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Impact of vessels on sediment transport and diversity in Lake Taihu, China

Qhtan Asmaa and Yiping Li*

Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Ministry of Education, College of Environment, Hohai University, Nanjing, 210098, China.

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In shallow lakes, waves from different sources play a major role in sediment transport and the release of associated nutrients. This study was conducted to analyze the impacts of waves generated by wind or vessels, on nutrient concentrations and microbial diversity in China's third largest lake, Taihu. The study area is fixed at 100 m length of sailing vessel and 10 m width from where water samples were collected, near the Taihu Laboratory for Lake Ecosystem Research (TLLER) Station, at Meiliang Bay. The average flow velocity changed during passages of the vessel from -0.1 to + 0.1 m/s with high-speed vessel compering by the time before and after passages for one hour. The significant wave height ranged from 0.002 to 0.698 m. Turbidity ranged from 29.5 to 65.5 NTU. The concentration of Chl-a (μgL^{-1}) and nutrients total nitrogen (TN), total phosphorus (TP), ammonium (NH_4^+) and phosphate (PO_4) were resuspended in the three depths of the water column, as a response to the turbulence caused by waves-waves collision and rivers waves. Microbial amount concentration in the two layers changed over time. It increased in the surface from 5.03 to 8.3 ng μl^{-1} and decreased in the bottom from 5.03 μl^{-1} to 2.93 ng μl^{-1} over a 45 min period. This study points to the importance of sediment resuspension as a factor influencing nutrient availability and microbial community structure, and as such it plays an important role in the eutrophication dynamics of Lake Taihu.

Key words: Destructive interference, wave, vessels, hydrodynamics, nutrients resuspension, microbial diversity.

INTRODUCTION

Water quality is affected by natural and anthropogenic factors. Natural factors include drainage density, lake interchange coefficient, temperature and precipitation within the watershed, lake morphology, water depth, wind and waves. The anthropogenic factors include industrial effluent, agricultural runoff, and effluent from wastewater treatment facilities (Epele et al., 2018; Wang et al., 2009; Xian et al., 2007; Zhou et al., 1996). Algal blooms are indicative of accelerating eutrophication and resultant of poor water quality (Li et al., 2017; Qin et al., 2010; Stumpf et al., 2012). In Lake Taihu, China, poor water quality has become a serious threat to lake, reservoir and other freshwater ecological and economic status and sustainability (Li et al., 2017; Qin et al., 2010). Sediments

*Corresponding author. E-mail: liyiping@hhu.edu.cn. Tel: +86 13951787286.

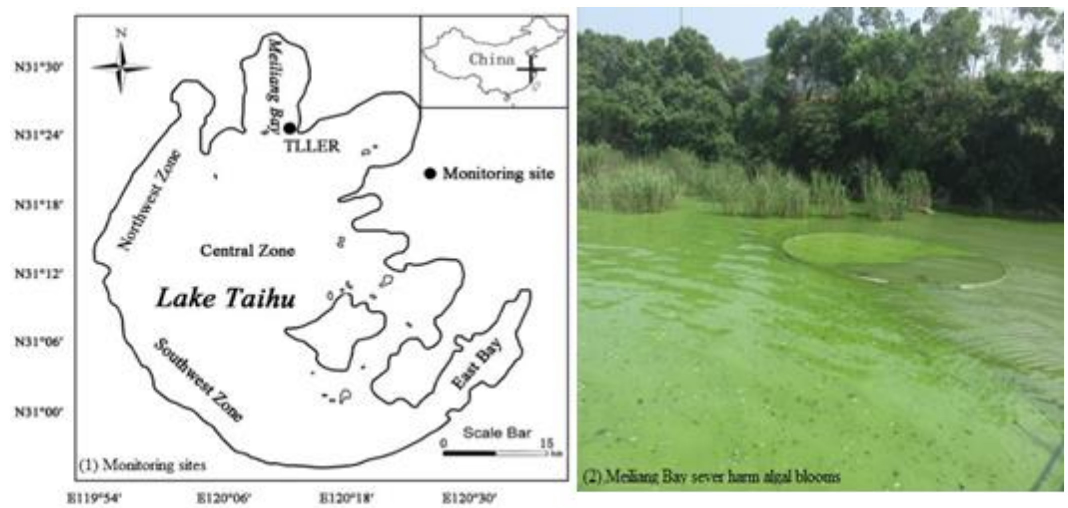


Figure 1. Map shows the sites of field of experiments.

are a major internal source of nutrients in shallow lakes like Taihu, where sediment resuspension resulting from currents, waves, dredging, and ship-induced waves can be a source of nutrient enrichment (Gabel et al., 2012; Garrad and Hey, 1987; Maynord, 2005; Qin et al., 2007; Schneider et al., 2007). Microorganisms play a major role in the degradation of organic matter, and the cycling of nutrient elements in freshwater lake sediments (Junier et al., 2007). The lake microbial community is influenced by fluctuating environmental factors, including conductivity, nutrients and organic matter. An increase of organic matter content in the sediment promotes bacterial activity and can influence diversity of prokaryotic populations (Edlund et al., 2006; Fry et al., 2006; Muylaert et al., 2002; Nelson et al., 2007). Excessive nutrient inputs can increase the growth rate of some microorganisms while also affecting microbial habitats and diversity (Weisse, 1991). Studies have shown that the vertical variation of general microbial groups is related to sediment dynamics (Koizumi et al., 2004; Wilms et al., 2006). It is important to know how the partial and temporal distribution of microorganisms responds to environmental drivers accordingly therefore this study: 1) examined impacts of waves generated by wind and vessel on nutrient loads in each layer of water column, 2) measured microbial abundance in water layers, and 3) examined the relationships between microbial abundance and sediment resuspension.

MATERIALS AND METHODS

Study area

Lake Taihu is a large freshwater lake located in the lower Yangtze River Delta between 30° 56′– 31° 33′ N and 119° 53′–120° 36′ E. It has a surface area of 2338 km^2 and a mean depth of 1.9 m. Meiliang Bay is a semi-enclosed bay with a surface area of 129.3 km^2, 1.9 m average depth and it is located in the northern part of Lake Taihu (Gao et al., 2017; Li et al., 2017; Liu et al., 2014). Meiliang Bay is extremely eutrophic, as indicated by cyanobacterial blooms during summer leading to severe water quality problem (Gao et al., 2017; Li et al., 2017). Meiliang Bay has average annual wind speed that varies from 3.5 to 5.0 m/s, with dominant summer winds from the southeast and dominant winter winds from the northwest (Gao et al., 2017; Li et al., 2017; Wu et al., 2013) (Figure 1).

Field observations and instrumentation

Field observations were made on 26 May 2016 in Meiliang Bay Taihu Laboratory for Lake Ecosystem Research, Chinese Academy of Sciences (TLLER). Wind speeds and wind direction, were monitored by a PH-Ⅱ handheld weather station and PHWD wind direction transducer; the frequency was set at 5 min. The wind monitoring instruments were positioned at 10 m above the water surface. The data collection interval was 5 min. The data were calibrated with the automatic wind speed and direction recorder (10 m above the water surface, 10 min monitoring interval) located at the TLLER. Wave parameters, including wave height, wave energy, and wave period were measured by Red Blue Reader (RBR) duo T.D wave situated at 50 cm below the water surface. The acoustic Doppler velocimeter (ADV) is the most important instrument to determine and obtain a good understanding for suspended sediment transport. In our field study, we used Acoustic Doppler Velocimeter (ADV) 100 Hz and optical backscatter sensor (OBS-A3) instruments, which have capability to measure the field velocities and suspended sediment concentration (SSC) in the bed layer of Lake Taihu. During the field observation, the vessel moved from one point to another and returned to the beginning several times over a time frame of 60 min. The goal was to understand the precision of effect wave induced by wind (vessel). Water samples were collected during the experiment. The sampling site was located in Meiliang Bay (31°25′7.41″N, 120°12′46.90″E (Figure 1).

Sample collection techniques

Water samples were collected near the TLLER (311240N, 1201130E) in Meiliang Bay on 26 of May 2016. Samples were collected at different depths; 5 cm above the bottom layer, which is considered descriptive of the water column because of the shallow, middle layer (1 m above the bottom) and near surface 1.8 m above the bottom. One type of sterile bottles (20 samples) was dispensed for DNA extraction and the other 40 samples were collected for water quality from the same site--Meiliang bay and in-lake monitoring stations. Water quality samples were transported to the laboratory for filtration to obtain suspended particulate matter (SPM) content by filtering only 250 mL of water through cellulose acetate membranes (0.45 µm), followed by analyses directly including total phosphorus (TP); total nitrogen (TN); sediments solid; chlorophyll-a (Chl-a) phosphate (PO_4) and ammonium (NH_4^+). These nutrient measurements were according to the Chinese standard methodology for Lake Eutrophication Surveys (Jin and Tu, 1990). This technique is similar to the American standard methods (APHA, 1998), for those parameters (James et al., 2009) while the DNA samples were filtered by using 0.2 µm polycarbonate membrane for DNA extraction in Meiliang Bay. Then the total DNA was removed using the procedure illustrated by Tang et al. (2009) and Zhou et al. (1996). Finally, DNA was measured using 454 pyrosequencing of 16S rRNA genes by using polymerase chain reaction (PCR). The first time sample was collected at zero time, the second time samples was after passages of vessel after 10 min, the third time samples was 20 min, the fourth time samples was 45 min. The vessel moved for 1 h continuously from one point to another point, 100 m distances far away from site of collection the samples.

Data analysis

Acoustic method measures high-frequency suspended sediment concentration (SSC). To obtain high-frequency SSC, we combined Acoustic Doppler Velocimeter (ADV Ocean, SonTek Inc.) and Optical Backscatter Sensor (OBS) turbidity meter, and bottle samples. The first step was to use bottle samples to calibrate with OBS turbidity, and then SSCs was measured by OBS (one datum every 3 min) arithmetic mean value of 3-min echo intensity (EI) data measured by ADV (which frequency was 10 data per second) and obtained logarithmic relationship between EI and SSC. Finally, high-frequency simultaneous SSC and water vertical flow velocity were obtained by ADV according to Gao et al. (2017) and Voulgaris and Meyers (2004). Wind speed and direction were measured at the meteorological station every 5 min at 5 m above water surface. The wind speed was scaled using the logarithmic profile law Equation 1:

$$U_{10} = U_{measured} \ \frac{\ln(\frac{10}{z_0})}{\ln(\frac{z}{z_0})} \tag{1}$$

Where, z is the height of the instrument with respect to the water surface level, and z0 is a sea-surface roughness length set equal to 10.3 m (Donelan et al., 1993) .

Various simplified wave methods were applied in shallow lake based on characteristic wave methodology. Wave (ζ) record was calculated by using RBR duo T.D simple method. The wavelength was calculated according to the observed wave parameters given in Equation 2:

$$L_s = (\frac{gT_s^{\ 2}}{2\pi})\tanh(\frac{2\pi h}{L_s}) \tag{2}$$

Where, Ls is the significant wavelength, Ts is the significant wave period, and h is the depth of observation points. Nutrient concentrations are shown as mean, minimum and maximum values at each layer.

RESULTS

Wave characteristics

On 26 May, 2016, the significant wave height ranged from minimum value of 0.002 to maximum value of 0.612 m; the wave energy increased after time experiment from 0.03 to 0.09 NdBar$^{\wedge 2}$ m$^{\wedge -3}$ and maximum wave height ranged from 0.005 to 0.023 m; the wind speed ranged from 0.5 to 2.5 (m/s) (Figures 2 and 3).

Frequency distribution of wind directions

Major wind directions can have impact on the upper and lower velocities of flow area study and inverse wave flow during strong wind speed. For this determination, wind directions were separated into 14 sides North; East South East; North North East; East; South South East; North East; South West; South; West South West; West North West; West; North West; East North East and North North West. The flow directions were also converted into the same 14 directions to compare them with wind directions (Figure 4).

Wind directions data are presented as dominate north direction with frequencies N (0.166); ESE (0.05); NNE (0.05) E (0.1); SSE (0.0166); NE (0.016); SW (0.066); S (0.016); WSW (0.016); WNW (0.1); W (0.016); NW (0.066); ENE (0.016); NNW (0.083) (Figure 4a). The blue color demonstrates the ranges of wind directions while the white represents the degree of the opposite flow directions which were considered before the experiments. It can be perceived from the frequency statistics that the quadrant directed to the north side creates the highest percent (16.66%) of total frequencies, followed by NNW (8.33%), WNW (10%) and East (10%) of total wind directions (Figure 4b). Thus, it is important to consider them as prevailing wind directions for impact assessments on the flow before vessel passage. Each flow direction was deliberated opposite if it was 90° more than the direction of that precise wind as shown in Figure 4.

Average flow velocities distributions

Table 1 shows that there was a significant strong correlation determination by positive value of P (value < 0.5). The average flow velocities changed during passages of vessel compared to the time before passages of vessel; during the time passages of vessel, the curve shows that the flow average velocities had value that ranged from -0.1 to + 0.1 m/s with high-speed vessel as sweep and ejection events. The varying curve of the flow velocities looks similar and has kelvin wave shape especially after 16 min averages seconds recording measured by Acoustic Doppler velocity (ADV) near distance fixed. The average flow velocities curve

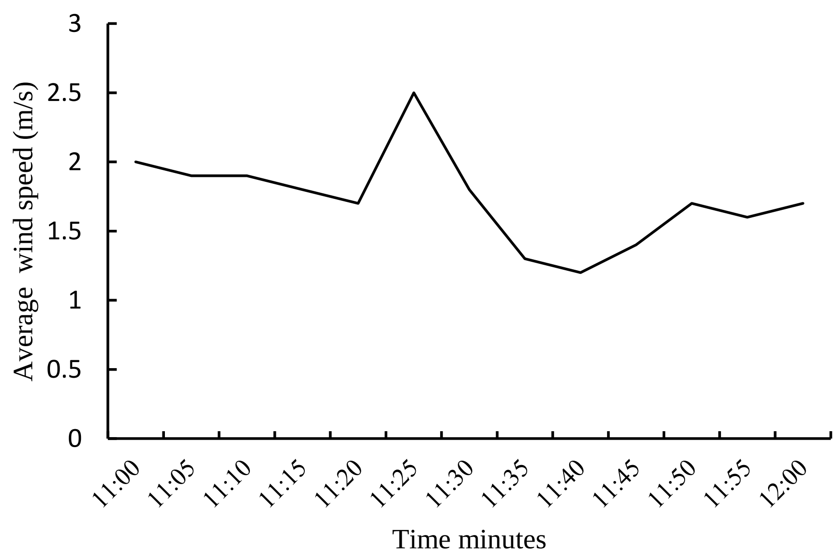


Figure 2. Average wind speed (m/s) during passages vessel.

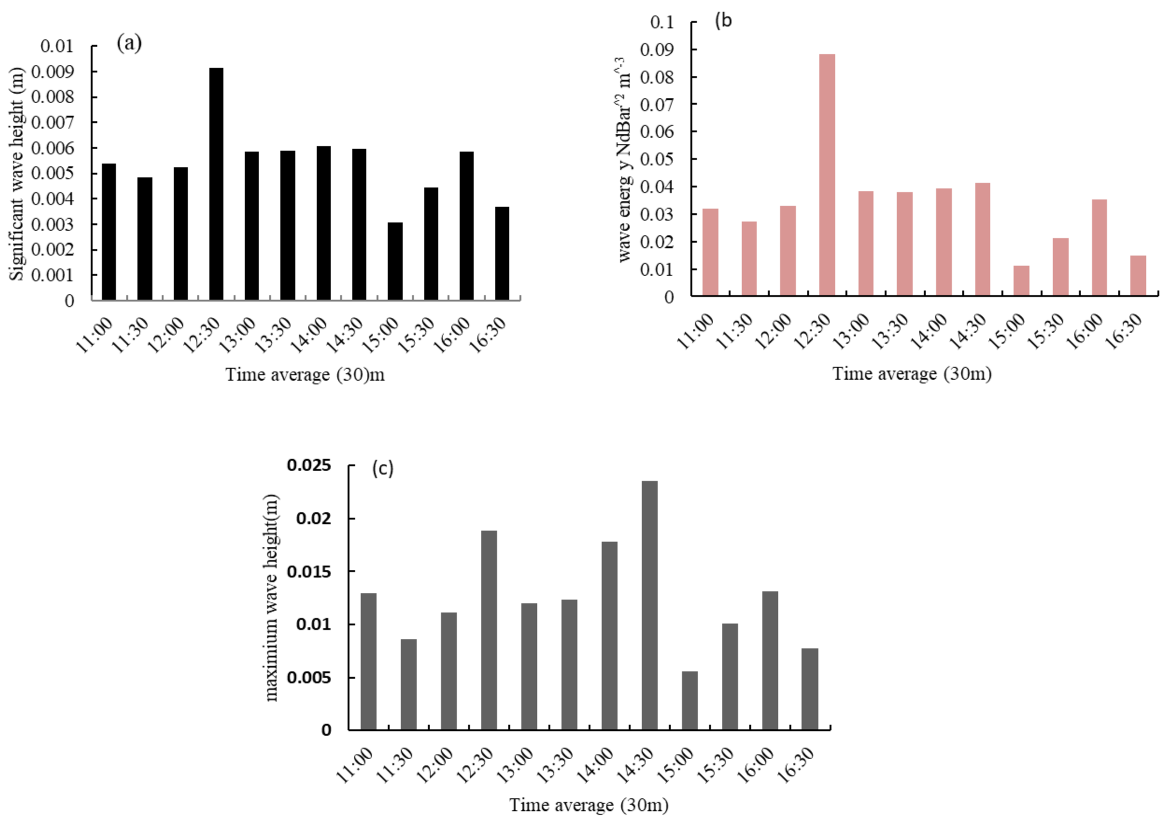


Figure 3. Wave features during vessel passages (a) significant wave height (m) (b) total wave energy NdBar^^{2} m^$^{-3}$ (c) maximum wave height (m).

gives a clear event of ejection and sweep processes (Figure 5). While, the statistical data of the average velocities during passages and after 5 h passages vessel show that there is no significant correlation determination by P (value > 0.5) with values ranging from minimum value of -0.11 to maximum value of 0.06 (Figure 6; Table 2).

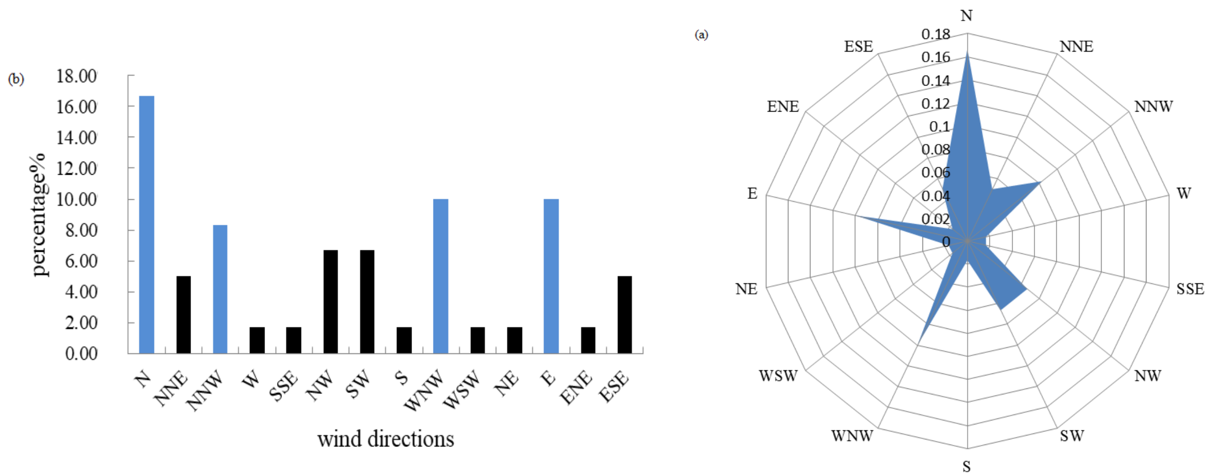


Figure 4. Chart diagrams showing (a) the method approved to estimate flow directions with dominant wind north directions (b) the percent of wind direction.

Table 1. Shows the statistical significance of the average flow velocity cm/s during moving vessel and before moving vessel.

ANOVA					
Source of Variation	**SS**	**Df**	**MS**	**P-value***	**F crit**
Between Groups	0.0147	1	0.015	0.0500	3.922
Within Groups	0.214	116	0.002		
Total	0.228	117			

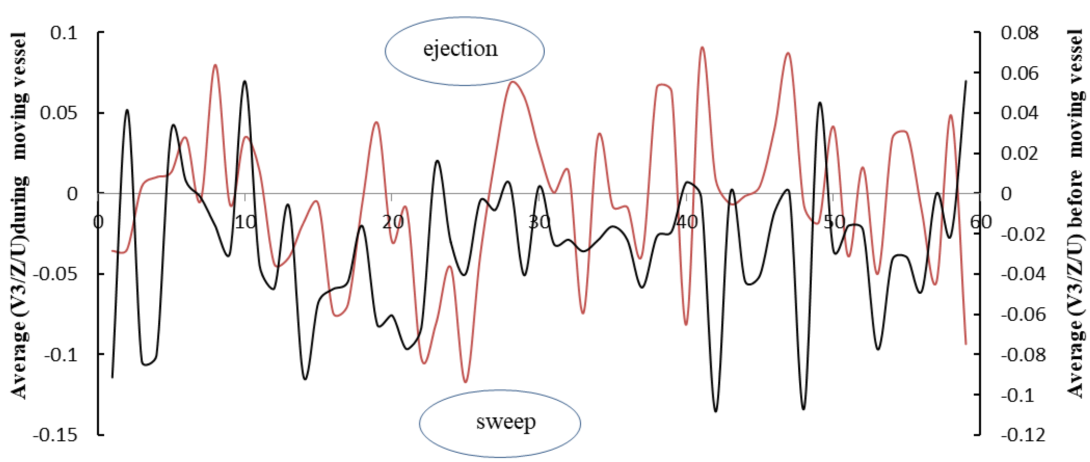


Figure 5. Average flow velocities (V3/Z/U) (cm/s) for 60 minutes before moving vessel and 60 minutes during moving vessel.

Turbidity and SSC

Nutrients are released from sediment resuspension processes, which encouraged algal growth in the open shallow lakes. The result shows positive relationship between SSC and turbidity (R^2=0.538; P<0.5) during passages of vessel (Figure 7).

Wind speed ranged from a minimum of 1.5 to maximum of 2.5 ms^{-1}. Water temperature and pH measurements averaged as 14.3°C and 9.17. Correspondingly, turbidity

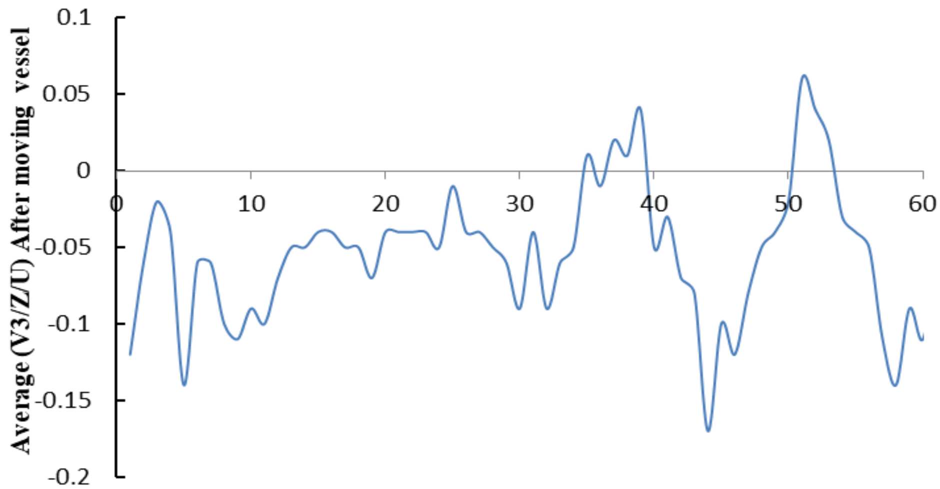


Figure 6. Average flow velocities (V3/Z/U) cm/s for 60 minutes after 5 h moving vessel.

Table 2. Shows the statistical significance of the average flow velocities cm/s during moving and after moving vessel.

Source of Variation	SS	df	MS	F	P-value*	F crit
Between Groups	0.071	1	0.071	32.478	9.300	3.922
Within Groups	0.251	116	0.002			
Total	0.322	117				

*There is no significant correlation P (value > 0.05).

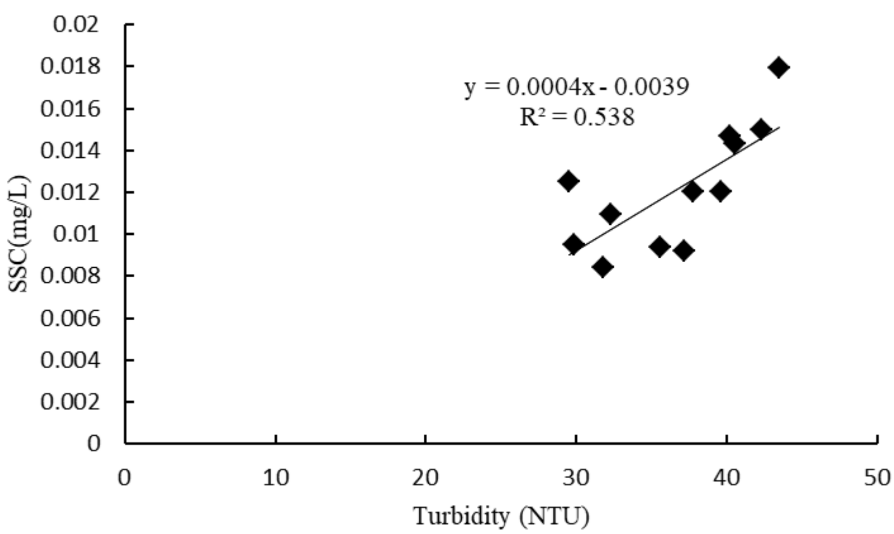
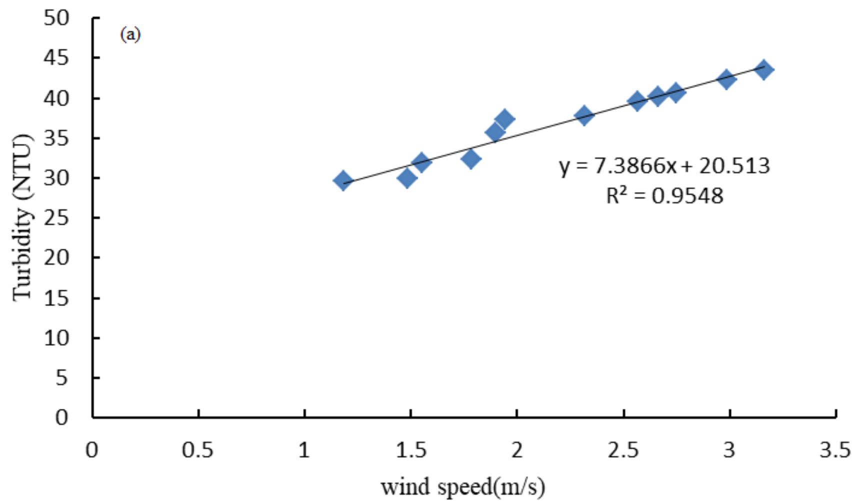


Figure 7. The relationship between SSC (mg/L) & Turbidity (NTU).

ranged from 29.5 NTU at 11:00 to a maximum of 50.00 NTU at 12:00 (Figure 8a). Concentrations of TP increased from a minimum of 0.5 mg^{-1} at 11: 00, to a maximum of 0.14 at 14:00. The data showed a positive correlation between wind speed and turbidity R^2= (0. 95, P<0.05) and Figure 8b shows correlation between wind speed and total phosphorus (TP) concentrations [R^2 = 0.7698, P (value < 0.5)].



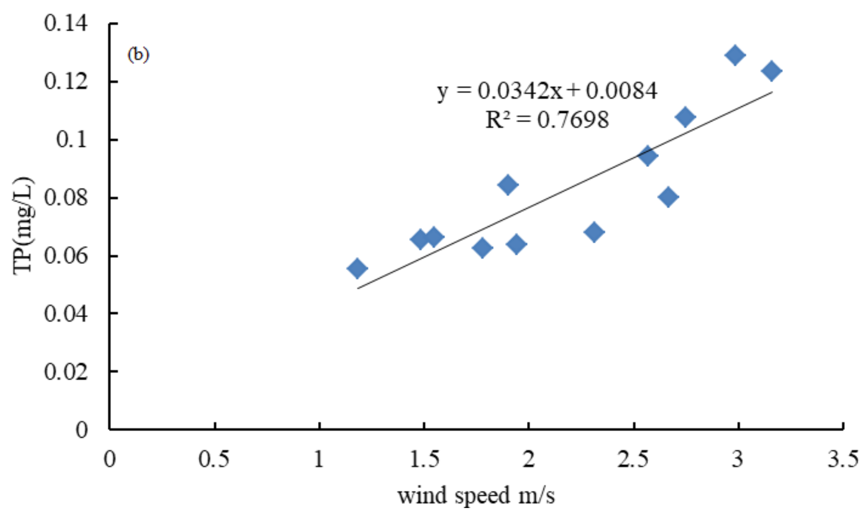


Figure 8. Shows relationship between (a) the turbidity (NTU) and wind speed (m/s) and (b) total phosphorus (TP) (mg/L) and wind speed (m/s).

Nutrients loads

Figure 9 shows the average of chlorophyll-a (µgL^{-1}) and nutrient concentrations during the experiment at three depths; bottom, middle and surface layers. The results demonstrated that the concentration of Chl-a (µgL^{-1}) decreased at bottom from 21.5 to 12.5 µgL^{-1}, middle layer (45.1-22.9 µgL^{-1}) and surface layer (50.2-34.4 µgL^{-1}). TN increased at each layer; bottom (1.8-2.7 mgL^{-1}), middle layer (1.7-2.5 mgL^{-1}) and surface layer (1.7 -2.1 mgL^{-1}), while TP increased in the middle layer (0.09-0.12 mgL^{-1}) and modestly decreased in the bottom (0.8-0.09 mgL^{-1}), and surface layer (0.09-0.11 mgL^{-1}). NH_4 increased in the bottom (0.14-0.19 mgL^{-1}), middle (0.13-0.18 mgL^{-1}) and surface (0.14-0.18 mgL^{-1}). PO_4 decreased in the bottom layer (0.02-0.03 mgL^{-1}), middle layer (0.01-0.02 mgL^{-1}) and surface layer (0.01- 0.06 mgL^{-1}). SS also increased in each layers (7.93-11.67, 7.8-9.07, 10.93-11.4 mgL^{-1}).

Wave-effect and diversity

Lake Taihu has suffered from severe eutrophication and harmful algal blooms for several decades (Abdul et al., 2017; Li et al., 2017; Paerl and Huisman, 2008). There are multiple sources of pollution, including urban runoff, industrial sewage, and agricultural runoff, and Meiliang Bay is the main drinking water source of Wuxi City (Epele et al., 2018; Li et al., 2017; Zheng et al., 2015). This Bay is the most pollution part and growing different microbial diversity and harmful algal blooms in the Lake. Table 3 shows changes in the distribution of microbial diversity in the two layers during the experiment, with the abundance concentration of total DNA in the bottom layer at 5.03 ng/µl^{-1} and 8.3ng/µl^{-1} in the surface layer. Ten minutes after start of the experiment the concentrations in surface and bottom layers decreased to 3.52 and 5.50 ng/µl^{-1} respectively.

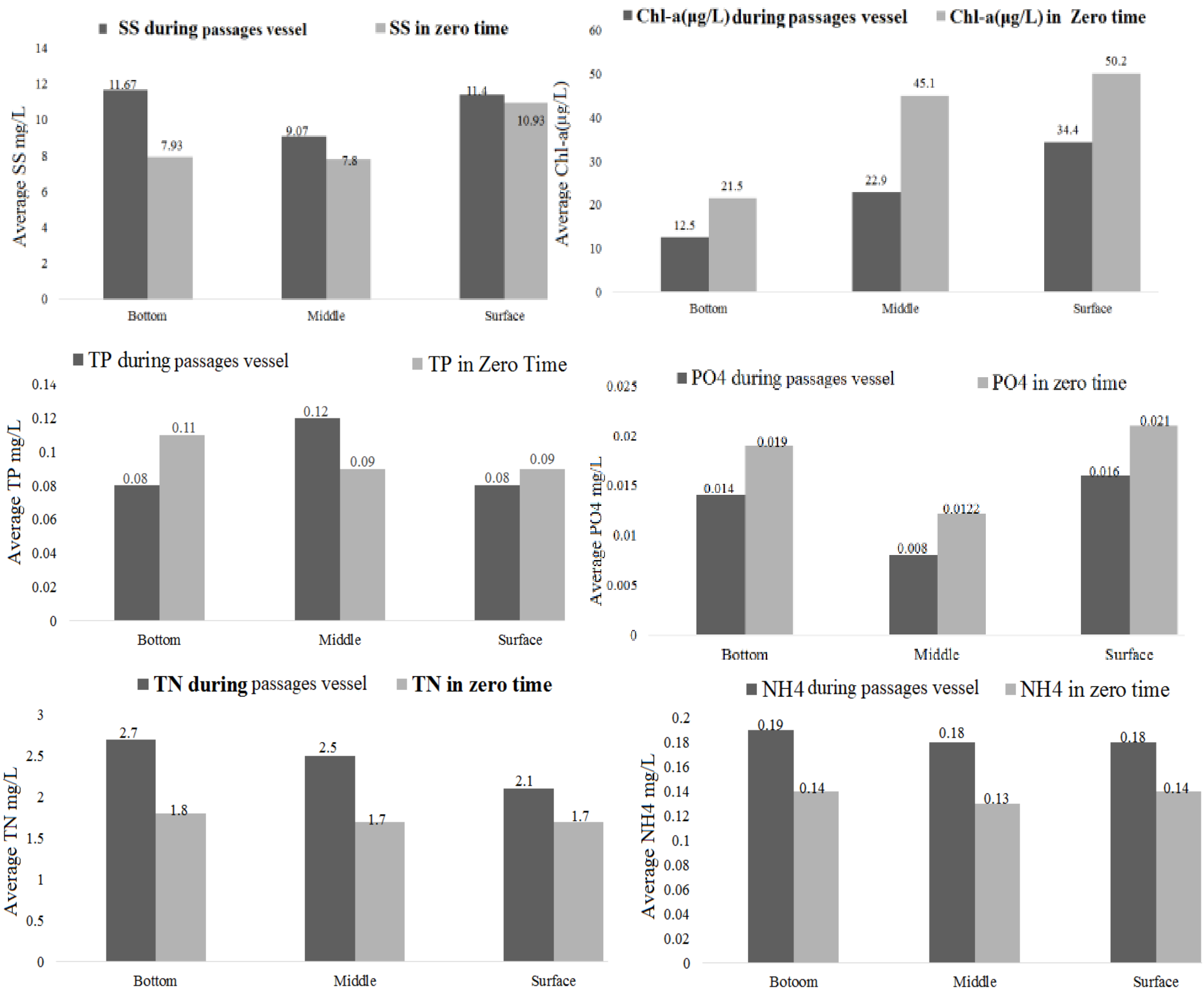


Figure 9. Sediment suspension during time experiments.

Table 3. Showed the concentration of microbial community in two layers.

Time during the experiment	Site	Con.(ng/µl)
Con. 1: in normal state	Bottom	5.03
	Surface	8.3
Con. 2: after 10 min	Bottom	3.52
	Surface	5.50
Con. 3: after 20 min	Bottom	3.30
	Surface	7.08
Con. 4: after 45 min	Bottom	2.93
	Surface	9.92
Con. 5: after experiment 2 h	Bottom	3.28
	Surface	15.5

After 20 min, the concentration increased slightly at the surface, to 7. 08 ng/µl^{-1}, and decreased at the bottom to 3.30 ng/µl^{-1}. The concentration at the bottom decreased to 2.93 and increased at the surface to 9.92 ng/µl^{-1} after 45 min passages vessel. Two hours after the experiment, the concentration increased at the bottom to 3.28 ng/µl^{-1} and increased to 15.5 ng/µl^{-1} at the surface.

DISCUSSION

Wave characteristics and hydrodynamic disturbances

The waves in Lake Taihu are produced by surface strong wind disturbance, and their characteristics essentially depend on wind speed, wind fetch, water depth and size of the vessel. In large shallow lakes, open water area waves are generated when the wind blows across the lake surface (Huang and Liu, 2009); wind energy was absorbed by the surface waves and turbulence, and then degenerated by bottom friction (Green and Coco, 2014; Li et al., 2017). The strong wind can cause algal blooms and other microbial communities to be completely mixed throughout the water column. In addition, the main factor inducing the distributions of wind speed and wave parameters is wind direction (You et al., 2007).

The direction of wind during experiment varied considerably, but dominated from the north. Other study analyzed the directions in Lake Taihu and found the predominant winds were southeast, during summer and the dominant wind speed range was 1.7-6.0 m/s (You et al., 2007). Li et al. (2017) confirmed that the wave heights created by southeast winds were considerably more than wave heights produced by northwest winds during the two periods (5/25/2014 and 5/27/2014), even with similar wind speeds. This is mostly due to varying wind fetch lengths and wind energies. The association between wind speed and wave height at the site showed that the wind speed and wave height were closely related. The waves generated by vessels have raised concerns about their effects on the water body, such as bank erosion, and damage to aquatic plants (Erfurt-Cooper 2009; Gabel et al., 2017). Also, Gabel et al. (2012) demonstrated that ship-induced waves can affect the physical characteristics of lake and river shorelines. Pettibone et al. (1996) found that the waves from a ship cause resuspension of bacteria-colonized bed sediments. The resuspension events occur frequently, internal nutrient loading and high concentrations of suspended particulate matter which can negatively impact in the water quality (Hartmann and Ronneberger, 1996; Li et al., 2017).

In the present study, when the vessel moved forward in the length area of 100 m and 10 m width from site collected the data, and returned to the starting point, it generated progressive waves. The progressive waves were created by the forward movement and the waves created by dominant north wind from the opposite direction collided. The analyses of wind and wave characteristics at steady time and during the experiment showed little to no significant change. This is possibly because both waves have the same amplitude and energy and caused phenomena called destructive interference. The significant wave height ranged from minimum value of 0.002 to maximum value of 0.612 m, the wave energy increased during time experiment from 0.03 to 0.09 NdBar$^{\wedge 2}$ m$^{\wedge -3}$ and the wind speed ranged from 0.5 to 2.1(m/s).

This findings show the likelihood of wave-wave to collision caused by the waves from the vessel and waves from north winds in the opposite direction. However, the presence of Southeast and Southwest winds caused reverse waves after hitting the solid stage of the site monitoring the Lakeshore and led to exerting an equal downward force on the end of the string. This new force creates a wave pulse that propagates from right to left with the same speed and amplitude as incident wave, but with opposite polarity (upside down) of strong reflectional waves according to Newton's third law (Brown, 1989; Svendsen and Madsen, 1981). The same effort and strength that led to impact on the water surface of the study area lead to generate small waves downwards causing resuspension of sediments and increased the microbial biomass at the time of experiment. Also, the dominant winds from the north directed towards the lakeshore in Meiliang bay caused the same inverse waves, which could be the most important reason for sediment resuspension in this bay (Figures 5 and 6).

Dynamic nutrients loads

The increased turbidity and the positive correlation between wind speed, turbidity R^2= (0. 97, P<0.05) may be due to the impact of waves generated by wind (vessel). The wind speed during experiment did not exceed the critical point 3.5 m/s that gave key factor for the resuspension to occur in the water body during weak wind speed and nutrients released. This may consider the cause of eutrophication phenomena and make algal bloom grew in the lake maybe by waves generated by vessels. The mixing of sediments resuspension into the water column does lead to nutrient release, the recurrence and period of resuspension events, as well as relation bioavailability of nutrients (TP, TN, NH_4, PO_4); therefore, factor in determining the magnitude of water quality impacts from waves.

The slope of relationship (TP=3.98x+55.4, R^2 = 0.7698, P (value < 0.5) (Figure 9) during May 26, 201, had weak wind occurrence, suggesting its potential to provide accurate prediction of the size of change in TP due to sediment resuspension in Meiliang Bay. The enrichment of water column by TP from the sediments could promote nitrogen limitation if a significant proportion of mobilized TP is bioavailable. Furthermore, a large flux of bioavailable phosphorus could maintain eutrophic conditions, in spite of large reductions in external phosphorus loading. On the other hand, if resuspended nutrients continue to exist largely as particle-bound and inaccessible to the biota, the effect on water quality could be comparatively small. Our assessments of resuspension are similar to other shallow eutrophic lake which were determined by Anthony and Downing (2003). Our results in Taihu Lake therefore show that resuspension of the bottom area may be influenced by waves. Frequent wave influence may be by strong wind, vessels, and disturbance of sediments. Efforts should be taken to research more about waves induced by wind, vessels to minimize influence of them, distinguish their impact exactly from the separate wave, which can further minimize the resuspension possibility in the shallow lake.

Many organisms were found in the sediments in higher concentrations than in the water column (Burton et al., 1987). Some microorganisms such as, Sediment-bound enteric bacteria may become resuspended by a verity of perturbations including dredging, storm events, boats and ships traffic (Garrad and Hey, 1987; Pettibone et al., 1996; Yousef et al., 1980). The concentration of some indicator microorganisms increase of 40-50 times in waters below dredging operation as compared to upstream waters (Grimes, 1980; Pettibone et al., 1996). The results indicated (Table 1) that there was a slight decrease of the microbial abundance concentration in the bottom layer especially during time passages of vessel 45 min and increased in the surface layer. This result may be because momentum wave shear stress and wave-wave collided the waves generated by vessel or SE, SW wind. This collide induced turbulence which increased the dissolved solids, soluble reactive phosphorus, turbidity and resuspending the microbial community associated with bottom sediments in the water bodies. Sediments may be resuspended as flocculated particles and sediment gathers can be a dominant form of sediment transport in freshwater. Generation of a wave makes resuspension in the layers (Perkins et al., 2014; Van Donsel and Geldreich, 1971).

In addition, slight increase of microbial abundance in surface layer also provides the suspension process in the lake. Moving the vessel generated waves, resuspending bacteria-colonized bed sediments. The microbes in different layers may also move by motility or a momentum change because the average velocity hydrodynamics change during the experiment. At the beginning of experiment, microbes move from the bed to water column, leading to increased microbial abundance in the others layers Table 1; and at the bottom layer, the wave's energy transmission to sediments particles attached. This leads to a different transport dynamic of sediments thus changing their mode of transport and deposition processes. The vessels had an impact on the physical characteristic of lake and river shorelines (Gabel et al., 2012; Garrad and Hey, 1987). Vessels induced waves and currents are effects on sediment resuspension and shoreline erosion and it began decades ago (Gabel et al., 2017; Garrad and Hey, 1987; Mason and Bryant, 1975). As a result of flow velocities changed and nutrients concentrations during passages of vessel induced waves and currents. This led to increase effect of shear stresses and sediments particles suspended fallowing by nutrients released which is the reason for supplying algal bloom for growth in a huge quantity. Increased wave energy, turbidity and changing the velocities during the time passages boat are similar with the results of (Gabel et al., 2012; Gao et al., 2017; Garrad and Hey, 1987) (Figures 5, 6). This led to alterations of the bottom morphology, sediment grain sizes and bank collapses (Gabel et al., 2017; Garrad and Hey, 1987; Nanson et al., 1994).

The vessel generated waves and the shear stress from those waves motivated the bottom sediment partials and liberation nutrients and maybe this shear stress is momentum mechanisms according to the turbulent burst that happened, ejections and sweeps during passages of vessel. The results are given a start point for more concentration of the mechanisms happened during momentous events on the bottom layer. In Lake Taihu there were a lot of vessels traveling in the lake and maybe the amount eroded materials depends on the characteristics of the vessels and its waves such as, travelling speed, distance to shore Lake, significant wave height, wave length. Also the characteristics of the location water depths are different in the lake, steepness of shoreline, sediment characteristics, grain size and cohesively, therefore leading to different erosion or suspension rates in the lake. May be in Meiliang bay the lakeshore was eroded from different waves generated by vessels and north winds.

Nutrient concentrations during the experiment at three depths

The average Chl-a μgL^{-1} and nutrient concentrations during the experiment at the three depths showed changes, with the concentration of Chl-a μgL^{-1} decreasing at the bottom. Wind-induced waves, especially strong winds, participate in 95% of sediment resuspension and nutrient release and are important for understanding how hydrodynamics affect eutrophication. The water depth at sites of data collection was only a few meters because Lake Taihu is a shallow lake, hence causing long-period waves move to the bottom layer and infiltrate the sediment water boundary that may bring about sediment resuspension and nutrient liberation (Jin and Tu, 1990; Li et al., 2017). Our results appear similar to Carper and Bachmann (1984) which showed that the resuspension of sediments in the lake by waves action and moments shear stress resulted in increased turbidity, thereby circling sediment nutrients back into the water column.

Conclusion

Field observations, analysis of the water column characteristics, effects of vessels and wind-generated waves on SS and microbial abundance were determined in this study. Examinations of nutrient loads in water layers suggest that both waves generated by wind or vessels can be responsible, by increasing resuspension and turbidity in the water column. In the lake, the variances of induced wave such as wind, boats and ships passages may differentially impact the concentration of suspended solid. Our results indicate that waves have a significant impact on suspended sediment concentration. Management strategies in Lake Taihu have thus far concentrated on the mitigation of algal blooms by nutrient load reductions. Future studies should focus on field observations of vessel waves shear stress, their effects on sediment resuspension and nutrient cycling, and their roles in eutrophication and algal bloom the changes in the hydrodynamic of the shallow Lake.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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