Ecological Informatics 5 (2010) 281–292

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Effective visualization for the spatiotemporal trend analysis of the water quality in the Nakdong River of Korea

Hye Won Lee, Kon Joon Bhang, Seok Soon Park *

Department of Environmental Science and Engineering, College of Engineering, Ewha Womans University, Seoul, 120-750 Republic of Korea

ARTICLE INFO

Article history:
Received 15 January 2010
Received in revised form 22 May 2010
Accepted 23 May 2010

Keywords:
LOcally WEighted Scatter plot Smoother
Seasonal Mann–Kendall
Spatiotemporal trend table
Trend analysis
Visual trend graph
Water quality information system

ABSTRACT

Spatial and temporal trend analyses were performed to obtain more meaningful water quality information in table and three-dimensional graph forms. Using the statistical approaches of the Seasonal Mann–Kendall (SMK) and LOcally WEighted Scatter plot Smoother (LOWESS) methods, the trends of three water quality parameters, including Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), and Total Phosphorus (TP) measured along the Nakdong River of Korea between 1992 and 2002 were analyzed. The trends of the slopes were calculated using the SMK method for two consecutive stations and years. These values are provided in the trend tables which indicate the extreme upward and downward trends. Also, three-dimensional graphs of the water quality in the Nakdong River were generated with respect to the distance from upstream of the river and time of month. From this study, it was concluded that these tables and three-dimensional maps could be used as a useful tool to provide the spatiotemporal trend information such as the hot spots/moments of improvement and deterioration in the water quality of the Nakdong River, with the present web-based information system.

1. Introduction

Water quality management policy is often associated with judgments not only by present situations, but also by past records. From the monitoring data of water quality, it can be determined whether the previous policy was good enough or further regulations will be needed. These types of judgments are usually obtained from the statistical trend analysis of water quality data.

Statistical trend analysis makes water quality data to be more comprehensible such that it can provide the scientific guideline to policy decision makers (Helsel and Hirsch, 1992; Paul and Linfield, 1997). Several statistical methods, such as the Seasonal Mann–Kendall test (SMK) and LOcally WEighted Scatter plot Smoother (LOWESS) methods, have been developed and widely used in water quality management (Cleveland and Devlin, 1988; Lettenmaier et al., 1991; Walker, 1991; Zipper et al., 2002; Passell et al., 2004; Boeder and Chang, 2008; Chang, 2008). Recently, the trend analysis and other statistics are getting more attention due to two emerging issues in water quality management. First, the information techniques for water quality data, such as world wide web (www), Geographic Information System (GIS), database, and highly sophisticated computer models and graphics, are now available in most industrialized countries, for a representative example; http://waterdata.usgs.gov/nwis (Norman et al., 2000; Liang and Frank, 2001; Chang, 2008). Second, an active participation of local watershed residents, as a part of an integrated watershed management, becomes more important for water quality improvement (Cobourn, 1999; Walesh, 1999). For effective water quality management, therefore, the statistically summarized data in numeric and visual formats is needed to provide the quantitative and qualitative information of water quality condition for local residents as well as policy decision makers through the web-based information system.

The water quality of major river systems in Korea has been monitored since late 1970 and the water quality information system based on the web (http://water.nier.go.kr) was developed in 1998 by the National Institute of Environmental Research (NIER) under the supervision of the Ministry of Environment of Korea. The system is web-based and includes GIS, database of pollution source, water quality models, and computer graphics. Due to the lack of statistical tools, the water quality data are currently provided with the raw data, where only limited information can be obtained from the system. Some statistical values and simple graphs, including means, standard deviations, and bar and line graphs, can be obtained along with measured raw data in the present system. Pollution loads from point and non-point sources, sewer systems, land use types, geography of watershed, and some other information for water quality management, are also available. The system continues to be updated with recent monitored water quality data and information periodically.

In previous researches, various visualization techniques with statistical methods were attempted for trend analysis of water quality (Garbrecht and Fernandez, 1994; Zhang, 1998; Miller et al., 2001; Yang et al., 2002). Boyer et al. (2000) proposed various visualization approaches, such as a 1 dimensional box and whisker plots at a single

* Corresponding author. Tel.: +82 2 3277 3546; fax: +82 2 3277 3275.
E-mail address: ssp@ewha.ac.kr (S.S. Park).

1574-9541/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecoinf.2010.05.004

station, 1 dimensional time series line graphs at a single or group station, 2 dimensional contour maps (snapshot in time), 2 dimensional time series animation of contours, and 3 dimensional isosurface slicing animation. Each technique of visualization showed its own characteristics in demonstrating a trend of water quality (Cleveland and Devlin, 1988; Lettenmaier et al., 1991; Walker, 1991; Helsel and Hirsch, 1992; Paul and Linfield, 1997; Zipper et al., 2002; Bekele and McFarland, 2004; Passell et al., 2004; Boeder and Chang, 2008; Chang, 2008). The snapshot indicates the spatial or temporal variation of specific station or period separately. Although the computer-aid animation could display temporal and spatial changes of water quality, its applicability is limited within the printed snapshot. The limitation of the snapshot could be overcome by the three-dimensional graph, which supplies an overall trend temporally and spatially.

In this study, the statistical and visual tools were proposed in order to upgrade the present water quality information system, which can be more useful and fit well to the recent water quality issues. This paper focused on the spatial and temporal trend analyses of water quality in a large river system, where the results were presented in visual graphs and numeric tables. These quantitative and qualitative analyses are useful tools to analyze and display the long-term trend of water quality.

2. Materials and method

2.1. Study area and data collected

The Nakdong River located in the southeastern region of the Korean peninsula (35–37°N, 127–129°E) (Fig. 1) is 525 km in length and drains an area of approximately 23,800 km^2. The river watershed is affected by large amounts of precipitation in the monsoon season between June and July with several typhoon events. The mean annual precipitation is 1028 mm and more than 60% of the total rainfall occurs during the monsoon season (Fig. 2). The river, which is one of four major river systems in South Korea, plays an important role as a water resource for agriculture, industry and municipalities in the southeastern area of Korea. Currently, about 7 million people reside within the basin and more than 13 million people intake a drinking water from the river (Park and Lee, 2002; Park et al., 2006).

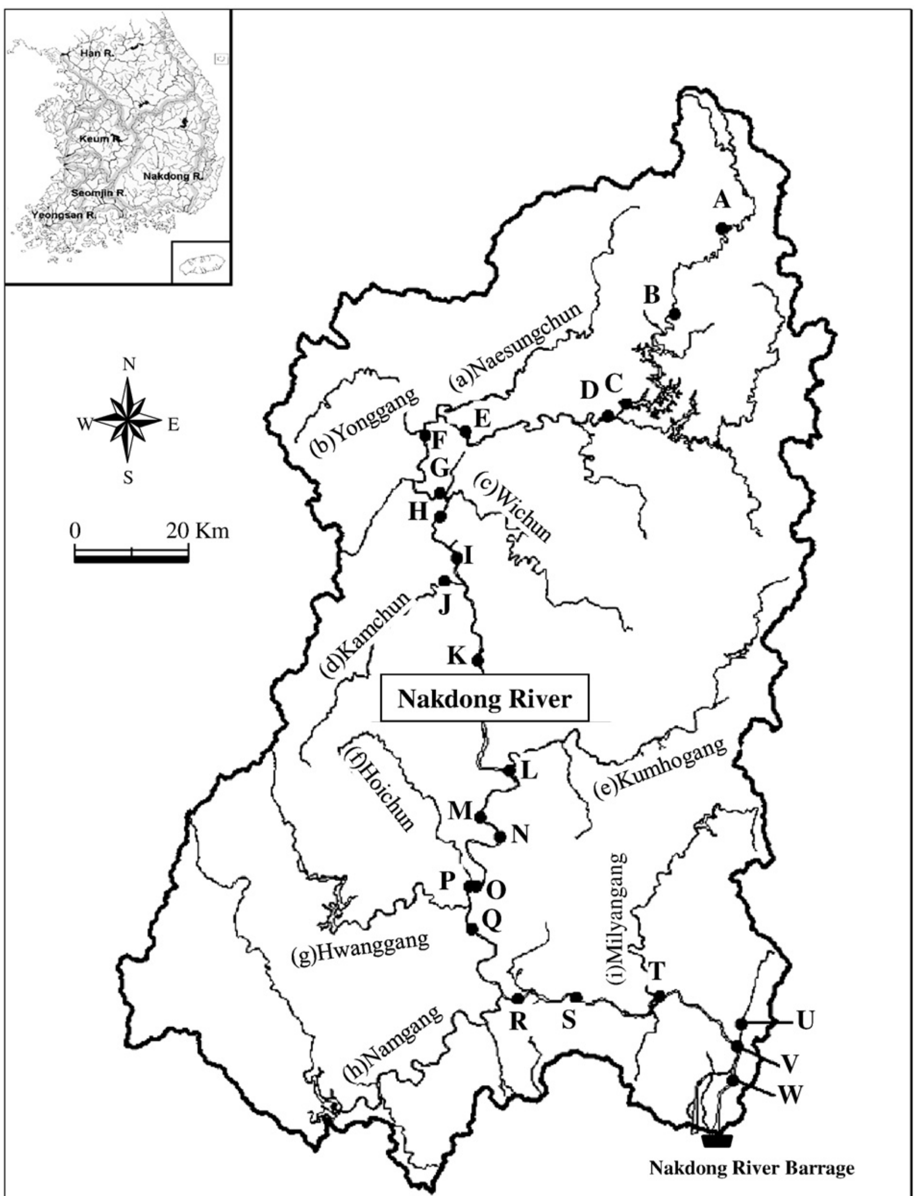

Fig. 1. The monitoring locations in the Nakdong River and watershed.

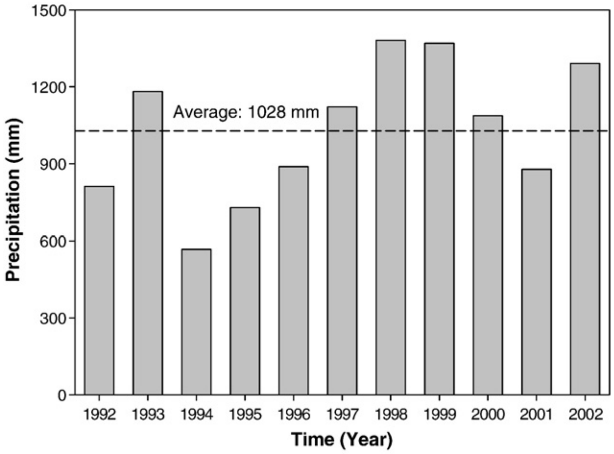

Fig. 2. The precipitation data of study area, the Daegu Metropolitan station.

The water quality of the Nakdong River is generally good in the upstream. However, the combination of rapid population growth coupled with industrial and urban development had resulted in a serious deterioration of water quality in the downstream area of the Nakdong River during the last several decades. Major pollution sources are domestic sewage, industrial wastewater, and urban and agricultural runoff. The industrial use in the Nakdong River watershed covers about 0.8% of the total area and large complexes of industrial facilities are located near or along the Nakdong River and its tributaries. Also, the river flow is impounded in the downstream area because of the construction of a river barrage at the estuary to protect fresh water from saltwater intrusion. Over the last few decades there have been several attempts to improve the water quality. As the results of construction and renovation of sewage treatment plants, the water quality of the effluent has improved in some tributaries since the mid 1990s (Jeong et al., 2001; Park and Lee, 2002; Yang et al., 2002). The Korean government established the water quality improvement plan in 1997 to accomplish either Korean Water Quality Standard I or II (BOD<1 or 3 mg/L, respectively). Despite such improvements, the downstream water quality remains eutrophic in the lower part of the Nakdong River and algal blooms have often been observed over the last several years, especially after short rainfall events in summer (Chun et al., 2001; Ha et al., 2000).

In this study, the water quality data monitored by NIER between 1992 and 2002 were used. These data include the Biochemical Oxygen Demand (BOD), Total Nitrogen (TN) and Total Phosphorus (TP) measured at 23 monitoring stations along the main stream during the study period. There were very few missing water quality data (less than 1% of the total).

2.2. Statistical methods and visualization

Water quality data have positive skewed distribution, seasonality, missing values, and outliers. In this study, some observations for the analyzed data included unusual outliers suspected as measurement errors such that they were removed from statistical analysis as the initial screening procedure, following the US EPA guidance (Zipper et al., 2002; USEPA, 2007). Then among several statistical methods developed for the trend analysis of water quality data, the Seasonal Mann–Kendall method is often applied to determine trends in water qualities (Mann, 1945; Hirsch et al., 1982; Walker, 1991; Helsel and Hirsch, 1992). The Seasonal Mann–Kendall method is a non-parametric procedure in which the magnitude of a trend can be determined by a slope estimate, the median of all ranked seasonal regression slopes (Helsel and Hirsch, 1992). This provides an outstanding capability for identifying water quality trends. However, it was assumed that the Seasonal Mann–Kendall method would be likely to provide only linear trend such that it may not be appropriate for non-linear trends and can distort the results of the trends (Lettenmaier et al., 1991; Zipper et al., 2002; Bekele and McFarland, 2004; Chang, 2005; Boeder and Chang, 2008; Chang, 2008).

To overcome such limitations and provide the qualitative results, the LOWESS method is used for the long-term data with non-linear trends. As a non-parametric smoothing procedure and locally weighted average model for each observation point, the method produces transformed coordinates instead of a regulated curve, such as a regression line. LOWESS does not include a measure of statistical uncertainty. Nonetheless the fact that the results usually agree in direction and magnitude suggests that the trends detected in the modified data are generally applicable to the untransformed data. This provides a useful exploratory tool because it fits a regression model for all available data without any assumption about the modes of fit to the data (Cleveland, 1979; Jacoby, 2000; Richards and Baker, 2002).

The Seasonal Mann–Kendall method has been useful for non-parametric trend analysis of water quality. The method judges the existence or non-existence of trend. The Seasonal Mann–Kendall test statistic is given as follows (Burn, 1994; Westmacott and Burn, 1997),

$$\begin{aligned} Zc &= \frac{S-1}{\sqrt{var(S)}}, \quad S>0 \\ &= \quad 0 \qquad , \; S=0 \\ &= \frac{S+1}{\sqrt{(S)}} \quad , \; S<0 \end{aligned} \tag{1}$$

where S and S_i are $S=\sum_{i=1}^{12} S_i$, $S_i=\sum_{k=1}^{n_i-1}\sum_{j=k+1}^{n_i} \mathrm{sgn}(x_{ij}-x_{ik})$, x_{ij} and x_{ik} are the sequential data values, n is the length of the data set, and $\mathrm{sgn}(x_{ij}-x_{ik})$ is equal to 1, 0, −1 if θ is greater than, equal to, or less than zero, respectively. S_i is approximately normally distributed and the mean and variation of S are defined as follow;

$$var[S] = \sum_{i=1}^{12} var[S_i] = \sum_{i=1}^{12} \frac{n_i(n_i-1)(2n_i+5) - \sum_{t_i} t_i(t_i-1)(2t_i+5)}{18} \tag{2}$$

where n_i is the number of sample and t_i is the number of pairs having the same concentration in a month, i. The null hypothesis H_0 is accepted if $-Z_{1-\alpha/2} \le Zc \le Z_{1-\alpha/2}$. In this study, each season is defined as monthly units and all significant tests were tested at the 95% confidence level.

In the Seasonal Mann–Kendall method, another very useful index is the Kendall slope, which is the magnitude of the monotonic trend. Non-parametric trend line indicating the relationship between continuous variables (X, Y) is present by following equation.

$$Y = \alpha + \beta \cdot X \tag{3}$$

Slope (β) is computed as $\beta = Median\left(\frac{xi-xj}{i-j}\right), \forall j<i$, in which $1<j<i<n$. The estimator β is the median over all combination of record pairs for the whole data set and thereby resistant to the effect of extreme values in the observation. A positive value of β means upward trend, and a negative value of β means downward trend. And intercept (α) is computed as $\alpha = Y_{med} - \beta \cdot X_{med}/12$. Slopes are calculated by all possible pairs (X, Y) in a month, i. To figure out the inflection point of the trend and compare relative slope of location or time, each spatial or temporal interval is considered as between consecutive two stations or two years.

In the LOWESS method, a moving average is calculated for extracting a smooth set of values from a scattered time series data with a noisy relationship between two variables (Cleveland, 1979; Cleveland and Devlin, 1988). At a point x, the mean of $E(Y)$ is estimated by a weighted polynomial regression of (x_i, y_i) located in the neighborhood of x. The dependence of $E(Y)$ on X is represented by a smooth curve without any strict parametric assumption. The non-parametric estimation gives the data more of a chance to speak for themselves in choosing the model to be fitted (Silverman, 1985). When scatter plot $(x_i, y_i)_{i=1...n}$ is smothed by using LOWESS $l(x)$ at x with a smoothing factor, $0<f\leq 1$. The fraction of the data (f) in each local neighborhood controls the smoothness of the curve, with larger value minimizing the response of the smoothing function to variability in the data and smaller value maximizing the response of smoothing to data variability, similar in nature to inverse distance weighting. The choice of a smoothing factor 0.5 (50% of the data incorporated into each smoothing iteration) is adequate for reducing the variability in constituent and the value is used in this study (Bekele and McFarland, 2004). The neighborhood weight w_i (x) given to the observation point (x_i, y_i) for the fit at x can be defined as

$$w_i = T \cdot \frac{\Delta_i(x)}{d(x)} \tag{4}$$

where Δ_i (x) is the distance from x to x_i ($|x-x_i|$), $d(x)$ is the distance x to the qth-nearest x_i; q is fn truncated to an integer which is the corresponding number of points in the neighborhood of x; T is the tricube weight function, which is a traditional weight function used for LOWESS, $T(u) = (1-|u|^3)^3$, *for* $|u|<1$ and $T(u)=0$, *for* $|u|\geq 1$. Weight equals zero for points left out or the span. Local regression may be linear but a possible extension to quadratic regression is obvious in the former case the values for a_x and b_x are chosen to minimize.

$$\sum_{i=1}^{n} w_i(x)(y_i - a_x x_i - b_x)^2 \tag{5}$$

and the fit at x equals

$$l(x) = \hat{a}_x x + \hat{b}_x \tag{6}$$

3. Results and discussion

3.1. Trend analysis

The water quality of the Nakdong River was analyzed using the statistical methods of the SMK and LOWESS. In this study, three water quality parameters (BOD, TN and TP) were collected through the NIER web database and the period was 1992 to 2002. Although the SMK method is generally used for the whole study period, the trend slopes obtained by the SMK method in this study were calculated between two consecutive stations and years to identify important sites or times, so-called hot spots or moments, for stations with significant water quality changes. Hot spot was defined as a site showing a disproportionately high improvement or deterioration relative to the surrounding sites, and a hot moment as a short period relative to the whole period (McClain et al., 2003). When identified, the past events can be traced and the critical causes of a change in water quality found, which will assist decision making for improvement of the water quality.

Figs. 3–5 show the trend results of the water quality data using the SMK and LOWESS methods for five stations (Station A, E, K, M and T). Stations A and E were located at the upper, K at the middle, and M and T at the lower part of the Nakdong River. At Station A and E, the BOD concentrations were less than 2 mg/L. There were no discernible differences in the trends for the BOD concentration from Station A to E, possibly because there were no significant pollution sources or events along the upstream of the river. However, the concentration downstream was more than doubled over the study period (Fig. 3). At Station M and T, however, the concentration increased up to 12 mg/L with large variation over time and the water quality was more deteriorated from Station M to T. For the upstream stations (A through J), it was difficult to describe any discernable trend in the BOD concentration over the whole period (LOWESS). Typically, the stations at the upper upstream region did not show an obvious trend, even for each result of the two consecutive years (the Seasonal Mann–Kendall). During the time span from 1992 to 2003, the trend of the BOD concentration at Station K decreased from 1997 to 1999, and showed a significant trend variation; therefore, 1997 was able to be marked as a hot moment.

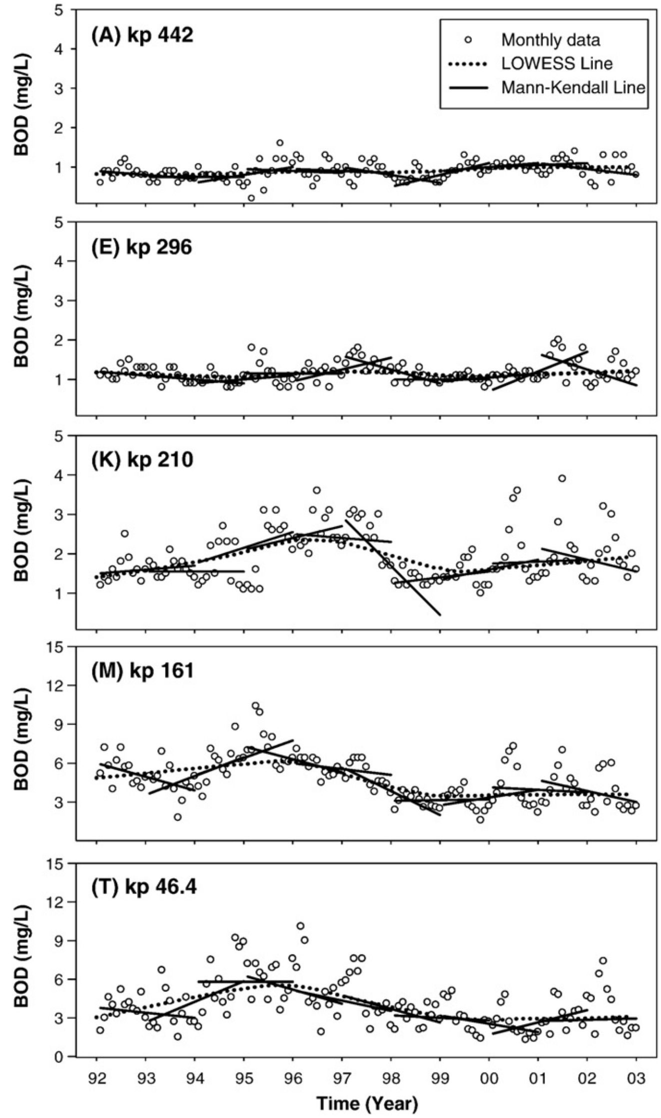

Fig. 3. LOWESS and Seasonal Mann–Kendall tests of BOD.

For Total Nitrogen (TN), all stations showed increasing trends during the study period using the LOWESS, even though there were local fluctuations around 1996 and 1997 (see Fig. 4). As before with the BOD, the TN concentration was significantly increased at Station M, the middle-downstream of the Nakdong River, possibly due to the heavy loading of pollutants from the Kumho River. However, the TN concentration decreased as the river water flowed down river to Station T. Again, the hot moment of the years where the TN was heavily loaded was 1996, as found from the localized SMK trends. It was suspected that the peak in the TN concentration at Station M was due to another source of pollution prior to Station M.

The fluctuations in the TP concentration did not correspond with those of the previous parameters because the BOD and TN concentrations after 1998 remained constant or were slightly lower than in 1998. There was the peak of TP in 1999 at Station A, E, and K (Fig. 5). Considering several water quality policies were established to improve

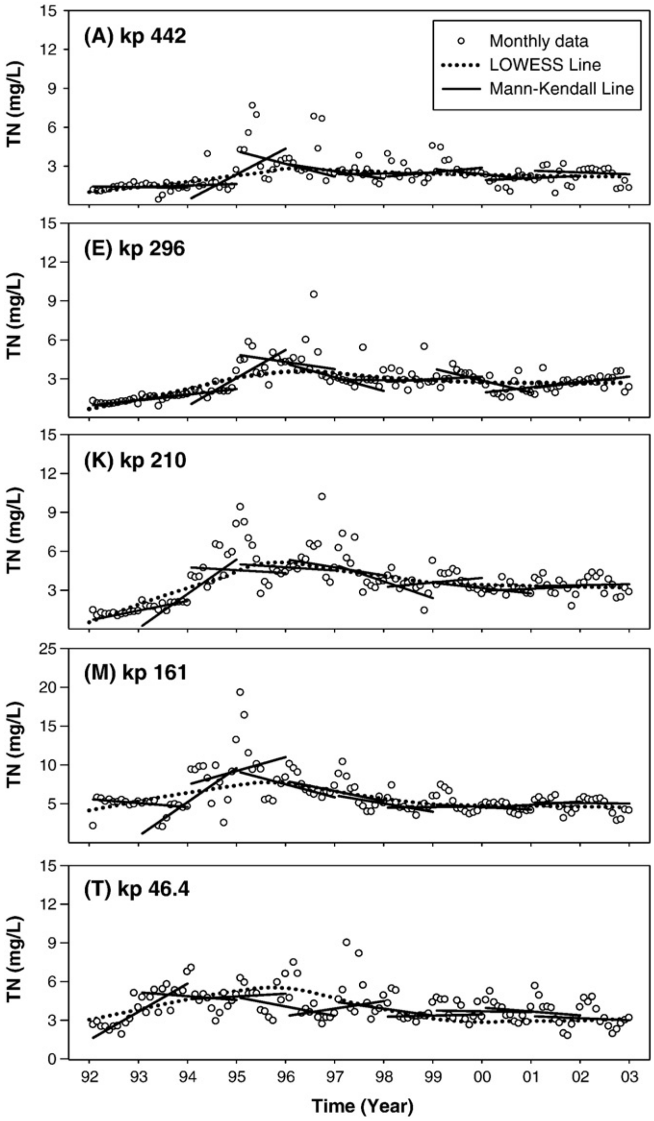

Fig. 4. LOWESS and Seasonal Mann–Kendall tests of TN.

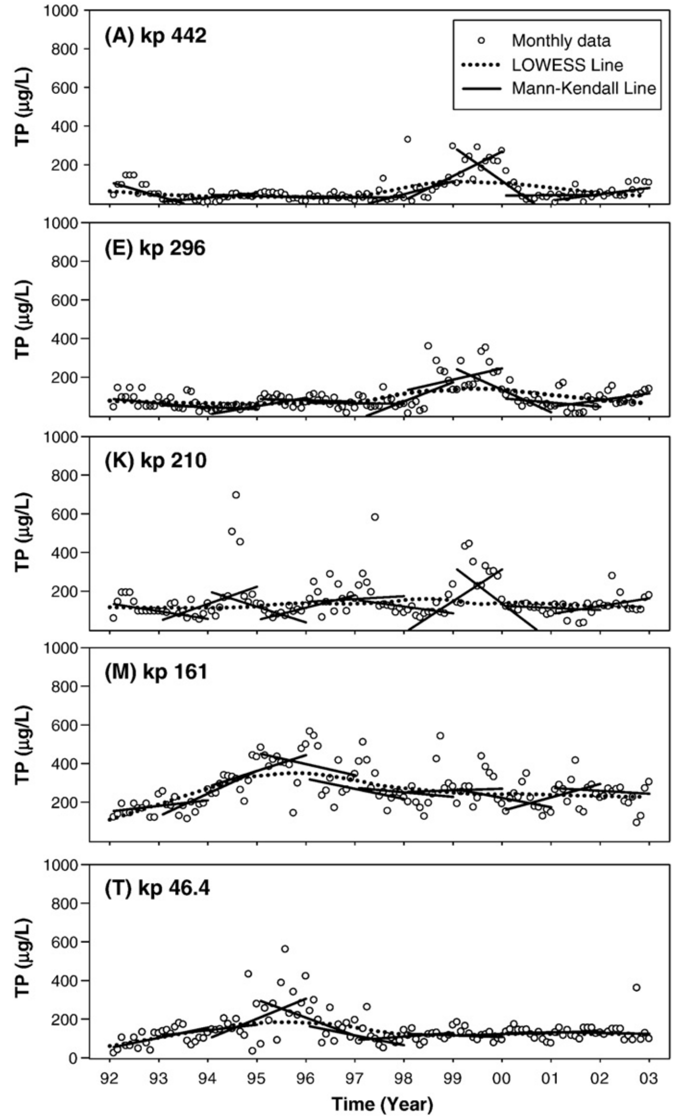

Fig. 5. LOWESS and Seasonal Mann–Kendall tests of TP.

the water quality of the Nakdong River, the TP concentration in the upper flow of the river was worse than before. From the LOWESS method, the long term trend of the water quality seemed to be improving, even though there was a blip between 1998 and 2000. However, with the Mann–Kendall method, there was a short fluctuating term trend in the TP concentration, and typically showed an obvious deterioration in the TP concentrations in the upper river.

A simple listing of illustration for all 23 stations did not describe the continuous variation of the water quality in a large river system. From the examinations, as shown in Figs. 3–5, the conventional trend analysis provided limited information for the detection of changes in the water quality due to the limitation of the SMK method for long-term trend visualization. Since the data showed large fluctuations due to seasonal variations, point and non-point pollution sources, precipitation, etc., it is sometimes difficult to find temporal and spatial trends from the raw data themselves, especially in a large river system.

3.2. Trend tables

Trend tables were developed for utilization in the spatial and temporal trend analyses of the water quality data acquired from the NIER database. As shown in Tables 1–3, the slopes of trends for the BOD, TN and TP calculated from the SMK are provided in triangular boxes, the upper and lower triangles include the temporal and spatial trends, respectively. Again, to show the numerical signs and values of the slopes and identify the comparable significance in the trends, each temporal and spatial interval was segmented, as shown in Tables 1–3 (two consecutive years in column, with stations in rows for temporal and spatial intervals, respectively). The numerical values with signs (− or +) represent decreasing or increasing slopes for two consecutive years and stations. Also, the table provides the minimum and the maximum signs where (↑, ↓) and when (▲, ▼) water quality highly improved or deteriorated.

In Table 1, the BOD concentration shows three significant time segments in the deterioration of the water quality, the years 93 and 94, 94 and 95, and 97 and 98. The water quality of the river was degraded downstream (from Station M through W) from 1993 to 1994 and upstream (from Station A through L) from 1994 to 1996. The table also shows that the water quality of the river significantly improved from 1997 to 1998 throughout the whole river. Spatially, there are significant changes of the BOD concentration at Station L, P and U. Station P and U did not draw much attention due to the downward trend in the BOD concentration. However, Station L experienced year-by-year deterioration due to continuous loading of pollution sources.

The important years for the TN concentration were the periods 92–93, 93–94 and 94–95, which required investigation of the past events. Table 2

Table 1
Temporal and spatial trend table—Biochemical Oxygen Demand (BOD).

	92–93	93–94	94–95	95–96	96–97	97–98	98–99	99–00	00–01	01–02	
A) kp. 442	− / +	+ / +	+ / +	− / +	− / +	−0.20 ▼ / +	+0.30 ▲ / +	+ / −	+ / −	− / +	−5 / +5
B) kp. 403	−0.20 ▼ / −	- / −	− / +	+ / +	− / +	+0.10 ▲ / +	+0.10 ▲ / +	+0.10 ▲ / +	+ / +	− / +	−5 / +5
C) kp. 351	− / +	+ / +	+0.30 ▲ / +	−0.30 ▼ / +	+ / +	− / +	+ / +	+ / +	+ / +	− / +	−4 / +6
D) kp. 346	− / +	− / −	+0.25 ▲ / −	+ / −	+ / +	−0.15 ▼ / +	− / +	+ / +	+ / +	− / +	−5 / +5
E) kp. 296	− / +	− / +	+ / +	+ / +	+ / −	− / −	+ / −	+ / −	+0.50 ▲ / +	−0.40 ▼ / −	−4 / +6
F) kp. 278	− / +	− / +	+0.30 ▲ / +	−0.40 ▼ / −	− / +	− / +	− / +	+ / +	− / +	− / +	−8 / +2
G) kp. 258	− / +	− / +	+ / +	+0.30 ▲ / +	−0.25 ▼ / +	− / +	+ / +	+0.30 ▲ / +	− / +	−0.25 ▼ / +	−6 / +4
H) kp. 251	− / +	− / +	+0.40 ▲ / −	− / +	− / +	−0.40 ▼ / +	− / +	+ / +	+ / +	− / +	−7 / +3
I) kp. 238	− / +	+ / +	+ / +	+0.45 ▲ / +	−0.40 ▼ / +	− / +	− / +	+ / +	+ / +	−0.40 ▼ / +	−5 / +5
J) kp. 228	− / +	+ / +	+0.60 ▲ / +	− / +	− / +	−0.60 ▼ / +	− / +	+ / +	+ / +	− / +	−6 / +4
K) kp. 210	+ / +	+ / +	+0.40 ▲ / +	+ / +	− / +	−1.25 ▼ / +	+ / +	+ / +	+ / +	− / +	−3 / +7
L) kp. 178	− / ↑ +0.19	+ / ↑ +0.18	+0.85 ▲ / ↑ +0.22	− / ↑ +0.22	+ / ↑ +0.18	−0.95 ▼ / ↑ +0.11	+ / ↑ +0.09	+ / ↑ +0.10	+ / ↑ +0.11	− / ↑ +0.09	−4 / +6
M) kp. 161	− / ↓ −0.04	+1.45 ▲ / −	+ / −	− / −	− / +	−1.85 ▼ / +	+ / +	+ / +	− / +	− / +	−6 / +4
N) kp. 153	− / −	+2.25 ▲ / −	+ / −	− / −	− / −	−1.60 ▼ / +	+ / +	+ / +	− / −	− / −	−6 / +4
O) kp. 133	− / −	+2.55 ▲ / +	+ / +	− / +	− / +	−1.60 ▼ / +	+ / +	+ / −	− / −	− / −	−6 / +4
P) kp. 121	− / −	+3.20 ▲ / ↓ −0.08	+ / ↓ −0.15	−2.65 ▼ / −	+ / −	− / −	− / ↓ −0.04	+ / ↓ −0.04	+ / ↓ −0.06	− / ↓ −0.06	−5 / +5
Q) kp. 112	− / −	+2.60 ▲ / +	+ / −	− / −	− / −	−1.70 ▼ / −	− / −	− / −	+ / −	− / +	−7 / +3
R) kp. 84	+ / −	+1.75 ▲ / −	+ / −	− / +	− / −	−1.45 ▼ / −	− / −	− / −	− / −	− / +	−7 / +3
S) kp. 68	+ / +	+ / +	+2.05 ▲ / +	+ / −	− / −	−1.65 ▼ / +	− / +	− / +	+ / +	− / +	−5 / +5
T) kp. 46	− / −	+1.60 ▲ / −	+ / −	−1.10 ▼ / −	− / −	− / −	− / −	− / −	+ / +	+ / −	−6 / +4
U) kp. 27	+ / +	+1.45 ▲ / +	+ / −	− / ↓ −0.12	− / ↓ −0.05	−1.40 ▼ / ↓ −0.07	− / −	− / +	+ / −	− / −	−6 / +4
V) kp. 22	+ / −	+2.20 ▲ / −	− / −	+ / +	+ / −	−1.95 ▼ / +	− / +	+ / +	− / +	− / +	−5 / +5
W) kp. 12	+	+0.65 ▲	+	−	−	−0.70 ▼	−	−	+	−0.70 ▼	−6 / +4
	−9 / +13	−8 / +14	−10 / +12	−9 / +13	−9 / +13	−6 / +16	−6 / +16	−7 / +15	−7 / +15	−6 / +16	

Table 2
Temporal and spatial trend table—Total Nitrogen (TN).

	92–93	93–94	94–95	95–96	96–97	97–98	98–99	99–00	00–01	01–02	
A) kp. 442	– / –	+ / +	+1.98 ▲ / –	–0.98 ▼ / +	– / +	+ / +	+ / +	– / +	+ / +	– / +	–5 / +5
B) kp. 403	+ / +	+ / –	+1.16 ▲ / +	+ / +	– / –	– / –	+ / –	–0.98 ▼ / –	+ / –	– / –	–4 / +6
C) kp. 351	+ / +	+ / +	+1.98 ▲ / +	–1.16 ▼ / +	– / +	– / +	– / +	– / +	+ / +	– / +	–6 / +4
D) kp. 346	+ / –	+ / –	+1.88 ▲ / –	–1.41 ▼ / +	– / +	– / +	+ / +	– / +	+ / +	+ / +	–4 / +6
E) kp. 296	+ / –	+ / –	+2.16 ▲ / –	– / –	–1.06 ▼ / +	– / +	+ / +	– / –	+ / –	+ / –	–4 / +6
F) kp. 278	+ / +	+ / +	+3.08 ▲ / +	– / +	–1.10 ▼ / +	– / +	+ / +	– / +	+ / +	– / +	–5 / +5
G) kp. 258	+ / +	+ / +	+2.05 ▲ / +	– / +	–1.12 ▼ / –	+ / +	– / +	– / +	+ / +	– / +	–5 / +5
H) kp. 251	+ / +	+ / –	+2.87 ▲ / –	–1.07 ▼ / –	– / –	– / –	– / +	– / –	+ / –	+ / –	–5 / +5
I) kp. 238	+ / +	+ / +	+3.05 ▲ / +	–1.02 ▼ / –	– / +	+ / +	+ / +	– / +	+ / +	+ / +	–3 / +7
J) kp. 228	+ / –	+ / +	+2.44 ▲ / +	– / +	– / +	– / +	– / +	–0.45 ▼ / +	+ / +	+ / +	–5 / +5
K) kp. 210	+ / –	+2.66 ▲ / –	– / +	– / +	– / –	–1.28 ▼ / –	+ / –	– / –	+ / –	+ / –	–5 / +5
L) kp. 178	+ / +	+1.97 ▲ / +	↑ + / +0.27	↑ –1.55 ▼ / +0.22	↑ – / +0.19	↑ + / +0.08	↑ – / +0.07	– / +	↑ + / +0.11	↑ + / +0.07	–4 / +6
M) kp. 161	– / –	+4.39 ▲ / –	↓ + / –0.20	–1.68 ▼ / –	– / +	– / –	+ / –	– / +	+ / +	– / +	–6 / +4
N) kp. 153	+ / –	+3.75 ▲ / –	– / +	– / –	–1.42 ▼ / –	– / –	+ / –	– / –	+ / –	– / +	–6 / +4
O) kp. 133	+ / +	+5.58 ▲ / +	+ / –	↓ –1.37 ▼ / 0.08	– / –	– / –	+ / –	– / +	+ / +	– / –	–5 / +5
P) kp. 121	+2.58 ▲ / –	– / –	+ / –	–1.83 ▼ / –	↓ + / –0.06	↓ – / –0.08	↓ + / –0.11	↓ – / –0.11	↓ – / –0.08	↓ – / –0.06	–6 / +4
Q) kp. 112	+2.43 ▲ / –	– / –	+ / –	– / –	– / –	–1.90 ▼ / +	+ / +	– / –	– / –	– / –	–7 / +3
R) kp. 84	+2.08 ▲ / –	– / –	+ / –	– / +	+ / –	–1.49 ▼ / –	+ / –	– / –	– / –	– / –	–6 / +4
S) kp. 68	+ / +	+ / +	+1.35 ▲ / +	– / –	+ / –	–0.90 ▼ / +	+ / –	+ / –	– / –	– / –	–4 / +6
T) kp. 46	+2.20 ▲ / –	– / +	+ / –	–0.73 ▼ / –	+ / +	– / –	+ / –	– / –	– / –	– / +	–6 / +4
U) kp. 27	↓ +2.41 ▲ / –0.40	↓ –0.94 ▼ / 0.46	+ / –	– / +	– / +	– / +	– / +	↑ – / +0.09	– / +	– / –	–8 / +2
V) kp. 22	↑ – / +0.26	↑ + / +0.29	+2.01 ▲ / +	– / +	+ / +	–1.34 ▼ / +	+ / –	+ / –	– / +	+ / +	–4 / +6
W) kp. 12	+2.24 ▲	–1.31 ▼	+	–	+	–	+	–	–	–	–6 / +4
	–12 / +10	–11 / +11	–11 / +11	–10 / +12	–10 / +12	–9 / +13	–11 / +11	–10 / +12	–10 / +12	–10 / +12	

Table 3
Temporal and spatial trend table—Total Phosphorus (TP).

	92–93	93–94	94–95	95–96	96–97	97–98	98–99	99–00	00–01	01–02	
A) kp. 442	− / −	+ / −	− / −	− / +	+ / +	+ / −	+127.0 ▲ / −	−177.5 ▼ / +	+ / +	+ / +	−4 / +6
B) kp. 403	+ / +	− / −	+ / +	+ / +	− / +	+ / +	+142.0 ▲ / −	−142.0 ▼ / −	− / −	+ / −	−4 / +6
C) kp. 351	−77.0 ▼ / +	+ / +	+ / +	− / +	+ / +	+ / +	+ / +	− / ↑ +8.00	− / +	+56.5 ▲ / −	−4 / +6
D) kp. 346	− / +	+ / +	− / +	− / +	+ / +	+ / +	+70.5 ▲ / +	−123.0 ▼ / +	− / +	+ / +	−5 / +5
E) kp. 296	− / +	− / −	+ / −	− / −	− / −	+98.5 ▲ / −	+ / −	−115.5 ▼ / −	− / −	+ / −	−6 / +4
F) kp. 278	− / +	− / +	+ / −	− / −	+ / +	− / +	+140.0 ▲ / −	−141.0 ▼ / +	− / +	+ / +	−6 / +4
G) kp. 258	− / +	+ / +	+ / +	+ / +	+ / −	− / −	+99.0 ▲ / +	−82.0 ▼ / +	− / +	+ / +	−4 / +6
H) kp. 251	− / −	+ / −	+ / −	− / −	+ / −	− / +	+106.0 ▲ / −	−95.0 ▼ / +	− / +	+ / −	−5 / +5
I) kp. 238	+ / +	+ / +	+ / +	− / +	+ / +	− / +	+104.0 ▲ / +	−103.0 ▼ / +	− / +	+ / +	−4 / +6
J) kp. 228	+ / +	+ / +	+ / +	+ / +	+ / +	− / +	+137.0 ▲ / +	−192.0 ▼ / +	− / −	+ / −	−3 / +7
K) kp. 210	− / −	+ / −	− / +	+ / +	+ / −	− / −	+164.5 ▲ / −	−192.0 ▼ / −	− / −	+ / −	−5 / +5
L) kp. 178	− / +	+ / ↓ +9.97	+ / ↑ +11.71	− / ↑ +13.68	− / ↑ +11.35	+76.0 ▲ / ↑ +7.50	+ / ↑ +4.50	−91.0 ▼ / +	+ / ↑ +8.65	+ / ↑ +7.21	−4 / +6
M) kp. 161	+ / −	+117.5 ▲ / −	+ / −	−57.5 ▼ / −	− / −	− / −	+ / −	− / −	+ / −	− / −	−5 / +5
N) kp. 153	+ / −	+ / −	+101.5 ▲ / −	− / −	− / −	− / −	− / −	− / −	+ / −	−71.5 ▼ / −	−6 / +4
O) kp. 133	+ / −	+ / +	+79.0 ▲ / +	− / −	− / −	+ / ↑ −5.82	+ / ↑ −6.48	−50.0 ▼ / ↑ −4.67	− / −	+ / +	−4 / +6
P) kp. 121	+ / −	+ / −	+125.5 ▲ / −	−97.0 ▼ / −	− / −	+ / −	− / −	− / −	+ / ↓ −4.71	− / ↓ −4.42	−5 / +5
Q) kp. 112	+ / −	+ / −	+212.0 ▲ / −	−209.5 ▼ / −	− / −	− / −	+ / −	− / −	+ / +	− / −	−5 / +5
R) kp. 84	+ / −	+ / −	+166.0 ▲ / −	−186.0 ▼ / −	− / −	− / −	+ / −	− / −	+ / −	− / −	−5 / +5
S) kp. 68	+ / +	+ / +	+237.0 ▲ / +	−124.0 ▼ / −	− / −	+ / −	+ / −	+ / −	+ / −	− / −	−3 / +7
T) kp. 46	+ / +	+ / +	+104.0 ▲ / +	−93.5 ▼ / +	− / +	+ / +	− / +	+ / +	+ / −	− / −	−4 / +6
U) kp. 27	+64.5 ▲ / ↓ −10.0	+ / ↓ −13.22	+165.0 ▲ / ↓ −8.64	−196.5 ▼ / −5.85	− / ↓ 483	− / −	+ / −	− / −	− / −	− / −	−6 / +4
V) kp. 22	− / ↑ +6.11	+ / +	+185.5 ▲ / +	−177.0 ▼ / +	+ / +	+ / +	− / +	+ / +	− / +	− / +	−5 / +5
W) kp. 12	+	+	+157.0 ▲	−150.0 ▼	+	−	+	+	+	−	−3 / +7
	−10 / +12	−11 / +11	−11 / +11	−10 / +12	−10 / +12	−9 / +13	−11 / +11	−10 / +12	−10 / +12	−10 / +12	

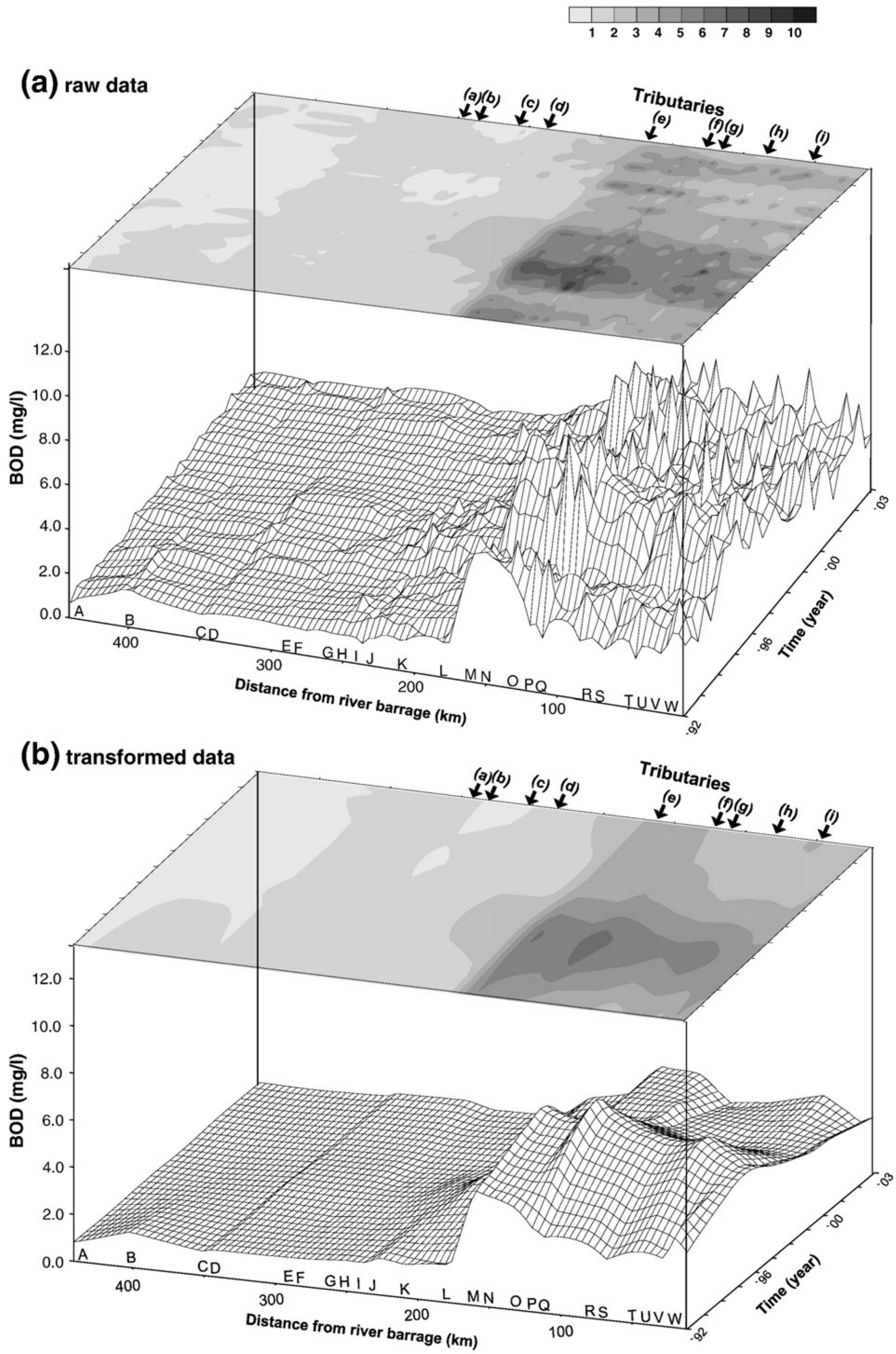

Fig. 6. The three-dimensional graph of BOD.

shows that TN significantly increased from 1994 to 1995 and decreased from 1995 to 1997 in upstream. In downstream, high deterioration and improvement of the TN occurred from 1992 to 1993 and from 1997 to 1998, respectively. Spatially, the TN was significantly deteriorated at Station L and improved at Station P. From Table 3, the TP significantly increased from 1998 to 1999 and decreased from 1999 to 2000 in upstream. In downstream, high deterioration and improvement of the TP occurred from 1994 to 1995 and from 1996 to 1997, respectively. Spatially, the water quality of the TP significantly deteriorated at Station L and improved at Station P and U.

From the comparison of the three tables, there were similar spatial and temporal trends in all three parameters with some exceptions. Temporally, the water qualities were increased in 1995 and then have improved since 1996. It indicated that the pollution loads from point and non-point sources were increased since 1990s because of urbanization and livestock farming and then the water qualities deteriorated. After 1996, the sewer systems were changed, the sewage treatment plants were constructed and the standard of the effluent was enforced in the study area such that the water qualities have improved. The spatial trends are mainly due to the locations of polluted or clean incoming tributaries, especially the Kumho River.

These facts could obviously help trace events that occurred along the Nakdong River during that time period, and finally affect policy establishment to improve the water quality. The analyses, coupled with

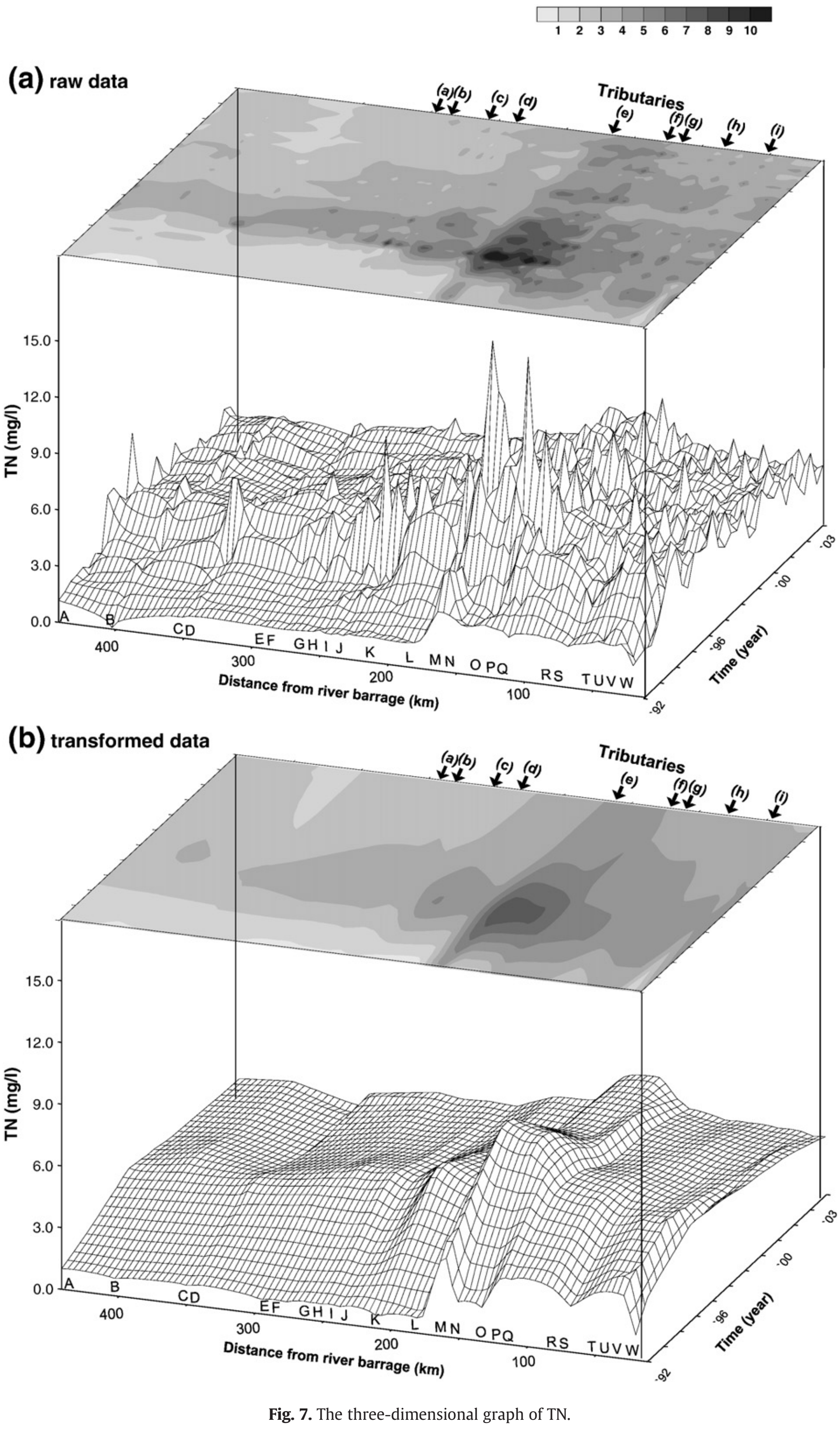

Fig. 7. The three-dimensional graph of TN.

the temporal and spatial trend tables for three water quality parameters, could have been more effectively conducted with Figs. 6–8.

3.3. Spatiotemporal visualization

To visualize the spatial and temporal trends in the water quality of the river, three-dimensional water quality graphs were constructed with respect to the distance from upstream river and time with monthly intervals (Figs. 6–8). Figs. 6a–8a show the three-dimensional graphs constructed with the raw BOD, TN, and TP data. The rough evaluation of the water quality trends could include that the downstream river typically had a serious problem at Stations M and P and in 1995 and 1996. Because the water quality data were highly variable, it is difficult for the spatial and temporal trend to recognize

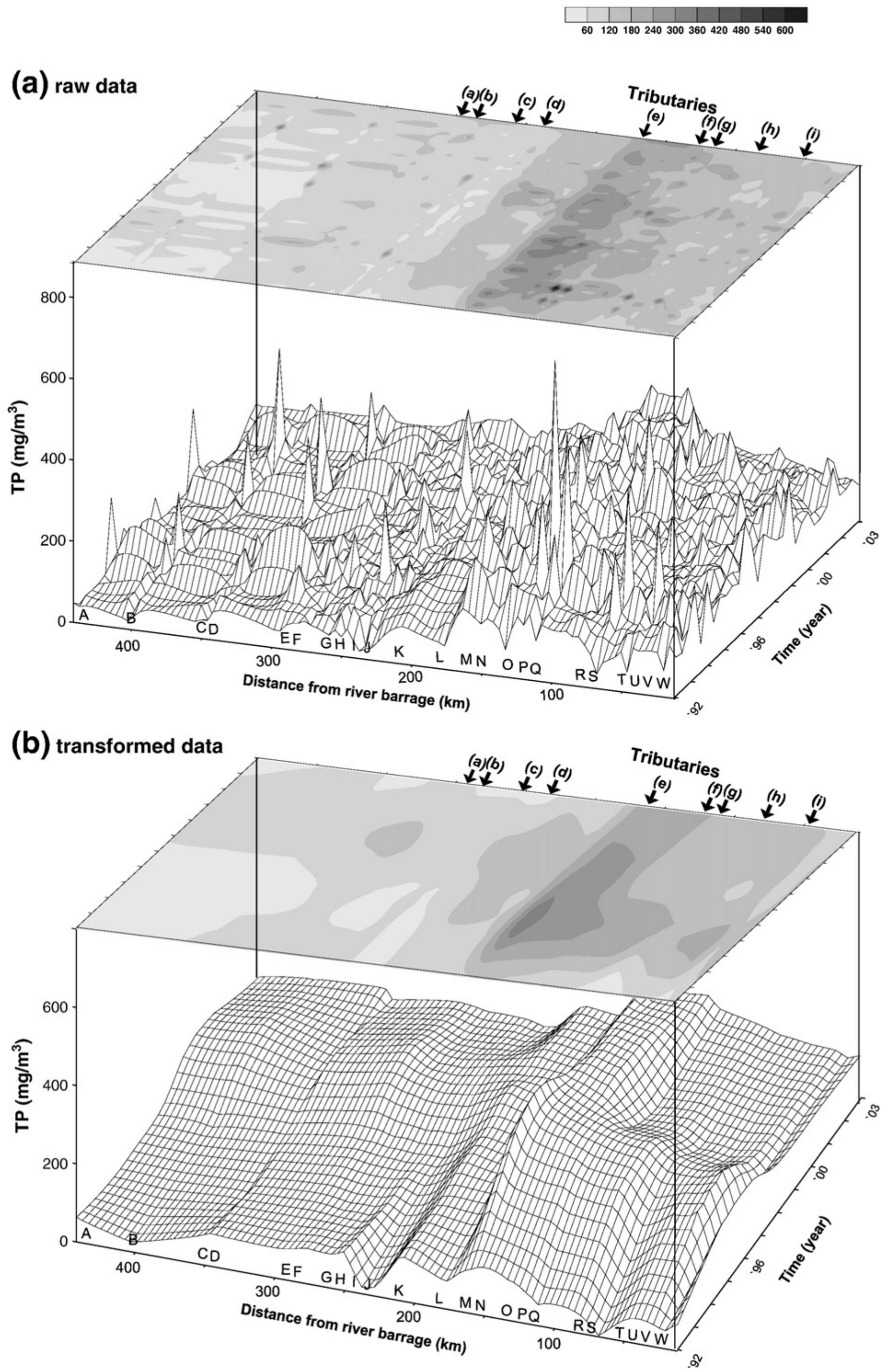

Fig. 8. The three-dimensional graph of TP.

from the rough plots of the raw data. For a more valuable evaluation, the raw data were transformed by the LOWESS method such that the spatial and temporal trends were visualized in Figs. 6b–8b.

With these visual graphs, the hot spots or moments of improvement and deterioration in water quality could easily be identified. The peak of each parameter (the BOD, TN, and TP) commonly occurred at Station M, indicating that there might be serious pollutant loading near the station. Also, the general trend of water quality for each year along the river increased as the river flowed downstream. A tributary passing by a large residential area was discharging to the river, and industrial facilities were located between Station L and M along the river. The BOD level was as marked as the peak in 1996, which was dissimilar to those of the other parameters. Both trend tables and graphs, as summaries of trends in the water quality, were found to compensate for each other. Numerical values for the trend analyses could be visually found in the tables and the graphs and illustrated the spatial and temporal trends.

4. Conclusion

Spatial and temporal trend analyses were performed to obtain more meaningful water quality information in table and three-dimensional graph forms, using the statistical approaches of the Seasonal Mann–Kendall (SMK) and LOcally WEighted Scatter plot

Smoother (LOWESS) methods. The proposed tools were applied to water quality data collected at 23 monitoring stations in the Nakdong River of Korea during the period 1992–2002. Water quality parameters include Biochemical Oxygen Demand (BOD), Total Nitrogen (TN) and Total Phosphorus (TP).

The trend tables included the slope values calculated by the SMK, where temporal and spatial intervals were segmented by two consecutive stations and years with the upper and lower triangles and arrows. The hot spots and moments significantly influencing the water quality of the Nakdong River were able to be easily recognized with the tables. To visualize the spatiotemporal trends in the water quality of the river, three-dimensional graphs for the water quality were constructed with respect to distance from the upstream of the river and time, with monthly intervals. Since water quality data are usually highly variable, spatial and temporal trends are hardly recognized from the graphs drawn with raw data. In this study, therefore, the graph is proposed, where water quality data were transformed by the LOWESS method. The graph could clearly summarize the spatial and temporal trends in the long-term water quality of a large river system.

The performed visualization tool in this study provided more understandable information for the spatiotemporal trend analyses of water quality. From this study, it was concluded that these tables and three-dimensional graphs could be used as a useful tool to provide the spatiotemporal trend information (i.e., the hot spots/moments of improvement and deterioration in the water quality of the Nakdong River) with the present web-based information system.

References

Bekele, A., McFarland, A., 2004. Regression-based flow adjustment procedures for trend analysis of water quality data. Transactions of the American Society of Agricultural and Biological Engineers 47 (4), 1093–1104.

Boeder, M., Chang, H., 2008. Multi-scale analysis of oxygen demand trends in an urbanizing Oregon watershed, USA. Environmental Management 87 (4), 567–581.

Boyer, J.N., Sterling, P., Jones, R.D., 2000. Maximizing information from a water quality monitoring network through visualization techniques. Estuarine Coastal and Shelf Science 50 (1), 39–48.

Burn, D.H., 1994. Hydrologic effects of climate change in west-central Canada. Journal of Hydrology 160, 53–70.

Chang, H., 2005. Spatial and temporal variations of water quality in the Han River and its tributaries, Seoul, Korea, 1993–2002. Water Air and Soil Pollution 161 (1–4), 267–284.

Chang, H., 2008. Spatial analysis of water quality trends in the Han River basin, South Korea. Water Research 42 (13), 3285–3304.

Chun, K.C., Chang, R.W., Williams, G.P., Chang, Y.S., Tomasko, D., LaGory, K., Ditmars, J., Chun, H.D., Lee, B.K., 2001. Water quality issues in the Nakdong River Basin in the Republic of Korea. Environmental Engineering and Policy 2 (3), 131–143.

Cleveland, W.S., 1979. Robust locally weighted regression and smoothing scatter plots. Journal of the American Statistical Association 74 (368), 829–836.

Cleveland, W.S., Devlin, S.J., 1988. Locally weighted regression: an approach to regression analysis by local fitting. Journal of the American Statistical Association 83 (403), 596–610.

Cobourn, J., 1999. Integrated watershed management on the Truckee River in Nevada. Journal of the American Water Resources Association 30 (3), 623–632.

Garbrecht, J., Fernandez, G.P., 1994. Visualization of trends and fluctuations in climatic records. Journal of the American Water Resource Association 30 (2), 297–306.

Ha, K., Kim, H.W., Jeong, K.S., Joo, G.J., 2000. Vertical distribution of microcystis population in the regulated Nakdong River, Korea. Limnology 1 (3), 225–230.

Helsel, D.R., Hirsch, R.M., 1992. Statistical methods in water resources. Studies in Environmental Science, 49. Elsevier.

Hirsch, R.M., Slack, J.R., Smith, R.A., 1982. Techniques of trend analysis for monthly water quality data. Water Resource Research 18 (1), 107–121.

Jacoby, W.G., 2000. Loess: a nonparametric, graphical tool for depicting relationships between variables. Electoral Studies 19 (4), 577–613.

Jeong, K.S., Joo, G.J., Kim, H.W., Ha, K., Recknagel, F., 2001. Reduction and elucidation of phytoplankton dynamics in the Nakdong River (Korea) by means of as recurrent artificial neural network. Ecological Modelling 146 (1–3), 115–129.

Lettenmaier, D.P., Hooper, E.R., Wagoner, C., Faris, K.B., 1991. Trends in stream quality in the Continental United States 1978–1987. Water Resource Research 27 (3), 327–340.

Liang, S.J., Frank, M., 2001. A virtual GIS-based hydrodynamic model system for Tamshui River. Journal of Hydroinformatics 3, 195–202.

Mann, H.B., 1945. Nonparametric tests against trend. Econometrica 13 (3), 245–249.

McClain, M.E., Boyer, E.W., Dent, C.L., Gergel, S.E., Grimn, N.B., Groffman, P.M., Hart, S.C., Harvey, J.W., Johnston, C.A., Mayorga, E., McDowell, W.H., Pinay, G., 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. Ecosystem 6 (4), 301–312.

Miller, J.D., Adamson, J.K., Hirst, D., 2001. Trends in stream water quality in Environmental Change Network upland catchments: the first 5 years. Science of the Total Environment 265 (1–3), 27–38.

Norman, L.J., James, E.N., Colby, T.M., 2000. Managing temporal data in a comprehensive modeling environment. Journal of Hydroinformatics 2, 105–112.

Park, S.S., Lee, Y.S., 2002. A water quality modeling study of the Nakdong River, Korea. Ecological Modelling 152 (1), 65–75.

Park, S.Y., Choi, J.H., Wang, S.K., Park, S.S., 2006. Design of a water quality monitoring network in a large river system using the genetic algorithm. Ecological Modelling 199 (3), 289–297.

Passell, H.D., Dahm, C.N., Bedrick, E.J., 2004. Hydrological and geochemical trends and patterns in the upper Rio Grande, 1975–1999. Journal of the American Water Resource Association 40 (1), 111–127.

Paul, M.B., Linfield, C.B., 1997. Statistics for Environmental Engineers. Lewis publishers.

Richards, R.P., Baker, D.B., 2002. Trends in water quality in LEASEQ rivers and streams (Northwestern Ohio), 1975–1995. Journal of Environmental Quality 31 (1), 90–96.

Silverman, B.W., 1985. Some aspect of the spline smoothing approach to nonparametric regression curve fitting. Journal of Royal Statistical Society Series B:Methodological 47, 1–52.

U.S. Environmental Protection Agency (USEPA), 2007. Guideline for Data Quality Assessment, Washington, DC. http:www.epa.gov/OUST/cat/epaqag9.pdf2007.

Walesh, S.G., 1999. DAD is out, POP is in. Journal of the American Water Resources Association 35 (3), 535–544.

Walker, W.W., 1991. Water quality trends at inflows to Everglade's National Park. Journal of the American Water Resource Association 27 (1), 59–72.

Westmacott, J.R., Burn, D.G., 1997. Climate change effects on the hydrologic regime within the Churchill-Nelson river basin. Journal of Hydrology 202, 263–279.

Yang, H.S., Hwang, D.W., Kim, G.B., 2002. Factors controlling excess radium in the Nakdong River estuary, Korea: submarine groundwater discharge versus desorption from riverine particles. Marine Chemistry 78 (1), 1–8.

Zhang, P., 1998. An image construction method for visualizing managerial data. Decision Support Systems 23 (4), 371–387.

Zipper, C.E., Holtzman, G.I., Darken, P.F., Gildea, J.J., Stewart, R.E., 2002. Virginia USA water quality, 1978 to 1995: regional interpretation. Journal of the American Water Resource Association 38 (3), 789–802.