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RESEARCH ON THE WEST LAKE ECOSYSTEM IN THE CONTEXT OF CLIMATE CHANGE

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INTRODUCTION

1. Motivations

According to many intentional studies, climatic change has been recognized as an important factor capable of influencing the lake ecosystems. Increased temperature and CO_2 concentration, extreme weather events will lead to change physical and chemical properties of the water and affect water quality and the life of creatures in the lake. At the same time, increased rainfall will lead to erosion, increase sediment for the lake, and reduce the life of the lake. The ecosystem services of the lake are also severely affected [76].

West Lake is the largest urban lake of Hanoi capital, has important ecological, historical and cultural significance. However, the rapid urbanization of West Lake has resulted in the deterioration of surface water quality, affecting the ecosystem in the lake. West Lake has been considered as one of the most sensitive and vulnerable ecosystems under the impact of climate change. Up to now, several studies have shown that there is a scientific basis for the impact of climate change on the West Lake ecosystem. However, the specific trends that climate change will affect the lake ecosystem have not been analyzed [47]. To contribute to identifying causes and impacts of climate change on the West Lake ecosystem to provide solutions to protect and develop the West Lake ecosystem under climate change, the study has been proposed: "**Research on West Lake ecosystem in the context of climate change**".

2. Research objectives

- Assessment of the impact of climate change on the West Lake ecosystem through the impact of climate change on phytoplankton.
- Propose solutions to mitigate the impact of climate change to sustainably develop the West Lake ecosystem.

3. Research subject and scope

Research subject: Some parameters of water quality, species of organisms, and ecosystem services in the West Lake are the subjects of research as follows:

- Water quality factors: temperature (t^{o}C), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), Ammonium($N\text{-}NH_4^+$), Nitrate ($N\text{-}NO_3^-$), Total Nitrogen (TN), Phosphate ($P\text{-}PO_4^3$), Total Phosphorus (TP).
- Organisms in the West Lake ecosystem focusing on phytoplankton and West Lake fish
- West Lake ecosystem services: supply services, regulatory services, cultural services, support services.

Research scope: The study mainly focuses on studying and analyzing the impact of temperature and extreme weather (extreme heat) on the trends of water quality, biodiversity (phytoplankton, fish fauna) of the West Lake ecosystem. The rainfall regime (increased rainfall and abnormal changes) is also considered to assess the impact on some features of the ecosystem.

4. Research questions and defending points

4.1 Research question

- Question 1: How is the trend of changing water quality and the West Lake ecosystem? What are the factors influencing this trend?
- Question 2: How has climate change (temperature, temperature extremes) affected the quality and services of the West Lake ecosystem over periods? How are the impacts of climate change on the West Lake ecosystem projected in the future?
- Question 3: What measures can be taken to limit the deterioration of water quality and biodiversity of the West Lake ecosystem in the context of climate change, and contribute to maintaining and conserving the West Lake ecosystem?

4.2 Dissertation defending points

***Point 1*:** Climate change (temperature and weather extremes) will change the exchange of matter and energy in the aquatic environment, promote growth and changes the composition of phytoplankton, affect to water quality and composition of fish species, contribute to accelerate degradation and affect to the sustainable development of the West Lake ecosystem.

Point 2: It is possible to mitigate the impacts of climate change and improve the adaptive capacity of the West Lake ecosystem through solutions that promote the strengths (S) and limit the intrinsic weaknesses (W) of the ecosystem based on identifying the external factors that have an impact on the lake ecosystem about climate change, including both challenges (T) and opportunities (O).

5. Scientific and practical significance

5.1 Scientific significance

The study presented a method to assess the impact of climate change on aquatic ecosystems, criteria, indicators, and the correlations between climate and environmental parameters. The evaluation method can be applied to other research subjects.

5.2 Practical meaning

The study has systematized the evolution of water quality and the West Lake ecosystem over a long time. The study has provided a general overview of changes in water quality, and ecosystem as well as ecosystem services in the West Lake as a basis for proposing solutions to conserve the lake ecosystem.

Analyzes of climate change impacts (increased temperature, rainfall regime changes and extreme weather events) on water quality and ecosystem change as well as ecosystem services are conducted in detail with clear evidence to show that the impact of climate change on the lake ecosystem is obviously.

6. New contributions

- Analyze and determine the correlation between increased temperature and algae density, in which some nutritional parameters change leads to increased algae density, pH, and cyanobacteria with the predominant density in the phytoplankton population of the West Lake.

- Develop a method to assess the impact of climate change on aquatic ecosystems through assessing the correlation between temperature and algae growth, water quality criteria (pH, DO, nutrient index), the level of eutrophication, determining the correlations between climate and environmental parameters to assess the impact of climate change and forecast the impact of climate change on the ecosystem.

7. Dissertation structure

In addition to the Introduction, Conclusion and Recommendations, the study was composed of 4 chapters. Chapter 1 presented an overview of national and international research on the impact of climate change on the lake ecosystem. Chapter 2 presented the object, scope, and content of the study. Chapter 3 presented research results on climate change impacts on the West Lake ecosystem. Chapter 4 presented the proposed solutions to minimize climate change impacts to promote the development of the West Lake ecosystem. The Appendix included questionnaires, calculation results, and illustrations in the study area.

CHAPTER 1. OVERVIEW OF STUDIES ON CLIMATE CHANGE EFFECTS ON THE LAKE ECOSYSTEM

1.1 Climate change impacts on urban lake ecosystems

1.1.1 Climate change impacts on abiotic and biotic components of urban lake ecosystems

According to many studies in the world, climatic factors including temperature, humidity, light intensity, rain, and wind have impacted hydrology, water chemical composition, and the ecological regime of lakes. In which, the temperature has the most significant effects on surface water quality. Increased air temperature and water combined with CO_2 concentrations will increase biological yield and decomposition, nutrient cycling, and eutrophication, result in water quality being degraded [87]. High temperature affects photosynthesis, respiration, stimulates the production of phytoplankton [79], as well as increases microbial activities and rates of reactions involving microorganisms. This leads to an increased proportion of dissolved organic carbon in the soil and ecosystem nutrients [96]. High temperature also increases the rate of chemical reactions of surface water such as nitrification and denitrification [58]. When the temperature has been increased the dissolved oxygen will be decreased, the more oxygen demand for biological activities, the more oxygen deficiency in the surface water system [91]. Increased temperature also increases the concentration of toxins in the lake, leading to the organism will absorb more toxins through digestion and respiration [59], [60]. Increased water temperature and nutrients may contribute to the transmission of water-borne diseases [76]. However, the temperature can affect the pH of freshwater ecosystems but make the water more alkaline than acidification.

Rainwater can affect water quality. Increased rainfall promotes eutrophication and water acidification, lake water pollution from nonpoint sources [85]. Rain affects the turbidity of the lake by

increasing the presence of some particulate matter and increasing the nutrient load (due to soil erosion) and reducing the threshold value of nutrients required in systems from clear to turbid. [67].

In summary, climate change has affected in the direction of increasing impact on water quality

1.1.2 Effects of climate change on biodiversity

Fish is a vertebrate animal and makes up a large proportion of aquatic ecosystems and lives in most water layers. According to Ficke (2007), increased water temperature, decreased oxygen concentration, changed nutrient loads, and hydrological regimes have driven many fish species to the verge of extinction and changing fish speices composition and decreasing natural fish production [66].

1.1.3Climate ChangeMitigation Strategies for lake ecosystem

According to Hulme (2005), a climate change mitigation strategy for lake ecosystem should cover three major purposes: (i) Increase flexibility in the management of vulnerable ecosystems (ii) Enhance intrinsic responsiveness of species and ecosystems in vulnerable ecosystems; (iii) Reduce pressures that increase injury [73]. The ecosystem approach is also considered to apply to recover the lake ecosystem. The approach has 12 key principles and 5 implementation steps, in which human is a part of the ecosystem and all stakeholders play an important role in the decision-making process of the use and protection of the lake ecosystem [30].

1.2 Overview of national research on the West Lake ecosystem and climate change impact on the West Lake ecosystem

1.2.1 Overview of the West Lake ecosystem development

Water quality: Studies from the 90s of the last century by Nguyen Kien Cuong et al. (1998), Le Thu Ha (1995), Nguyen Viet Anh, Le Hien Thao (2000) showed that the West Lake water was still clean and

or only lightly polluted [3], [12], [15]. Starting in 2000, many studies have shown that the water of the West Lake was eutrophicated and has begun to become more polluted such as the study of Pham Van Ninh (2001), Ho Thanh Hai et al (2001), Luu Lan Huong (2010) [17], [22], [28]. According to the research of the Institute of Ecology and Biological Resources (2011), the West Lake‘s water quality was polluted and eutrophication [52]. According to a study of the Aquaculture Research Institute No I (2017), the lake water quality was in eutrophication and super eutrophication [44].

Thus, the surface water quality of the West Lake was declining and becoming more eutrophic. However, the main cause of this situation mentioned by recent studies was that the West Lake receives directly wastewater from the household living around the lake and from business activities as well. The cause of impact of climate change impact on the lake ecosystem has not been mentioned clearly.

Biodiversity: the West Lake also has a unique value of biodiversity, containing diverse and unique animal and fauna resources. Several groups of plants and animals have been studied [25], [34], [50, [52].

Recently, some studies have mentioned changing the West Lake’s biodiversity such as the rapid growth of Cyanobacteria, the decline of natural fish populations, or the strong development of the organism-eating species in the *Rotifera* groups [50], [52]. These studies have shown that changes in environmental factors affected the biodiversity of the West Lake.

Lake depth: Lake has been getting shallower. In 1961 the deepest height was 3.5 m but in 2012 the deepest height was only 2.5 m. The lake’s bottom mud layer was increased from 0.5m (in 1961) to 1.5m (in 2012) [71]. The most recent survey results conducted by the Institute of Environmental Science, Hanoi University of Science and Technology showed that the mud layer in the lake was very thick,

ranging from 0.6-1 m, the depth of the layer in the middle of the Lake was thicker than the one in the coastal areas, partly due to the basin-shaped structure of the West Lake. The mud layer contained inorganic and organic pollutants, dead organisms, animal excreta which have become polluted sources to lake water [50].

Ecosystem services: The West Lake ecosystem has basic value functions as a wetland ecosystem with ecosystem services such as supply, regulatory, cultural, and support services. However, the roles of these services also have been changed over time.

1.2.2 Research on climate change impact on urban lakes in Vietnam and the West Lake

There are not many studies focusing on climate change impact of urban lake ecosystems in Vietnam. However, the initial studies showed that climate change has affected the volume and quality of lake water, and the habitat of the ecosystem, contributed to an increased risk of imbalance in the natural ecosystem. Algae will grow rapidly and the algae bloom phenomenon will occur more frequently [16], [19, [20].

The studies of Mai Dinh Yen (2011) [56], Hoang Van Thang et al., (2016) [33] have initially provided a scientific basis for the impact of climate change (increasing temperature and intense rain) on the West Lake ecosystem (biodiversity, ecosystem services). However, these studies just discussed the general trend of climate change impact on the West Lake ecosystem but the specific assessment of climate change impact on the components of the ecosystem (phytoplankton, water quality…), as a basis to build forecasts on climate change impacts and develop solutions to mitigate climate change impacts have not been studied.

CHAPTER 2: RESEARCH SUBJECT AND METHODOLOGY

2.1 Research location and subject *2.1.1 Research location*

The West Lake is located at 21º04'N, 105º50' E in Tay Ho district, northwest of Hanoi. This is the largest natural lake of the Red River Delta, originating from the Red River. The current area of the West Lake is 527,517 ha. The West Lake is relatively shallow, the depth ranges from 0.1 m to 2.8 m. The lake water level ranges from + 6.31 m to + 5.28 m. Around the lake, there are 12 main culverts pouring wastewater into the lake. The West Lake is located in an area with an average annual air temperature of 23.4˚C, average annual rainfall of 1,624 mm; influenced by the monsoon, the summer is the southeast monsoon while the winter is the northeast monsoon. From 2012-2016, the average l amount of radiation per year reached 120-123 kcal/cm^2/year [11], [21], [53].

Socio-economic characteristics: There are 6 wards directly related to the West Lake, with a total population of 160.3 thousand people in 2015, the density of 6572 people/km^2, mainly living by handicrafts and small trade. In addition, there are about 200 hotels, service companies, restaurants located on the lakeside and operating around the lake [30].

2.1.2 Research subject

(i)Water quality parameters: temperature (toC), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), Ammonium($N\text{-}NH_4^+$), Nitrate ($N\text{-}NO_3^-$), Total Nitrogen (TN), Phosphate ($P\text{-}PO_4^3$), Total Phosphorus (TP); (ii) Phytoplankton and fish or the West Lake; (iii) the West Lake ecosystem services: supply services, regulatory services, cultural services, support services.

2.1.3 Sample collection area and time

Samples were collected for the first time on 7/ 2020 at 9 points including 7 points near the sewers and 2 points in the middle of the West lakes (small and big lakes) and the second time on 1/ 2021 at 4 points.

2.2 Research time and data source

2.2.1 Research on climate properties (1960-2019)

Annual average temperature and rainfall from 1960 to 2019 of Hanoi (information on cold air waves causing severe cold, harmful cold weather, heat wave, and heavy rains affected Hanoi in recent years (2016 to 2020)) were collected at Lang hydro-meteorological monitoring station.

2.2.2 Ecosystem features

10 – year data of water quality data in the West Lake (from 2010 to 2019) with the following parameters: temperature (t^oC), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), Ammonium($N\text{-}NH_4^+$), Nitrate ($N\text{-}NO_3^-$), Phosphate ($P\text{-}PO_4^3$), provided by Hanoi Department of Environmental Protection.

Refer to the results of research on species composition, phytoplankton density in the period from 1996 to 2018, the West Lake fish composition from 1992 to 2017.

2.3. Methodology

2.3.1 Data collection

Collecting water samples and measuring water quality parameters: collecting samples at 9 points according to Vietnamese National Standard TCVN 6663:3-2016. Measure the parameters of temperature (t^oC), pH, dissolved oxygen (DO) by Japanese Water Quality Checker TOA-QC 22A. Collecting phytoplankton samples: Using nets to collect phytoplankton samples at the point or along the pond bank, then fix the samples with 1% Lugol or 2% Formaline.

Review literature: review, inheritance, and synthesis of national and international experiences. Collect data and documents on natural and socio-economic conditions around the West Lake based on previous studies and related websites. Sociological surveys and expert consultation are also applied.

2.3.2 Analyzing water quality criteria in the laboratory

Chemical analysis of nutritional parameters: Ammonium(N-NH_4^+), Nitrate (N-NO_3^-), Total Nitrogen (TN), Phosphate (P-PO_4^3), Total Phosphorus (TP) are analyzed according to the Vietnamese National Standards (TCVN).

Analysis of algae samples: Qualitative algae samples were observed under the microscope with phase contrast and fluorescence. Quantitative algae samples are filtered and counted by a Sedgewick-Rafter counting chamber with a volume of 1 ml to settle (3-5 min) and count cells according to the method of UNESCO (1978).

Analysis of Chlorophyll according to the method of Lorenzen (1967).

2.3.3 Data analyzing

Using Microsoft Excel to analyze biological statistics, build charts.

2.3.4 Synthetic assessment

Assessment of water quality based on some water quality parameters according to Surface Water Quality Standards QCVN 08-MT: 2015/BTNMT column B1; and WQI (Water Quality Index) according to Decision No. 1460/QD-TCMT issued on 12/11/2019. Evaluation of the eutrophication of lake water according to the Vollenweider Trophic Index - TRIX [95] and the Trophic State Index - TSI [61]. Assessment of lake pollution by biological index using Palmer method (1969) [88].

Correlation assessment: Air temperature (x) and surface water temperature (y), Surface water temperature (x), and pollution indexes (y) including BOD_5, COD, Surface water temperature (x) and nutritional indicators (y) including $N\text{-}NH_4$, $N\text{-}NO_3$, TN, $P\text{-}PO_4^3$, TP, Surface water temperature (x) and Chlorophyll-a content (y) using Excel software, testing the reliability according to Pham Tien Dung (2006) [26].

2.3.5 Assessment of the impact of climate change assessment

The expected impact and experimental analogous methods will be used in combination with the matrix method to assess the impact of climate change on the elements of the West Lake ecosystem (water environment parameters, phytoplankton composition, and diversity of the West Lake fish fauna, ecosystem services). All methods are used based on the "Guidelines for assessing the impacts of climate change and identifying adaptation solutions" (2011) and "Climate change and impacts in Vietnam" (2010) of the Vietnam Institute of Meteorology, Hydrology and Climate Change [48, 49]. SWOT analysis will be used to identify causes and solutions to mitigation the impact of climate change [43].

CHAPTER 3: RESEARCH RESULT ON THE IMPACT OF CLIMATE CHANGE ON THE WEST LAKE ECOSYSTEM

3.1. Assess the current status and role of the West Lake ecosystem

3.1.1 Assess the current status of water quality in the West Lake

DO in the West Lake water has a wide range from 4.9 mg/l to 9.31 mg/l. The pH also reaches a high level, in the range of 8.4 to 10.63, exceeding the standard of 5.5 - 9 according to QCVN 08-MT:2015/BTNMT (column B1). Ammonium concentration is within the allowable range according to the B1 value of QCVN 08-MT:2015/BTNMT. The nitrate amount is generally low, the highest in the survey points is 0.12 mg/L but still lower the allowable range

according to the B1 value of QCVN 08-MT:2015/BTNMT (Column B1: 10). Phosphate amount ranges from 0.21 to 0.46 mg/L, at some points near the sewers, the Phosphate amount is higher than the one in the middle of the lake, exceeding the standard according to QCVN 08:2015/BTNMT (Column B1). BOD_5 and COD ranges are 23.59 mg/l and 53.8 mg/l, respectively, exceeding the standard according to QCVN 08:2015/BTNMT (Column B1).

Based on the Water Quality Index (WQI): the water quality of the West Lake reaches a medium level. The WQI values at the sampling points range from 43 to 56, most of them in the medium level.

The ratio of TN/TP at all points was at ≥6, ranging from 9 to 19.8 (average 14.23). This shows that P is the limiting factor for the West Lake eutrophication. The result of the research conducted in July 2020 showed that the lake water was super eutrophication, as follows: The TSI index value is from 70.2 to 74.3 on average, 73; The TRIX index value ranges from 8.7 to 8.9 with an average of 8.8.

Thus, at present, the lake water is eutrophication and heavily polluted for parameters of BOD_5, COD, PO_4^{3-}, NH_4^-

3.1.2 Assess water quality in the West Lake for the period 2010-2020

The pH range of the West Lake had a wide range from 8.2-8.9, but it was under the allowable threshold according to the B1 value of QCVN 08-MT:2015/BTNMT (Column B1). Meanwhile, COD and BOD_5, Ammonium, Phosphate-4 main parameters representative for organic and nutrient pollution in the lake exceeded the allowable threshold according to QCVN 08:2015/BTNMT for several years

The WQI value of the West Lake water in the period 2010 - 2020 was mostly medium level and there was no period WQI was in the good level, even down to the bad level in 2016. Although the year

2020 WQI index was still medium level, it had been improved and higher than the index in previous years.

The West Lake management policy and factors that affect the West Lake water quality: The People's Committee of Tay Ho District is responsible for managing the West Lake and actively coordinating with city departments to manage and exploit the West Lake effectively [45]. Point pollution sources (wastewater from residential areas, restaurants, hotels, vehicles operating on the lake) have been controlled basically. However, many business households are encroaching on the landscape around the lake, which also affects the lake environment. Some diffuse source pollution and internal – lake source from very thick sediments (from 0.6 -1 m) are still potential sources of pollution [50].

3.1.3 Assess the current status of the West Lake's phytoplankton composition

Species composition: From 1996 to 2018, phytoplankton composition in the West Lake changed significantly, the diatoms increased while the green algae decreased. The species composition of ophthalmic algae and cyanobacteria also increased significantly.

Algae density: the density of Cyanobacteria increased gradually (since 1997 only accounted for 40.3%, in 2012 accounted for 60% of the density and by 2018 accounted for 90% of the density) showing that cyanobacteria were the dominant species of phytoplankton community in the West Lake.

In January 2021, algae bloom occurred in the West Lake: Cyanobacteria accounted for the main density (from 75% - 78%), followed by Green algae (from 20.3% to 21.8%), other algae species (Silic algae, Eye algae) accounted for no significant density.

3.1.4 Assess the current status of the West Lake fish fauna

Studies in the period from 1992 to now, especially the period after 2016 showed that the fish species composition was decreased

significantly, of which farming fish species ware decreased at least, the most decreased was fish species belonging to the group of rare and endemic species. The production of fish has also decreased gradually over the years.

3.1.5 Assess values/functions of the West Lake ecosystem services

The West Lake with 4 ecosystem services and 12 main functions is assessed from important to very important for urban areas. While some services still perform well, such as regulation services (flood regulation, microclimate), the scale and quality of some other ecosystem services have changed significantly compared to the past such as supply services (material production, water supply, water quality purification); support services (biological support, nutritional cycle support). Although cultural services (leisure tourism, heritage value) are being developed well, many activities are spontaneous and unplanned, so the development of these services sometimes affects the West Lake environment. Education value has not been taken advantages ofwhen the West Lake has not yet been used as a learning model for the student at all levels in Hanoi.

3.2 Assess the extent of climate change in Hanoi over the past 60 years

3.2.1 The temperature trend over the past 60 years

The average air temperature was uneven throughout the year, the highest temperature was in the summer months from May to September ranging 27.5-29.5^{o}C, the lowest temperature was in the winter months from December to February, ranging from 16.5-18.5 ^{o}C. From 1960-2019, the annual average temperature, summer average temperature, and winter average temperature tended to increase gradually over the years by 1.69^{o}C, 1.36 ^{o}C, 1.65 ^{o}C respectively.

The minimum air temperature tended to increase from 1960-2000 by 1.4^{o}C, from 2000-2019 gradually increased by 0.68^{o}C.

The maximum air temperature tended to increase gradually, from 1960-2000 by 1.7 ^oC, from 2000-2019, gradually increasing by 0.82^oC.

3.2.2 The rainfall trend over the past 60 years

The average annual rainfall from 1960 to 2019 mostly tended to increase. The number of rainy days/years tended to decrease.

3.2.3 Extreme weather events

Extreme cold in recent years has occurred from December last year to March next year, the temperature has dropped below 10^0C. Hot weather has occurred from May to August. The highest temperature reach 41.8^0C. In the Hanoi area, heavy rain has been increased in recent years (from May to October).

3.2.4 Climate change scenario and impact forecast for Hanoi

Air temperature is forecasted to increase within 100 years from 2000 to 2100 according to two scenarios RCP 8.5 and RCP 2.6, from 2.6 to 4.8 ^oC, and from 0.3 -10.7^oC, respectively.

The air temperature is forecast to increase by 1.9÷2.4^oC in North Vietnam and 1.7÷1.9^oC in South Vietnam according to the RCP 4.5 scenario and by 3.3÷4.0^oC in North Vietnam and 3.0÷3.5^oC in South Vietnam according to the RCP 8.5 scenario

The impact of climate change on Hanoi: Temperature in the Red River Delta will continue to increase next the decades, especially in Hanoi, the temperature will be higher than in the surrounding areas. The highest temperature could reach new records with lengthening hot season, increase in heat waves, and hot days. The erratic of the rainfall regime increases, the record of the daily rainfall in months and monthly rainfall may occur with higher values than before.

3.3. The impact of climate change on the West Lake ecosystem

3.3.1 Identify the relationship between temperature, nutritional parameters, and algae growth

The correlation coefficient between air temperature and water temperature: r*= 0.834 at the significance level of α = 0.05. According to this result (0.7≤ r *≤ 0.9), the two parameters have a close relationship according to the correlation equation as follows y= 0.9836x+0.8333.

The correlation coefficient between water temperature and N-NH4 amount: r*= 0.777, between water temperature and P-PO4 amount: r*= 0.763 at the significance level of α = 0.05. This result (0.7≤ r *≤ 0.9) shows that they have a close relationship. Thus, in the rainy season, the temperature may be one of the reasons for the increase of N and P amount in the lake.

The correlation coefficient between temperature and Chl-a amount is: r*=0.9451 at the significance level of α = 0.05. This result (0.9 ≤ r ≤ 1) shows that they have a very close relationship. The correlation coefficient between Chl-a and total phosphorus (TP) is 0.672 at the significance level of α = 0.05. According to this result (0.5 ≤ r ≤ 0.7), they have a relatively close relationship.

3.3.2 Impact of climate change on phytoplankton development

Based on the biological assessment index using Palmer method (1969), the relationship between algae distribution and ecological conditions are: Algae genera with high tolerance to environmental pollution such as genera Nitzschia, Navicula, Chlorella, Euglena grow stronger. Cyanobacteria are the dominant species in the phytoplankton community in West Lake, especially genera that can cause algae bloom such as Microcystis, Anabaene.

Effects of climate change on the growth of cyanobacteria include (i) Increased temperatures also promote increased nutrition and lead to an increase in phytoplankton biomass. (ii) The increased biomass of phytoplankton causes the pH to increase gradually because the process of algal photosynthesis uses a lot of CO_2 to shift the pH balance in the water towards alkalization. High pH is a favorable condition to promote

the growth of cyanobacteria, especially toxic genera and algae outbreaks.

Through the interaction of rising temperatures, especially weather extremes, in the interaction between biotic and abiotic components in the ecosystem, it is shown that increased temperature leads algae grow stronger in many ways, leading to an increase in water pollution (in contaminated water conditions). The more increased water pollution the more polluted tolerance species appear; High temperatures, especially weather extremes, promote the growth of thermophilic algae and cyanobacteria, especially the genus Mycrositys.

The forecast of the impact of climate change on phytoplankton development is that algae will develop more strongly, with a predominance of Cyanobacteria with the estimation of (++) level. The high pollution tolerance, toxic and blooming algal genera will appear more in phytoplankton species composition with the estimation of (+) level.

3.3.3 Impact of climate change on water quality of West Lake

Based on the analysis of the correlation between temperature and ecosystem factors (nutrition, algae growth) showing that climate change has contributed to increasing eutrophication, cause a sharp decrease in dissolved oxygen at the special time before dawn, pH being increased and water quality being declined in the West Lake.

Based on this correlation, it is predicted that the impacts of climate change on the water quality of West Lake will be: (i) The eutrophication will be accelerated strongly, with the estimation of (++) level; (ii) DO will decrease sharply especially during the night to before dawn and may last longer, affecting the life of aquatic species, with the estimation of (++) level; (iii) Lake water pollution is getting worse due to indirect effects from algal biomass increase with the estimation of (+) level.

3.3.4 The impact of climate change on the diversity of the fish fauna

Based on the relationships between temperature, algae growth, and water quality it is shown that climate change, especially weather extremes (high temperature and hot- prolonged weather) could be one of the main causes of mass fish deaths, happened in the year 2016 and 2018. One of the main reasons is due to the lack of oxygen occurring in high temperature and hot- prolonged weather at shallow, eutrophic, and non-stratified lakes as West Lake.

Based on foreseen relationship and the current situation at the lake, the impact of climate change on the West Lake fish fauna is forecasted as follows: climate change will reduce the number of fish species, the rare and endemic species may be destroyed, species with low environmental tolerance may be reduced maximum, native -South species and high tolerance species are the dominant species in the fish fauna.

3.3.5 Impact of climate change on ecosystem services

Climate change will lead to several causes affecting ecosystem services such as reduced water quality, reduced biodiversity, reduced natural fish stocks. High temperatures and heavy rains will affect outdoor activities. Supply services such as water supply functions will be affected in terms of quantity and quality; fewer and fewer naturally originated fish species will be provided, and fish production will be less than today. Many regulatory functions will be affected such as water quality regulation, disease regulation, groundwater recharged capacity. Outdoor activities and water-related tourism sports activities will be affected. Biodiversity support functions will be most affected by changes in the habitats of species. The nutrient cycling support function will also be affected.

CHƯƠNG 4: PROPOSE SOLUTIONS TO MITIGATE CLIMATE CHANGE IMPACTS

4.1 Principles to populate solutions to mitigateclimate change impacts

- Based on the current status of the West Lake ecosystem and the forecast of the impacts of climate change on the West Lake ecosystem.

- Applying climate change mitigation strategies to vulnerable ecosystems is to increase the resilience of ecosystems, reduce anthropogenic pressures, and increase biodiversity conservation to develop goals for populating solutions to mitigate climate change impacts (3 goals)

- For each goal, apply the SWOT analysis method to identify the strengths (S) and weaknesses (W) of the internal West Lake ecosystem as well as the external factors that have an impact on the West Lake ecosystem concerning climate change – including challenges (T) and opportunities (O); thereby orienting appropriate climate change mitigation solutions

4.2 Apply the SWOT method to populate solutions to mitigate the impact of climate change, promoting sustainable development the West Lake ecosystem

4.2.1 Goal 1: Restore and maintain water quality

To increase the West Lake ecosystem resilience, the West Lake water quality needs to be restored to ensure it meets current standards (B1 QCVN 08:2008/BTNMT) and reduce factors to cause eutrophication. This is a goal that needs to be done immediately to ensure the ecosystem gradually increasing its resilience. Based on the SWOT analysis, some solutions are proposed focusing on the following aspects:

- Water pollution control policy: Keep doing the water pollution control policies which have been implemented by Hanoi authority such

as monitoring polluted activities from shore restaurants, continuing to maintain the oxygen aeration system for the lake. At the same time, it is necessary to strengthen communication about the automatic monitoring system, develop an emergency response process.

- Intrinsic factors affecting lake ecosystem: To minimize the effect of intrinsic factors on the lake ecosystem, many solutions are proposed to enhance the self-cleaning ability of the lake, prevent nutrient sources from reaching the lake, replenish water for the West Lake.

- Extrinsic factors affecting the lake ecosystem: To reduce extrinsic factors affecting the lake, some solutions are proposed to limit nutrients coming into the lake as well as strengthen communication to raise public awareness to limit domestic wastewater discharging directly into the lake.

4.2.2 Goal 2: Biodiversity conservation

Maintaining Biodiversity is considered as a key factor to obtain freshwater ecosystem services, as well as being able "insurance" to prevent the ecosystem from collapse when facing adverse factors. Therefore, increasing conservation and restoration of biodiversity will contribute to increasing the resilience of the West lake ecosystem, contribute to minimizing the impacts of climate change. Based on the SWOT analysis, several proposed solutions to overcome the internal weaknesses of the lake such as reducing the dominant cyanobacteria density, creating favorable conditions for the development of rare and endemic fish species which are increasingly declining, overcoming the current status of embanked wetland ecosystems which cause loss of habitat for some species.

4.2.3 Objective 3: Harmonize with the development of urbanization in the West Lake

The management system of West Lake uses mainly a top-down approach, lacks a management method that can be maintained and

developed lake ecosystem. It is possible to apply the ecosystem approach strategy which has been used commonly to wetland ecosystems to a harmonious development of the West Lake ecosystem, both to satisfy human needs and to conserve the ecosystem.

Based on the SWOT analysis, some proposed solutions to strengthen the strong points and opportunities and overcome the weakness and challenges to the harmonious development with urbanization in the West Lake area.

4.3 Proposing specific solution groups

Based on the proposed solutions for the three goals, groups of solutions will be recommended as follows:

(i) *The group of technological solutions includes* strengthening the aeration system, dredging the lake, recovering algae, control the growth and outbreak of algae in the lake, remove the cyanobacteria, controlling wastewater from households, and embankment.

(ii) *The group of ecological solutions includes* conservation and development of biodiversity in West Lake, evaluating the valuation of ecosystem services, creating controlled wetlands, building a biodiversity museum of living genetic resources in West Lake, research and develop solutions to use ecosystem services according to the strategy of "win-win".

(iii) *The group of communication and training solutions includes* strengthening communication on climate change, automatic monitoring system, capacity building training including using West Lake as a visual and continuous educational model, increasing awareness of the effects of eutrophication on lake water quality.

(iv) *The group of policy solutions*: Continue the lake pollution control policy being applied, strengthen the policy of control and response to incidents, the policy of involving stakeholders in the decision-making process, and the development of policy on use and management of lakes.

CONCLUSION AND RECOMMENDATION

A.Conclusion

1. Trends in water quality and ecosystem of West Lake

The trend of water quality in West Lake showed that the WQI in 10 years (2010 -2020) was mostly at an average level (from 50 to 70), especially in 2016 it was a bad level (WQI below 50), Ammonium, Phosphate, BOD_5, COD in most years exceeded the regulated threshold according to QCVN 08-MT: 2015/BTNMT (column B1), pH was high and tended to increase during 2016-2020 (pH from 8.2-8, 9). Dissolved oxygen tended to decrease sharply from midnight to before dawn.

The increasingly super-eutrophic environment resulted in the rapid growth of the phytoplankton community, algae bloom. In January 2021, when algae blooms happened, the densities were up to 69 million cells/l to 89 million cells/l with the main composition of cyanobacteria, accounting for 75-78%. Urbanization and climate change have led to an imbalance use of ecosystem services. Regulatory, supply, biodiversity functions are severely affected

2. Impact of climate change on the West Lake ecosystem

Climate change with increasing temperature and extreme weather events (high temperature and prolonged hot weather) has an impact on the West Lake ecosystem. High temperature promotes algae growth rapidly, photosynthesis of algae causes pH to gradually increase. High pH is a favorable condition to promote the development of Cyanobacteria to become the dominant species in phytoplankton community in the West Lake, especially toxic and algae bloom genera. Through the impact on the phytoplankton, climate change causes pH to increase, dissolved oxygen to decrease sharply at night and before dawn. Climate change also contributes to increasing eutrophication and pollution levels in the lake. High temperature and prolonged hot weather can cause mass- dead fish phenomenon due to lack of oxygen combined with the polluted environment, generating toxic gas to cause fish being shocked, poisoned, reduced resistance.

Climate change will aggravate the elements of the ecosystem: Cyanobacteria will continue to develop; accelerate eutrophication; Dissolved oxygen drop sharply and last for a longer time affecting the aquatic species; Organic pollution increases; pH keeps rising; The composition of the fish fauna will be affected in which precious endemic species may be destroyed, low environmental tolerance species can be minimized, South- originated species and high tolerance species will be the dominant species in the fish fauna.

It is possible to assess the impact of climate change on aquatic ecosystems by evaluating the correlation between temperature and algae growth, water quality criteria (pH, DO, nutrient salts), eutrophication level. Methods of expected impact and experimental analogy could be applied to predict the impact of climate change on the ecosystem.

3. Solutions to minimize the impact of climate change

The strategy of proposed solution groups to minimize the climate change impacts is to increase the ability to restore ecosystems and conserve biodiversity with the goals of (i) Restoring water quality (ii) Restoring and conserving biodiversity (iii) Developing the West Lake ecosystem in harmony with the process of urbanization.

On that basis, 4 groups of solutions are proposed, including a group of technology solutions (5 main solutions); a group of ecological solutions (5 main solutions); a group of communication solutions (4 main solutions), and a group of policy solutions (4 main solutions).

B. Recommendation

1. Continue to evaluate the correlation between rainfall amount and frequency with lake ecological factors to make a more comprehensive assessment of the impacts of climate change on the West Lake ecosystem.

2. The assessment of impacts of climate change on West Lake has just been based on evaluating the correlation between climatic factors and intrinsic factors of the lake ecosystem. On that basis, predictions about the impacts of climate change on the ecosystem have been populated. It is recommended to continue modeling these projections to get a more specific assessment of the impacts of climate change on the West Lake ecosystem.

LIST OF PUBLICATIONS

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2. Nguyen Tram Anh, Nguyen Thi Thanh Hoai (2019), "Assessment of Climate change impact to West Lake fish", *Scientific and Technology Hydro-Meteorological Journal*, 10, pp. 65- 72.

3. Nguyen Tram Anh (2018), "Impacts of climate change on lake water quality: Case study for West Lake, Ha Noi", *Scientific and Technology Hydro-Meteorological Journal*, 5, tr. 11-20.

4. Nguyen Tram Anh, Mai Dinh Yen, Trinh Thi Thanh (2018), *A Proposal plan of Restoration of Ho Tay (West Lake) – (Hanoi Capital Vietnam) for Sustainable development in the Context of Global Climate change*, Hanoi Forum 2018. Towards Sustainable Development Climate Change Response for Sustainability and Security.

5. Doan Mai Huong, Mai Dinh Yen, Phan Thi Hien, Nguyen Tram Anh (2018), *Climate change impact assessment on ecosystem services of West Lake, Hanoi capital and suggestion a system of mitigation and adaptation measures*, 17th World Lake Conference, Lake Kasumigaura, Ibaraki, Japan**.**