provides better-quality predictions than a model based on BP neural network, and therefore provides a valid method of assessing water quality (He & Chen 2010).

He et al. (2008) studied a water quality management system using wavelet analysis. This approach was applied to a river water quality system to demonstrate its practicability in data processive and parameter estimation.

Jamshidi et al. (2010) studied nitrate pollution in the Jajrood River, in Iran. Nitrate is a major water quality problem during the spring season. The annual nutrient input to water-courses is an issue of concern, particularly with regard to nitrate pollution.

In recent decades, nitrate concentrations in the Jajrood River have increased significantly, due to insufficient management, uncontrolled application of agricultural fertilizers, and the discharge of untreated wastewater, which has resulted in eutrophic conditions in the Latian Dam reservoir (Caldy 2004).

There is low or high chlorine concentration in all natural waters in Kocaeli and it's near vicinity. Chloride salts are supplemented to the soil and water resources from industrial wastes, fertilizers and stable manure (Dökmen & Kurtuluş 2009).

pH level is a very important factor in determining water quality. Generally, pH levels of natural waters fix the concentration of soluble carbonate, bicarbonate and carbon dioxide (Dökmen & Kurtuluş 2009).

The aim of the paper is to determine some water-quality parameters and the effects on water quality variations by using wavelet analysis. This new technique would be valuable to assist decision-makers in reporting the status of water quality, as well as investigating spatial and temporal changes.

2 Study Area and Data

Gölcük is a town of Kocaeli Province, in the Marmara Region of Turkey. The town is located on the Coast of Marmara Sea (40°40′ N, 29°50′ E), in the south of the province. Kocaeli, together with its surrounding vineyards and orchards extend over to the north side of the

Table 1 The water sources and their characteristics

Spring no.	Location	Name of the spring	Flow (ms^{-1})	Soil characteristics	Agricultural crop pattern
1	Ummiye	Selale	0.5	Sandy	Orchard-Breeding
2	Mamuriye	Altınoluk	1.0	Sandy-Lime	Orchard-Breeding
3	Ferhadiye	Çürükbayır	0.5	Clayish-Lime	Orchard-Breeding
4	Nüzhetiye(1)	Karanlıkdere	0.3	Lime	Orchard-Vegetable
5	Nüzhetiye(2)	Değirmendere	0.9	Lime-Sandy	Orchard-Vegetable
6	Nüzhetiye(3)	Sakarbıçkı (1)	0.5	Sandy-Lime	Orchard-Vegetable
7	Nüzhetiye(4)	Sakarbıçkı (2)	0.5	Clayish-Lime	Orchard-Vegetable
8	Yeniköy	Havuzlubahçe	0.9	Clayish-Lime	Orchard-Breeding
Mean value			0.63		

Samanlı Mountains, and the Izmit Gulf is on the north side of the city. The town of Gölcük has experienced rapid growth (the population was 131,450 in 2010). There are 23 villages in Gölcük.

This study analyzed NO_3-N, Cl^- concentrations and pH values of eight surface water resources located in five villages in the vicinity of Gölcük-Kocaeli. Eight samples were collected monthly (13 months) from water sources in Ummiye, Mamuriye, Ferhadiye, Nüzhetiye and Yeniköy villages during the period 1999 to 2000. The names, places and characteristics of the water sources are shown in Table 1.

Agricultural activities in the research area comprise orchards, vegetable growing and breeding, as shown in Table 1.

The research area has a mean annual temperature of 23.6 °C, long-term average annual rainfall is 808.4 mm/year (higher than the Turkish average of 600 mm/year). The long-term (1975–2006), total annual potential evaporation height 540.5 mm/water/year and total annual real evaporation in the research area is 476.9 mm (Anonymous 2007).

The research area and surface water resources are shown in the Fig. 1. All of the study sites are located very close to each other, and therefore show similar general characteristics. The main inputs to the study sites are snow-melt, rainfall and springs, depend on the climatic conditions of the region.

Water resources in the watershed have been analyzed in detail. Five villages and water resources are in the same watershed. A model was created of the watershed in the research area (Fig. 2).

Fig. 1 The map of study area and surface water resources in Gölcük-Kocaeli, Marmara Region, Türkiye

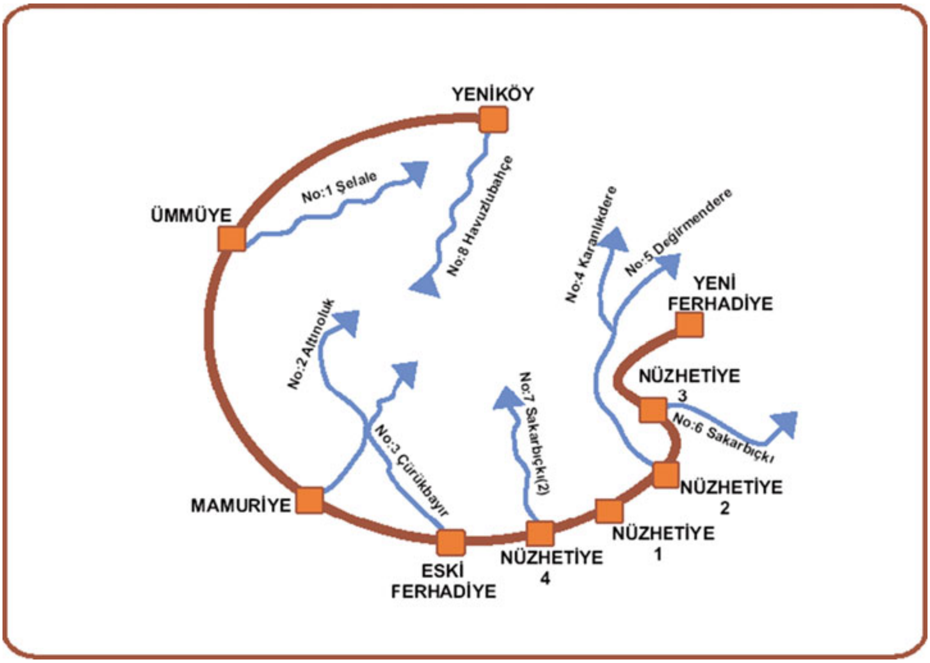

Fig. 2 Schematic illustration of water resources in the research area

3 Methods

3.1 Methodology for Analysis of Water Quality Parameters

This study used standard sampling and analysis methods, in accordance with APHA(1985, 1992). The spectrophotometric method developed makes it possible to determine nitrate-nitrogen (NO_3-N) in the concentration range of 0.0–1.0 ppm (sensitivity 0.018 ppm). Ion of NO_3^- was analyzed acidification as using characteristic of absorb of ultraviolet radiation by UV spectrophotometer at 220 nm (nanometer). The amount of NO_3-N was determined according to absorption of this wavelength light.

Analysis of Cl^- was based on the principle of Mohr titration. Titration was done using soluble of silver nitrate ($AgNO_3$) and potassium chromate (K_2CrO_4) was used as an indicator in the process (Tuncay 1994).

pH was determined by a pH-meter (Best-Nr 100; 330-/set-1) with a glass-electrolyte. The results for NO_3-N, Cl^- and pH are shown in Table 2.

As given in Table 2, the pH values are neutral (pH 7.0–8.0). Mean pH was 7.26 over all sample sites. Mean nitrate and chlorine values were 0.26 mg/L and 0.44 mg/L, respectively for all springs.

3.2 Methods of Wavelet Analysis

A wave is usually referred to as an oscillating function of time or space, such as a sinusoid. Wave transformation of signals has proven to be extremely valuable in mathematics, science, and engineering, especially for periodic, time-invariant, or stationary phenomena. A wavelet

Table 2 Values of water quality parameters according to the results of analysis

Spring no.	pH	NO_3-N (mg L^{-1})	Cl^-(mg L^{-1})
1	7.34	0.28	0.09
2	7.31	0.25	0.05
3	7.15	0.24	0.15
4	7.21	0.27	0.09
5	7.29	0.21	0.09
6	7.23	0.24	2.88
7	7.28	0.27	0.12
8	7.27	0.33	0.11
Mean values	7.26	0.26	0.44

is a small wave, in which finite energy is concentrated in time or space to give a tool for the analysis of transient, non-stationary, or time-varying phenomenon. The wavelet retains the oscillating wavelike characteristics, but also has the ability to allow simultaneous time–or-space, and frequency analysis with a flexible mathematical foundation (Sharma 2006). For simplicity, in wavelet transform, reference to frequency is replaced by reference to scale. Another aspect of the wavelet transform is that the localization or compactness of the wavelet increases as frequency or scale increase. In other words, higher scale corresponds to finer localization in Discrete Wavelet Transformation (DWT). Unlike Continuous Wavelet Transform (CWT), information provided by DWT is irredundant as far as the reconstruction of the signal is concerned. Moreover, the computational requirement of DWT is less than for CWT. Wavelets are families of small waves that are generated from a single function f(t), which is called the mother wavelet. A sufficient condition for f(t) to qualify as a mother wavelet is given below (Meyer 2000; Siddiqi 2010):

This is called the wavelet variance or wavelet spectrum. It may be observed that the scalogram can be represented either as a three-dimensional plot or as a two-dimensional greyscale image (Siddiqi et al. 2002).

Wavelet analysis has been increasingly used in hydrology. In hydrology, while we could have continuous stream flow data for long periods, unevenly distributed data of water quality are common, owing to shortage of auto-monitoring facilities and high expense of sample analysis for water quality indicators. Thus, a modified wavelet analysis method is required for unevenly sampled water quality data (Kang and Lin 2007). In this paper, instead of signal variables, f(t); pH values, NO_3-N nitrate and Cl^- concentrations have been analyzed.

4 Analysis

The following part of the paper are presents Wavelet 1D, frequency, decomposition of signal, continuous wavelet 1D, descriptive statistics, temporal variations and trend analysis of pH, NO_3-N and Cl^- concentrations were observed for water samples obtained at eight stations (Ummiye, Mamuriye, Ferhadiye, Nüzhetiye (1–4) and Yeniköy) between December 1999 and 2000.

4.1 Analysis of pH

Figure 3a shows 1D wavelet analysis of pH values at eight study areas.

Small-scale fluctuations increase in the second part of the observation. Compared with other stations, small-scale factors play more important role in pH variation at the Yeniköy site. The effects of small-scale factors are also strong in Yeniköy. The small strolls of small-scale fluctuations are observed in Ferhadiye, Nüzhetiye 1 and 2.

Mean pH value for the observation period is 7.158. Median, mode, maximum, minimum, range and standard deviations are 7.9, 7.95, 8.45, 5.15, 3.3 and 1.35, respectively. The frequency histogram shows negative skewness (Fig. 3b).

Figure 3c shows decomposition of pH signal between December 1999 and 2000. The narrowest variations in pH are observed in Nüzhetiye 1 and 2. The amplitude of pH values

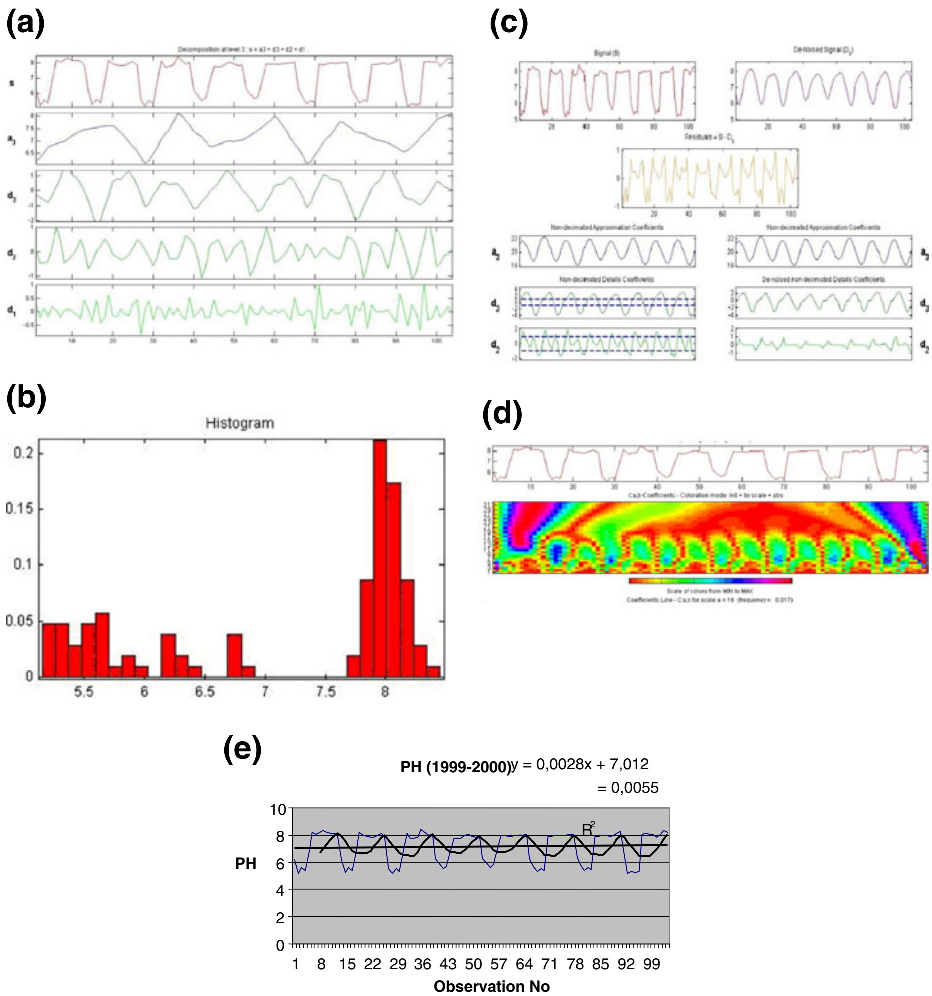

Fig. 3 **a** Analysis of pH variation, db3, Wavelet 1D, Dec. 1999–2000. **b** Relative frequency histogram of original signal; pH variation, db3, Dec.1999–2000. **c** Decompose signal (Selected threshold method: Fixed from threshold; Selected noise structure: scaled white noise); pH variation, db3, level 3 Dec. 1999–2000. **d** Analysis of pH variation, db3, Continuous Wavelet 1D, Dec. 1999–2000. **e** Temporal variation of pH Linear trend, moving average (lag: 12)

decreased in late spring and summer. The roles of large-scale factors are more important in Ummiye and Yeniköy at the end of the year, than other study areas, with 3–14 months periodicity (Fig. 3d). The role of large-scale fluctuations was also observed during winter in Ferhadiye, and in Nüzhetiye 2 and 3, with 5–9 months periodicity.

The maximum role of large-scale effects on pH variations was observed in winter. In general small-, meso- and large-scale factors play an important role on monthly variations of pH values throughout the year.

Temporal variation of pH values shows a slightly increasing trend, beginning from December 1999 to 2000. However, there is a sufficient evidence of this relationship with α=0.25 (Fig. 3e).

4.2 Analysis of Nitrate ($NO_{3-}N$)

Temporal variation of nitrate concentration shows a slightly increasing trend at the eight study areas during the last part of the period (Fig. 4a).

Annual variations of amplitudes (a3) are similar in Ummiye and Mamuriye. Similar variations are observed in Ferhadiye and Nüzhetiye 1. The lowest amplitudes are recorded in Nüzhetiye 3 at the end of the year, and in Nüzhetiye 4 at the beginning for the year. Largest values are observed in Yeniköy. The greatest role of large-scale factors was observed in Nüzhetiye 1 (after d3).

High frequency variations (in other words, small-scale fluctuations) are higher in Yeniköy than other areas. Large (d3, low frequency) and small-scale (d1, high frequency) effects play a less important role in the variations of nitrate concentrations in Nüzhetiye 3 and 4. An important role of both small- and large-scale factors is observed on annual nitrate concentration variation in Nüzhetiye 4 and Yeniköy in the second part of the year.

Mean and median nitrate concentrations are 0.283 mg/L and 0.25 mg/L between 1999 and 2000, respectively (Fig. 4b). Maximum and minimum nitrate concentrations are 0.654 mg/L and 0.112 mg/L, and the range and standard deviations are 0.542 mg/L and 0.095 mg/L.

There is a positive skewness of nitrate concentrations from the normal distribution. The modal value (35 % of all data) is 0.229 mg/L.

Increasing trend and seasonal variations of nitrate contents are observed in the de-noising signal (Fig. 4c), and nitrate contaminants increase during winter. Higher values were recorded in late spring and early summer.

The extreme role of large-scale factors was observed in Nüzhetiye 1 and Ferhadiye in May, June, July with periodicity of 7–15 months (Fig. 4d). Large-scale effects are also observed with lower periodicities (2–5 months) in Mamuriye. At the beginning of the year, meso-scale factors with 9–15 months periodicity play an important role in nitrate variations in this area. Other large-scale fluctuations are observed in Yeniköy, with periodicity of 5–9 months.

It was found that nitrate contents decrease in autumn (Fig. 4e). The lowest values are observed in Nüzhetiye 3 and 4, and the highest values are recorded in Yeniköy. In general, monthly variations of nitrate concentrations shows an increasing trend (α=0.05).

4.3 Analysis of Chlorine (Cl^-)

Figure 5a presents monthly and annual variations of Cl^- concentration in the eight study areas between 1999 and 2000.

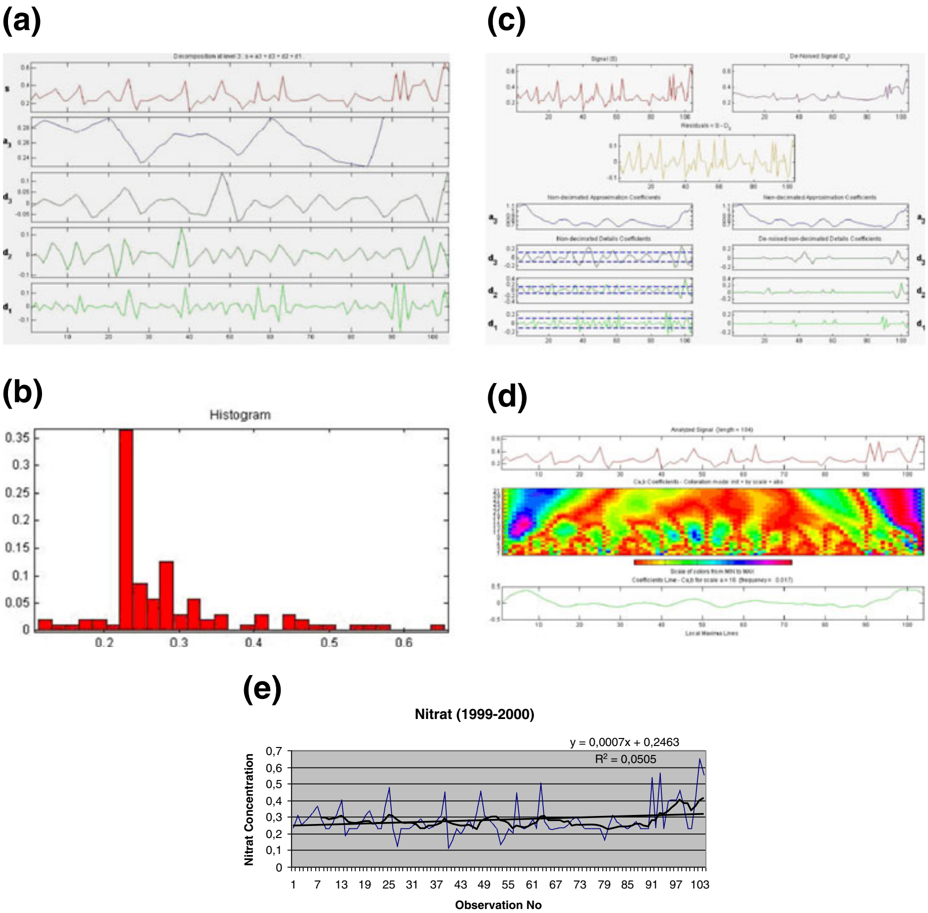

Fig. 4 **a** Analysis of nitrate concentration (mgL^{-1}), db3, Wavelet 1D, Dec. 1999–2000. **b** Descriptive statistics of original signal; nitrate variation, db3, Dec. 1999–2000. **c** Decompose signal (Selected threshold method: Fixed from threshold; Selected noise structure: scaled white noise); nitrate variation, db3, level 3 Dec. 1999–2000. **d** Analysis of nitrate variation, db3, Continuous Wavelet 1D, Dec. 1999–2000. **e** Temporal variation of Nitrate concentrations (mgL^{-1}), linear trend, moving average (for lag: 12)

Cl^- values increase slightly beginning from late spring 2000. Amplitudes of Cl^- concentration increase in the observation period. High-frequency fluctuations (d3, large scale events) are important in Nüzhetiye 2, Yeniköy and Mamuriye. In Yeniköy, large- and small-scale factors play an important role on variations in Cl^- concentrations. These factors are associated with the volcanic structure of the study area. In Değirmendere (Nüzhetiye 2), artificial annual fish farming and, agricultural activities cause increasing Cl^- concentration. The role of meso-scale fluctuations (d2) in Ferhadiye and Nüzhediye 1 are more pronounced than in the other study areas. Small-scale fluctuations and their role on variation of Cl^- concentration are important in Mamuriye, Nüzhetiye 1, 3 and Yeniköy. Monthly variation fog and Cl^- concentrations are less than the combined effects of seasonal and annual fluctuations. Combined effects of small- and large-scale factors play an important role in Cl^- concentration.

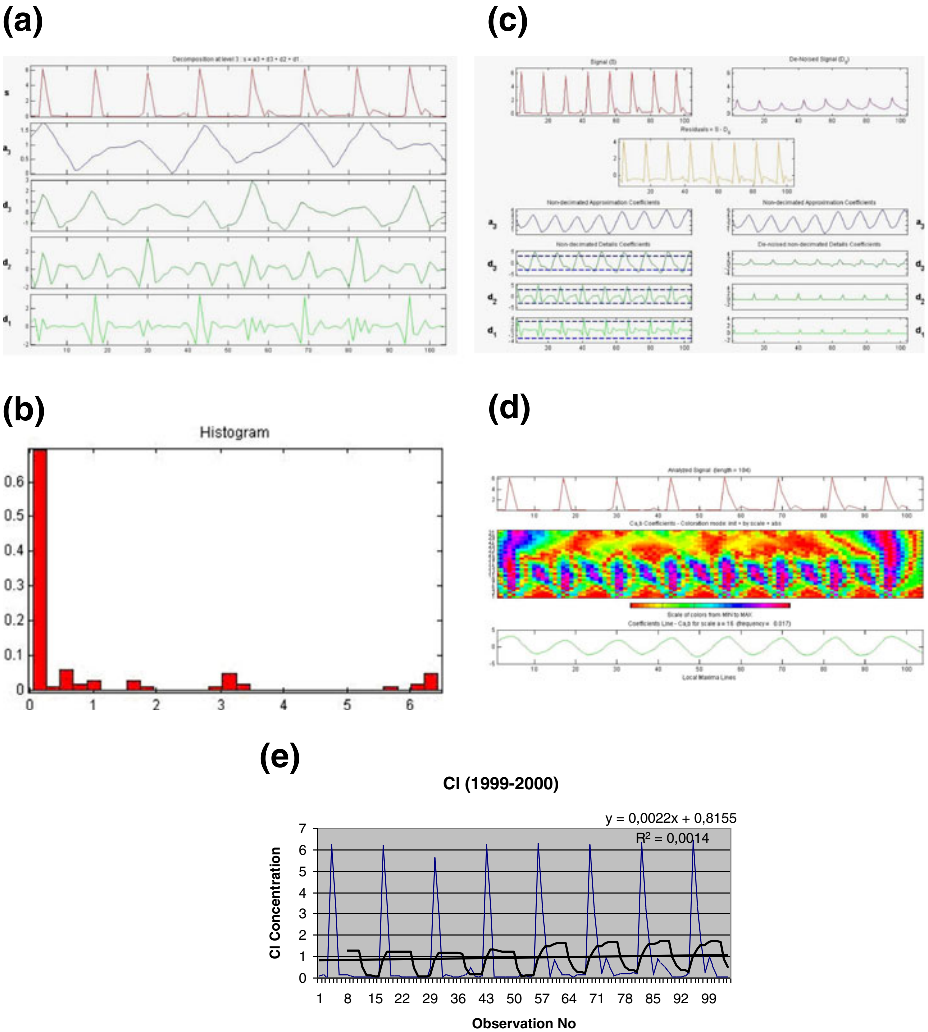

Fig. 5 **a** Analysis of Cl⁻ variation, db3, Wavelet 1D, Dec. 1999–2000. **b** Relative frequency histogram of signal; Cl⁻ concentration (mgL^{-1}), db3, Dec. 1999–2000. **c** Decompose signal (Selected threshold method: Fixed from threshold; Selected noise structure: scaled white noise); Cl⁻ variation, db3, level 3 Dec. 1999–2000. **d** Analysis of Cl⁻ variation, db3, Continuous Wavelet 1D, Dec. 1999–2000. **e** Temporal variation of Cl⁻ Linear trend, moving average (for lag: 12)

The distribution of Cl^- showed positive skewness (Fig. 5b). Mean Cl^- concentration is 0.931 mg/L, and the median, mode, maximum, minimum, range and standard deviations are 0.138, 0.156, 6.44, 0.05, 6.39 and 1.753, respectively. Monthly variation in amplitude shows a slightly increasing trend in the second part of the period (Fig. 5c). The combined effects of small-, meso- and large-scale fluctuations on Cl^- concentrations were observed in all study sites (Fig. 5d). A slightly increasing trend was observed in the temporal variation of Cl^- content between 1999 and 2000 (Fig. 5e). However, there is not a sufficient evidence (α>0.25) of the linear trend for all study areas.

5 Discussion

The performance of the proposed model was examined and evaluated in comparison with data for the 13-month field-study period. This section presents the result from modelling different point-source and non-point-source impacts on pH values, and the fate and transport of nitrate and chlorine in the surface water resources of the research area. The main role of large-scale factors on pH variations is observed in winter at all stations. Extreme effects are observed in Ummiye.

The average values of the samples for 13 months were as follows: pH 7.15–7.34, NO_3-N 0.21–0.33 mg/L and Cl 0.05–2.88 mg/L.

All of the sample sites satisfy the first class water quality in terms of pH. The pH values of all the water sources (pH 7.0–8.5) are suitable for drinking water and irrigation, in accordance with TSE 266 (Anonymous 1986). There was no significant change in pH values and the values were similar for all water resources.

Concentrations of NO_3-N in rainy months are related to the leaching of N (nitrogen) applied for agricultural purposes, and water erosion occurred by the effect of precipitation.

The elevations in NO_3-N concentration must be considered in the usage of irrigation water, including NO_3-N fertilizers, in agricultural purposes.

The modelling results indicate that leaching, runoff from orchards, uncontrolled application of agricultural fertilizers, breeding, and a faulty septic system are the main sources of nitrate loading in the springs. Moreover, measurements indicate that the maximum flow rate and nitrate load in the springs occurs from October to June, which implies that the nitrate load in the river increases at high flow rates. As result, the water quality can be affected by fertilizer applied during irrigation treatments to orchards, which subsequently drains into rivers. Nitrate concentrations show an increasing trend between December 1999 and 2000 (α=0.25). Large-scale factors are important in nitrate concentrations in Nüzhetiye 1. Extreme nitrate concentrations are observed in Yeniköy.

An increase of 0.05–0.15 mg/L was detected in Cl^- concentration during autumn and spring seasons. The Cl^- concentration increased during summer (June–July 1999). Cl^- concentration must be taken into consideration in water resources used for irrigation in arid summer periods because the lowest amount of Cl^- can cause a greater risk to economic crop specimens. The Cl^- concentrations in the surface water resources were below the respective levels set by the Turkish Standards Institution (TSE) health-based guidelines (Allowable limit for drinking water Cl^-<200 mg/L and for spring water Cl^-<20 mg/L.) Large-scale factors like aridity play an important role in Cl^-concentrations in Mahmuriye, Nüzhetiye 2 and Yeniköy. There is no significant evidence of an increasing trend in Cl^{-1} concentration between December 1999 and 2000. Long-term data and detailed analysis are necessary to more accurately determine trends. Variations in Cl^- concentrations are influenced by the combined effects of small- and large-scale events, based on continuous 1d analysis.

6 Conclusions

The wavelet analysis was successful in identifying the location, duration and transient events in these data sets. The methods may be refined to automate detection and classification of transient events in a water-quality time-series (Dohan & Whitfield 1997). There are many opportunities to obtain theoretical results for wavelet packets, which may find valuable applications in relation to water quality. Selection of Db wavelets is more convenient for analysis to explain the role of different-scale fluctuations. However, selection of an optimal, and more suitable wavelet is the subject of extended work in future studies.

The specific results of this study are:

(1) Composition of spatial and temporal variation of variables.
(2) Experience with the application of signal analysis (such as wavelet analysis) in water management.
(3) To define the role of small-, meso- and large-scale factors on water quality parameters.
(4) Composition and interpretation results of signal analysis by conventional measurements.
(5) Time series analysis show significant evidence of the linear relationship of temporal variations of nitrate concentrations.

Continuous monitoring of water quality and prevention of pollution problems are some of the most important issues to ensure sustainable use of water resources. New methodologies and techniques have been commonly applied to such problems in recent years. It is concluded that wavelet analysis can be useful tool to analyze detailed temporal patterns of water quality signals over different temporal scales.

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