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Appearance's Aesthetic Appreciation to Inform Water Quality Management of Waterscapes

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Abstract

The appearance of the water is just one aspect of a waterscape that can be appreciated aesthetically. Water appearance is affected by water clarity and water colour. Here, an aesthetic assessment model of waterscape was suggested. In the model, water clarity and colour have direct effects, whereas water quality and phytoplankton biomass have indirect effects, on tourists' aesthetic assessment of water bodies. The preferred water colour is aquamarine to blue, regardless of depth of clarity. Water colour ranges from pastel yellow to yellow-green are not favoured by tourists. Four water-quality parameters were correlated with water clarity and phytoplankton biomass. The coefficient of indirect effect of river pollution index on tourists' aesthetic valuation of aquamarine to blue water colour was −0.457, and for pastel yellow to yellow-green, it was −0.209. The research results showed observation of water colour could not only reflect waterscape aesthetic value, but also serve as a guide of judging water quality, and the status of phytoplankton benefited to simplify the process of water-quality management for waterscape.

Keywords

Aesthetic Preference, Phytoplankton, Water Clarity, Water Colour, Water Quality

1. Introduction

Waterscapes have high visual values and are the most preferred landscape for the public. Thus, they might serve as a dominant contributor to visual amenity [1] [2] [3]. Moreover, public experience and preference for waterscapes extend well beyond the domain of aesthetics in that they can not only arouse positive emotion but also promote restoration from psychological stress and mental fatigue [4] [5] [6] [7] [8] [9]. The appearance of water bodies influences the public's preferences and aesthetic evaluation, and these preferences are most affected by water clarity and water colour [10]-[17] [18]. Sakici [19], Gregory & Davis [20] pointed that the water colour and quality are the predictors of river scenic aesthetic preference; and water bodies with algae were disliked [21]. Because waterscape are an important resource for tourism, there needs to classify and manage [22]. Understanding the relationship between the appearance of water body (e.g. water clarity, water colour) and tourists' aesthetic assessments of water bodies is important for attracting tourists to waterscapes.

Water quality is assessed on the basis of water clarity, with increased clarity positively influencing the assessment of the scenic beauty of waterscapes [14] [16] [17] [23] [24], and tourists' recreational preferences [12] [14] [24]. Water clarity results from a combination of various water-quality parameters. Meanwhile, changes in water colour can override water quality as a determinant of aesthetic value [25].

Water clarity and water colour is affected by water quality; for example, suspended material causes light attenuation, which reduces the visual range, clarity and changes water colour [11] [15] [16] [17] [26]. Phytoplankton also contributes significantly to reducing clarity [27], whereas changes in transparency of water bodies may be caused by increasing turbidity due to rising concentrations of mineral materials or increasing plankton biomass [28].

Phytoplankton can also affect water colour [29]. The level of water quality has a great influence on algal growth; for example, the amount of phosphorus in water bodies has a negative effect on water quality, leading to phenomena such as algal blooms [30], which can also degrade the visual appeal of water bodies. Further, excess algae may lead to oxygen depletion, which can again impact water clarity. Dissolved material, suspended material, and phytoplankton bloom may change the colour of water [31], which can impact aesthetic assessments. For example, blue water colour has been assessed to have a higher aesthetic value; gray colour is perceived as non-vigorous; brown water is perceived as unclear, which might arouse negative emotions and convey a low aesthetic value [16] [17] [25] [32].

Water quality is influenced by several parameters, including water temperature, chlorophyll content, turbidity, total phosphorus (TP), nitrogen, *Escherichia coli* (*E. coli*), and oil content [25] [33] [34] [35]. Different physico-chemical water parameters may positively or negatively influence water quality. For example, increased dissolved oxygen (DO) is typically associated with high water quality. Conversely, increased biological oxygen demand (BOD) is associated with low water quality. The US National Sanitation Foundation considers concentrations of seven water-quality parameters (including DO, *E. coli*, BOD, ammoniac nitrogen [NH3-N], suspended solids [SS], and TP) as the main parameters to determine water quality levels [36]. In Taiwan, the Environmental Protection Administration (EPA) uses four parameters, namely, DO, BOD, SS and NH3-N concentrations, to determine river water quality [37], and also conducts assessments of water temperature, pH, conductivity, TP, and *E. coli* to determine general water quality. In contrast, Taiwan's Water Resources Agency (WRA) [38] stresses that seven water-quality parameters (water temperature, pH, DO, BOD, NH3-N, SS, and conductivity) must be measured during a river-water quality investigation.

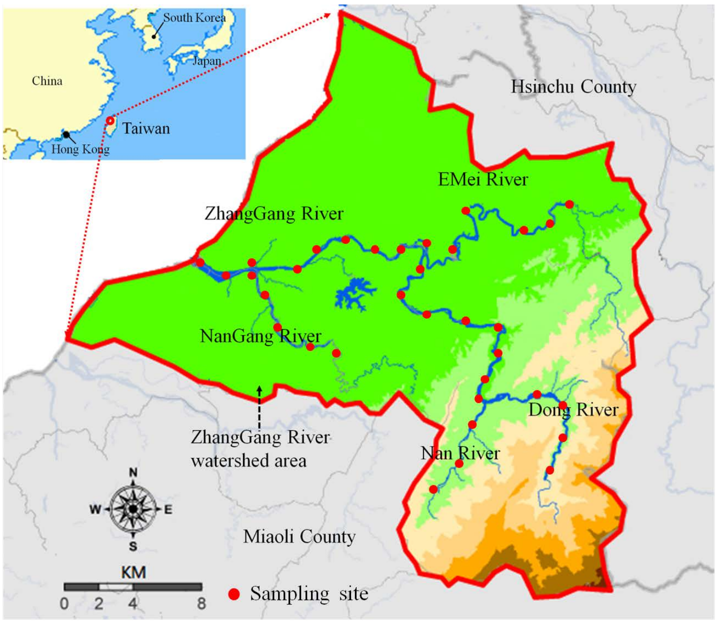
This present study addresses the connection between perceptions of scenic beauty and waterscapes using the aesthetic-related variables of water clarity, water colour, phytoplankton biomass, and water quality. We suggest that a connection framework may help manage water quality by improving water clarity and water colour, as well as help attain better aesthetic assessments of waterscapes. These considerations led to the current research focus; that is, the formulation of a connective path diagram of aesthetic assessment. We tested the path diagram by considering water-quality parameters, including water clarity, water colour, phytoplankton biomass, and tourists' aesthetic assessment of waterscapes. We find that: 1) water clarity and water colour have a direct effect, whereas water quality and phytoplankton biomass have an indirect effect, on tourists' aesthetic assessments; 2) water quality has a direct effect on water clarity and phytoplankton biomass; and 3) water quality involves the reactions of complex parameters, four of which, namely, DO, BOD, NH3-N, and SS are used as water-quality parameters to determine the influence on water clarity and phytoplankton biomass in this work. We believe that these findings should facilitate the improvement of the overall water quality of waterscapes. Tourists are generally willing to incur additional costs to visit high-quality waterscapes [39] [40] [41]. For that reason an effective method of water-quality management provides to improve water clarity and water colour, which not only could reduce the management cost, but also made high waterscape aesthetic value and attracting more tourists [24].

2. Materials and Methods

2.1. Study Site

The ZhangGang River and its four tributaries, the NanGang, EMei, Nan, and Dong rivers, are located in North Taiwan. The ZhangGang River is 54 km in length and has a watershed area of 445.6 km^2 that covers Hsinchu and Miaoli Counties. Of the tributaries, the NanGang river is 32.6 km long, originates 762 m above sea level, and has a watershed area of 103 km^2; the EMei river is 28.9 km long, originates 1,579 m above sea level, and has a watershed area of 69.5 km^2; the Nan river is 13.8 km long, originates 2200 m above sea level, and has a watershed area of 50.9 km^2; and finally, the Dong river is 21.5 km long, originates 2616 m above sea level, and has a watershed area of 80.8 km^2 (**Figure 1**). Many scenic spots line these five rivers, and the waterscape is highly regarded by tourists [42].

There are both urban commercial and industrial areas concentrated in the downstream areas, and sources of water pollution include domestic, industrial, and feedlot wastewater in the ZhangGang and NanGang Rivers. In other regions of the ZhangGang and NanGang Rivers, as well as in the E-Mei, Nan, and Dong Rivers, we found the primary pollution sources to be residential, agriculture, and



River	Length (km)	Watershed area (km²)	Originated above sea level (m)	Number of sampling sites
ZhangGang river	54	445.6	2616	15
NanGang river	32.6	103	762	6
EMei river	28.9	69.5	1579	5
Nan river	13.8	50.9	2200	4
Dong rive	21.5	80.8	2616	4

Figure 1. Map of the ZhangGang River watershed area, and sampling sites indicated.

tourist related [38] [42] [43]. The morphologies include riffle, glide, pool, run, slow-run, slack, and alluvial land in the Zhang-Gang River system; in addition to alluvial land, the average flow rate ranges from 0.07 m/sec to 1.06 m/sec [42]. Flow rates of riffle, glide, and run are higher than 30 cm/sec, whereas those for pool, slow-run, and slack are lower than 30 cm/sec [42] [44] [45].

2.2. Data Collection

We identified 34 sampling sites in the ZhangGang, NanGang, EMei, Nan, and Dong Rivers, according to the operation guideline of river status investigation of WRA [38]. The river morphology of these sampling sites includes pool, slow-run, slack, and still water; the flow at these sampling sites is relatively slow. We also eliminated the downstream area of ZhangGang and NanGang Rivers, whose water colour was affected by industrial pollution sources.

We measured water-quality parameters, water clarity, species, and number of phytoplankton, water colour, and spectral distribution characteristics of water colour at the 34 sampling sites. Each site was sampled four times; the sampling times were July, October 2007, and March, June 2008. Further, we tried as far as possible to avoid periods with large volumes of precipitation or long periods of drought. And, visitors' aesthetic assessments and preferences related to water colour and clarity of the body of water at each sampling site and each sampling time were surveyed.

Total 11 water-quality parameters was measured: BOD, conductivity, DO, *E. coli.*, NH3-N, pH, salinity (Sal), SS, total dissolved solids (TDS), TP, and water temperature. Meanwhile, water clarity was measured. The survey and analysis method for each water-quality parameter and clarity was based on the standards specified by Taiwan's EPA [46] (2015).

Then, the River Pollution Index (RPI) value of each site for each sampling time was calculated. RPI is an integrated indicator used by the EPA [46] to determine the level of pollution of a river. The index value is calculated using the concentration of BOD, DO, NH3-N, and SS. Point scores were integrated into the pollution index integral value. A large RPI value indicates that water pollution is more serious, whereas an RPI value ranging from 1.0 to 4.5 indicates that pollution levels are low to moderate [46].

Three species of phytoplankton were identified and sampled: diatom, green algae, and blue-green algae. The average density of phytoplankton at each site was also measured. The survey method was based on the operation guidelines of river status investigation used by the [38]. We also calculated the Shannon Wiener Diversity Index (H') of each site at each sampling time; the value of H' ranged from 0.84 to 1.46.

The water colour and spectral distribution characteristics of the water bodies were also measured. Water colour is apparent colour that was identified by CMYK colours sample book, whereas the reflectance spectra were recorded using a spectrometer. A diagram of the normalized reflection spectra was drawn.

In addition to water-quality sampling, we used questionnaire surveys to understand and assess visitors' aesthetic assessments and preferences of water colour and clarity of waterscapes at each sampling time. Apart from their demographic information, the participants were asked to report their aesthetic assessments and preferences regarding the colour and clarity using a scale from 1 (very ugly/strongly dislike) to 7 (very beautiful/like very much). Total of 4786 completed questionnaires, at the 34 sampling sites and four times each site. The response rate was 89.16% and 4267 questionnaires were available.

Each participant's aesthetic assessment and preference were used to conduct a reliability analysis. The Cronbach's alpha was 0.882 and 0.887, which shows that the questionnaire was reliable. The participants' answers for gender, age, occupation, place of residence, and aesthetic assessment and preference were compared using a *t*-test, which showed that aesthetic assessment and preference were not significantly correlated with demographic details. The mean values of aesthetic assessment and preference were calculated.

2.3. Data Analysis Methods

We adopted correlation analysis, analysis of variance (ANOVA), multi-way contingency table, and path analysis to derive our research findings.

First, we adopted correlation analysis to identify correlations between measures of tourists' aesthetic assessments and preferences of water clarity and water colour. The results indicated that aesthetic assessment achieved a significant correlation with preference (r = 0.942, p = 0.000). Subsequently, we retained tourists' aesthetic assessments of water clarity and water colour of waterscape. However, the preference value was ignored in further steps of the analysis, due to the preference judgments probably stems from the aesthetic consciousness [47] [48]. Next, we tested the correlation between tourists' aesthetic assessments and water clarity, and the difference between tourists' aesthetic assessments and water colour. A multi-way contingency table was used to test the difference between water clarity entailing a variety of water colours, and tourists' aesthetic assessments.

Next, the correlations between water clarity and 12 variables (11 water-quality parameters and RPI value), and phytoplankton were tested using correlation analysis. The significant correlations are discussed below.

The results above formed the foundation of the path diagram for tourists' aesthetic assessment of waterscapes, as shown in **Figure 2**. Path analysis was adopted to verify the research framework. In the model, water quality and phytoplankton biomass were extraneous variables modelled as being correlated and as having indirect effects, through water clarity, on tourists' aesthetic assessments. Water clarity, water colour, and tourists' aesthetic assessments were endogenous variables in this model. Variance in tourists' aesthetic assessments of waterscapes was the result of variance in water clarity, water colour, and extraneous factors (not in the model). Variance in water colour resulted from variance in phytoplankton biomass, and extraneous factors; variance in water clarity resulted from variance in phytoplankton biomass, water quality, and extraneous factors.

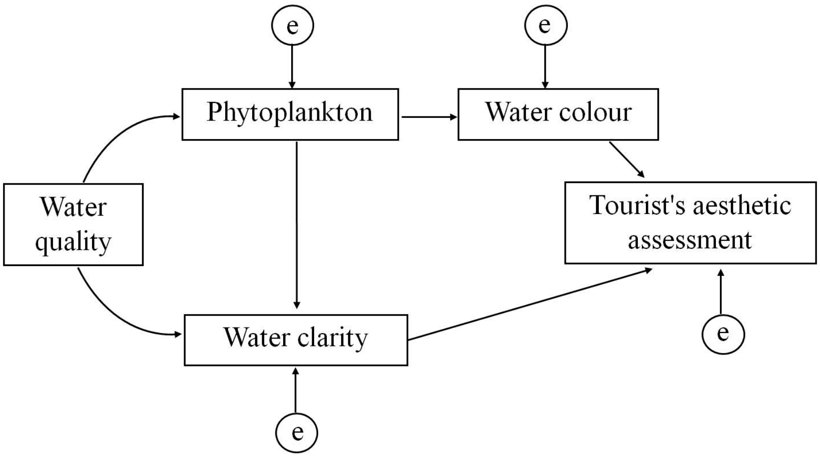


Figure 2. Research framework. This schematic drawing shows the research framework. We proposed that Tourists' aesthetic assessments of waterscapes are directly influenced by water colour and clarity, and indirectly by phytoplankton and water quality. The change in phytoplankton biomass is affected by water quality, which in turn impacts water colour, and phytoplankton also has a direct impact on water clarity. Water quality has both direct and indirect impacts on water clarity.

3. Results

3.1. Water Clarity, Water Colour, and Tourists' Aesthetic Assessments

3.1.1. Water Clarity and Tourists' Aesthetic Assessments

We used correlation analysis to test correlation between water clarity and tourists' aesthetic assessments. Previous studies have suggested that tourists' aesthetic assessments are positively correlated with water clarity [14] [16] [17] [23] [24]. We examined the relationship between both of these variables. The result of Pearson's correlation analysis showed that the correlation of both variables was significant, with a correlation coefficient of 0.708 ($p = 0.000$).

3.1.2. Water Colour and Tourists' Aesthetic Assessments

Total of 98 colour names using the CMYK colours sample book from 136 sampling sites were recorded, in general tourists were not quite capable to clearly distinguish analogous colours. If 98 colours and aesthetic value score were deal with by T-test, the trivial results were not adapted for water quality management. Then, we overlapped all diagrams of the reflection spectra of each sampling site, which yielded eight water colour series: two yellow, three green, and three blue colour series. One-way ANOVA was performed to test for differences among the eight water colour series and tourists' aesthetic assessments. The results showed that the difference between both was significant (F = 19.244, $p = 0.000$). Additionally, the results of the post hoc analysis showed that the eight colour series could be reduced to three condensed categories: pastel yellow to yellow-green, green to blue-green, and aquamarine to blue.

The mean aesthetic values were significantly different across water colour categories (F = 63.422, $p = 0.000$). The highest aesthetic value was aquamarine to blue water colour (mean = 4.74, SD = 0.82), followed by green to blue-green (mean = 3.89, SD = 0.96), and finally pastel yellow to yellow-green (mean = 1.77, SD = 0.39).

3.1.3. Water Clarity and Water Colour with Tourists' Aesthetic Assessments

Water clarity was divided into four categories, based on depth of visibility: less than 1.0 meter, 1.0 to 2.0 meters, 2.0 to 3.0 meters, and more than 3.0 meters. Next, a multi-way contingency table was devised to test for differences among water clarity and water colour with tourists' aesthetic assessments.

The results showed three categories of visibility for depths of less than 1.0 meter, 1.0 to 2.0 meters, and 2.0 to 3.0 meters; we found a significant difference between water colour and visitors' aesthetic assessments ($p = 0.000$, $p = 0.003$, $p = 0.000$). However, if the depth of visibility was higher than 3.0 meters, the difference between water colour and visitors' aesthetic assessments was not significant (Table 1).

Alternatively, when the water colour was pastel yellow to yellow-green, and green to blue-green, the difference between water clarity and visitors' aesthetic

Table 1. Contingency table showing the three categories of water colour for a variety of water clarities, along with tourists' aesthetic assessments.

	Water colour					
	Pastel yellow to yellow-green		Green to blue-green		Aquamarine to blue	
	Aesthetic value					
	Mean	SD	Mean	SD	Mean	SD
Water clarity <1.0 m	1.66	0.21	2.81	0.53	4.21	0.90
Water clarity ≤1.0 to <2.0 m	1.79	0.09	3.68	0.80	4.03	0.62
Water clarity ≤2.0 to <3.0 m	3.06	0.34	4.10	0.71	5.30	0.38
Water clarity ≤3.0	3.98	0.76	4.24	0.99	4.70	0.83

assessments was significant ($p = 0.020$, $p = 0.004$). However, if the water colour was aquamarine to blue, the difference between water clarity and visitors' aesthetic assessments was not significant.

3.2. Phytoplankton and Water Clarity, and Water Colour

3.2.1. Phytoplankton and Water Clarity

Three types of phytoplankton were sampled in our research: diatom, green algae, and blue-green algae. The correlation analysis was adopted to test the relationship between water clarity and total number and diversity of each of the three species separately, and overall total numbers. The correlation coefficients were not significant between water clarity and the total number of each species and diversity value of phytoplankton.

However, the correlation coefficient between water clarity and overall total number of phytoplankton was significant: Pearson's correlation coefficient was −0.475 ($p = 0.000$). Thus, the relationship between both variables was negative.

3.2.2. Phytoplankton and Water Colour

We applied the contingency table to test the difference between the three water colour categories with total number and diversity of each of the three species separately, and overall total numbers of phytoplankton. The results showed no significant difference between the variables.

Further, the relationships between the three water colour categories of four different water clarity depths and total number and diversity of each of the three species separately, and with the overall total numbers of phytoplankton were tested. The results of the contingency table analysis show that the differences between the three water colour categories of four different water clarity depths in the overall total numbers of phytoplankton was significant (F = 2.923, $p = 0.012$); however, no significant difference was seen between the other variables. Thus, the relationship between water colour and total number and diversity of each of the three phytoplankton species separately were not discussed in the path analysis.

3.3. Water Quality Related to Phytoplankton and Water Clarity

3.3.1. Water-Quality Parameters, Phytoplankton, Water Clarity

Eleven water-quality parameters, the overall total number of phytoplankton, and water clarity were tested using Pearson's correlation analysis. The results show that the correlations between the overall total number of phytoplankton and six water-quality parameters (DO, NH3-N, BOD, SS, TP, and *E. coli*) were significant. The overall total number of phytoplankton had a moderate positive correlation with NH3-N, BOD, SS, TP, and *E. coli*, but a negative correlation with DO.

Water clarity and seven water-quality parameters (TDS, Sal, NH3-N, BOD, SS, TP, and *E. coli*) had a significant moderate to high negative correlation; however, there was a significant positive correlation between water clarity and DO.

3.3.2. RPI Value, with Phytoplankton and Water Clarity

We tested the correlation between RPI value and the overall total number of phytoplankton and water clarity. The results showed that the correlation of the RPI value with the overall total number of phytoplankton ($R = 0.485$, $p = 0.003$), and water clarity ($R = -0.754$, $p = 0.000$) was significant.

Regarding the results of the correlation analysis of water-quality parameters with phytoplankton and water clarity (as shown in Section 3.3.1), six of the 11 water-quality parameters exhibited simultaneity; these were DO, NH3-N, BOD, SS, TP, and *E. coli*. These six parameters and RPI value were tested via correlation analysis. There was a moderate to high correlation between the six parameters and RPI value.

To streamline the analysis further, we retained RPI value in the next analysis step, but did not discuss the six water-quality parameters separately.

3.4. Path Model of Tourists' Aesthetics on Waterscapes

Path analysis was adopted to decompose the research framework into the sources of the correlations between independent variables (water colour, water clarity, overall total number of phytoplankton, and RPI value) and tourists' aesthetic assessments of waterscapes, as shown in **Figure 3**.

The dummy variables of water colour and water clarity had a direct effect on tourists' aesthetic assessments. The relationship between the water colours of pastel yellow to yellow-green and aquamarine to blue and water clarity with tourists' aesthetic assessments was significant. When water colour was pastel yellow to yellow-green, water clarity had a positive impact on tourists' aesthetic assessments regarding the water bodies, but water colour was found to have a negative impact. When water colour was aquamarine to blue, water clarity and water colour had a positive impact on tourists' aesthetic assessments of the water bodies.

Where the water colour was green to blue-green, the standardized regression coefficient of water clarity with tourist's aesthetic assessments was significant, but that with water colour was not.

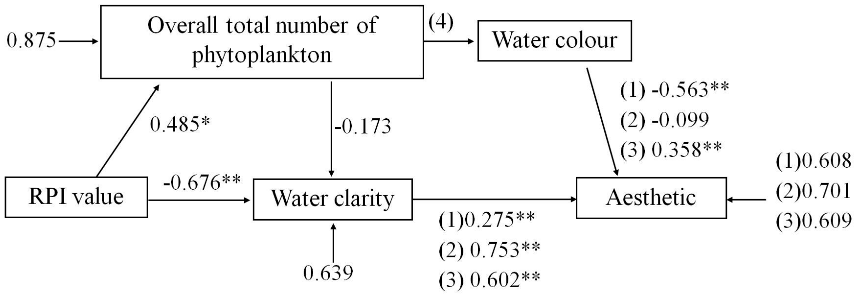


Figure 3. Path diagram for tourists' aesthetic assessments of waterscapes. 1) Pastel yellow to yellow-green water colour; 2) Green to blue-green water colour; 3) Aquamarine to blue water colour; 4) Not tested. The path analysis was not applied to estimate the relationship between water colour and phytoplankton numbers due to the dependent variable of water colour being nominal in scale.

The RPI value had two indirect effects, whereas the overall total number of phytoplankton had an indirect effect on tourists' aesthetics. The overall impact of RPI value on tourists' aesthetic assessments of pastel yellow to yellow-green water colour was −0.209; with green to blue-green water colour, it was −0.572; and for aquamarine to blue water colour, it was −0.457. The overall impact of the total phytoplankton numbers on tourists' aesthetics at pastel yellow to yellow-green water colour was −0.048; at green to blue-green water colour, it was −0.130; and at aquamarine to blue water colour, it was −0.104.

Moreover, RPI value had both a direct and an indirect effect on water clarity. The magnitude of the direct effect quantified by the standardized regression coefficient was −0.676 (p = 0.003), whereas the indirect effect was −0.084. RPI value had a direct effect on the overall total number of phytoplankton, and the standardized regression coefficient was 0.485 (p = 0.000).

4. Discussion

This study examined the extent to which the public's aesthetic assessments regarding waterscapes is connected to water clarity and water colour, and the indirect connection between aesthetic assessments and water quality and phytoplankton biomass. Tourists' aesthetic assessments are affected by water clarity and water colour, and this influence is especially positive and strong with respect to water clarity [14] [16] [17] [24] [49] [50]. At high water clarity levels, aesthetic assessment is not significantly influenced by water colour; conversely, the most preferred water colour is aquamarine to blue, whereas pastel yellow to yellow-green has a negative impact on tourists' aesthetic assessments. Thus, compared with water colour, water clarity may be more beneficial to visual aesthetic value [14] [49].

Water clarity is affected by water quality and phytoplankton. As reflected in several extant studies, DO, BOD, SS, and NH3-N are the main influencing parameters of water quality. As noted above, DO is an important parameter for assessing water quality, while BOD is widely used as an indicator of the organic quality of water [51]. SS can lead to physical alterations in a body of water, such as reduced penetration of light; these alterations are associated with decreased water clarity, which leads to undesirable aesthetic effects [52]. Meanwhile, increasing algae will also reduce water clarity, thus causing a shortage of oxygen in the water. Phosphorus has a negative effect on water quality, leading to algal blooms [30]. In our research, Pearson correlation coefficient showed TP highly related to RP; for this reason, we consider both to have similar impacts on phytoplankton.

Furthermore, aquamarine to blue water colour was assessed to have a greater aesthetic value compared with other colours. Water colour may result from dissolved, suspended material and algae. Colours resulting from phytoplankton blooms can cover a wide range [31], and specific types of phytoplankton communities will produce characteristic colours [53]. For example, a bloom of diatoms will make the water colour look brown, whereas green algae gives water a light-green colour. However, our research did not show a relationship between phytoplankton communities and water colour. Boyd & Tucker [31] also indicated that methods for assessing the relationship between these variables have not been developed.

5. Conclusions

Waterscapes are considered among the most important aesthetic landscape elements [2]. Improved water quality of waterscape is associated with increased numbers of visits [54]. Furthermore, users are willing to pay for changes in water quality [22]. The research results showed that greater water clarity and water colour improve tourists' aesthetic assessments of waterscapes. This result indicates that the appearance of slightly polluted waterscape was aquamarine to blue colour with high water clarity, and was more preferred. In nutrient-rich waters, the appearance might show green to blue-green water colour that most people dislike. To take effective and economic measures to manage water quality of waterscape is important. The 11 water-quality parameters were reduced to four, which not only simplify water-quality management toward improving the appeals of waterscapes but also cut management costs for stakeholders. Further, the appearance of waterscape, *i.e.* water colour evinced tourist's aesthetic preference and water quality. Observation water colour is easy to practice for general public; that made the monitor of water quality by public participation feasible.

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