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# Influence of Atmospheric Particulate Matters on Underlying Surface of Water Body

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## Abstract

The air quality and the river water quality of the underlying surfaces in Shanghai and some areas of the Netherlands after environmental treatment were analyzed respectively, and the correlation between them was explored. A long-term family experiment was carried out to figure out the causes of water turbidity, and the correlations of turbidity and pH in water with the PM2.5 index in air quality were probed. Then, the air quality was found to be correlated, to some extent, with the river water quality of underlying surfaces, in which the PM2.5 index was strongly correlated with the river water quality.

## Keywords

Air Quality, River Water Quality, Correlation, PM2.5 Index

## Highlights

- A correlation was found between air quality and the water quality of its subsurface river water bodies, especially the PM2.5 index.
- Compare the water quality of the Rhine River and its basin air quality after long-term treatment with the water quality of rivers and urban air quality in Shanghai undergoing environmental treatment, providing a basis for predicting future environmental changes in Shanghai.

## 1. Introduction

As atmospheric control has been continuously promoted in recent years, the air quality has been significantly improved, but air pollution incidents caused by atmospheric particulate matters such as sulfur dioxide, nitrogen dioxide, and inhalable particulate matters still take place from time to time [1]. Air quality is not only an environmental problem but also a public health and economic problem. Poor air quality will lead to many possible diseases and also bring about economic losses [2]. Meanwhile, the problem of river pollution cannot be underestimated. Among more than 1200 rivers tested in China, 850 rivers are polluted to varying degrees, showing a growing trend [3]. A long-lasting family experiment was designed to explore and verify the correlation between air quality and the water quality of the underlying surface. Considering the process of environmental governance after development in Europe, the historical air quality data and river water quality data in three stages, from the beginning of environmental governance to the initial effect of environmental governance until the environment is greatly improved, in the Netherlands, Europe, were chosen. Then, its air quality (PM10 and $NO_2$) (PM10 refers to particulate matters with a particle size below 10 microns) was analyzed. Next, the relationship between PM10 and the water quality (ammonia nitrogen and total phosphorus) of the underlying surface was compared with the air quality of Shanghai and its water quality of the underlying river after treatment (2014-2022) was probed. Moreover, the relationship between air change and the river water quality of the underlying surface under different governance policies in different countries was investigated. The purpose of this study is to explore the correlation between air quality and water quality of the underlying surface, and to compare the effects of different environmental governance policies on these two aspects in different countries, especially China and the Netherlands. We hope to provide some insights and references for improving the air and water quality in China and other developing countries.

## 2. Experimental Research

### 2.1. Experimental Apparatuses and Conditions

In this study, a simple family experiment was designed to explore and verify the cumulative effect of air quality changes on water quality changes. In this experiment, particulate matters with a diameter less than or equal to 2.5 microns in the atmosphere (hereinafter referred to as PM2.5) were measured, and air humidity and pH of water were detected. The experiment was performed on the 14th floor in a community in Minhang District, Shanghai, at a height of about 40 m from the ground. The glass jars were illuminated from the north, accompanied by smooth circulation between air around the jars and the external atmosphere (experimental environment in **Figure 1**). Two types of water samples were adopted, namely, tap water (DB31/T 804-2014) and bottled natural drinking water (abbreviated as natural water) (GB 19298-2014).

Air PM2.5 was monitored using a PM2.5 detector (SW-825) manufactured by Dongguan Sunway Electronics Co., Ltd. A sealable transparent glass jar 30 cm in diameter was used for water storage with storage capacity of 40 L. The pH meter (PHS-25) was produced by Shanghai Inesa Scientific Instruments Co., Ltd. To prevent large foreign objects from entering the open container, the open glass jar was covered by a nylon filter with a mesh diameter of 4.2 mm.

**Figure 1.** Experimental environment.

## 2.2. Experimental Steps

The field experimental environment is displayed in **Figure 1**. It could be seen that the experimental environment was directly connected with the outdoor atmosphere. Four glass containers were placed side by side, and the experimental glassware could be irradiated by sunlight. When the water level in the container was obviously lower than the experimental water level due to the natural evaporation, the corresponding type of water source should be replenished in time.

Four groups of glass containers were set as four control groups, numbered one by one, and treated as follows: 40 L of tap water was added to the first glass container, and the opening of the filter screen was covered. 40 L of tap water was added into the second glass container, and the sealing cap was sealed. 40 L of natural water was added to the third glass container, and the opening of the filter screen was covered for treatment. 40 L of natural water was added to the fourth glass container, which was sealed with a sealing cap. The indoor air temperature and PM2.5 content of the container were recorded every day. Every seven days, the turbidity and pH value of water samples in four groups of containers were detected, and the water in the containers was replenished to 40 L. The actual change of the glass container was recorded by a camera (**Figure 2**).

## 2.3. Experimental Results

As shown in **Figure 3**, the actually measured water turbidity and pH value in the four containers are displayed in the bar graph. The seven-day average air temperature and PM2.5 index, and the then temperature and index actually measured are displayed in the broken line graph. Among which, the seven-day average air temperature and PM2.5 index came from the official website of Shanghai Municipal Bureau of Ecology and Environment, and the actual data were self-detected through the aforesaid method. As a whole, the seven-day average data from the official website of Shanghai Municipal Bureau of Ecology and Environment deviated, to some extent, from the self-measured data at the time, but a good synergistic relationship was observed.

**Figure 2.** Actual changes of glass containers recorded by the camera.

**Figure 3.** Gradual color changes of water body (shot on May 29, 2022).

The bar graphs a and b in **Figure 4** show the data on water turbidity detection every seven days from the end of February to the end of June. The changes in water turbidity in the two groups of open containers were in good consistency with those in the two groups of sealed containers, in which the changes in water turbidity in the sealed containers were relatively stable, while the water turbidity in the open containers experienced a process of rapidly rising, declining slowly, and then gradually rising again, especially the water quality in the open treatment group with canned tap water was improved substantially in a short time. In the meanwhile, it was found that the change in water turbidity in the open container was quite consistent with the change in the atmospheric PM2.5 index, and no significant microbial reproduction was ob-served in water in the containers during the early middle experimental stages. There-fore, it was thought that the main factors leading to the change in water turbidity in the early and middle stages were atmospheric sedimentation and the precipitation of particulate matters in water after atmospheric sedimentation, that is, atmospheric particulate matters settled on the water surface of the container and eventually fell to the bottom. This was why the water did not show the continuous atmospheric sedimentation when the PM2.5 index decreased in the early and middle experimental stages. At the end of the experiment, the water color in the open container gradually changed (**Figure 3**), and the PM2.5 index decreased in the end of the experiment, but the turbidity of the water still increased. Therefore, it was

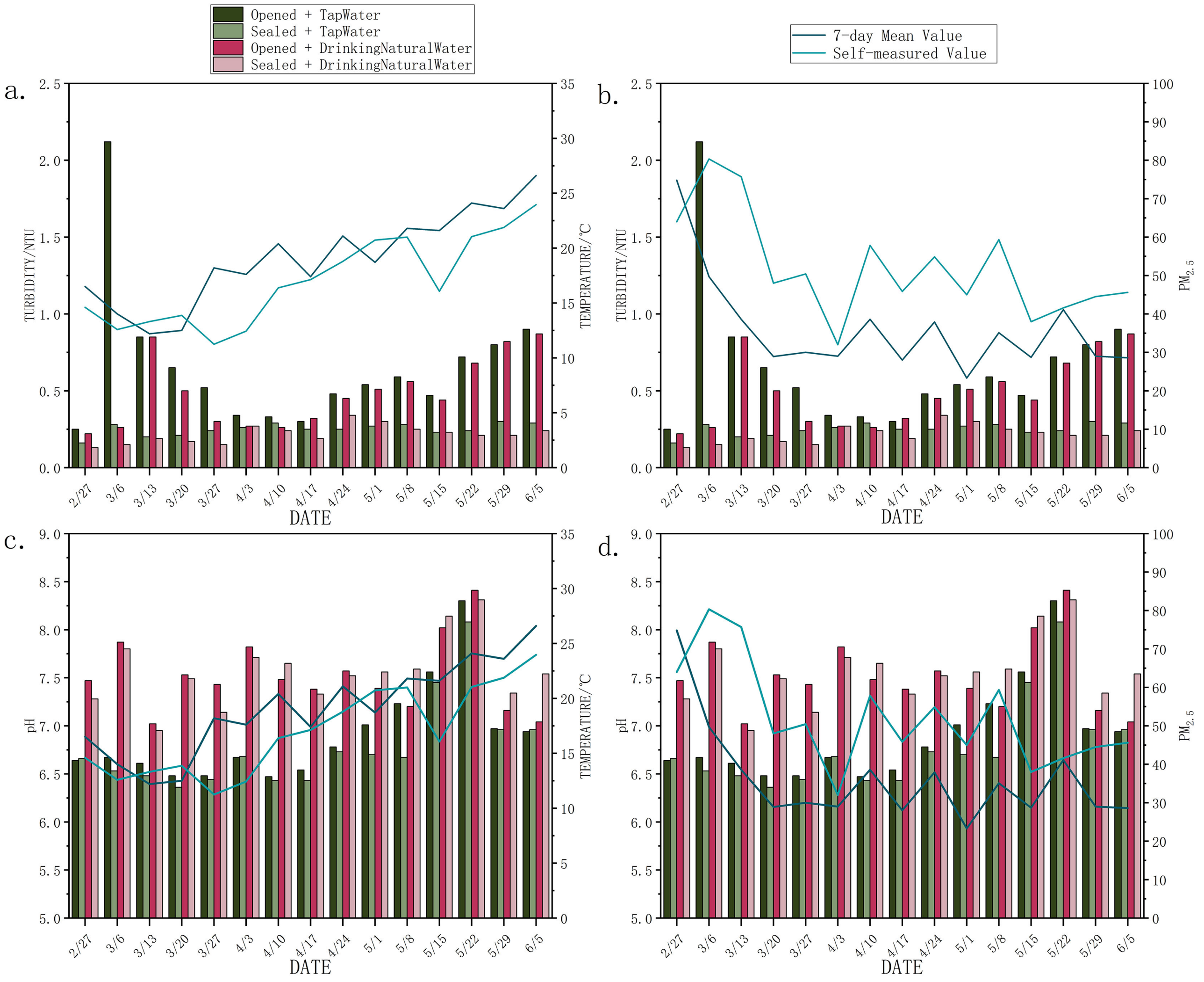

**Figure 4.** Changes of detection data in water turbidity detection (the bar graph represents the turbidity and pH of water quality; the broken line graph represents the PM2.5 index and temperature of air quality).

believed that the leading factor of the turbidity increase in the end of the experiment was the total amount of microorganisms and bacteria in water. Meanwhile, the outdoor temperature increased in the later stage of the experiment, which also accelerated the microbial growth in water to some extent.

The pH data in water detected every seven days from the beginning of the experiment at the end of February until the ending of the experiment at the beginning of June are given in the bar graph in c and d of **Figure 3**. It could be seen that the initial pH value was about 7.3 in the pure water group, while that in the tap water group was about 6.6.

Generally speaking, the pH value of water body in four experimental groups experienced the fluctuation of the initial pH value, which grew firstly and then declined, and afterward, the pH value was stabilized near a neutral level. In addition, the pH value was influenced greatly by the temperature. This was possibly because the high-temperature environment accepted algae growth and reproduction in water, their photochemical effect was enhanced, especially a chemical equilibrium between carbonates was reached. As a result, the pH value in water increased, and the specific mechanism is shown below [4]:

$$CO_2 + H_2O \xrightarrow{\text{light}} \{CH_2O\} + O_2$$

$$HCO_3^- + H_2O \xrightarrow{\text{light}} \{CH_2O\} + OH^- + O_2$$

The decrease in the pH value at the end of the experiment might be attributed to the massive death of algae reproducing one week ago under the lack of nutrient sub-stances and the release of intracellular substances.

Compared with the situation in the open treatment group, the variation amplitude of the pH value in the sealed treatment group was smaller. A possible reason was that there lacked material replenishment given by atmospheric sedimentation to the water body, which further led to the lack of nutrient substances required by algae growth and reproduction and limited the quantity of algae in growth and reproduction. Hence, the decline in the pH value owing to the photochemical effect and the subsequent algae decay was gentler.

## 3. Changes in Air and River Water Quality in Shanghai in Recent 8 Years

Since the 20th century, China's eco-environmental governance has been mainly divided into two stages: from 2000 to 2012, in which the environment-friendly strategy created for eco-environmental demonstration was gradually promoted, and the total quantity of pollutant discharge was controlled. From 2013 till now, the ecological civilization strategies of environmental quality improvement and "beautiful China" has been promoted, and China has entered a deeper eco-environmental governance stage [5].

The ecological environment of Shanghai, a typical city example of economic development in China, has been significantly improved after long-term governance [6] (Lu *et al.*, 2019). To further explore the relationship between China's air quality and the water environmental quality of the underlying surface, the air quality and surface river water quality data of Shanghai in 2014 and 2022 were selected. The air quality data included two indicators that could comprehensively characterize the air pollution degree or air quality level, namely, the air quality index (AQI), which is calculated based on the concentrations of six major pollutants (PM2.5, PM10, CO, $SO_2$, $NO_2$, and $O_3$) and their corresponding health effects [7] [8], and the concentration of dust with a diameter of ≤2.5 micrometers or floating dust in the ambient air (hereinafter abbreviated as PM2.5). Three routine river water quality monitoring data were selected as water quality data, namely, permanganate index, ammonia nitrogen, and total phosphorus.

**Figure 5** shows the inter-monthly air quality from 2014 to 2022. It could be seen that the AQI and PM2.5 content fluctuated in the whole year, and decreased in a fluctuating way in many years, with high air quality in summer and autumn, low AQI and PM2.5 content, low air quality in spring and winter, and great differences between different months.

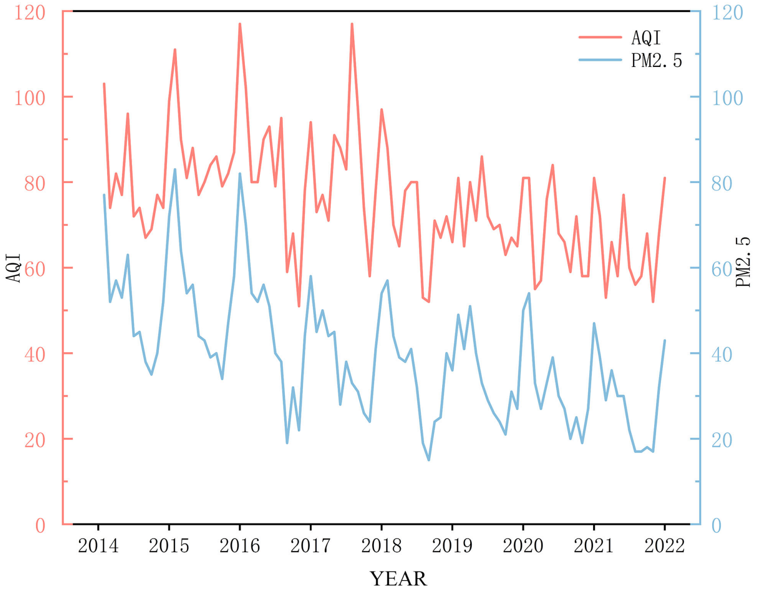

**Figure 5.** Changes in inter-monthly air quality during 2014-2022.

In **Figure 6**, the bar graph displays the interannual average changes in three conventional pieces of monitoring data on river water quality, and the broken line graph exhibits the interannual average changes in AQI and PM2.5. The permanganate index and total phosphorus content in rivers were relatively stable from year to year, while the ammonia nitrogen content tended to be stable after a significant decline. Judging from the average data for many years, the AQI had a positive correlation with the change in the PM2.5 value in all year except 2017. According to the 8-year data, the air quality was fluctuating and rising, and the improvement degree was great. The water environmental quality showed a steady upward trend, with the worst water environment and air quality in 2015 within the 8 years, but the overall improvement range was far less than that of air quality, that is, the improvement of river water quality was weaker than that of air quality. It was found that, except for AQI in 2017 and AQI and PM2.5 values in 2019, the AQI in other periods changed in the same direction as that of water quality index, that is, water quality and air quality presented the same change trend in most periods. Meanwhile, it was found that the improvement of water quality was often accompanied by a significant decrease in the content of PM2.5 in the air, such as that in 2015-2017. Therefore, it was deemed that there was a strong correlation between the change in urban air quality and the change in urban water environmental quality. Hereby a foreign environmental governance case will be further explored.

## 4. Changes in Air and Water Environmental Quality in Rhine River Basin

The Rhine River is the largest river in northwest Europe, with a drainage area of 168,000 square kilometers, including most of Switzerland, Austria, Germany, France, Luxembourg, Belgium, and the Netherlands, as well as a small part of Italy

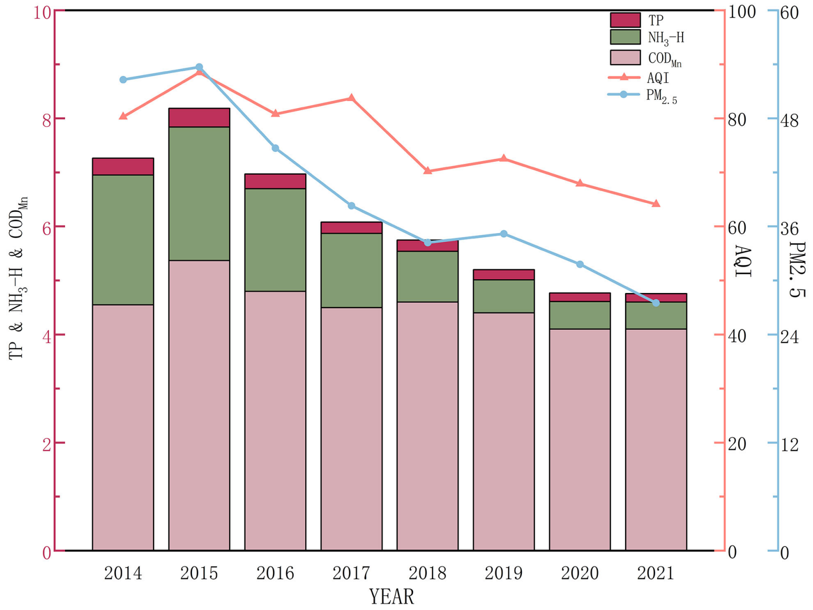

**Figure 6.** Interannual average changes in three conventional items of monitoring data of river water quality.

and the whole Liechtenstein. The major industrial areas in Europe are located in the Rhine River basin, including Ruhr area in Germany and Rijnmond area near Rotterdam. Due to the lagged environmental management in the Rhine River basin in the last century, the Rhine River became the best sewage disposal site for surrounding industries and agriculture at that time, so the Rhine River accumulated a large number of pollutants were accumulated in the Rhine River, which was faced with serious pollution [9]. In addition, water quality is deteriorated because of intense human activities like riverbed renovation and weir building [10].

The water quality problem of the Rhine River became particularly serious in the 1960s and 1970s. In 1963, the International Commission for the Protection of the Rhine against Pollution (ICPR) came into being, and determination was made to adopt substantive prevention and control measures, marking an initial sewage treatment stage. The subsequent two major environmental accidents, which respectively occurred in Switzerland and Germany, forced governments of different countries to pass “The Rhine Action Programme” in 1987, thus entering a water quality recovery stage of the Rhine River. On the basis of water quality recovery, ICPR further proposed to improve the eco-environmental quality of the basin on the premise of ensuring the water use safety in the basin. With the implementation of the “Rhine 2020 Plan” in 2000, the governance of the Rhine River turned to higher-quality eco-environmental construction to solve a wider range of ecological problems [11] [12].

By comparing the air quality and the river water quality of the underlying surface in Shanghai in recent 10 years, it could be known that there was a good correlation between the surface river water quality and the air quality after China entered the stage of in-depth treatment. To further explore the correlation between the surface river water quality and air quality after long-term treatment, the water quality data of the Rhine River after long-term (30 years) treatment and the monitoring data from the urban air quality testing center near the water quality monitoring station were selected, and the river water quality data in Shanghai were compared with the water quality data from the Lobit Water Environmental Monitoring Station of the Rhine River, expecting to figure out the variation trends of surface rivers and urban air quality environment in China after long-term governance.

The water quality monitoring data from the Lobit Water Environment Monitor-ing Station in the Netherlands from 1985 to 2005 [11] [13] was chosen. This station was jointly established with the German Bimmen Water Environment Monitoring Station in 2001 as one of the international water environment monitoring stations responsible for monitoring the water environment of the Rhine River. Urban air quality data were selected from the Netherlands National Air Quality Testing Network [14]. Specifically, the annual average concentration of nitrogen dioxide from 1986 to 2005 and the annual average concentration of PM10 from 1992 to 2005 were acquired from the multi-year continuous measurement results of urban stations.

In **Figure 7**, the bar graph displays the annual average total phosphorous and ammonia nitrogen content in water quality detection, and the broken line graph exhibits the air quality data, namely, nitrogen dioxide and PM10. As a whole, both water and air quality data showed a fluctuating declining trend in 30 years, the river water quality tended to be stable after 2000, but the air quality data still kept a considerable declining trend. It could be seen that the water quality of the Rhine River was improved to a great extent in 1998, 1992, and 1995. The air monitoring data near Lobit Monitoring Station was also improved, to a great extent, in the three periods. Given this, the air quality and water quality in the Rhine River basin presented certain variation trends.

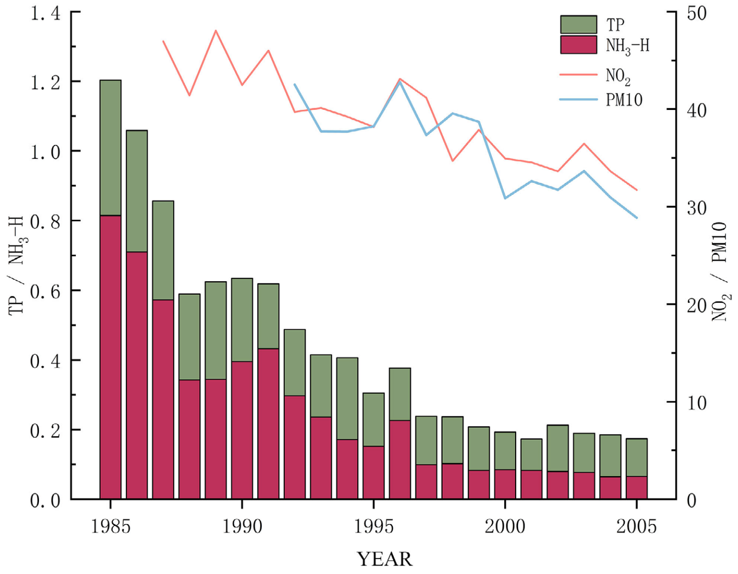

**Figure 7.** Annual average total phosphorous and ammonia nitrogen content in water quality detection correlate with air quality data: nitrogen oxide and PM10.

As revealed by river water quality data, the ammonia nitrogen value of the river was improved after a long period of environmental governance, but the total phosphorus value changed not obviously, which was similar to the change trend of river water quality data in Shanghai, that is, ammonia nitrogen in the river could be easily removed, while total phosphorus could hardly be removed. According to the air monitoring data, there was still much room for improvement after the river water quality tended to change gently, and the improvement of air quality was accelerated. It could be seen that in the early stage of pollution control, the water quality could be greatly improved. Although the improvement of air quality was consistent with the variation trend of water quality, the change in air quality lagged behind more, that is, the significant improvement of air quality lagged behind the significant improvement of river water quality by about 15 years. By comparing the changes in air quality and river water quality in Shanghai, it was found that the two places had different characteristics of air quality and river water quality: in Shanghai, the improvement of water quality lagged behind the improvement of air quality, but in the Rhine River basin, the result was just the opposite, which might be related to the governance policies, industrial structures, and governance measures of various countries.

## 5. Conclusions

Since the 1960s, substantive prevention measures have been initially adopted in countries along the Rhine River, aiming to prevent the continuous deterioration of its water quality. Through long-term treatment, the water quality of the Rhine River and its surrounding air quality have been greatly improved. The river water quality and air quality data can be highly correlated in the case of the great changes in the eco-environmental quality. Since 2013, China's eco-environmental construction has entered a new stage. In the past decade, the quality of urban air and river water has been greatly improved, especially the air quality has been significantly improved. By comparing the relationship between urban air quality and river water quality, it is found that the change in river water quality has a strong correlation with the change in air PM2.5 index, and the change in urban air quality is highly correlated with the change in urban water environmental quality.

In this study, the influence of air quality on different water quality for a long time was explored through family experiments. The experimental results show that in the early and middle stages, the leading factor of water turbidity in water storage containers was particulate matter sedimented in the atmosphere. In the later experimental stage, however, microorganism growing in water became the dominant factor blamed for water turbidity. Meanwhile, it was found that in the open container, no matter whether tap water or natural water was added, the change in water turbidity was considerably consistent with the change in the atmospheric PM2.5 index. Therefore, it was concluded that the change in urban air quality is correlated, to some extent, with the change in water quality of the underlying surface, in which water turbidity shows a strong correlation with the atmospheric PM2.5 index.

## Data Availability Statement

All data, models, and code that support the findings of this study are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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