Seasonal Water Quality Trends in the Feitsui Reservoir Watershed, Taiwan

Pei-Te Chiueh, Hsiao-Ting Wu and Shang-Lien Lo

***Abstract*—**Protecting is the sources of drinking water is the first barrier of contamination of drinking water. The Feitsui Reservoir watershed of Taiwan supplies domestic water for around 5 million people in the Taipei metropolitan area. Understanding the spatial patterns of water quality trends in this watershed is an important agenda for management authorities. This study examined 7 sites in the watershed for water quality parameters regulated in the standard for drinking water source. The non-parametric seasonal Mann-Kendall's test was used to determine significant trends for each parameter. Significant trends of increasing pH occurred at the sampling station in the uppermost stream watershed, and in total phosphorus at 4 sampling stations in the middle and downstream watershed. Additionally, the multi-scale land cover assessment and average land slope were used to explore the influence on the water quality in the watershed. Regression models for predicting water quality were also developed.

***Keywords*—**Seasonal Mann-Kendall's test, Flow-adjusted concentrations, Water quality trends, Land-use

I. Introduction

SOURCE water protection is an integral part of the process of multi-barrier approach to safe drinking water [1]. Maintaining good water quality in the source area could reduce the process load in water treatment and ensures the safety and health of the drinking water. To understand how and why water quality is changing over time in the source area is essential for effectively managing and protecting the water source. Natural changes in precipitation and stream flow and human activities can influence water quality in watersheds [2, 3]. Two types of concentration trends can help discriminate the effects of natural and human activities on water quality. Observed concentrations indicate the human and natural changes, while flow-adjusted concentrations indicate the human changes. A comparison of trends in flow-adjusted and observed concentrations can provide insight into the effects of changes in stream flow on source water quality [2]. Land use in the watershed is also considered the main cause affecting the water quality [3, 4]. Therefore, multi-scale land use approach was often used to study the correlation of parameters - such as the land use, stream habitat, water quality, and fish assemblages - on various watersheds.

The Feitsui Reservoir of Taiwan serves as the main water source for the Taipei metropolitan area. The upstream watershed of the Feitsui Reservoir encompasses 213 km^2 of the BeiShi stream basin. A newly developed monitoring plan started from 2006 and conducted monthly sampling to identify the long term trends in the water quality data. This study uses the Seasonal Kendall trend test (SKT) [2], based on non-parametric statistics, to analyze the water quality trends in the study area.

SKT has been widely used in the study of water quality trends of various water sources. The study of Yu et al. [5] used SKT to examine 15 sampling stations in Kansas, USA, to detect the seasonal trends in 17 water quality components - such as the discharge rate, pH, water temperature, and dissolved oxygen - during 1975 and 1989. The test results indicated that, at a $p < 0.05$ level of significance, most of the water quality parameters have a significant downward, which might be related to increases in discharge or decreases in sources of pollution. Passel et al. [6] examined the nutrients, organic carbon, and the water quality trends at 6 sampling stations in the up-stream watershed of the Rio Grande in New Mexico and Colorado, USA, over 25 years from 1975 to 1999. Two trends tests, the SKT, and the non-seasonal Mann-Kendall test (MK) were used to test the diversity. The results showed that most of the water quality parameters are affected by seasonal factors, and hence are seasonal. Chang [7] used SKT to examine the water quality trends for 118 sampling sites in the Han River watershed for 8 water quality parameters, such as DO, pH, BOD, and SS, between 1993 and 2003.

The trend in the changing of water quality is a long-term and on-going process. The study on the change of trends should be based on water data observed over a long period, and on the information being collected to analyze the possible causes affecting trends in water quality. While the influence of land use type on water quality can be considered reasonably understood, the causes of temporal change in water quality and impacts of spatial scale from land use remain more uncertain. The objectives of this study are as follows: (1) To study the spatial distribution of water quality trends from 2006 to 2009; (2) To study the effects of flow adjustment regarding the water quality trends; and (3) To study the possible influencing factors of various land uses regarding water quality in the watershed. These results can provide practice for maintaining water resources and establish management policies for environmental issues.

II. Materials and Methods

Seven sampling sites were chosen in the Feitsui Reservoir watershed on the basis of the site distribution of main stream and tributaries (Fig. 1). Seven water quality indicators, including suspended solids (SS), biochemical oxygen demand

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(BOD), pH, ammonia-nitrogen (NH_3-N), dissolved oxygen (DO), total coliform (TC), and total phosphorus (TP) were examined. These water quality components are listed by the Environmental Protection Agency as water quality standards in surface water. The flow data were obtained from the 4 flow stations administered by the Water Resources Agency. In this study, the land use data and the digital elevation model (DEM) were obtained from photographs established by the National Land and Surveying Mapping Center in 2007. The land use is composed of forest land, agricultural land, and urban land. The data correlation between water quality and land use was analyzed, and regression models were developed to estimate water quality for various land uses.

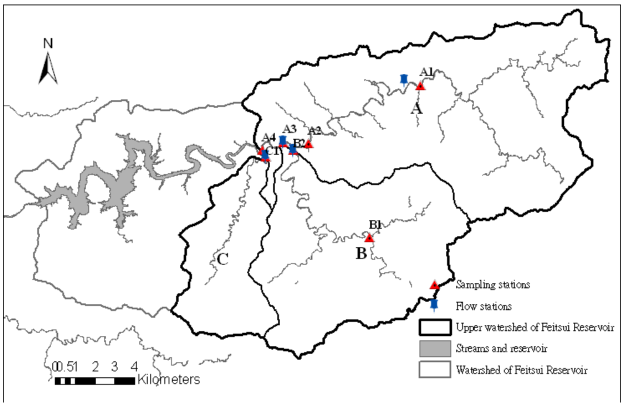
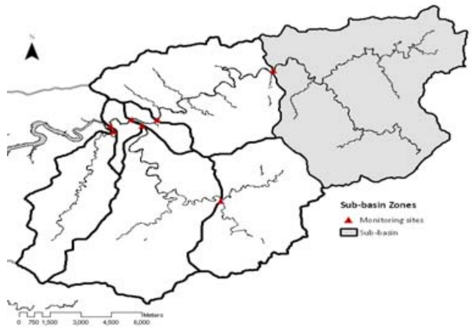


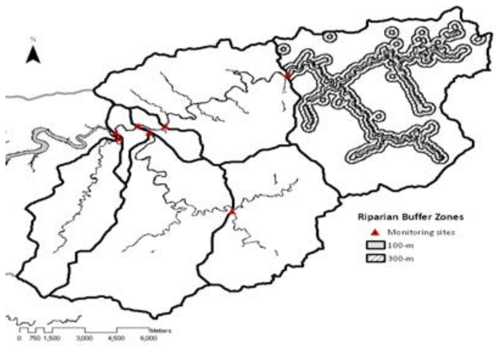
Fig. 1 Study area

Seasonal trends in observed and flow-adjusted concentrations were examined for each month from 2006 to 2009, using the SKT. The null hypothesis of the SKT is that there is no seasonal trend. Rejection of the null hypothesis will occur when a change in the same direction occurs at a site. Failure to reject the null hypothesis may result from a lack of trend at most data for the site. Hirsch and Slack [8] recommended the SKT as a robust method for accommodating seasonality in trend estimation for water quality records. In the present study, seasonal trends results were considered significant if the p-value was less than or equal to 0.10. The algorithms are described in detail by Evans et al. [9]. In order to account for the influence of flow rate variability in trend analysis, Hirsch et al. [10] suggested measuring trends in residuals from the flow and concentration relationships called Locally weighted scatterplot smoothing (LOWESS) approach [3]. Flow-adjusted concentrations were calculated as residuals from the LOWESS with a span of 0.5 in this study.

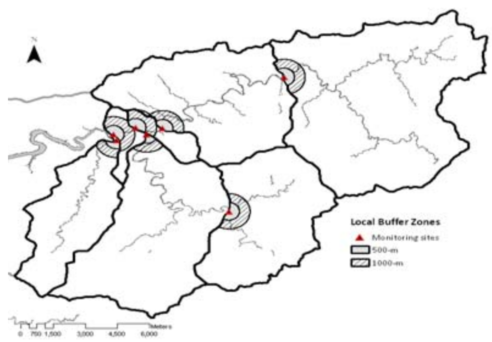
Based on previous research [3, 4], the study used 3 different scales of sub-watersheds as follows: (1) The zone at each sampling station; (2) The zone between 100 and 300 m from the stream side at each sub-watershed; and (3) The zone between 500 and 1000 m upstream from each sampling site (Fig. 2). The various land use percentages and the average land slopes were calculated according to multi-scale zones. The correlation between the percentages of various land usage and the average slopes in addition to variations in water quality were analyzed. In addition, multivariate regression analysis was used to establish the regression model of various land uses and average land slopes with respect to variations in water quality. The optimal model for predicting various parameters in water quality was derived to estimate the impacts caused by land use in the watershed.



(a) Sub-basin zone



(b) Riparian buffer zone



(c) Local buffer zone

Fig. 2 Multi-scale analysis

III. RESULTS AND DISCUSSION

A. Analysis Results of SKT

The results of SKT analysis on various components of water quality show that only the NH_3-N at B1, and the pH at the A1 and A3 sampling stations of the Beishi River have significant increasing trends. All other components show no significant trend, and hence are stable (Table I).

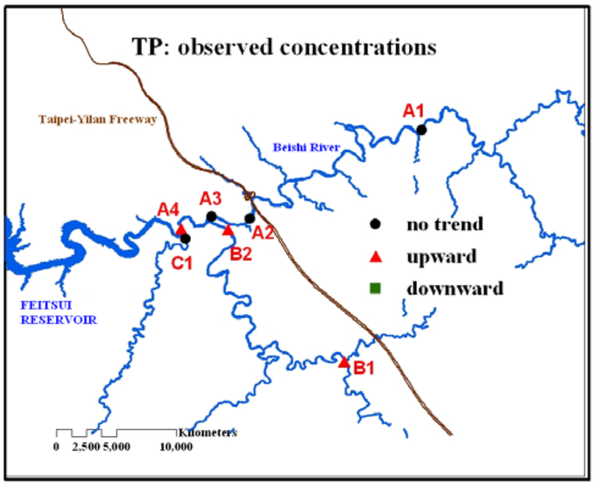
TABLE I
WATER QUALITY TRENDS OF 2006-2009 IN THE STUDY AREA

Constituents Station codes	DO (mg/L)	BOD (mg/L)	TC (CFU/100mL)	SS (mg/L)	NH_3-N (mg/L)	pH
A1	-	-	-	-	-	↑
A2	-	-	-	-	-	-
A3	-	-	-	-	-	↑
A4	-	-	-	-	-	-
B1	-	-	-	-	↑	-
B2	-	-	-	-	-	-
C1	-	-	-	-	-	-

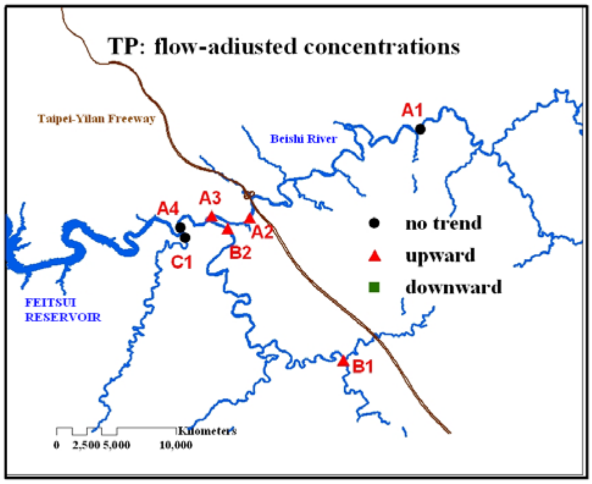
B. Trend Analysis of Flow-adjusted Concentrations

The spatial distributions of TP trend analysis of flow-adjusted concentrations for the 7 sites are illustrated in Fig. 3. The significant seasonal trend occurred at the A2, A3, B1, and B2; and also in the flow-adjusted concentrations of NH_3-N. It was considered which may correspond to the increase of agricultural activities in the same region. The increased use of fertilizer increases TP in the surface runoff, and thus upward trends were found in TP and NH_3-H concentrations.

The BOD measured at the B1 station, after its flow was adjusted, has a decreasing trend, which may be attributed to decreases in recreational activities after 2006, and hence improved water quality. The pH sampled at the A1 station located at the uppermost stream has an increasing trend. This upward trend may account for the fact that there is a lot of forest land coverage at upper reaches, and riparian agriculture land coverage, which results in the increase of nutrients facilitating algal eutrophication in the water. The photosynthesis of algae also consumes CO_2 in the water, and thus increases the pH concentrations.



(a) Observed concentrations



(b) Flow-adiusted concentrations
Fig. 3 Seasonal Kendall test results for TP

C. Regression Analysis on Multi-scale Land Use, Land Slope, and Water Quality

The sample data of water quality concentrations used at each sampling station are based on the median average value, taken over four years from 2006 to 2009 (Table II). Table III illustrates the correlations between land cover and TP median concentration based on of different analysis scales. The percentage of land use within 300 m of riparian and the average land slope has optimal explanatory power on the TP concentrations (R^2 = 0.823). The average land slope is negatively correlated with TP concentrations. Most urban and agricultural land has a flat slope, which means higher TP concentrations. Additionally, the urban development at both sides of riparian increases the percentage of impervious areas, which increases the chance of storm water runoff and slope erosion, hence increasing concentrations of TP.

TABLE II
MEDIUM VALUE OF THE ANALYSIS DATA

Median	DO (mg/L)	pH	BOD (mg/L)	TC (CFU/100mL)	TP (mg/L)	NH_3-N (mg/L)
A1	7.95	7.4	0.71	215	0.0208	0.0298
A2	7.79	7.3	0.70	1695	0.0198	0.0300
A3	7.86	7.4	0.73	1364	0.0246	0.0263
A4	7.91	7.6	0.66	579	0.0241	0.0325
B1	7.98	7.3	0.73	518	0.0225	0.0219
B2	7.93	7.6	0.75	599	0.0180	0.0363
C1	7.83	7.7	0.65	869	0.0225	0.0244

TABLE III
CORRELATION RESULTS FOR LAND COVER AND TP CONCENTRATIONS

TP(mg/l)	Land use %	Sub-basin	Riparian 100 m	Riparian 300 m	Local 500 m	Local 1000 m
Coefficients of Regression model	Urban	-0.06	0.036	0.228	-0.040	-0.041
	Agricultural	-0.078	0.015	0.113	-0.039	-0.038
	Forest	-0.069	0.011	0.110	-0.037	-0.030
	constant	0.089	0.1	-0.088	0.053	0.051
R^2		0.412	0.373	0.623	0.253	0.076

In the buffer zone within 1000 m, the regression model for predicting TC concentrations shows the highest explanatory power ($R^2 = 0.954$). Average land slope is negatively correlated with TC concentrations. Likewise, the slope of urban land use tends to be flat, which is prone to produce higher TC concentrations. It is most likely that urban land use accounts for the increase in TC concentrations.

In the buffer zone within 300 m, the regression model for predicting BOD concentrations shows the best explanatory power ($R^2 = 0.967$). It is noted that there is no effect on the increase in explanatory power regarding average land slope. The result suggests that BOD concentrations are mostly affected by land used within a buffer zone of 300 m. Moreover, the higher the percentage of land that is used for agriculture, the greater the increase in BOD concentrations in the stream. It is noted that pollutants from agricultural land use contain a large amount of nutrients, which provides sustenance for micro organic life forms, while increasing the BOD in the water.

IV. Conclusion

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

SKT can be used to estimate the water quality trends affected by seasonal changes. However, SKT cannot remove the possible effects of flow on the trends in water quality. To reduce the possibility that the trends are affected by the human factors, flow-adjusted concentrations are used in the test of trend analysis. In addition, a regression model based on the multi-scale land coverage assessment and average land slope is developed. The analysis indicates that the percentage of land use has an influence on water quality. If variables such as the percentage of riparian land use and average land slope are all incorporated in the regression model, the prediction of TP, TC, and BOD concentrations at the Feitsui Reservoir watershed can be significantly improved. The established regression models can be used to evaluate the impact of various land usages at the watershed on water quality, and thus provide an assessment tool for future planning and management.

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