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CO₂ and Humidity Affect the Characteristics of Surface Water Quality Response to Climatic Factors

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Abstract: Climate factors such as precipitation and temperature impact the surface water quality through complex physical and chemical mechanisms, which is one of the recent focuses of the IPCC Water Resources Assessment Working Group. Due to the differences in environmental factors and human activities, the response characteristics, i.e. sensitivity, of water quality to climatic factors is not the same among regions. This paper presents an interesting and important question: Will environmental factors such as carbon dioxide emissions and humidity affect the response characteristics of water quality to climatic factors? Based on the long-term observations of large rivers around the world and the model of climate elasticity of water quality, big data analysis on three scales of global, hemisphere and climatic regions was carried out. It includes 12 major water quality parameters of 52 monitoring points of 14 large rivers. The results show that environmental factors such as carbon dioxide concentration, relative humidity and soil moisture enhance the climate response of water temperature, dissolved oxygen, turbidity, total phosphorus and phosphate, while the increase of carbon dioxide emission stabilizes the temperature response of ammonia nitrogen and nitrogen oxides. In the southern hemisphere, soil moisture brings stability, carbon dioxide concentration produces variability, and relative humidity plays a dual role. Soil moisture plays a role in stabilizing water quality response in tropical and arid regions, while relative humidity plays a role in destabilizing water quality response in arid regions. In temperate climate zone, the effects of wind speed are prominent. The high wind speed enhances the rainfall response of non-filtered total phosphorus and the temperature response of dissolved oxygen. Carbon dioxide emissions enhances the temperature response of dissolved orthophosphate. The paper explains the possible mechanisms of these environmental factors with literature support. This study provides directional guidance for future water environment management in the context of climate change.

Keywords: Water Quality Climate Elasticity, River, Risk, Sensitivity, Carbon Dioxide, Humidity

1. Introduction

Global warming is fueled by enhanced human greenhouse gas emissions [1] which can influence surface waters. Increasing air temperature leads to warmer climate which is associated with varying hydrological cycle including varying precipitation and enhanced atmospheric evaporation [1-3]. Varying climatic conditions will fuel surface waters pollution [4-6]. The potential climate driven changes in surface water quality stimulates the author for the examination of water quality sensitivity to climatic drivers at global scale.

According to Intergovernmental Panel on Climate Change (IPCC) air temperature will rise from 1.8 to 4.0°C at global scale [7] during 21st century. Air temperature is the main factor impacting majority biological reactions and physico-chemical equilibrium in surface waters. Rise in water temperature will favor several processes including complexation, degradation, dissolution, solubilisation, evaporation, etc. On one hand the above mentioned phenomenon will elevate the concentration of dissolved

substances while on the other hand concentration of dissolved gases decreases [8]. Flood and drought are the strong consequences of climate change which can impact water quality. The concentration of dissolved substances increases while the concentration of dissolved gases decrease during low flow conditions of rivers [9, 10]. Solid material transportation via surface runoff is the main consequence of intense storms and strong hydrologic conditions [8]. As rivers water quality is sensitive to climate change [11], particularly precipitation and air temperature, which is the principle aim of the present study.

Precipitation, air temperature, humidity and wind speed are the strongest determinants effecting surface water quality. The above mentioned factors substantially varies with climate change [12]. Conventional tillage practices expose top soil layer to wind and water erosion which facilitates sediments entry to nearby waterbodies [13, 14]. Wind speed produce strong waves which causes in reservoir shoreline erosion [12]. Persistent unidirectional winds make surface water turbid especially in shoreline [15]. Tillage conservation practices improve surface water quality by reducing soil erosion via wind and water [16]. Wind and water accelerate sandy loam topsoil erosion during winter months [17]. Air humidity and soil moisture consistently depends on each other. Air humidity has significant effect on wind erosion because threshold velocity is influenced by soil moisture content in the top soil layer [18]. To date, impacts of wind speed on surface water quality is investigated while research on variability consequences of climate elasticity of water quality is not reported which motivates the author for the present study. The current study aims at assessing the variability consequences of climate elasticity of water quality (CEWQ) due to environmental determinants at global scale.

Soil moisture has strong consequences on surface water contamination. Less soil moisture will favor the absorption of organic contaminants, retained in soil in solid form, into soil particles. Runoff will sweep the binded organic contaminants into surface waters [19-23]. Moreover, microbial activities are enhanced by soil moisture and better soil ventilation which favor the transformation of urea nitrogen into ammonium nitrogen. Surface runoff transport ammonia nitrogen from soil into nearby water bodies [19, 24]. Pollution yield rate and leaching rate are negatively associated with soil moisture while positively linked with storm intensity [9]. Evaluation of the vulnerability of CEWQ to soil moisture at global scale is the motive for the present study.

Generally, higher concentration of CO_2 will elevate the flow volume by reducing transpiration losses through stomata as long as the precipitation and temperature remains constant [25, 26]. Industrialization and urbanization favor the release of CO_2 in atmosphere. Growing population and world economy are the two most important drivers of CO_2 emission in atmosphere produced from the combustion of fossil fuels [27]. CO_2 per capita emission has increased at global scale from 4.6 to 4.9 metric tons. Growing urbanization and industrialization speed up surface water pollution [28]. To date no research is reported on the variability consequences of CO_2 on surface waters which stimulates the author for the present study.

The principle aim of the current study is to evaluate variability of CEWQ (P, N, C nutrients, turbidity, DO) due to environmental determinants at global scale. This study is based on 12 main water quality parameters from 52 monitoring sites at 14 large rivers using extensive data record.

2. Materials and Methods

2.1. Study Area

The current study is based on 52 monitoring stations covering 14 large global rivers, 15 countries (5 different continents) and 10 various types of climatic conditions. The detail of monitoring sites is shown in Table A1 and Figure 1 [29].
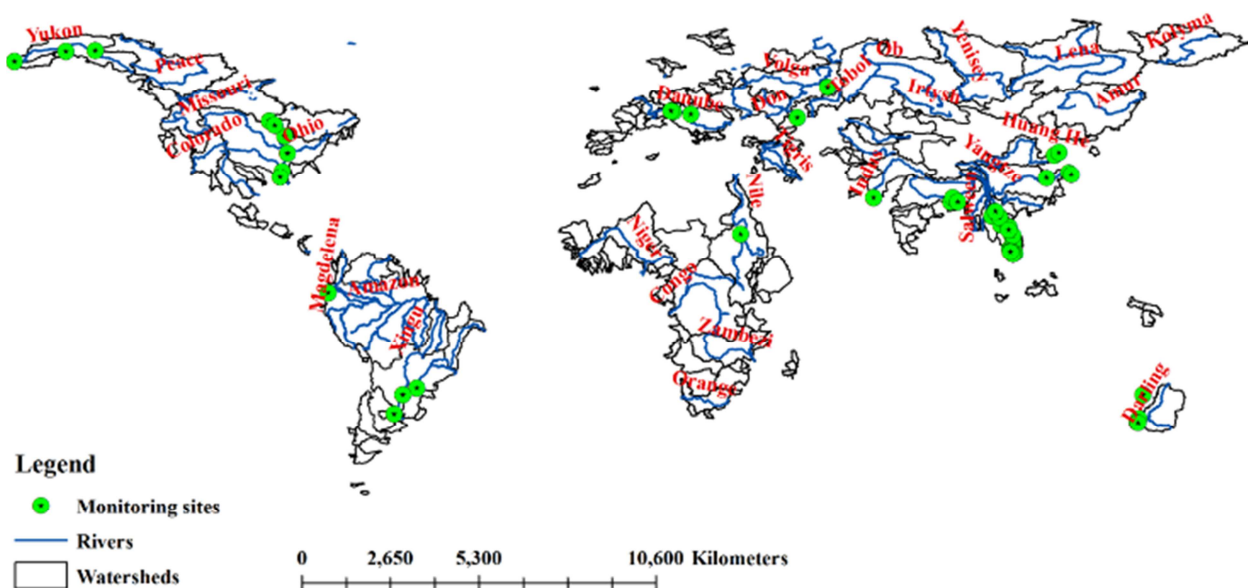

Figure 1. Water quality monitoring stations on large rivers in this study.

2.2. Data Sources

2.2.1. Water Quality Data

The present study is data extensive. We obtained water quality data for Murray–Darling River from EPA webpage: (http://www.epa.sa.gov.au). For the remaining monitoring sites, time series water quality data was obtained from UNEP/GEMS/Water webpage: (www.gemstat.org). This study is based on 52 monitoring sites located under different climatic and socioeconomic conditions. Here, we used 12 main water quality parameters whose detail is presented in Table A2.

2.2.2. Climatological Data

Global gridded meteorological, mean monthly air temperature (T,°C) and precipitation (P, mm), data are mined from Global Historical Climatology Network (GHCN) [30, 31]. The above stated meteorological variables data sets are freely accessible at 0.5° × 0.5° lat/long finer grid resolution.

2.2.3. Other Ancillary Data

Data matrix for relative humidity, soil moisture and wind speed were extracted from the gridded dataset (Climate Forecast System Reanalysis) created by the National Centers for Environmental Prediction (NCEP)[32]. CO$_2$ per capita per year was downloaded from the web page: http://edgar.jrc.ec.europa.eu/overview.php?v=CO$_2$ts_pc1990-2015.

2.3. Data Analysis

2.3.1. Nonparametric Elasticity Technique

The idea of nonparametric approach, climate elasticity of water quality, was presented by Jiang et al. (2014). This technique gauge the sensitivity of water quality parameters to meteorological variables i.e. precipitation and temperature [33]. Temperature and precipitation elasticity is based on the median values as shown in equation (1) and equation (2).

$$\varepsilon_P = median\left(\frac{WQ_t - \overline{WQ}}{P_t - \overline{P}}\frac{\overline{P}}{\overline{WQ}}\right) \tag{1}$$

$$\varepsilon_T = median\left(\frac{WQ_t - \overline{WQ}}{T_t - \overline{T}}\frac{\overline{T}}{\overline{WQ}}\right) \tag{2}$$

Where $\overline{T}$= mean monthly air temperature, $\overline{P}$= mean monthly precipitation and $\overline{WQ}$= mean monthly water quality while T_t= air temperature at any given time, P_t= precipitation at any given time and WQ_t= water quality at any given time.

As elasticity approach is based on mean monthly values, it gauges the response of mean monthly water quality to mean monthly precipitation and temperature, ignoring the rest socioeconomic, environmental and topographic factors. This technique does not consider the variability produced due to changes in the above stated variables which is the main objective of the current study.

2.3.2. Statistical Analyses

The strength and statistical significance of the linkage between CEWQ and environmental determinants was assessed by Spearman's correlation coefficient. Stepwise multiple regression was carried out to develop empirical equations between CEWQ and environmental determinants [34, 35].

3. Results and Discussion

3.1. Global Patterns of CEWQ

Precipitation and temperature elasticity results are shown in Figure 2. The correlation results between CEWQ, precipitation and temperature elasticity, and environmental factors are demonstrated by Table A3 and Table A4.
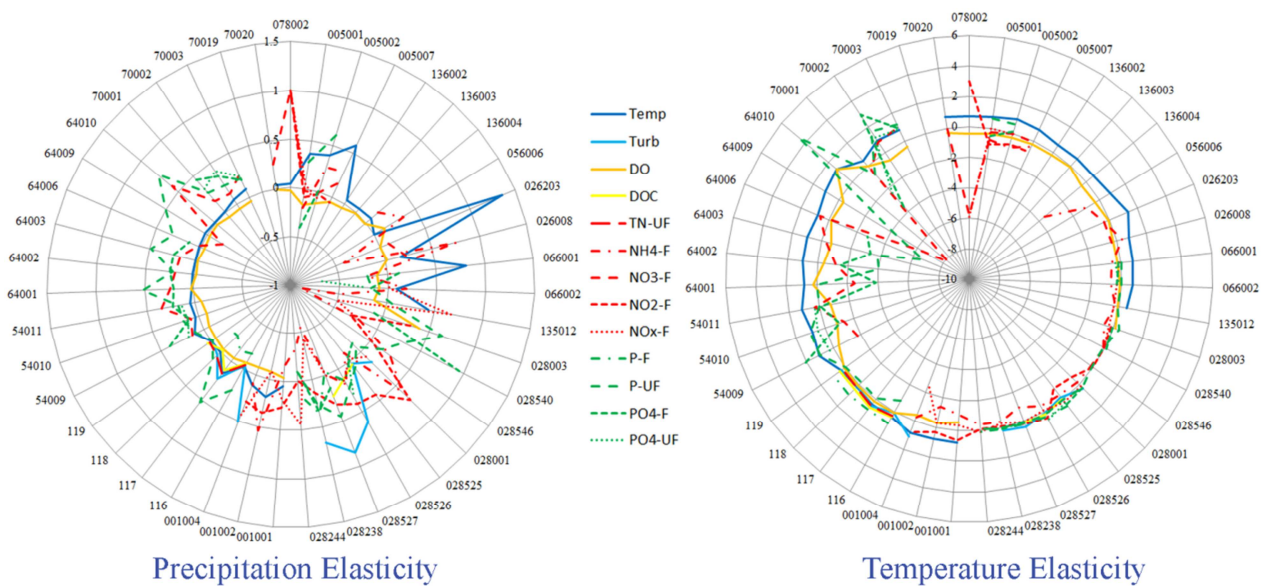

Figure 2. *Distribution patterns of global precipitation and temperature elasticity.*

3.2. Influence of CO_2 Concentration and Humidity on CEWQ

Table 1. *Spearman correlation coefficients between climate elasticity of water quality and environmental determinants.*

	CO_2	RH	SM
ε_P (P,Turb)	0.610*		
ε_P (P,P-F)	0.730**		
ε_P (P,PO_4^{3-}-F)		0.456*	
ε_P (P,PO_4^{3-}-UF)		0.664**	
ε_T (T, NH_4^+-F)	0.440*		
ε_T (T, NO_x^--F)	0.620**		
ε_T (T,Temp)		0.419**	
ε_T (T,DO)			-0.328*
ε_T (T,P-F)		-0.612*	

Note: * There is a good correlation at the significance level of 0.05 (bilateral test).** There is a good correlation at the significance level of 0.01 (bilateral test). RH=Relative humidity, WS=Wind Speed, SM=Soil Moisture

It can be seen from Table 1 that carbon dioxide concentration is positively correlated with turbidity rainfall elasticity εP (P, Turb) and total phosphorus rainfall elasticity εP (P, P-F), and the correlation coefficients is R=0.610, p<0.05; R=0.730, p<0.05 respectively, and the elasticity values of both are positive [28]. Urbanization and industrialization are associated with rising CO_2 levels. This positive correlation may be due to the high level of urbanization and industrialization in areas with high carbon dioxide concentration, resulting in more significant increases in turbidity and total phosphorus brought by precipitation. CO_2 concentration is indirectly related to these two water quality and climate elasticity characteristics.

The temperature elasticity of ammonia nitrogen ε_T (T, NH_4^+-F) and the temperature elasticity of nitrate nitrite nitrogen ε_T (T, NO_x-F) is positively correlated with CO_2 concentration, and the correlation coefficients is R=0.440, p<0.05; R=0.620, p<0.01 respectively. The temperature elasticity of these two nitrogen water quality parameters is mainly negative. It indicates that the climate elasticity of water quality tends to be inelastic in areas with high CO_2 concentration, which makes nitrogen water quality parameters in this region insensitive to temperature changes. Burning fossil fuels releases nitrogen oxides and carbon dioxide into the air. Then the emission of nitrogen oxides in the atmosphere could improve the concentration of N-parameter in surface water to a certain extent through the function of rainfall cleaning, thus promoting algal reproduction [36].

The relative humidity is positively correlated with the precipitation elasticity ε_P (P, PO_4^{3-}-F) of dissolved orthophosphates and the rainfall elasticityεP (P, PO_4^{3-}-UF) of unfiltered total orthophosphates, and the correlation coefficients is R=0.456, p<0.05; R=0.664, p<0.01,

respectively. Orthophosphate, also known as active phosphate, is an important source of orthophosphate in rivers due to the particulate matter brought into the water from the land during the water flow process. In catchments with large snow cover and high humidity index, the sensitivity of river flow to precipitation is often low and stable [37]. Therefore, the concentration of active phosphate in water is more sensitive to rainfall with the increase of atmospheric humidity. From the perspective of hillside hydrology, in the humid area, on the one hand, the humus soil layer is thick and the active phosphate content is high; on the other hand, the infiltration capacity of the soil layer is large. When the soil moisture of the topsoil reaches saturation, saturated overland flow will be generated, bringing nutrients into the water. On the one hand, the phosphate content in the soil layer is relatively low in the arid region, on the other hand, the runoff production is mainly over permeability, and the increase of active phosphate in the water body caused by rainfall is relatively small.

The relative humidity is positively correlated with the elasticity of water temperature and temperature ε_T (T, Temp), the correlation coefficient is R=0.419, p<0.01. In other words, water temperature in humid region is more sensitive to air temperature. The relative humidity is negatively correlated with the temperature elasticity of dissolved total phosphorus ε_T (T, P-F), the correlation coefficient R=-0.612, p< 0.05. ε_T (T, P-F) is generally positive elasticity, indicating that dissolved total phosphorus in water bodies in arid areas is more sensitive to temperature increase. Compared with the humid area, the arid area has more evapotranspiration loss, and the river flow decreases more due to the rising temperature. The dilution effect is relatively weakened under the condition of the increase of exogenous total phosphorus, so that the concentration of dissolved total phosphorus in water increased more. This is also the reason why our northern arid rivers are prone to eutrophication in summer.

There is a weak negative correlation between soil moisture and dissolved oxygen temperature elasticity ε_T (T, DO), the correlation coefficient R=-0.328, p<0.05. Lower soil moisture can enhance the retention ability of soil particles to organic pollutants, and more organic pollutants adsorb in soil particles [9, 19, 20]. When post-drought rains occur, long-accumulated organic pollutants migrate with runoff, which in turn increases the concentration of dissolved oxygen in surface water.

3.3. Linear Models Between CEWQ and Environmental Determinants

Models between CEWQ parameters and environmental determinants are demonstrated by Figure 3 (for complete detail see (Table A5). Both precipitation and temperature elasticity develop models with environmental determinants. It highlights that environmental determinants effects stabilization of CEWQ parameters, precipitation and temperature elasticity, at global scale.
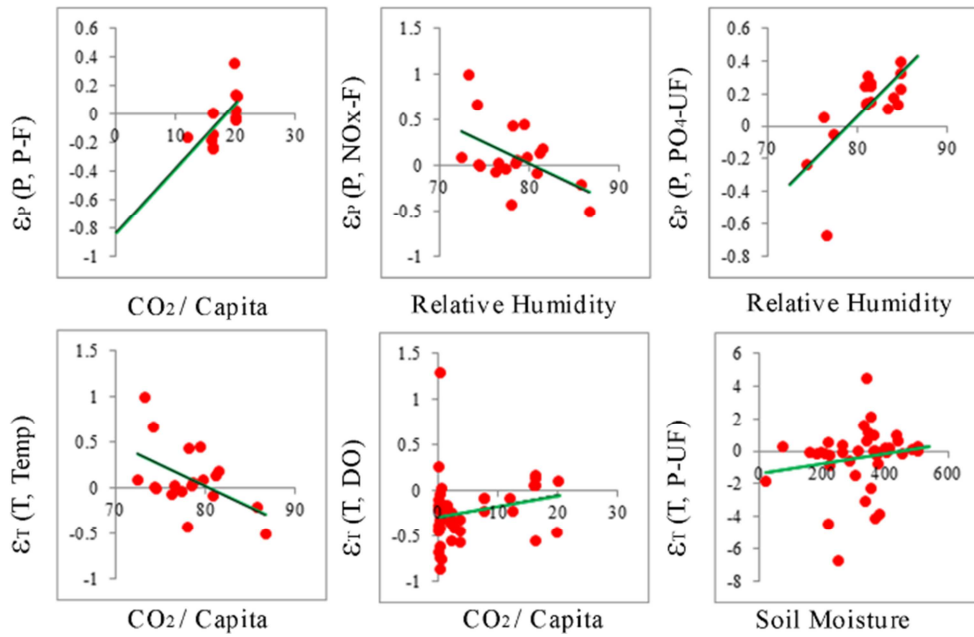
Figure 3. Regression between CEWQ and environmental determinants at global scale.

3.4. Different Influence Modes in the Northern and Southern Hemispheres

Regression models for northern and southern hemisphere are demonstrated by Table 2.

3.4.1. Variability of CEWQ in Northern Hemisphere

CO_2 has positive coefficient for ε_T (T, DO). Northern Hemisphere is thickly populated which enhance CO_2 concentration in air due to urbanization and industrialization [27] which increase the stability of ε_T (T, DO). It suggests that large paved area at urban communal level elevate flow volume which saturates surface waters with oxygen. First flush of rain is extremely polluted while the rest may cause oxygen saturation due to low pollution level. However previous studies show that overland flow sweeps pollutants which enhance surface water pollution and decline oxygen concentration [38-40].

Soil moisture showed negative coefficient for ε_T (T, NOx$^-$-F). Fertilizer application for better crop production is higher in the Northern Hemisphere [41]. Decreasing soil moisture have good effect on the retention capacity of pollutants in soil particles which decline leaching rate [9, 19,

20]. Lower soil moisture increase stability of pollutants attachment with soil particles.

3.4.2. Variability of CEWQ in Southern Hemisphere

Soil moisture displayed negative coefficient for ε_P (P, P-F). Dissolved phosphorous is negatively associated with soil moisture which may decrease pollution yielding rate [9, 19, 20]. It may decline leaching rate which brings stability in surface waters.

Soil moisture has negative coefficient while relative humidity has positive coefficient for ε_T (T, DOC). Lower soil moisture contents reduce the risk of variability by enhancing the soil retention capacity [9, 19, 20]. The positive coefficient of relative humidity for DOC may be attributed to wetter and warmer climatic conditions [42] which favor the risk of variability for ε_T (T, DOC).

Relative humidity has negative coefficient while CO_2 has positive coefficient for ε_T (T, P-UF). Growing humidity decline evapotranspiration losses which enhance flow volume [25, 26] which may cause dilution effect. CO_2 concentration in air is related with urbanization and industrialization [27] which increase the risk of variability of ε_T (T, P-UF).

Table 2. Regression Models for CEWQ at Northern and Southern Hemisphere.

Hemisphere	Elasticity Type	CEWQ	Regression Model	R	R2	ΔR2	F-Value	P-Value
Northern Hemisphere	Precipitation Elasticity	DO	-0.088 + 0.011 x CO_2	0.489	0.240		4.726	.046
		NOx-F	3.179 – 0.04 x RH	0.603	0.363		5.137	.050
	Temperature Elasticity	NOx-F	-0.589 + 0.001 x SM	0.780	0.609		13.992	.005
	Precipitation Elasticity	P-F	0.113 - 0.002 x SM	0.948	0.900		26.894	.014
Southern Hemisphere		DOC	-17.853 + 0.246 x RH	0.907	0.822		13.841	.034
	Temperature Elasticity		-35.567 + 0.494 x RH - 0.004 x SM	0.997	0.995	0.173	187.280	.005
		P-UF	-51.609 + 3.184 x CO_2	0.891	0.793		11.503	.043
			-30.39 + 2.804 x CO_2 – 0.203 x RH	0.990	0.980		49.178	

RH= Relative humidity, WS= Wind Speed, SM= Soil Moisture

3.5. Climatic CEWQ Patterns

Regression models under different Koppen climate classes are tabulated in Table 3.

3.5.1. Variability Consequences of CEWQ in Tropical (A) Climate Class

Soil moisture has shown negative coefficient for ε_T (T, NO_3^--F). In tropical climate class temperature relatively remains hot, mean temperature is 18°C, throughout the year. Lower soil moisture contents may be due to high temperature which brings stability by enhancing the soil retention capacity of contaminants [9, 19, 20].

3.5.2. Variability Consequences of CEWQ in arid (B) Climate Class

Arid regions are characterized by lower amount of precipitation and relative humidity, and high temperature and wind speed. Soil moisture has negative coefficient for ε_P (P, P-F). Lack of water in arid regions decline soil moisture which brings stability in ε_P (P, P-F) due to higher pollutants retention capacity and lower rate of leaching [9, 19, 20].

Soil moisture has shown negative coefficient for both ε_T (T, DO) and ε_T (T, Temp). In arid regions, lower moisture contents increase soil water holding capacity which decline flow volume and thereby increase water temperature. The lower leaching rate and higher pollutants retention capacity due to lower soil moisture in arid regions may increase DO concentration [9, 19, 20].

Relative humidity has displayed positive while soil moisture has shown negative coefficient for ε_T (T, DOC). Lower relative humidity and high air temperature in arid regions fuels the risk of variability of temperature elasticity of DOC due to warmer climatic conditions [42]. Lower moisture contents bring stability in temperature elasticity of DOC by retaining DOC in soil particles [9, 19, 20].

Relative humidity exhibited negative coefficient for ε_T (T, P-UF). Humidity and wind speed depend on each other. Lower humidity favor high wind speed in arid climate conditions which enhance wind erosion in top soil layer [13, 14] and thereby causes variability of ε_T (T, P-UF) in surface waters.

3.5.3. Variability Consequences of CEWQ in Temperate (C) Climate Class

Temperate climate class is characterized by moderate climate i.e. without extreme of precipitation and temperature. Wind speed exhibited positive coefficient for εP (P, P-UF). Farming is practiced on large scale in temperate climatic conditions due to warm summers and plenty rainfall. Wind erode the top soil, ploughing loosen the soil structure, layer and accelerates the overland flow which transport pollutants to nearby waterbodies which enhance the risk of variability of εP (P, P-UF) in surface waters [13, 14]. It may be attributed to instream bank erosion fueled by wind speed [12, 15].

Wind speed has displayed negative coefficient for εT (T, DO). Traditional tillage practices expose top soil layer to wind which transport pollutants to surface waters [13, 14] which may pose risk of variability to temperature elasticity of DO. It may be attributed to hot winds which strike the water surface which increase water temperature and decrease DO concentration.

CO_2 exhibited positive coefficient for εT (T, PO_4^{3-}-F). Majority of the world population lives in temperate climatic conditions which lead to large urban areas. Growing urbanization and industrialization in temperate climate class speed up phosphorous related surface water pollution [28] which increase the risk of variability of εT (T, PO_4^{3-}-F).

Table 3. Regression Models for CEWQ at different Koppen climate classes.

Koppen climate class	Elasticity Type	CEWQ	Regression Model	R	R2	ΔR2	F-Value	P-Value
Class - A	Temperature Elasticity	NO_3-F	8.643 - 0.023 x SM	0.968	0.938		45.143	.007
	Precipitation Elasticity	P-F	0.113 - 0.002 x SM	0.948	0.900		26.894	.014
		Temp	0.922 - 0.003 x SM	0.958	0.917		44.406	.003
		DO	-0.485 - 0.003 x SM	0.823	0.677		8.368	.044
Class - B	Temperature Elasticity	DOC	-17.853 + 0.246 x RH	0.907	0.822		13.841	.034
			-35.567 + 0.494 x RH - 0.004 x SM	0.997	0.995	0.173	187.280	.005
		P-F	-17.629 + 0.249 x RH	0.966	0.934		42.334	.007
		P-UF	21.913 - 0.298 x RH	0.924	0.853		23.233	.009
Class - C	Precipitation Elasticity	P-UF	-0.943 + 0.180 x WS	0.829	0.688		13.207	.011
	Temperature Elasticity	DO	0.305 - 0.089 x WS	0.837	0.701		14.050	.010
		PO_4-F	-0.527 + 0.038 x CO_2	0.903	0.815		13.233	.036

3.6. Ecological and Management Implications

We found that environmental factors alter the stability of precipitation and temperature elasticity in surface waters. The developed models can be used to check the variability consequences of environmental factors. This study will help the watershed managers to alleviate the problem of variability and bring sustainability in water environment.

Many useful models between CEWQ parameters (turbidity, DO, water temperature, nutrients (C,N,P)) and environmental factors have been developed. Watershed managers can take advantage from the developed models to resolve the problem of variability in CEWQ. We found that each CEWQ parameter face different variability consequences due to environmental determinants. The variability consequences of CEWQ parameters have significant biological implications in

forthcoming world. Variability consequences of CEWQ parameters due to anthropogenic stressors have strong consequences on fisheries production and marine ecosystems [43, 44] which could be substantial in future world.

The developed models can be used in unmonitored watersheds to predict the variability consequences owing to environmental factors. The developed models can be used to bring stability in CEWQ parameters via implementing innovative strategy to modulate the effects of environmental determinants. Moreover, it will be handy in preparing water pollution control strategies to decline nutrients load via integrated interdisciplinary approach to bring stability in CEWQ parameters.

3.7. Limitations

Because the uncertainty of regression equation coefficients is not discussed in this paper, the linear relationship equation obtained from the research cannot be directly used for scenario based analysis calculation. This study focuses more on the semi quantitative analysis of trends and relationships to provide directional suggestions and guidance. In the section of climate regional analysis, there are only five or six regression equations with a small number of samples. Although R^2 is very high, it is difficult to get accurate explanations and conclusions, and the uncertainty is large. If some want to predict the trend of river pollution load with climate change, he/she can refer to the multivariate elasticity method of K M MUNSON et al.. In addition, due to the failure to collect monthly data of carbon dioxide at the basin level, the study also has some limitations.

4. Conclusion

This study assessed the impact of environmental determinants on the water quality and climate resilient stability, that is, sensitivity. The results show that, in the global scope, in addition to the stabilization of the temperature elasticity of ammonia nitrogen and nitrogen oxides due to the increase of carbon dioxide concentration. Environmental factors such as carbon dioxide concentration, relative humidity and soil humidity all have the effect of increasing the elasticity of the water quality climate elasticity, making the water quality response more sensitive.

There are some new relationships in the northern and southern hemispheres and different climatic regions, environmental factors have an impact on the climate elastic variability of total phosphorus and DOC water quality. In tropical and arid climate types, high soil moisture plays a positive role in maintaining the stability of climate elasticity of multiple water quality. In arid climate type, relative humidity and soil moisture have opposite effects on temperature response of DOC. In temperate climate types, the role of wind speed began to highlight, and strong wind speed played a strengthened role in the rainfall response of unfiltered total phosphorus and the temperature response of DO. Similarly, large carbon dioxide emissions have a destabilizing effect on the temperature response of dissolved orthophosphate.

The elastic method provides useful information about the impact of water quality on the variability of climate response, indicates the trend of water quality sensitivity change, and can guide the formulation and verification of water ecological environment management plans.

Acknowledgements

Appendix

Table A1. Summary of rivers and monitoring sites.

Continent	River	Number of stations	Record length (yrs)	Number of WQ indices	Country/ies station located	Koppen Climate type	Rank by river length (a)
Africa	Nile	1	13	8	Sudan	BWh	1
	Yangtze	1	9, 10, 17	8	China	Cfa	3
	Yellow	2	10, 17	11	China	Cwa	6
Asia	Mekong	19	5–24	12	Cambodia, Laos, Thailand, Vietnam	Aw	12
	Ganges–Brahmaputra	3	16, 17, 17	5	Bangladesh	Aw, Cwa	29
	Indus	1	25	9	Pakistan	BWh	22
Europe	Volga	2	16, 31	5	Russia	Dfb, BSk	17
	Danube	3	17, 18	12	Hungary, Germany	Cfb	30
North America	Yukon	3	6, 21, 27	11	US	Dfc, Dsc	21
	Mississippi	6	14–22	16	US	Cfa, Dfa	4
South America	Parana	3	20, 26, 30	11	Argentina	Cfa	8
	Amazon	1	8	6	Ecuador	Cfb	2
Australia	Murray	4	36–39	12	Australia	Aw	15

(a). Wikipedia (2013)

Table A2. *Summary of water quality parameters evaluated in the study.*

Class	Abb.a	Name	Unit
Phys.	Turb	Turbidity	NTU
O	DO	Dissolved oxygen	mg O2/L
C	DOC	Dissolved organic carbon	mg C/L
	TN-UF	Total nitrogen i.e. TN	mg N/L
	NH_4^+-F	Ammonia as N	mg N/L
N	NO_3^--F	Nitrate as N	mg N/L
	NO_2^--F	Nitrite as N	mg N/L
	NO_X^--F	Nitrate + Nitrite as N	mg N/L
	P-F	Dissolved phosphorus	mg P/L
	P-UF	Total phosphorus i.e. TP	mg P/L
P	PO_4^{3-}-F	Dissolved orthophosphate as P	mg P/L
	-UF	Total orthophosphate as P	mg P/L

a. Abbreviation. F: filtered, UF: unfiltered.

Table A3. *Spearman correlation coefficient of precipitation elasticity.*

	Temp	Turb	DO	DOC	TN-UF	NO_3^--F	NO_X^--F	P-F	P-UF	PO_4^{3-}-F	PO_4^{3-}-UF	CO_2	RH	SM	WS
Temp		.886*	-.501**		.886*					-.538*					
Turb	.886*		.738*						.645*			.610*			
DO	-.501**				.943**										
DOC		.738*													
TN-UF	.886*		.943**												
NO_3^--F										.474*					
NO_X^--F									-.618*						
P-F												.730**			
P-UF		.645*					-.618*				.532*				
PO_4^{3-}-F						.474*					.636*		.456*		
PO_4^{3-}-UF									.532*	.636*			664**		

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).
RH= Relative humidity, WS= Wind Speed, SM= Soil Moisture

Table A4. *Spearman correlation coefficient of temperature elasticity.*

	Temp	Turb	DO	DOC	NO_2^--F	NO_X^--F	P-F	P-UF	PO_4^{3-}-F	CO_2	SEE	RE	SM	WS
Temp			-.336[*]								-.340[*]	.419[**]		
Turb									-.900[*]					
DO	-.336[*]			.900[*]									-.328[*]	
DOC			.900[*]											
NH_4^+-F										.440[*]				
NO_3^-F														
NO_2^--F						-.654[**]								
NO_X^--F					-.654[**]					.620[**]				
P-F								-.618[*]	.900[*]		.820[**]	-.612[*]		
P-UF							-.618[*]							
PO_4^{3-}-F		-.900[*]					.900[*]							

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table A5. *Regression Models for CEWQ at global scale.*

Elasticity Type	CEWQ	Regression Model	R	R^2	ΔR^2	F-Value	P-Value
Precipitation Elasticity	Turb	$-2.31 + 0.146 \times CO_2$	0.725	0.526		6.66	0.042
		$-4.979 + 0.16 \times CO_2 + 0.358 \times WS$	0.905	0.918	0.292	11.25	0.014
	NOx-F	$3.209 - 0.04 \times RH$	0.612	0.375		5.99	0.034
	P-F	$-0.934 + 0.048 \times CO_2$	0.766	0.587		9.954	0.016
	P-UF	$-0.394 + 0.086 \times WS$	0.424	0.18		4.615	0.044
	PO_4-UF	$-5.203 + 0.065 \times RH$	0.797	0.635		12.204	0.01
Temperature Elasticity	Temp	$0.803 - 0.022 \times CO_2$	0.619	0.383		11.811	0.003
	DO	$-0.413 + 0.026 \times CO_2$	0.626	0.392		12.919	0.002
	NOx-F	$-0.546 + 0.001 \times SM$	0.678	0.460		8.526	0.015
	P-F	$3.374 - 0.159 \times CO_2$	0.827	0.684		15.119	0.006
		$5.203 - 0.297 \times CO_2 + 0.002 \times SM$	0.953	0.908	0.225	29.702	0.001
	P-UF	$-0.615 + 0.002 \times SM$	0.430	0.185		4.775	0.04

RH = Relative humidity, WS = Wind Speed, SEE = Secondary Education Enrollment, SM = Soil Moisture

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