PRELIMINARY CORRELATIONS BETWEEN CLIMATE CHANGE AND WASTEWATER TREATMENT PLANT PARAMETERS

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ABSTRACT

Wastewater treatment plants (WWTPs) provide an immensely valuable service to the environment and the public, which makes them a necessity for proper functioning. These plants must work in accordance with the Sustainable Development Goals, the circular economy and the FIT for 55 indications. They are susceptible to climate change, i.e., critical weather: excessive or minimum rainfall and droughts. That impacts the wastewater quality and quantity, characteristics, and removal of parameters such as phosphorus, chemical oxygen demand, nitrate, and biochemical oxygen demand. WWTPs in connection with circular sustainability and climate change are an emerging concept. Various sustainable circular ways could relate to WWTP, as treated wastewater could be reused and/or recycled from a circular economy view but depends strongly on the efficiency of WWTP to remove the hazardous substances and to provide a clean effluent. To achieve the full potential of WWTP, it is important that they can manage the effects of climate change with adequate functioning in the process and infrastructure to produce an effluent that meets environmental standards. Limited studies are present in the literature regarding the full understanding of the importance of WWTPs concerning climate change and circular sustainability considering treatment process and effluent quality. Therefore, this research aims to illustrate the influence of climate change on a real WWTP in the north of Italy, Como. The results are useful not only for the WWTP managers and policy makers, but also for the scientific world. They also raise attention to the actual seriousness of climate change impacts and could help to prepare and cope with future environmental changes.
Keywords: wastewater treatment plant, climate change, sustainability, circular economy.

1 INTRODUCTION

Exponential urbanization, population escalation, and contaminants surfacing with intensified water scarcity are the challenging variables in the wastewater treatment plant (WWTP) system for its sustainable circularity [1]. Climate change is one of the major triggers to aggravate these variables and thus has a crucial impact on WWTP operations, accompanied by high temperature and inflow rates. High temperature disturbs oxygen solubility, microbial metabolism, and biodegradation processes, significantly undermining biological oxygen demand (BOD) levels and is harmful to aquatic ecosystems and communities [2], [3]. The challenge becomes complex with intensified future climatic changes. It aggravates wastewater treatment costs with declined effectiveness [4]. Harsh weather conditions such as warmer temperatures, intense precipitation, and sea-level surge extend the problems in WWTPs [5], [6]. Water recycling, resource recovery, digital systems, and zero waste are some of the ways to have circular sustainability to integrate wastewater commercialization along with the value of resource recovery to achieve a circular economy [7]–[10]. WWTP variables play an important role in process design and control, reducing operation costs, improving system reliability, predictive maintenance, and troubleshooting, increasing water quality, increasing stakeholder engagement, and endorsing optimization of the plant performance [1], [11]. Sustainable Development Goal 6 (SDG) clean water and sanitation is

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substantially interconnected with all the 11 SDGs given implicit direction toward the improvement of other SDGs [12].

Several studies indicate climate change impacts on WWTPs such as Jin et al. [13], the impact of rainfall on the performance of WWTP incorporated with combined sewerage systems using software. It was found that the treatment processes of this plant were substantially effective during rainfall in Tianjin having a warm temperate continental monsoon climate with intense rainfall. Also, another study (Rashid and Liu [14]) highlighted the impacts of rainfall on the centralized WWTPs and established a correlation between rainfall, and influent flow rate and compositions of wastewater in wet and dry seasons with two sewer systems, i.e., combined and separate. Furthermore, the enhanced correlation between rainfall and the influent flow rate was found in the WWTPs with either a combined sewer system or a separate sewer system. The rainfall impact promoted eutrophication. Both WWTPs resulted in a lower environmental burden in the wet season as compared to the dry season particularly due to dilution. Yet the WWTP with high strength in the wet season had higher environmental impacts due to inadequate treatment given the heavy rainfall. Similarly, Rouleau et al. [15] evaluated the impacts of a small WWTP at Roeschwoog, near Strasbourg, France equipped with a combined sewer system connected to the plant with a total population of 5,300 persons. The results revealed that rainfall significantly impacted the influent with higher suspended solids and chemical oxygen demand (COD) along with ammonia dilution. No impact was observed on nitrification-denitrification and carbon removal. On the other side, Tran et al. [16] illustrated the impacts of droughts and water conservation methods. The results revealed that drought impacted the influent quality and quantity for the treatment and thus, consequently declined the quality and quantity of the water for reuse method.

Further, Vidal et al. [17] evaluated the impacts of treatment efficiency and cold temperatures on Package plants particularly contaminants (organics, solids, nutrients, and indicator bacteria). High BOD removal was observed despite cold temperatures while nitrogen and bacteria removal were still difficult. Besides, a noticeable correlation in the effluent was not found concerning wastewater temperature and BOD, nutrients, and indicator bacteria. Whereas Yoda [18] illustrated the correlation between water quality parameters and precipitation at a sewage treatment plant. The results showed BOD and COD had a negative correlation with the amount of received water at the plant. There was no noticeable correlation between Cl (chloride) concentration and precipitation or received water quantity. Also, total suspended solids (TSS) did not show a significant correlation with precipitation or received water quantity.

Overall, this study suggested Cl concentration and TSS depend more on seasonal industrial conditions rather than weather conditions. All aspects considered there is still a need to consider the impacts of climate change on WWTPs.

Therefore, the paper aims to understand the impacts of critical moments concerning harsh weather conditions on municipal wastewater treatment plants (MWWTP) to cope with inconsistent climate conditions.

2 MATERIALS AND METHODS

2.1 Description of the framework

The Como Acqua Municipal Wastewater Treatment Plant (MSWWTP) is in Como, Italy. The plant's design capacity is 55,000 milligrams per cubic meter (mc). The composition of the water includes domestic 61.41%, industrial 8.61%, and storm 29.98%. The WWTP network is divided into aqueduct and sewerage. The aqueduct serves 42 municipalities in the local areas that receive water supply services from the aqueduct system with a population of 491,849 inhabitants. The total length of the water distribution network managed by the aqueduct system is 5,125 km of network. The sewage system serves 145 municipalities with 577,103 inhabitants.

2.2 Data measurement and analysis

In this study, daily wastewater parameters were assessed, i.e., total phosphorus, COD, BOD, and TSS for 4 months, i.e., May, June, July, and August in 2023, based on climatic conditions. With regard to the process of data analysis and interpretation, the use of the software Microsoft Excel was employed.

3 RESULTS AND DISCUSSIONS

Rainfall and temperature are essential factors altering with treatment process, plant functioning and consequently pose an impact on all parameters. The major reasons include rainfall acceleration increases the water influx and temperature influences BOD, COD, and TSS [19].

The wastewater parameters COD, BOD, TSS, pH, total phosphorus, nitrogen, ammonia, nitrite, and nitrate for In and Out of the plant were analysed for 5 months along with rainfall and temperature aspects of climate. pH was stable for both influent and effluent despite extreme rain and temperature. NO_2 and NO_3 were not analysed regularly and did not have fluctuations due to temperature and rainfall. Therefore, for this study, they were not considered significant.

The highest rainfall was 56.80 mm in May (week 18) and the lowest rain was 3.80 mm in May (week 1) (Fig. 1). Comparatively, considering the influent quality based on maximum and minimum rainfall, the influent values of COD 404.12 mg/L, BOD 199.20 mg/L, phosphorus 3.70 mg/L, TN 21.23 mg/L and NH_4 18.37 mg/L were less on the maximum rainfall as compared to minimum rainfall in which COD was 512.5 mg/L, BOD 270 mg/L, phosphorus 4.18 mg/L, TN 39.675 mg/L and NH_4 34.58 mg/L. This indicates the dilution of influent wastewater.Therefore, the effluent quality results better at high rainfall, i.e., COD

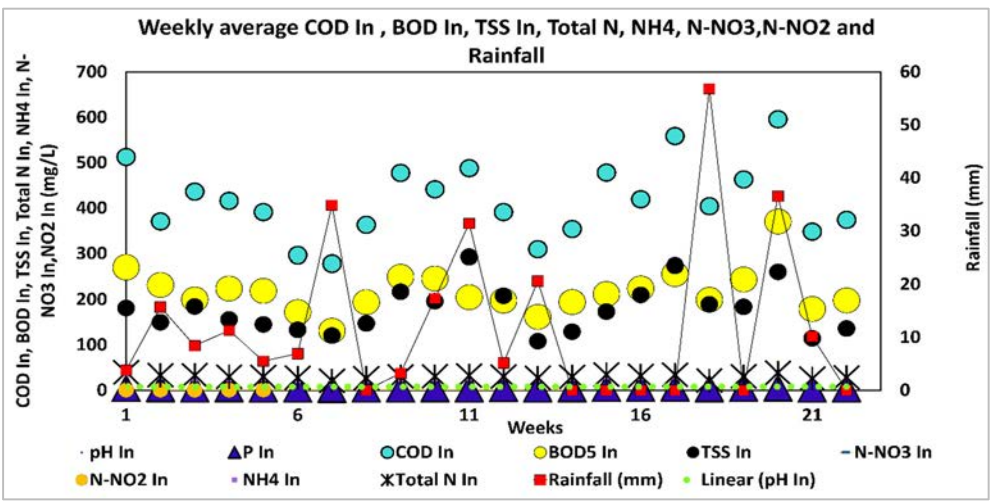

Figure 1: WWTP incoming parameters with respect to rainfall.

12 mg/L, BOD 1.96 mg/L, phosphorus 0.39 mg/L, TN 6.47 mg/L, as compared to minimum rainfall.

Consequently, the influent quality directly impacts the effluent quality. With maximum rainfall the effluent quality for COD 12.40 mg/L, BOD 1.96 mg/L, phosphorus 0.39mg/L, TN 6.47 mg/L was less as compared to effluent on minimum rainfall COD 23.25 mg/L, BOD 2.75 mg/L, phosphorus 0.41 mg/L, TN 8.25 mg/L (Fig. 2). Overall, NH_4 in the outflow was consistently removed to a minimum.

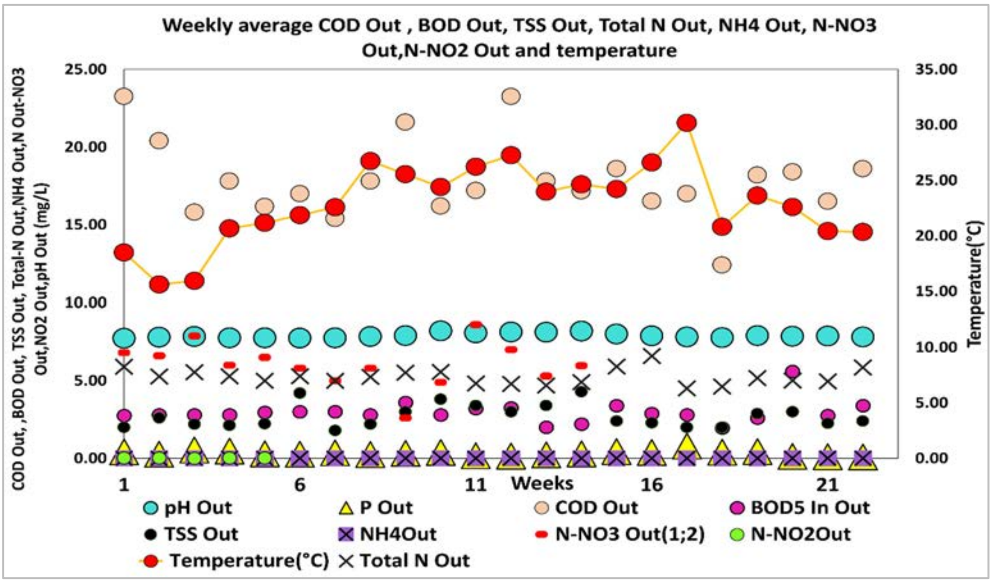

Figure 2: WWTP outgoing parameters with respect to rainfall.

The highest temperature occurred in week 17, i.e., 30.18°C and the lowest was in week 2 15.62°C (Fig. 3). Comparatively, considering the influent quality based on maximum and minimum temperature, the influent values of COD 558.6 mg/L, BOD 256 mg/L, TSS 274 mg/L, phosphorus 5 mg/L, TN 34 mg/L and NH_4 29.54 mg/L were higher on the maximum temperature as compared to minimum temperature in which COD 370.4 mg/L, BOD 232 mg/L, TSS 149 mg/L, phosphorus 3.74 mg/L, TN 33.18 mg/L and NH_4 28.7 mg/L. This indicates that at warmer temperatures influent wastewater has higher strength. Generally, BOD is the most influenced by temperature. It is because increasing temperature alone enhances the microorganisms [20] which is why influent BOD, COD, and TSS were higher at warmer temperatures.

For instance, in this study, the concentration of COD, BOD and TSS were higher at warm temperatures. Somehow, the warm season was better for the concentration of nitrogen compounds as they were lower due to the intensified nitrification and denitrification processes. Due to this, in warm seasons the higher temperature may act in a favourable way to the task of maintaining the ammonium concentration below the regulation limit [21]. But still the intense temperature increment in the future may have detrimental impacts on plant functioning.

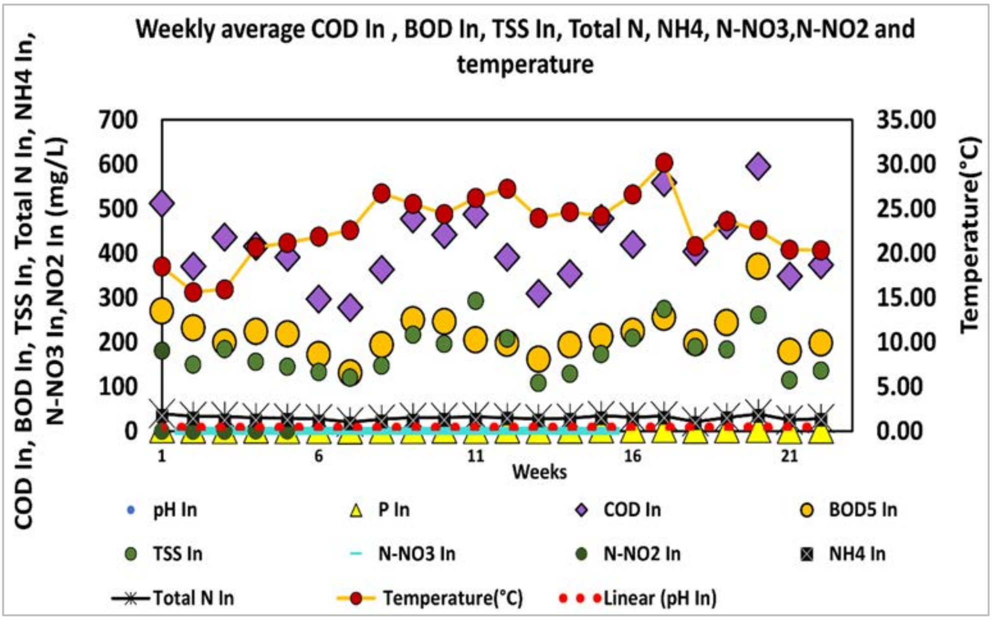

Figure 3: WWTP incoming with respect to temperature.

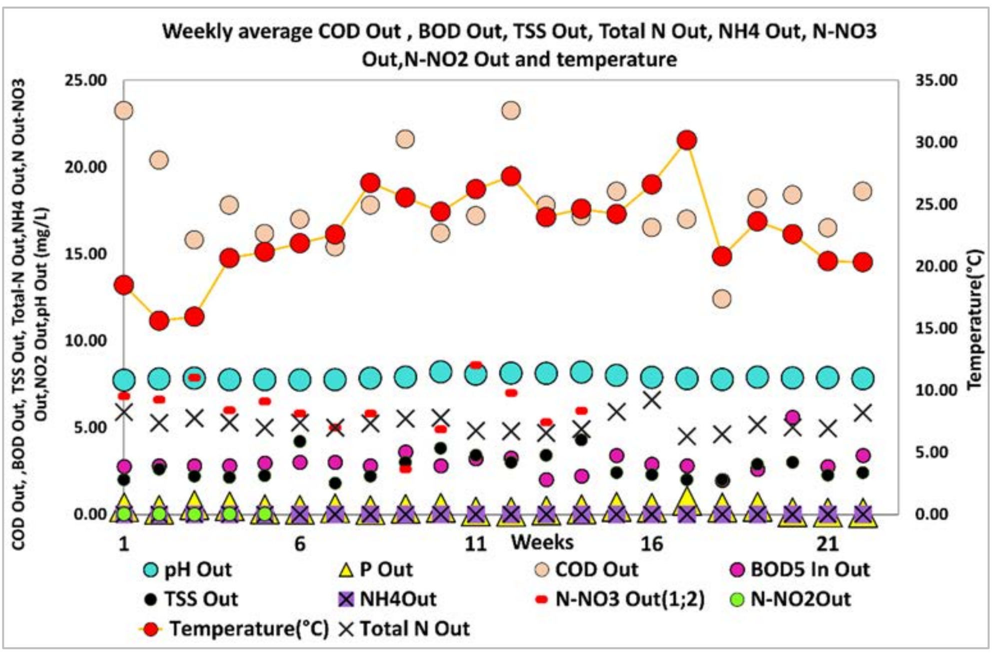

Figure 4: WWTP outgoing parameters with respect temperature.

In comparison, the effluent at maximum and minimum temperature results show the effluent results at high temperature were COD 17 mg/L, BOD 2.80 mg/L, phosphorus 0.78 mg/L, TN 6.30 mg/L, as compared to minimum temperature, i.e., COD 20.40 mg/L, BOD 2.80 mg/L, phosphorus 0.26 mg/L, TN 7.38 mg/L (Fig. 4). Surprisingly, quality at the peak temperature is similar to the minimum temperature illustrating enhanced plant performance.

As shown in Fig. 5, the highest rainfall occurred in August, i.e., 56.80 mm, and the removal efficiency of COD was 96%, BOD 99%, TSS 98%, phosphorus 90%, TN 75% and NH_4 100%, depicting a satisfactory performance of the plant. Only the TN efficiency was slightly reduced. It could be because TN removal is dependent on influent flow fluctuations by rainfall and pipe system such as in this study TN reduced from 15 mg/L to below 10 mg/L. Moreover, the practical functioning of WWTP rainfall fluctuation is influenced by leaks or cracks in pipes affecting nitrogen treatment [22]. Rainfall contributes 75% of sewage exceeding the plant design capacity [23]. Whereas the other parameters' efficiency was high. In this study, rainfall has improved the influent quality due to dilution, which is why despite the highest rainfall, removal efficiency was high. This could be due to lower environmental stress in the wet season compared to dry mostly as dilution of wastewater weakens its strength altering the composition. However, excessive rainfall in some cases puts extreme pressure when it exceeds the plant capacity resulting in inadequate treatment which is certainly not the case for this study period. The lowest rainfall was 10.70 mm in May and the plant treatment efficiency was stable and high. It is due to overflow, particularly rain can change the wastewater quality and subsequent treatment efficiency [24]. Even without overflow, rainfall still can affect environmental impacts from WWTPs by changing wastewater quality, quantity, and treatment performance. For instance, in this study, WWTP with a combined sewer system had varied extent of impact moderate to strong depending on the rain intensity, flow rates, and pollutant concentration in the influent [25]. Also, in many cases of WWTPs cases, rain reduces the effluent pollutant concentration due to dilution of wastewater [21], [22].

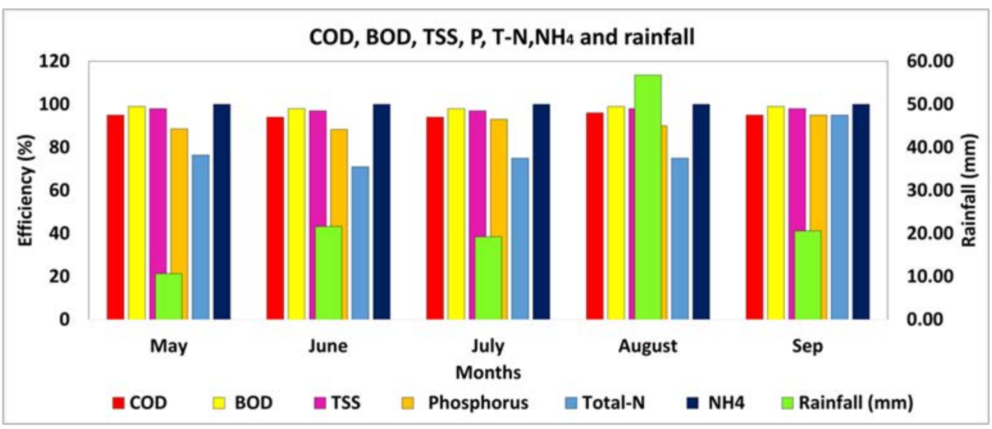

Figure 5: Monthly efficiency of WWTP with respect to rainfall.

As shown in Fig. 6, the highest temperature was recorded in August, i.e., 25.67°C. The efficiency for BOD was 99%, TSS 98%, COD 96%, phosphorus 90%, TN 75%, efficiency for NH_4 was consistent, i.e., 100%. The lowest temperature was recorded in May, i.e., week 18, BOD 99%, COD 95%, TSS 98%, phosphorus 89%, TN 76%. Both extreme temperatures depict the acceptable behaviour of plants. However, phosphorus was slightly reduced at low temperatures by 1%. Phosphorus removal is harder at low temperatures since the activity in microorganisms declines at low temperatures [26].

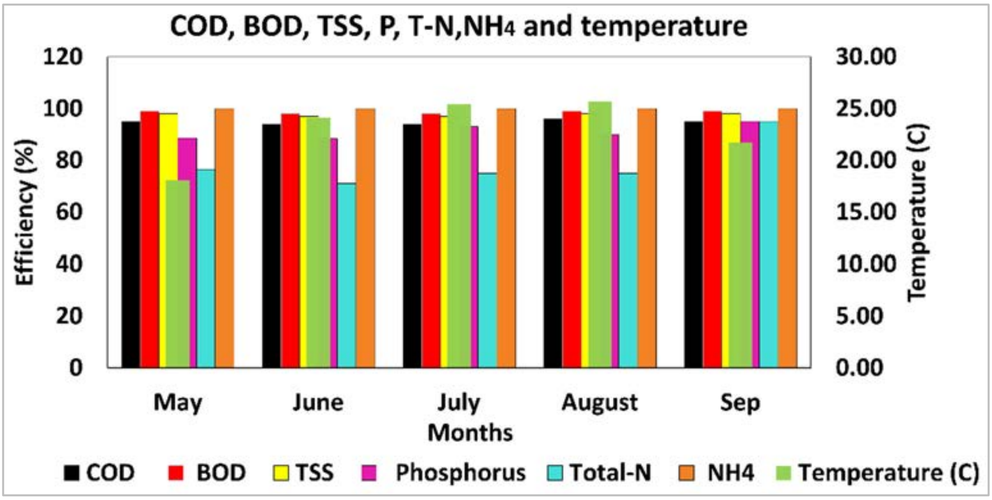

Figure 6: Monthly efficiency of WWTP parameters with respect to temperature.

Other than this, the extreme temperature values did not have a noticeable impact on the parameters and were consistent with In and Out values. It can be due to two reasons, i.e., mainly due to plant better working system. Secondly, analysis for a longer time was required to have more extreme temperature values to establish the pattern of parameters' behaviour with certainty. Besides, in those 5 months, significant temperature differences did not occur. However, it's a preliminary phase and the investigation is continual. Higher temperatures increase the biological functions producing the enhancement of BOD, COD and total phosphorus removal [27]. The pH of wastewater was not impacted by rain or temperature and was consistently maintained for In and Out in the acceptable range of 6.5–8.4.

It is important to highlight that there are negative consequences and implications of extreme weather conditions associated with WWTP, as increased rainfall is the prominent cause of flooding inconvenience, spillage and odour, which can downgrade economic, socio-cultural and environmental aspects. The negative consequences of not acting are summarised below:

- *Economic impact:* Exacerbated residential price and loss in business, i.e., loss in business and high cost to residents is one of the major consequences of water flooding or spillage [28], [29]. Intensified pathogens from human waste will cause hindrances in business and recreational purposes such as fetching and the seafood industry. The expense of maintenance fee and service provider for water quality management is to be given in case of intensified water quality decline [30], [31].
- *Socio-cultural impact:* For the residents, the mental health of the population becomes unhealthy and is constantly at risk due to untreated water and poor water quality causing

short and medium term infections [29], [32], [33]. From a cultural point of view, the disruption of community structures and the loss of cultural landmarks can lead to a decrease in tourism flow [34], [35]. In term of public health, faecal infections, skin diseases, water-borne diseases are common in the case of sewage spills [36], [37]. For tourists and not only, seafood and water-based recreational activities are highly valued and may not be readily available if waterways have low resilience [38].

- *Environmental:* The impact of water quality degradation due to increased unrestricted wastewater discharges is even more pronounced as rainfall increases: Sea level rise, rainfall deficits and surpluses, and warmer temperature extremes lead to water quality degradation due to unrestricted wastewater discharges, which further reduce the assimilative capacity of receiving waters [2]. One of the major consequences of water quality decline is the low resilience of waterways, which is directly triggered due to enhanced discharge of wastewater contaminants during high rainfall.

4 CONCLUSION

MWWTPs are affected by climate change. Extreme rainfall and temperature alter the influent composition, and flow and thus impact the operation and treatment process. Furthermore, this is a preliminary investigation and a longer period of research is needed to understand the behaviour of plants under extreme conditions. However, the weekly averages on the influent and effluent wastewater quality represent the impacts of weather conditions. Moreover, WWTP and climate change impacts pose cascading effects on circular economy and sustainability which makes it crucial for further investigation. Therefore, all this information can be used as an indicator to cope with future climate changes.

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