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Research Article

Effect of Rainfall on Water Parameters in Recreational Lakes in Heidelberg, Germany

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Abstract

This study evaluates the impact of precipitation on water quality in Heidelberg, Germany's recreational lakes during sporadic rainfall events from August to September 2023. Data were collected from five stations, monitoring physicochemical properties and nutrient levels before and after rainfall. Measurements of dissolved oxygen, pH, conductivity, and redox potential were conducted in situ, while turbidity, nitrates, phosphates, sulphates, zinc, and copper levels were analyzed in the SRH Heidelberg water laboratory. Findings indicate pH levels increased due to dilution effects, while conductivity rose due to runoff, enhancing ion concentration in the lakes. Dissolved oxygen levels also increased, attributed to aeration from rainfall-induced surface turbulence. Redox potential decreased, reflecting atmospheric oxygen dissolution. Nutrient concentrations, including nitrates and phosphates, along with sulphates, declined post-rainfall, suggesting a dilution effect without significant impact from surface runoff. This outcome implies the absence of major nutrient and sulphate sources upstream. Heavy metals like zinc and copper also decreased in concentration, indicating no introduction through runoff or sediment transport. The study underscores the variability of water quality parameters across different lakes, influenced by factors such as water sources, surrounding land use, geological conditions, and lake characteristics. Overall, water quality improved post-rainfall, making the lakes suitable for recreational activities, with the study establishing a non-linear correlation among the water quality parameters and deducing the P ratio for each parameter.

Introduction

In recent years the world has witnessed abrupt changes in precipitation patterns which culminated to serious challenges to water bodies including ponds, lakes and rivers. Precipitation patterns have varied effects on the status quo of water bodies.

Rainfall can have a significant impact on the transport and concentration of nutrients in surface water bodies. Rainfall can wash nutrients such as Nitrogen (N) and Phosphorus (P) from agricultural fields, urban areas, and other land surfaces into surface waters through runoff, leading to an increase in nutrient concentrations [1,2]. Also, heavy rainfall can cause soil erosion, carrying sediment-bound nutrients into surface waters. This process can contribute to elevated nutrient levels [3,4]. Rainfall can influence the discharge of treated or untreated effluents from wastewater treatment plants and industrial facilities, potentially increasing nutrient loads in surface water [5,6]. Rainfall can remove atmospheric nitrogen compounds (such as ammonia and nitrates) and deposit them into surface waters, contributing to nutrient enrichment [7,8].

Rainfall significantly impacts the physiochemical properties of surface waters, notably through dilution and aeration processes that can alter Dissolved Oxygen (DO) levels and redox potentials. Dilution of surface water by rainfall increases the water volume, potentially enhancing the mixing with oxygenrich groundwater, thereby increasing DO concentrations [9]. Rainfall-induced aeration, especially evident in smaller streams and rivers, amplifies water turbulence, facilitating atmospheric oxygen exchange with water, thus potentially raising DO levels [10]. However, this process can also introduce organic matter and nutrients into water bodies, heightening microbial activity and oxygen consumption, which may temporarily decrease DO levels [11].

Increased runoff following rainfall events introduces organic matter and microbial populations into aquatic ecosystems. The microbial decomposition of this organic matter consumes dissolved oxygen, impacting water quality [1]. Furthermore, rainfall influences redox potentials in water bodies by promoting oxidation-reduction reactions within the aquatic environment, affecting the chemistry of the water and the behavior of various contaminants, including heavy metals [12].

Heavy rainfall events mobilize heavy metals from urban, industrial, and agricultural sources, facilitating their transport into

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surface water bodies. This transport can lead to sediment-bound heavy metals becoming suspended in the water column. Depending on the water body's characteristics, heavy metal concentrations may be diluted due to increased rainfall, which mixes contaminated water with less contaminated sources. Additionally, rainfall can increase the discharge of heavy metals from point sources, such as industrial facilities, into surface waters [13].

Rainfall also influences the concentration of sulfates and pH levels in surface waters. It can lead to the dilution of sulfates and alter pH by mixing rainwater with existing water, introducing atmospheric elements, and affecting the chemical composition and equilibrium mechanisms controlling water pH [14,15]. These changes can have significant implications for the ecological health and usability of water bodies for recreational and other purposes [16,17]. This study assessed the effect of precipitation on recreational lakes in and around Heidelberg, Germany.

Materials and methods

The sampling sites were in the vicinity of Heidelberg City, Germany and were required to be for recreational purpose. The study was conducted on five recreational lakes with salient features are presented in Table 1 and Figure 1. Physical characteristics of the stations are presented in Table 2.

The study lasted over the period of sporadic rainfall in Heidelberg, Germany in the month of August and September 2023. Monitoring stations were established on all the lakes and were mapped with coordinates. The water quality parameters were measured in-situ and were performed at a depth of 15 cm from the water surface before and after an event of precipitation. To evaluate the day for sample collection prior to rain, weather forecast from Deutscher Wetterdienst Meteorological Service, based in Offenbach am Main, Germany. Precipitation measurements were acquired through the utilization of rain gauges installed across all study sites. These devices facilitated the collection of rainwater spanning a continuous 24-hour interval. Physiochemical parameters of pH, dissolved oxygen, redox potential, and conductivity were carried out in-situ using a multimeter supplied by Hach HQ40D along with associated probes. Turbidity was analyzed using turbidimeter supplied by Hach 2100Q. For lab analysis, the samples are collected in a 500mL sterilized glass bottles and each sample is labelled, dated and placed in a chilled cooler for transportation to the lab, after which it is kept at the laboratory refrigerator until further use. Lab analysis is carried out using powder pillows and Hach spectrophotometer DR 3900 for analysis of nitrate, phosphate, sulphate, zinc and cooper. Sampling carried out in five stations at two timing (before and after rainfall) at three timing replications for each station (Figure 2).

In this study, Statistical tests of Analysis of Variance (ANOVA) and the Duncan test were employed to rigorously assess and quantify significant variations in water quality parameters both before and after precipitation events. SPSS 27 was used to analyze the data at P< 0.05. Duncan (MRT) was applied post the

Table 1: Salient features of the five study sites in Heidelberg, Germany

Station	Co-ordinates	Length (m)	Width (m)	Depth (m)
Waidsee	49.53, 8.63	700	500	30
Waldsee	49.55, 8.58	155.4	160	12
Vogelstangsee	49.50, 8.54	346.4	318.1	5
Oberer Vogelstangsee	49.50, 8.54	390.2	156.1	1.7
SRH Lake	49.41, 8.65	41.3	17.9	2

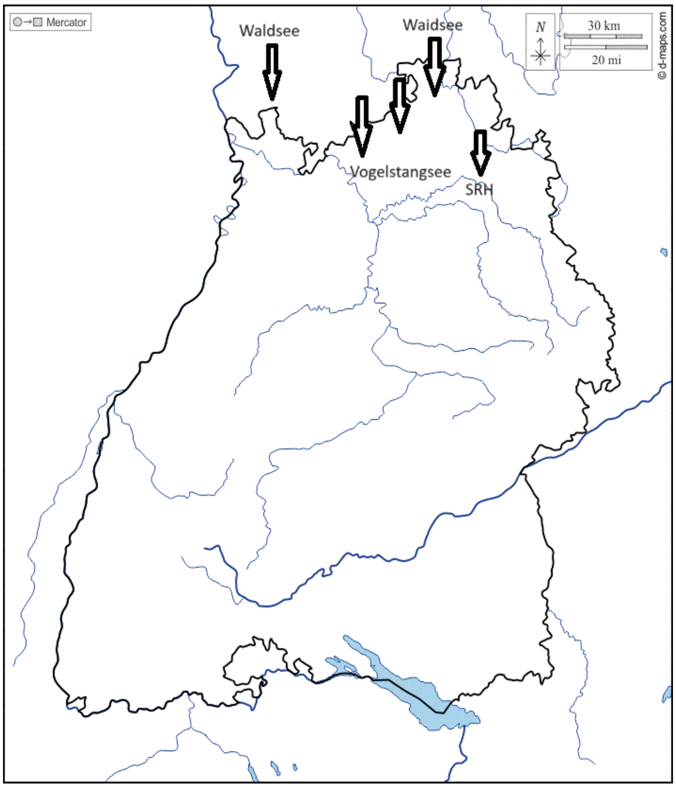

Figure 1: Locations of five (05) stations in Heidelberg, Germany

Table 2: Physical characteristics of the five study sites in Heidelberg, Germany.

Description	Waidsee	Waldsee	Vogelstangsee	Oberer Vogelstangsee	SRH Lake
Type	Recreational Lake	Recreational Lake	Recreational Lake	Recreational Lake	Recreational Lake
Isolation	Moderately opened	Opened	Opened	Moderately opened	Moderately opened
Water clarity	Clear	Clear	Clear	Clear	Turbid
Bottom substrate	Rock, boulders sand and dead organic matter	Rock, boulders sand and dead organic matter	Sand and boulders	Sand and boulders	Silt, detritus dead and organic matter
Aquatic plants	Watermilfoils, potamogeton, Elodea nuttallii (watergrass), Najas	Watermilfoils, potamogeton, Elodea nuttallii (watergrass), Najas	Watermilfoils, Elodea nuttallii (watergrass)	Watermilfoils, Elodea nuttallii (watergrass)	Typha latifolia, Nymphaea odorata
Human disturbance	Clearing of the riparian vegetation, runoff	Clearing of the riparian vegetation, runoff	Clearing of the riparian vegetation, runoff	Clearing of the riparian vegetation, runoff	Clearing of the riparian vegetation, runoff

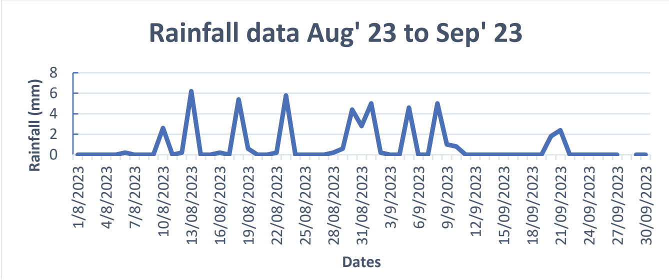

Figure 2: Precipitation details of the five study sites in Heidelberg, Germany.

ANOVA test pinpointing the exact mean difference. This post-hoc comparison controls for Type I error across multiple comparisons, making it suitable for experiments where the number of groups or treatments is relatively large.

Results

Results of water parameters among different stations before and after rainfall

Throughout the period 8 weeks, water quality parameters were observed among different stations before and after rainfall in all the 5 stations. The value of pH has increased after an event of rainfall due to dilution effect (p = 0.02). Dissolved oxygen was also recorded to improve with an event of rainfall (p = 0.94). Turbidity at Waidsee and Waldsee reduced with the event of rainfall event. Conversely, turbidity values of balance stations were recorded on a higher level (p = 0.1). Similarly, for Waidsee and Waldsee, the nutrient levels of nitrates, phosphates and sulphates recorded an increase in concentration post an event of rainfall. However, for the balance 3 stations recorded a decrease in nutrient contents (nitrate p = 0.35, phosphate p = .67 and sulphate p = 0.90). Concentration of metals of zinc and copper decreased post an event of rainfall (zinc p = 0.45 and copper p = 0.00). Superscript "a" suggests no significant difference between the values achieved. However, for instances with a superscript other than "a", it suggests a significant difference. Table 3 illustrates post hoc (Duncan) test results for comparison of the measurement parameters at different stations before and after rainfall.

Table 3: Post hoc (Duncan) test results for comparison of the measurement parameters at different stations before and after rainfall.

Parameters		Before		After		Rainwater
	n	Mean	SD	Mean	SD	Mean ± SD
pH	15	8.04 ^{a}	0.39	8.25 ^{a}	0.58	7.11 ^{b} ± 0.08
DO (ppm)	15	9.83 ^{a}	2.23	10.24 ^{a}	1.72	1.76 ^{a} ± 0.57
TDS (ppm)	15	20.24 ^{b}	5.36	20.79 ^{b}	11.10	43.9 ^{a} ± 3.50
Conductivity	15	532.53 ^{a}	119.64	536 ^{a}	120.81	47.56 ^{b} ± 4.47
Redox	15	175.01 ^{b}	40.34	156.68 ^{b}	8.34	259.33 ^{a} ± 17.61
Nitrate	15	0.387 ^{a}	0.27	0.49 ^{a}	0.19	0.59 ^{a} ± 0.03
Phosphate	15	0.11 ^{a}	0.13	0.22 ^{a}	0.52	0.12 ^{a} ± 0.01
Sulphate	15	75.53 ^{a}	30.59	69 ^{a}	22.11	0.00 ^{a} ± 0.00
Zinc	15	0.05 ^{b}	0.017	0.04 ^{b}	0.01	0.08 ^{a} ± 0.01
Copper	15	0.07 ^{b}	0.058	0.06 ^{b}	0.05	1.31 ^{a} ± 0.02

Results of comparison of means of water parameters among different stations

The water parameters were compared between stations as shown in Table 4. A significant variance is observed in water quality parameters in each lake with (p = 0) being for pH, dissolved oxygen, turbidity, conductivity, redox potential, nitrates, sulphates, zinc and copper. Conversely, no significant variance is recorded for phosphate values among the lakes.

Results of Intercorrelation among all parameters

All recorded parameters were tested for intercorrelation with other parameters. The correlation of various parameters with others is illustrated in Table 5. In the context of analysis, a statistically significant positive correlation was observed between the redox potential and turbidity levels at a significance level of 0.05 using a two-tailed statistical test. Likewise, the analysis revealed a statistically significant positive correlation between the conductivity and redox potential in relation to sulfate concentrations within the water body, with a significance level of 0.05 as determined by a two-tailed statistical analysis. Also, copper established positive variance with redox potential in a water body the 0.05 level of 2-tailed analysis. Inverse relation was also established between concentrations of copper on Ph level and conductivity in the sample size with a significance level of 0.05 as determined by a twotailed statistical analysis. In the analysis, an inverse relationship is established between the redox potential and the pH level of the water sample, with statistical significance observed at a 0.05 significance level through a two-tailed statistical analysis. Inverse relation holds good for sulphate concentration and dissolved oxygen levels also. Positive correlation between pH and dissolved oxygen is reported at a 0.01 significance level through a two-tailed statistical analysis. Redox potential established an inverse relation with dissolved oxygen and conductivity in the water samples at significance level of 0.01. Similarly, concentration of zinc in water has negative correlation with pH of the water sample at significance level of 0.01.

Discussion

Water quality parameters are pivotal in evaluating the ecological integrity of aquatic systems and their environmental service provision. In this investigation, the influence of precipitation on the ecological health of recreational lakes near Heidelberg, Germany, was examined. Precipitation events were determined to exert substantial impacts on various water quality metrics, elucidating the intricate dynamics governing these ecosystems. The findings suggest an enhancement in the ecological condition of these recreational lakes subsequent to precipitation events, in contrast to periods of aridity. These lakes, devoid of influent streams, were deemed relatively stable ecosystems. Nonetheless, precipitation was observed to significantly affect their water quality parameters.

An elevation in pH levels post-precipitation was noted, attributed to the dilution effect engendered by rainfall, a phenomenon well-established in existing literature [18]. Furthermore, the research corroborated prior observations that urban runoff could modify pH levels within aquatic systems [19]. Rainfall-induced surface turbulence facilitates atmospheric oxygen's integration into the water body [20]. Conversely to the study published [21], which attributed acid rain effects on water systems, the current study studies effect of non-acidic rainfall data.

Table 4: ANOVA and post hoc (Duncan) test results for comparison of the measurement parameters among different stations.

Parameters	Waidsee 1	Waidsee 2	Vogelstangsee	Oberer Vogelstangsee	SRH	Rain water
pH	$8.42^{ab} \pm 0.24$	$7.75^{c} \pm 0.19$	$7.72^{c} \pm 0.12$	$8.12^{bc} \pm 0.21$	$8.71^{a} \pm 0.64$	$7.11^{d} \pm 0.08$
DO (ppm)	$9.54^{bc} \pm 0.21$	$9.52^{bc} \pm 0.59$	$9.70^{bc} \pm 0.63$	$8.32^{c} \pm 1.63$	$13.1^{a} \pm 1.88$	$10.76^{b} \pm 0.57$
TDS (ppm)	$19.43^{c} \pm 6.84$	$16.70^{c} \pm 0.87$	$17.55^{c} \pm 1.25$	$30.29^{b} \pm 15.09$	$18.61^{c} \pm 0.98$	$43.90^{a} \pm 3.50$
Conductivity	$441.66^{c} \pm 8.71$	$416.33^{d} \pm 7.55$	$670.83^{a} \pm 4.70$	$677.16^{a} \pm 7.02$	$465.33^{b} \pm 34.54$	$47.56^{e} \pm 4.47$
Redox	$162.07^{b} \pm 11.33$	$168.37^{b} \pm 16.74$	$169.55^{b} \pm$ 22,.19	$182.96^{b} \pm 58.17$	$146.28^{b} \pm 10.99$	$259.33^{a} \pm 17.61$
Nitrate	$0.44^{ab} \pm 0.23$	$0.66^{a} \pm 0.15$	$0.48^{ab} \pm 0.09$	$0.30^{b} \pm 0.17$	$0.30^{b} \pm 0.31$	$0.59^{a} \pm 0.03$
Phosphate	$0.49^{a} \pm 0.79$	$0.05^{a} \pm 0.03$	$0.10^{a} \pm 0.14$	$0.10^{a} \pm 0.16$	$0.10^{a} \pm 0.08$	$0.11^{a} \pm 0.005$
Sulphate	50.33 ± 1.36	52.16 ± 1.94	98.16 ± 10.94	104.16 ± 22.88	56.49 ± 4.31	
Zinc	$0.06^{ab} \pm 0.01$	$0.04^{c} \pm 0.01$	$0.05^{abc} \pm 0.01$	$0.04^{bc} \pm 0.02$	$0.04^{c} \pm 0.02$	$0.07^{a} \pm 0.01$
Copper	$0.09^{b} \pm 0.06$	$0.06^{b} \pm 0.06$	$0.09^{b} \pm 0.05$	$0.03^{b} \pm 0.01$	$0.04^{b} \pm 0.04$	$1.30^{a} \pm 0.01$

Table 5: Intercorrelation among all parameters to see what parameters correlated to each other.

Parameters	pH	DO	Conductivity	Turbidity	Redox	Nitrate	Phosphate	Sulphate	Zinc	Copper
pH	1									
DO	0.36*	1.00								
Conductivity	0.25	-0.31	1.00							
Turbidity	-0.39*	-0.15	-0.34	1.00						
Redox	-0.48**	-0.38*.	-0.43*	0.59**	1.00					
Nitrate	-0.05	-0.03	-0.30	-0.18	0.31	1.00				
Phosphate	0.25	-0.05	-0.05	-0.12	-0.12	0.13	1.00			
Sulphate	-0.32	-0.48**	0.89**	0.35	0.53**	-0.17	-0.20	1.00		
Zinc	-0.37*	-0.12	-0.26	0.28	0.07	-0.25	0.20	-0.07	1.00	
Copper	-0.52**	0.10	-0.78**	0.61**	0.68**	0.22	0.03	-0.11	0.41*	1.00

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

Concentrations of nutrients such as nitrates, phosphates, and sulphates intensified with precipitation, attributed to urban area rain-wash [22,23]. Importantly, no point-source pollution discharges were detected at any water station, negating the input of effluents from wastewater treatment facilities or industrial sources. Metallic constituents, including zinc and copper, exhibited reduced concentrations post-precipitation, primarily due to dilution from the influx of less contaminated water [19].

The redox potential of water samples demonstrated a decline, influenced by the augmented dissolved oxygen levels and dilution effect [24]. This aligns with the notion that substantial rainfall can induce soil erosion and organic matter transport into aquatic environments, potentially diminishing redox conditions [25]. This study delineated interrelations among various water quality parameters across lakes in proximity to Heidelberg, Germany. Despite comparable climatic conditions, variances in water quality metrics were evident, potentially stemming from differential water sources, surrounding land use, geological factors, pollution inputs, and lake-specific attributes. Divergently, a study conducted establishes that introduction of redox-active compounds through various hydrological cycles, have increased after a rain even due to increase flow and sediment disturbance [26] Additionally, lake morphology, including size, depth, and circulation patterns, was found to affect water constituent retention and mixing, thereby influencing water quality [27-29].

Correlation analysis revealed positive associations between redox potential and measures of turbidity, conductivity, and sulphate concentration. These correlations are ascribed to the presence of redoxreactive entities in the water, capable of interacting with organic compounds and other substances, facilitating particle flocculation or aggregation, thereby reducing turbidity [30,31]. Redox potential also influenced the chemical properties of dissolved organic matter, affecting its interactions with suspended particles and impacting turbidity [32]. A statistically significant positive correlation was identified between conductivity and redox potential in relation to sulphate concentrations, indicating higher ionic concentrations, including sulphate ions, in the water as conductivity increased [33]. Lower redox potential values were indicative of more reductive conditions conducive to sulphate ion consumption and a consequent decrease in sulphate concentrations [34,35]. Copper demonstrated a positive correlation with redox potential, potentially affecting the overall redox chemistry of the water body [36,37].

An inverse relationship was observed between copper concentrations and pH, where copper contributed to water acidification through oxidation, leading to the formation of copper ions (Cu^2) [38]. Copper also forms complexes with various ligands in water, influencing conductivity, with certain complexes reducing it [39]. Lastly, an inverse relationship between redox potential and pH was established, where an increase in redox potential signified a higher propensity for oxidation reactions, leading to proton release into the solution and a decrease in pH [40,41].

Conclusion

This research investigated effect of precipitation on 05 (Five) recreational lakes in and around Heidelberg, Germany. The descriptive analysis of this study resulted in establishing variance relationship between water quality parameters before and after a precipitation event. Use of Anova oneway analysis interpreted the statistical significance of various water parameters after the event of rainfall. This study also established variance relation between water quality parameters in 5 recreation lakes based on different sampling timing before and after rainfall event. Moreover, the paper helps in establishing relation between water quality parameters between different lakes and highlighted that these parameters are not coherent among all lakes and are susceptible to vary based on factors such as different water sources, land use around the lakes, geological conditions, pollution inputs, and lakespecific characteristics. Finally, the paper established the direct and inverse co-relation data among various water quality parameters, quantifying the effect of each parameter on the concentration of other parameters.

The finding of the research exhibited that an event of rainfall generally has a dilution effect on various parameters of the water bodies, subject to non-interference of nutrient runoff, point pollution and sediment deposition. In summary, rainfall events and absence of polluting factors in the vicinity of the lakes have an improved effect on the water quality parameters of the recreational lakes in Heidelberg, Germany. This study concludes water parameters post a rainfall event is suitable for recreational activities in the studied stations.

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References

1. Andrade VS, Gutierrez MF, Regaldo L, Paira AR, Repetti MR, Gagneten AM. Influence of rainfall and seasonal crop practices on nutrient and pesticide runoff from soybean dominated agricultural areas in Pampean streams, Argentina. Sci Total Environ. 2021 Sep 20;788:147676. doi: 10.1016/j.scitotenv.2021.147676. Epub 2021 May 11. PMID: 34029815.

2. Ayele HS, Atlabachew M. Review of characterization, factors, impacts, and solutions of Lake eutrophication: lesson for lake Tana, Ethiopia. Environ Sci Pollut Res Int. 2021 Mar;28(12):14233-14252. doi: 10.1007/s11356-020-12081-4. Epub 2021 Jan 30. PMID: 33517530.

3. Boyd CE, Boyd CE. Eutrophication. Water Quality: An Introduction. 2020; 311-322.

4. Han X, Xiao J, Wang L, Tian S, Liang T, Liu Y. Identification of areas vulnerable to soil erosion and risk assessment of phosphorus transport in a typical watershed in the Loess Plateau. Sci Total Environ. 2021 Mar 1;758:143661. doi: 10.1016/j.scitotenv.2020.143661. Epub 2020 Nov 20. PMID: 33248771.

5. Preisner M. Surface water pollution by untreated municipal wastewater discharge due to a sewer failure. Environmental Processes. 2020; 7(3):767-780.

6. Sharma A. The wicked problem of diffuse nutrient pollution from agriculture. Journal of Environmental Law. 2020; 32(3):471-502.

7. Kelly NE, Guijarro-Sabaniel J, Zimmerman R. Anthropogenic nitrogen loading and risk of eutrophication in the coastal zone of Atlantic Canada. Estuarine. Coastal and Shelf Science. 2021; 263:107630.

8. Sun YF, Guo Y, Xu C, Liu Y, Zhao X, Liu Q, Jeppesen E, Wang H, Xie P. Will "Air Eutrophication" Increase the Risk of Ecological Threat to Public Health? Environ Sci Technol. 2023 Jul 25;57(29):10512-10520. doi: 10.1021/acs.est.3c01368. Epub 2023 Jul 10. PMID: 37428654; PMCID: PMC10373653.

9. Menberu Z, Mogesse B, Reddythota D. Evaluation of water quality and eutrophication status of Hawassa Lake based on different water quality indices. Applied Water Science. 2021; 11:1-10.

10. Pericherla S, Karnena MK, Vara S. A review on impacts of agricultural runoff on freshwater resources. Int. J. Emerg. Technol. 2020; 11:829-833.

11. Smith JS, Winston RJ, Tirpak RA, Wituszynski DM, Boening KM, Martin JF. The seasonality of nutrients and sediment in residential stormwater runoff: Implications for nutrient-sensitive waters. J Environ Manage. 2020 Dec 15;276:111248. doi: 10.1016/j.jenvman.2020.111248. Epub 2020 Sep 3. PMID: 32891029.

12. Domínguez-Villar D, Arteaga C, García-Giménez R, Smith EA, Pedraza J. Diurnal and seasonal water variations of temperature, pH, redox potential and conductivity in gnammas (weathering pits): Implications for chemical weathering. Catena. 2008; 72(1):37-48.

13. Ullah R, Mohiuddin S, Panhwar SK. Metal transportation mechanism by rainfall runoff as a contribution to the bioaccumulation in seafood. Environ Monit Assess. 2023 Feb 4;195(3):362. doi: 10.1007/s10661-023-10963-x. PMID: 36737551.

14. Jia Z, Chang X, Duan T, Wang X, Wei T, Li Y. Water quality responses to rainfall and surrounding land uses in urban lakes. J Environ Manage. 2021 Nov 15;298:113514. doi: 10.1016/j.jenvman.2021.113514. Epub 2021 Aug 11. PMID: 34391108.

15. Khilchevskyi VK, Kurylo SM, Sherstyuk NP, Zabokrytska MR. The chemical composition of precipitation in Ukraine and its potential impact on the environment and water bodies. Journal of geology, geography and geoecology. 2019; 28(1):79-86.

16. Guerrero JL, Gutiérrez-Álvarez I, Hierro A, Pérez-Moreno SM, Olías M, Bolívar JP. Seasonal evolution of natural radionuclides in two rivers affected by acid mine drainage and phosphogypsum pollution. Catena. 2021; 197:104978.

17. Prathumratana L, Sthiannopkao S, Kim KW. The relationship of climatic and hydrological parameters to surface water quality in the lower Mekong River. Environ Int. 2008 Aug;34(6):860-6. doi: 10.1016/j.envint.2007.10.011. Epub 2008 Feb 20. PMID: 18068783.

18. Yan L, Xue L, Petropoulos E, Qian C, Hou P, Xu D, Yang L. Nutrient loss by runoff from rice-wheat rotation during the wheat season is dictated by rainfall duration. Environ Pollut. 2021 Sep 15;285:117382. doi: 10.1016/j.envpol.2021.117382. Epub 2021 May 19. PMID: 34049130.

19. Yang L, Li J, Zhou K, Feng P, Dong L. The effects of surface pollution on urban river water quality under rainfall events in Wuqing district, Tianjin, China. Journal of Cleaner Production. 2021; 293:126136.

20. Zhang X, Qiao W, Huang J, Li H, Wang X. Impact and analysis of urban water system connectivity project on regional water environment based on Storm Water Management Model (SWMM). Journal of Cleaner Production. 2023; 423:138840.

21. Du J, Qv M, Zhang Y, Cui M, Zhang H. Simulated sulfuric and nitric acid rain inhibits leaf breakdown in streams: A microcosm study with artificial reconstituted fresh water. Ecotoxicol Environ Saf. 2020 Jun 15;196:110535. doi: 10.1016/j.ecoenv.2020.110535. Epub 2020 Mar 27. PMID: 32224368.

22. Fong CR, Gaynus CJ, Carpenter RC. Extreme rainfall events pulse substantial nutrients and sediments from terrestrial to nearshore coastal communities: a case study from French Polynesia. Sci Rep. 2020 Feb 19;10(1):2955. doi: 10.1038/s41598-020-59807-5. PMID: 32076043; PMCID: PMC7031339.

23. Kaur M, Das SK, Sarma K. Water quality assessment of Tal Chhapar Wildlife

Sanctuary using water quality index (CCME WQI). Acta Ecologica Sinica. 2023; 43(1):82-88.

24. Lynch SF, Batty LC, Byrne P. Environmental risk of metal mining contaminated river bank sediment at redox-transitional zones. Minerals. 2014; 4(1): 52-73.

25. Mok JS, Kim SH, Kim J, Cho H, An SU, Choi A, Kim B, Yoon C, Thamdrup B, Hyun JH. Impacts of typhoon-induced heavy rainfalls and resultant freshwater runoff on the partitioning of organic carbon oxidation and nutrient dynamics in the intertidal sediments of the Han River estuary, Yellow Sea. Sci Total Environ. 2019 Nov 15;691:858-867. doi: 10.1016/j.scitotenv.2019.07.031. Epub 2019 Jul 4. PMID: 31326809.

26. Borch T, Kretzschmar R, Kappler A, Cappellen PV, Ginder-Vogel M, Voegelin A, Campbell K. Biogeochemical redox processes and their impact on contaminant dynamics. Environ Sci Technol. 2010 Jan 1;44(1):15-23. doi: 10.1021/es9026248. PMID: 20000681.

27. Butcher JB, Nover D, Johnson TE, Clark CM. Sensitivity of lake thermal and mixing dynamics to climate change. Climatic Change. 2015; 129:295-305.

28. Lewis Jr WM. A revised classification of lakes based on mixing. Canadian Journal of Fisheries and Aquatic Sciences. 1983; 40(10):1779-1787.

29. Qin B, Zhou J, Elser JJ, Gardner WS, Deng J, Brookes JD. Water Depth Underpins the Relative Roles and Fates of Nitrogen and Phosphorus in Lakes. Environ Sci Technol. 2020 Mar 17;54(6):3191-3198. doi: 10.1021/acs.est.9b05858. Epub 2020 Feb 28. PMID: 32073831.

30. Kim J, Furumai H. Improved calibration of a rainfall-pollutant-runoff model using turbidity and electrical conductivity as surrogate parameters for total nitrogen. Water and Environment Journal. 2013; 27(1): 79-85.

31. Takarina ND. Effect of redox gradients on Cu and Zn concentrations in water of Blanakan River, West Java. In IOP Conference Series: Earth and Environmental Science. 2020; 535: 1; 012002. IOP Publishing.

32. Kim S, Kaplan LA, Benner R. Sedimentary organic matter in the Mississippi River and the Gulf of Mexico: compositional heterogeneity and potential for coastal hypoxia. Limnology and Oceanography. 2002; 47(1): 90-98.

33. Gibert J, Dalla Venezia L, Lefebvre S. Sulfate reduction in a river bed aquifer: Hydrochemical and isotopic evidence. Geochimica et Cosmochimica Acta. 2005; 69(23): 5477-5489.

34. Pellerin BA, Saraceno JF, Shanley JB, Sebestyen SD, Aiken GR, Wollheim WM. Taking the pulse of snowmelt: in situ sensors reveal seasonal, event and diurnal patterns of nitrate and dissolved organic matter variability in an upland forest stream. Biogeochemistry. 2012; 108(1-3): 183-198.

35. Waithaka A, Murimi KS, Obiero K. Effects of Temporal Rainfall Variability on Water Quality of River Ruiru, Kiambu County, Kenya. ChemSearch Journal. 2020; 11(1):59-65.

36. Hermann R, Neumann-Mahlkau P. The mobility of zinc, cadmium, copper, lead, iron and arsenic in ground water as a function of redox potential and pH. Science of the total environment. 1985; 43(1-2): 1-12.

37. Sodré FF, Schnitzler DC, Scheffer EW, Grassi MT. Evaluating copper behavior in urban surface waters under anthropic influence. A case study from the Iguaçu River, Brazil. Aquatic Geochemistry. 2012; 18:389-405.

38. Montecinos M, Coquery M, Alsina MA, Bretier M, Gaillard JF, Dabrin A, Pastén P. Partitioning of copper at the confluences of Andean rivers. Chemosphere. 2020 Nov;259:127318. doi: 10.1016/j.chemosphere.2020.127318. Epub 2020 Jun 6. PMID: 32593812.

39. Robson A, Neal C, Smith CJ, Hill S. Short-term variations in rain and stream water conductivity at a forested site in mid-Wales—implications for water movement. Science of the total environment. 1992; 119:1-18.

40. Lu HL, Li KW, Nkoh JN, He X, Xu RK, Qian W, Shi RY, Hong ZN. Effects of pH variations caused by redox reactions and pH buffering capacity on Cd(II) speciation in paddy soils during submerging/draining alternation. Ecotoxicol Environ Saf. 2022 Apr 1;234:113409. doi: 10.1016/j.ecoenv.2022.113409. Epub 2022 Mar 12. PMID: 35286955.

41. Lueder U, Jørgensen BB, Kappler A, Schmidt C. Photochemistry of iron in aquatic environments. Environ Sci Process Impacts. 2020 Jan 1;22(1):12-24. doi: 10.1039/c9em00415g. Epub 2020 Jan 6. PMID: 31904051

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