Stream water quality impacted by different plantations in south subtropics

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Abstract Four types of plantations in Yunyong forest farm in Foshan, including needle-broad leaf mixed plantations (MP), evergreen broadleaf plantations (EBP), *Eucalyptus* plantations (EP) and *Cunninghamia lanceolata* plantation (CLP), were studied to characterize local stream water quality. The results indicated that the stream water in all plantations was slightly acid with pH of 5.93–6.34. Total nitrogen concentrations of stream water in MP and EBP were significantly lower than that in EP. The total nitrogen concentration in water was above 2.0 mg·L^{-1} in EP and CLP, exceeding the level V of environmental quality limit of surface water standard (EQSSW), while total phosphorus concentration reached the level Ⅱ or Ⅲ of EQSSW. For stream water in all plantations at different stand age, total water hardness and the concentrations of Cd, Hg met the standards of drinking water standard, while fluoride, Pb, Cu, Zn and Cr^{6+} and As achieved level I of EQSSW. Grey correlation analysis and principal component analysis result shows that stream water quality was the highest in the CLP, followed by EP, MP and EBP.

Keywords Stream water quality · Stand age · Plantation · South subtropics

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Introduction

The stream water is formed from rain, runoff, soil flow and groundwater collection after the precipitation through the woodland (Shi et al. 2008). Vegetation and soils play an important role in the regulation of chemical substances in water during the process that the precipitation is converted into runoff in the forest ecosystem (Liu et al. 2013). Vegetation is very sensitive to the change in water environment chemistry while it can directly or indirectly influences water quality. Therefore, it is of great significance to analyze the effect of forest vegetation on water environment, to explore the mechanism of water purification of forest ecosystem, and to understand the response of regional geochemical conditions to water environment process (Bu et al. 2010). The relationship between forest and water quality has become a hot topic of forest hydrology research (Zhao et al. 2008). Recent research relating stream water quality to forest effect is mainly focused on the effects of forest surface on stream water quality (Luo et al. 2013; Xiang et al. 2012; Wang et al. 2007; Zhang et al. 2012; Qiu et al. 2013), forest space key layer of water quality (Jin et al. 2013; Liu et al. 2011; Li et al. 2004; Li et al. 2013; Zhang & Li, 2007; Li et al. 2010; Brun et al. 2008) and the relationship between watershed landscape pattern and surface water conditions (Ou et al. 2012; Zhao et al. 2012). However, studies on the effects of planting native hardwood species and *Eucalyptus* sp. on water quality in the *Cunninghamia lanceolata* forest are rarely reported (Xiang et al. 2012). In this study, we examined the impacts of several plantations including the coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, eucalyptus forest and *C. lanceolata* forest at different forest ages in Yunyong forest farm, Foshan city on stream water quality using the gray correlation degree and the principal component analysis method. The findings from this study will provide valuable information for functional evaluation and sustainable management of plantation ecosystem.

Materials and methods

Study area

Research site is in Gaoming district Yunyong forest farm (112°40′E, 22°43′N) in Foshan city, Guangdong province. Being in the south subtropical humid monsoon climate zone, the site has annual mean temperature, maximum temperature, and minimum temperature of 22.0, 34.5 and 3.5 °C, respectively. The average annual precipitation is 2 000 mm, concentrated in April- August. The study area was characterized by acid red deep soils developed from granite on hilly terrain.

From 2002 to 2011, *C. lanceolata* forest was deforested. Reforestation species were selected from native broadleaf species and eucalyptus while the germination of *C. lanceolata* was also preserved on a single plant. In this study, four forest types were selected: *C. lanceolata*, coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, and eucalyptus forest (Table 1). The main reforestation broadleaf species is *Rhodoleia championii*, *Spathodea campanulat*, *Michelia macclurei*, *Mytilaria laosensis*, *Cinnamomum burmannii*, *Elaeocarpus sylvestris*, *Liquidambar formosana*, *Cinnamomum camphora*, *Erythrophleum fordii*, *Schima superba*, *Castanopsis fissa*, *Evodia glabrifolia, Sterculia lanceolata*, *Toona sinensis, Cinnamomum porrectum*, *Manglietia glauca*.

Method

Some small streams within typical plantation (evergreen broadleaf forest, coniferous and broad-leaved mixed forest, *Eucalyptus* forest and *C. lanceolata* forest) were selected for the research. Three sampling locations were established for each forest type at 9-11 years old and 5-7 years old (Table 1) with a total of 21 sampling sites. Sampling points are located at the outlet of each small watershed. The distance between sampling points was greater than 500 m. Water samples were collected once per day for 3 days on sunny days in May, August, and October 2014. Each water sample was collected into a clean plastic bottle at volume of 550 mL for analysis.

All indicators of the measurement methods are reference to Chinese national standards (Xie & Wang, 1998) (Table 2).

Table 1 Sampling site description

Stand age (a)	Forest type	DHB (cm)	Height (m)	Canopy closure
9–11	Coniferous and broad - leaved mixed forest	9.0	8.1	0.9
	Evergreen broad - leaved forest	10.2	8.8	0.7
	Eucalyptus forest	11.1	10.4	0.7
5–7	Coniferous and broad - leaved mixed forest	5.7	4.8	0.6
	Evergreen broad - leaved forest	5.7	4.7	0.5
	Eucalyptus forest	12.7	11.5	0.6
12	*C. lanceolata* forest	11.6	11.5	0.7

Table 2 Indicators of the measurement method

Indicator	Abbreviation	Measurement method
pH value	pH	Ysi-6600eds environmental monitoring system
Dissolved oxygen		Ysi-6600eds environmental monitoring system
Chemical oxygen demand	COD	Potassium dichromate method
Permanganate index		Acid method
Biochemical oxygen demand	BOD_5	Dilution inoculation method
Ammonium nitrogen	NH_4^+–N	Nessler's reagent spectrophotometry
Nitrate nitrogen	NO_3^-–N	Phenols disulfonic acid photometric method
Total phosphorus		Potassium persulfate oxidation - molybdenum antimony spectrophotometric method
Total nitrogen		Potassium persulfate oxidation - ultraviolet spectrophotometry
Cu content	Cu	Flame atomic absorption spectrophotometry
Zn content	Zn	Flame atomic absorption spectrophotometry
As content	As	Flame atomic absorption spectrophotometry
Hg content	Hg	Cold atomic absorption method
Fluoride		Ion selective electrode method
Cd cotent	Cd	Graphite, atomic absorption spectrophotometry
Pb content	Pb	Graphite, atomic absorption spectrophotometry
Cr^{6+} content	Cr^{6+}	Diphenylcarbazide spectrophotometry

Data analysis

Microsoft excel 2010 and SPSS 16.0 were used for required data analysis. Based on the surface water quality standard, the representative water quality index of the stream is selected as the reference sequence, and the water quality evaluation standard is the comparative sequence. The level of the reference sequence corresponding to the maximum degree of correlation is based on the level of the stream (Zhang et al. 2004; Huang et al. 2014; Wang et al. 2012; Lv & Dong, 2011).

Results

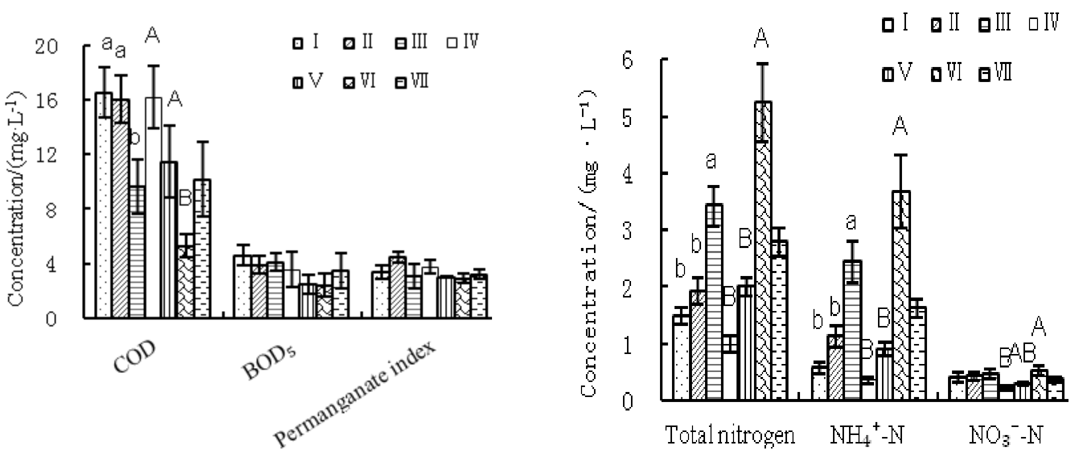
Water quality analysis of artificial forest stream in different age group

Water samples collected from stream within plantation forests has a pH varying between 5.93–6.34, slighly acid (Table 3). Acid rain and soil surface acidification may be the main reason for the low pH in the streams. The dissolved oxygen concentration sampled from stream within *C. lanceolata* was the highest. The dissolved oxygen of sample from stream under 9–11 years old and 5–7 years old forest of plantation was between 7.97–8.40 mg/L and 6.98–8.63 mg/L, respectively. Dissolved oxygen of stream water was higher under coniferous and broad-leaved mixed forest and *Eucalyptus* forest than under evergreen broad - leaved forest. The TDS of water samples from stream under 9–11 years old and 5–7 years old forest stands were between 0.037–0.053 g/L and 0.046–0.054 g/L, respectively. TDS was generally low in the stream under *C. lanceolata* (0.038 $g·L^{-1}$). The total chlorophyll content of *Eucalyptus* forest was lower than that of coniferous and broad - leaved mixed forest and evergreen broad - leaved forest. The total chlorophyll content (17.09 $g·L^{-1}$) of *C. lanceolata* forest was close to that of 5–7 years old evergreen broad-leaved forest.

The content of COD in the water flowing through plantation forest ranged from 5.33 to 16.56 $mg · L^{-1}$. The water COD from stream under 5–7 years old evergreen broad-leaved forest and 12-year-old *C. lanceolata* forest met the surface water Ⅰ Standard (≤ 15 $mg·L^{-1}$). However, the COD of stream water under *Eucalyptus* forest was significantly lower than that under coniferous and broad - leaved mixed forest and evergreen broad -

Table 3 Comparison of water quality indexes of artificial forest streams in different ages of south subtropics

Stand age (a)	Forest type	pH	Dissolved oxygen ($mg \cdot L^{-1}$)	Solid content ($g \cdot L^{-1}$)	Chlorophyll content ($mg \cdot L^{-1}$)
9–11	Coniferous and broad - leaved mixed forest（Ⅰ）	6.25±0.25	8.25±0.09	0.037±0.002	19.68±6.47
	Evergreen broad - leaved forest（Ⅱ）	6.05±0.29	7.97±0.28	0.041±0.003	18.39±6.33
	Eucalyptus forest（Ⅲ）	6.34±0.09	8.40±0.09	0.053±0.003	13.00±6.34
5–7	Coniferous and broad - leaved mixed forest（Ⅳ）	5.95±0.20	8.63±0.10	0.046±0.004	12.66±5.35
	Evergreen broad - leaved forest（Ⅴ）	6.28±0.27	6.98±0.41	0.054±0.008	17.50±6.35
	Eucalyptus forest（Ⅵ）	5.93±0.25	8.55±0.07	0.054±0.005	6.95±1.69
12	*C. lanceolata* forest（Ⅶ）	6.21±0.35	10.56±0.19	0.038±0.001	17.09±7.75



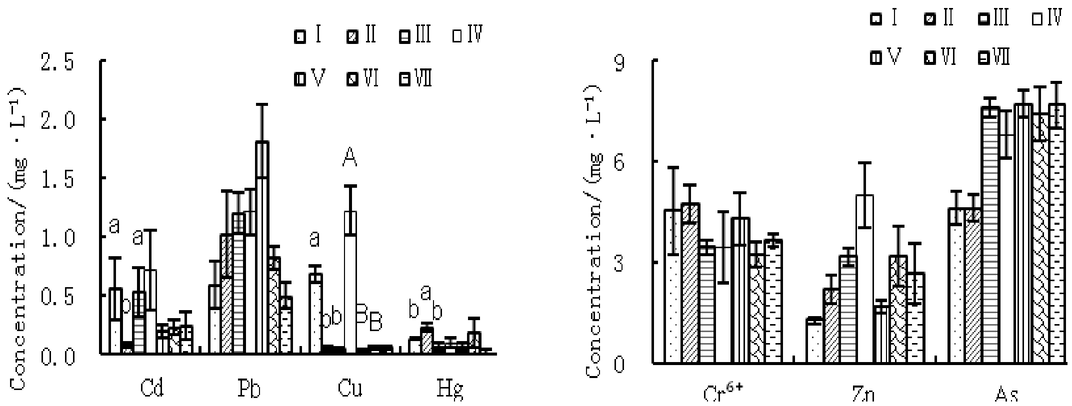
Note: Ⅰ, Ⅱ, Ⅲ for 9-11 years old coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest, Ⅳ, Ⅴ, Ⅵ for 5-7 years old coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest, and Ⅶ for 12 years old fir forest. Different lowercase letters indicate that the water quality index under 9-11 years old forest is significantly different at α = 0.05, and different uppercase letters indicate that the water quality index under 5-7 years old forest is significantly different at α = 0.05.

Figure 1 COD, BOD_5, permanganate, total nitrogen, NH_4^+-N and NO_3^--N of water under different types of plantations in Yunyong forest farm

leaved forest (P <0.05). The range of BOD_5 was 2.43–4.63 $mg \cdot L^{-1}$, and there was no significant difference among the artificial forest in the same age group. The BOD_5 level of stream water under 5-7 years old evergreen broadleaved forest and 5-7 years old *Eucalyptus* forest also met the standard of surface water Ⅰ (≤ 3 $mg \cdot L^{-1}$). The permafrost index ranged from 2.94 to 4.45 $mg \cdot L^{-1}$, showing no dependence on the artificial forest in the same age group. Except for the water under 9-11 years old evergreen broad-leaved forest, water under other plantations reached surface water Class II standard (2–4 $mg \cdot L^{-1}$).

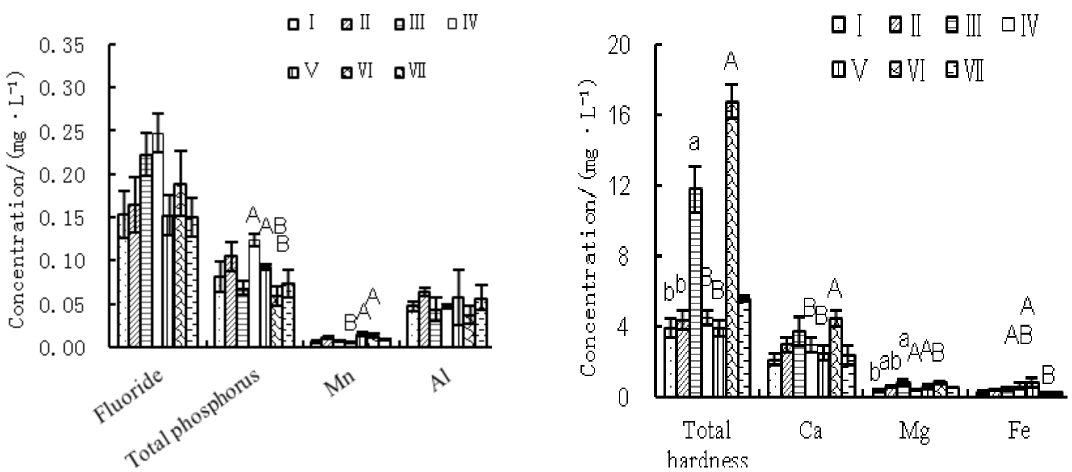
The changes of total nitrogen, NO_3^--N and NH_4^+-N contents were consistent, displaying some dependence on forests with *Eucalyptus* forest> *C. lanceolata*> evergreen broad - leaved forest> coniferous and broad - leaved mixed forest. Nitrogen is mainly present in the form of NO_3^--N in streams. The contents of total nitrogen and NO_3^--N of stream water in *Eucalyptus* forest were significantly higher than those in coniferous and broad - leaved mixed forest and evergreen broad - leaved forest (P <0.05). There was significant difference between 5-7 years old *Eucalyptus* forest, coniferous and broad - leaved mixed forest (P <0.05). The total nitrogen content of the stream in *Eucalyptus*, *C. lanceolata* and 5-7 years old evergreen broad - leaved forest exceeded the standard of surface water Ⅴ (> 2.0 mg·L^{-1}).

There was no significant difference in Pb, Cr^{6+}, Zn and As of stream water within coniferous and broad - leaved mixed forest, evergreen broad - leaved forest and *Eucalyptus* forest. The content of Cu of stream water varied with forest with coniferous and broad - leaved mixed forest, higher than that in evergreen broad - leaved forest and *Eucalyptus* forest (P<0.05). The Cd content of stream in 9-11a evergreen broad-leaved forest was significantly lower than that in the coniferous and broad-leaved forest and *Eucalyptus* forest (P <0.05), and the content of Hg was significantly higher than that of the latter two (P <0.05). The content of Cd of stream water in the plantation was lower than 1 mg·L^{-1} and the content of Hg was 0.03–0.24 mg·L^{-1}, which was lower than that of national drinking water (Cd: 5 mg·L^{-1}; Hg: 0.001 mg·L^{-1}). Pb and Cu contents were lower than 0.01 mg·L^{-1}, Cr^{6+} content is between 3.22–4.72 mg·L^{-1}, Zn and As contents were between 1.3–5.0 mg·L^{-1} and 4.6–7.7 mg·L^{-1}, respectively, which reached the standard of



Note: Ⅰ, Ⅱ, Ⅲ for 9-11 years old coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest, Ⅳ, Ⅴ, Ⅵ for 5-7 years old coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest, and Ⅶ for 12 years old fir forest. Different lowercase letters indicate that the water quality index in 9-11 years old forest is significantly different at α = 0.05, and different uppercase letters indicate that the water quality index in 5-7 years old forest is significantly different at α = 0.05.

Figure 2 Cd, Pb, Cu, Hg, Cr^{6+}, Zn and As of stream water in different types of plantations in Yunyong forest farm



Note: Ⅰ, Ⅱ, Ⅲ for 9-11 years old coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest, Ⅳ, Ⅴ, Ⅵ for 5-7 years old coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest, and Ⅶ for 12 years old fir forest. Different lowercase letters indicate that the water quality index of stream in 9-11 years old forest is significantly different α = 0.05, and different uppercase letters indicate that the water quality index of stream in 5-7 years old forest is significantly different at α = 0.05.

Figure 3 Fluoride, total phosphorus, Mn, Al, total hardness, Ca, Mg, and Fe for different plantations type in Yunyong forest farm surface water 1(Fig. 2).

The contents of fluoride, total phosphorus, Mn, and Al in plant water were between 0.150–0.247 mg·L^{-1}, 0.059–0.124 mg·L^{-1}, 0.005-0.015 mg·L^{-1} and 0.037–0.064 mg·L^{-1}, respectively. Among them, the fluoride content reached the surface water class Ⅰ standard. Total phosphorus content met the surface water class Ⅱ or Ⅲ standard. Mn, Al content was lower than the national drinking water health standards (≤ 0.1 mg·L^{-1}). The total phosphorus content of stream water in 5-7 years old coniferous and broad - leaved mixed forest was significantly higher than that of *Eucalyptus* forest (P <0.05), and the content of Mn was opposite. The difference between the other indexes was not significant. The total hardness of water in different plantations ranged from 3.94 to 16.77 mg·L^{-1}, which was much lower than the limit of hygienic standard of domestic drinking water (≤ 450 mg·L^{-1}). The total hardness, Ca, and Mg concentration of stream water at varied with forest type at same forest stage with *Eucalyptus*> evergreen broad - leaved forest and coniferous and broad - leaved mixed forest, indicating that the soil eruption of *Eucalyptus* forest was stronger. This may be due to the relatively low terrain of the *Eucalyptus* forest. Long-term soil water increases the solubility of CO_2 in soil water caused by plant root respiration. Soil insoluble $CaCO_3$ is converted to water soluble Ca $(HCO_3)_2$ (Man et al. 2006). The calcium content in the water in the *Eucalyptus* forest increased. Fe content was between 0.240 and 0.859 mg·L^{-1}. The Fe content of stream water in 5-7 years old eucalyptus forest and 12 years old *C. lanceolata* forest was lower than the limit of national drinking water health standard (≤ 0.3 mg·L^{-1}).

Water quality evaluation of stream water based on gray correlative degree analysis

The main pollution indicators that represent the environmental quality were used to carry out the environmental quality assessment. pH, dissolved oxygen, COD, permanganate index, BOD_5, NH_4^+-N, NO_3^--N, total phosphorus, total nitrogen, Cu, Zn, As, Hg, fluoride, Cd, Pb and Cr^{6+} are used as evaluation factors. The gray correlation model was used to evaluate the water quality of four forest types. As the water quality monitoring data and evaluation criteria in the parameters of the standard is not the same. To eliminate the inconsistency of the dimension, it is necessary to carry out dimensionless processing on the parameters of the observed data and the evaluation criteria (Li et al. 2014). This paper selects three standards of water quality evaluation as a reference value. The measured values of water quality and the standard values were divided by the reference values of the corresponding parameters to obtain dimensionless values of the parameters (Table 4-5). The correlation coefficient and correlation degree are deried by gray correlation degree calculation, and the correlation degree between water quality and water quality level of different forest stands was obtained (Table 6). If the stream water quality and a certain water quality level has the greatest degree of correlation, then that stream water quality belongs to the water quality level (Li et al. 2014). The forest water of different forest age coniferous and broad-leaved mixed forest, evergreen broad-leaved forest, *Eucalyptus* forest and *C. lanceolata* forest reached the standard of surface water Ⅰ (Table 6).

Evaluation of stream water quality based on principal component analysis

According to the principle of eigenvalue ≥ 1, five principal components are extracted (Table 7). The cumulative contribution rate of the first five principal components is 96.340%, which can reflect the water quality of the stream. The indexes of the first principal component factor load are COD and total nitrogen. The indicators of the second main component factor load are fluoride and Zn. The index of the third principal component factor load is NH_4^+-N and pH value. The indexes of the fourth principal component factor load are Hg and dissolved oxygen. The indexes of the fifth principal component factor load are dissolved oxygen and Cd.

The main components are the original 17 indicators (pH, dissolved oxygen, COD, permanganate index, BOD_5, NH_4^+-N, NO_3^--N, total phosphorus, total nitrogen, Cu, Zn, As, Hg, Cd, Pb and Cr^{6+}, hereinafter referred to as X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16} and X_{17}, respectively), and

Table 4 Non-dimensionality of water quality assessment criteria (reference series)

Index	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
pH	0.800	0.933	1.000	1.067	1.200
Dissolved oxygen	1.500	1.200	1.000	0.600	0.400
COD	0.750	0.750	1.000	1.500	2.000
Permanganate index	0.333	0.667	1.000	1.667	2.500
BOD_5	0.750	0.750	1.000	1.500	2.500
NH_4^+-N	0.150	0.500	1.000	1.500	2.000
NO_3^--N	0.400	0.500	1.000	1.000	1.250
Total phosphorus	0.100	0.500	1.000	1.500	2.000
Total nitrogen	0.200	0.500	1.000	1.500	2.000
Cu	0.010	1.000	1.000	1.000	1.000
Zn	0.050	1.000	1.000	2.000	2.000
As	1.000	1.000	1.000	2.000	2.000
Hg	0.500	0.500	1.000	10.000	10.000
Fluoride	1.000	1.000	1.000	1.500	1.500
Cd	0.200	1.000	1.000	1.000	2.000
Pb	0.200	0.200	1.000	1.000	2.000
Cr^{6+}	0.200	1.000	1.000	1.000	2.000

Table 5 Non-dimensional analysis of water quality observation indicators for different types of plantations in Yunyong forest farm (comparative series)

Index	9-11 years old forest			5-7 years old forest			*C. lanceolata* forest
	Coniferous and broad-leaved mixed forest	Evergreen broad-leaved forest	*Eucalyptus* forest	Coniferous and broad-leaved mixed forest	Evergreen broad-leaved forest	*Eucalyptus* forest	
pH	0.8340	0.8070	0.8450	0.7930	0.8370	0.7910	0.8280
Dissolved oxygen	1.6500	1.5930	1.6790	1.7250	1.3950	1.7090	2.1120
COD	0.8280	0.8010	0.4820	0.8090	0.5730	0.2660	0.5090
Permanganate index	0.5630	0.7420	0.5170	0.6230	0.4990	0.4890	0.5340
BOD_5	1.1580	0.9810	1.0330	0.8930	0.6310	0.6080	0.8710
NH_4^+-N	0.4140	0.4190	0.4650	0.3620	0.2990	0.5240	0.3630
NO_3^--N	0.0290	0.0560	0.1210	0.0100	0.0450	0.1830	0.0810
Total phosphorus	0.4060	0.5230	0.3390	0.6200	0.4670	0.2930	0.3680
Total nitrogen	1.4820	1.9260	3.4240	0.9870	2.0070	5.2360	2.7760
Cu	0.0007	0.0001	0.0001	0.0012	0.0000	0.0001	0.0001
Zn	0.0013	0.0022	0.0032	0.0050	0.0017	0.0032	0.0027
As	0.0927	0.0927	0.1527	0.1367	0.1533	0.1480	0.1533
Hg	1.3500	2.3633	0.6800	1.0167	0.6800	1.8567	0.3467
Fluoride	0.1532	0.1653	0.2228	3.7400	2.9933	2.9367	0.1503
Cd	0.1130	0.0158	0.1054	0.1436	0.0409	0.0459	0.0507
Pb	0.0119	0.0204	0.0239	0.0242	0.0362	0.0165	0.0101
Cr^{6+}	0.0901	0.0943	0.0687	0.0686	0.0858	0.0643	0.0729

Table 6 The correlation of water quality in different types of plantation in Yunyong forest farm

Class	9-11 years old forest			5-7 years old forest			12 years od *C. anceola-ta* forest
	Coniferous and broad-leaved mixed forest	Evergreen broad-leaved forest	*Eucalyptus* forest	Coniferous and broad-leaved mixed forest	Evergreen broad-leaved forest	*Eucalyp-tus* forest	
Ⅰ	0.889	0.874	0.889	0.885	0.891	0.853	0.887
Ⅱ	0.833	0.824	0.829	0.833	0.834	0.789	0.826
Ⅲ	0.779	0.766	0.756	0.785	0.752	0.713	0.743
Ⅳ	0.813	0.810	0.792	0.799	0.799	0.777	0.789
Ⅴ	0.762	0.770	0.751	0.750	0.762	0.736	0.750

the number is the feature vector *rij*. It can represent the importance of individual indicators for the principal component and determine the practical significance of the principal component. According to the principal component formula, we can get the linear combination of the five principal components and the original 17 indexes (Formula (1) -(5)).

$$Z_1 = 0.002X_1 - 0.044X_2 + 0.163X_3 + 0.117X_4 + 0.094X_5 - 0.087X_6 - 0.152X_7 + 0.135X_8 - 0.155X_9 + 0.098X_{10} - 0.016X_{11} - 0.115X_{12} + 0.028X_{13} - 0.018X_{14} + 0.049X_{15} + 0.018X_{16} + 0.111X_{17} \quad (1)$$

$$Z_2 = -0.098X_1 - 0.003X_2 - 0.009X_3 - 0.059X_4 - 0.111X_5 - 0.089X_6 - 0.055X_7 + 0.123X_8 - 0.048X_9 + 0.160X_{10} + 0.213X_{11} + 0.152X_{12} - 0.112X_{13} + 0.229X_{14} + 0.145X_{15} + 0.122X_{16} - 0.163X_{17} \quad (2)$$

$$Z_3 = -0.250X_1 + 0.147X_2 + 0.026X_3 + 0.141X_4 + 0.097X_5 + 0.231X_6 + 0.078X_7 + 0.011X_8 + 0.065X_9 + 0.136X_{10} + 0.182X_{11} - 0.123X_{12} + 0.191X_{13} - 0.012X_{14} + 0.090X_{15} - 0.223X_{16} - 0.114X_{17} \quad (3)$$

$$Z_4 = -0.207X_1 - 0.239X_2 - 0.024X_3 + 0.117X_4 - 0.215X_5 + 0.033X_6 + 0.054X_7 + 0.095X_8 + 0.058X_9 - 0.081X_{10} - 0.019X_{11} - 0.064X_{12} + 0.266X_{13} + 0.179X_{14} - 0.217X_{15} + 0.178X_{16} + 0.098X_{17} \quad (4)$$

$$Z_5 = 0.190X_1 - 0.517X_2 + 0.017X_3 - 0.227X_4 + 0.221X_5 + 0.348X_6 + 0.098X_7 - 0.158X_8 + 0.076X_9 + 0.180X_{10} - 0.078X_{11} - 0.135X_1 + 0.120X_{13} + 0.077X_{14} + 0.428X_{15} + 0.215X_{16} - 0.025X_{17} \quad (5)$$

The standardized data were substituted into the formulas (1) – (5), and the scores of the five principal components were obtained. According to $F = b_1Z_1 + b_2Z_2 + b_3Z_3 + b_4Z_4 + ... b_kZ_k$, the comprehensive score F is obtained. The larger the F value, the worse the quality of the water sample (Li et al. 2010). *C. lanceolata* forest water quality is the best. Among same age plantations, the water quality of stream is better for the *Eucalyptus* forest. While coniferous and broad-leaved mixed forest and evergreen broad-leaved forest are poor in water quality (Table 8).

Discussion

The results showed that stream water was weakly acidic regardless of plantation type and the pH value was lower than that of Qinling forest (Lv et al. 2011; Man et al. 2006). The forest runoff, acid rain and soil surface acidification in Xiaoxing'anling of Heilongjiang might be the main reason for the low pH value of the plantation water (Chen et al. 2004; Yao & Liang, 2012). During 2006–2010, the acid rain frequency was 79%, the mean pH value of atmospheric precipitation was 4.57, and the acid rain pollution was more serious in Foshan city (Yao & Liang, 2012). The effect of different forest types on the pH of rainwater is very different. The rainwater pH through *Pinus radiata* after is reduced, but the pH is increased through the forest of *Fagus orientalis* and *Quercus petraea* (Alfredsson et al. 1998; Eisalou et al. 2013). The reason is that the litter of coniferous forest is more acidic than that of broadleaf forest. Qinling forest can make neutral (pH=6.65) of atmospheric precipitation into weak alkaline (pH=8.05) (Zhang & Li, 2007). The change of pH of surface water is not only related to the physical and chemical properties of precipitation

Table 7 Factor load of water quality in different types of plantation in Yunyong forest farm

Index	First principal component	Second principal component	Third principal component	Fourth principal component	Fifth principal component
pH	0.002	–0.098	–0.250	–0.207	0.190
Dissolved oxygen	–0.044	–0.003	0.147	–0.239	–0.517
COD	0.163	–0.009	0.026	–0.024	0.017
Permanganate index	0.117	–0.059	0.141	0.117	–0.227
BOD_5	0.094	–0.111	0.097	–0.215	0.221
NH_4^+-N	–0.087	–0.089	0.231	0.033	0.348
NO_3^--N	–0.152	–0.055	0.078	0.054	0.098
Total phosphorus	0.135	0.123	0.011	0.095	–0.158
Total nitrogen	–0.155	–0.048	0.065	0.058	0.076
Cu	0.098	0.160	0.136	–0.081	0.180
Zn	–0.016	0.213	0.182	–0.019	–0.078
As	–0.115	0.152	–0.123	–0.064	–0.135
Hg	0.028	–0.112	0.191	0.266	0.120
Fluoride	–0.018	0.229	–0.012	0.179	0.077
Cd	0.049	0.145	0.090	–0.217	0.428
Pb	0.018	0.122	–0.223	0.178	0.215
Cr^{6+}	0.111	–0.163	–0.114	0.098	–0.025
Eigenvalues	6.116	3.639	2.839	2.636	1.147
Contribution rate (%)	35.979	21.403	16.700	15.508	6.749
Cumulative contribution rate (%)	35.979	57.382	74.083	89.591	96.340

Table 8 The main component score and comprehensive score table in different types of plantation in Yunyong forest farm

Age (a)	Forest type	F_1	F_2	F_3	F_4	F_5	F	Sequence
9–11	Coniferous and broad – leaved mixed forest	0.330	–0.190	0.027	–0.126	0.069	0.110	5
	Evergreen broad – leaved forest	0.330	–0.249	0.079	0.193	–0.042	0.311	6
	Eucalyptus forest	–0.241	–0.028	–0.037	–0.138	0.074	–0.369	2
5–7	Coniferous and broad – leaved mixed forest	0.339	0.405	0.132	–0.008	–0.003	0.865	7
	Evergreen broad – leaved forest	0.015	0.098	–0.343	0.126	0.003	–0.102	4
	Eucalyptus forest	–0.590	0.015	0.149	0.136	0.021	–0.269	3
12	*C. lanceolata* forest	–0.187	–0.050	–0.023	–0.184	–0.123	–0.567	1

and water body, but also to the ability of soil subsidence in subsurface waters, the rate of bedrock mineralization and vegetation type (Kernan et al. 1998). Chen et al (2004) found that the secondary forest in the Pearl River Delta and the secondary mixed forest could increase the pH of the rainwater entering the forest. The mechanism was mainly the neutralization effect of the cation in the weathered and hydrolyzed granite.

The content of total nitrogen in the water flowing through coniferous and broad-leaved mixed forest and evergreen broad-leaved forest was significantly lower than that of *Eucalyptus* forest, while the total phosphorus content was significantly higher than that of *Eucalyptus* forest. The total nitrogen content of water through eucalyptus and *C. lanceolata* was greater than 2.0 mg·L^{-1}, exceeding the standard value of the surface class Ⅴ, for the eutrophic type. In addition to the effects of soil physical and chemical properties, the nutrient use strategies of different species are also one of the factors that affect the N and P contents of the streams. As the age increases, the change of nitrogen leaching in the *Picea asperata* forest is very small, While the oak forest nitrogen leaching amount is declining, which will inevitably affect the forest stream water N content (Van der Salm et al. 2006). *Eucalyptus* herbaceous fertilization may influence the increase in the N content of the stream. The concentration of NO_3^--N was higher than that of NH_4^+-N in the stream. NO_3^--N is not easily adsorbed by the soil, but it is easy to fall with the precipitation and runoff, which leads to the high concentration of NO_3^--N in the stream (Foster et al. 1989; Simmons et al. 1992). In addition, the Pearl River Delta region of nitrogen deposition is serious, it is bound to enter through the precipitation more NO_3^-–N (Ren et al. 2000; Zhou & Yan, 2001). *Eucalyptus* forest water total phosphorus content is low. *Eucalyptus* forest is relatively low terrain. The soil is easy to accumulate water, while the water particles or soil adsorption of P will increase. Soluble inorganic phosphorus is easy to precipitate or adsorb with Al^{3+}, Fe^{3+}, Ca^{2+} in soil, which leads to the decrease of P content in stream water （Liang & Wu, 2000）.

The water quality of *C. lanceolata* is the best, followed by *Eucalyptus* forest, while coniferous and broadleaved mixed forest and evergreen broad-leaved forest are poor in water quality, but the water quality of these forest types is the standard class Ⅰ of surface water. The forest stands are middle and young plantations in our study. Forest structure and function are not mature. The interference of human activities is also greater. Therefore, the influence of multiple factors such as age, species physiological characteristics, soil physical and chemical properties, human disturbance and so on cannot be separated. It is still necessary to study the water quality of plantations of different forest types.

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