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Implementing the CCME Water Quality Index for the Evaluation of the Physicochemical Quality of Greek Rivers

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Abstract: Water quality indices (WQIs) are efficient tools, globally used for the determination of the quality status of water bodies. In Greece, for almost a decade, the physicochemical quality of water in rivers has been determined by a rigorous, biologically-based, national classification system, developed by the Hellenic Centre for Marine Research (HCMR), through the calculation of a simple water quality index (HWQI) that takes into account six water parameters: five nutrient species and dissolved oxygen. Taking the HWQI as a reference, the present study attempts to implement the Canadian Council of Ministers of Environment Water Quality Index (CCME WQI), which is globally applied and flexible in the number of parameters used, to investigate its possible suitability for Greek rivers, which are characterized by a variety of climatic, geologic, and hydrological conditions and have experienced anthropogenic impact. A large dataset consisting of 111 river sites and multiple sampling campaigns for each site in 2018–2020 were used in the analysis, giving rise to a representative application of the CCME WQI on a national scale. Furthermore, the physicochemical quality results were compared with those derived by the HWQI. Apart from the original equation of the CCME WQI for calculating the classification score, a modified version from the literature was used as well. Moreover, apart from the six conventional parameters, which offered a direct comparison with the output values of the HWQI, the CCME WQI and its modified version were recalculated based on a larger dataset, including four additional physicochemical water parameters. The comparative results from all calculations revealed the conservative behavior of the CCME WQI and confirmed the indications from several other Greek studies. Estimated water quality represented a status that consistently belonged to at least a two-class inferior category than the HWQI, while adequate reductions in this deviation could not be achieved with the modified index or with the increase in the number of parameters used in the analysis. It is thus concluded that the first calculation factor and the class boundaries of the CCME WQI are the limiting factors for successful implementation in Greek rivers, independent of the hydroclimatic, geomorphological, and anthropogenic impact variability across the country.

Keywords: CCME WQI; classification system; Greek rivers; HWQI; water quality

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1. Introduction

A variety of methods and tools have been developed to evaluate the quality of water resources in water bodies: one of them being the popular Water Quality Index (WQI) model [1]. Instead of evaluating water resources with the use of a single parameter, WQI models indicate quality based on an aggregation function that takes into account several water quality parameters [2]. Through the calculation of a single, dimensionless value, such models can facilitate the understanding of the water quality status, making it possible to assess, express, and communicate the overall quality of any water source, even to non-experts [3].

Despite the advantage of reducing the large amount of data into a simple and easy expression, most of the WQI models developed so far are characterized by subjectivity and limitations as regards being adopted widely across the globe. Subjectivity is inserted in almost all four standard steps of a WQI estimation: (1) selection of parameters; (2) generation of subindices through the transformation of the data from a parametric system to a dimensionless system; (3) calculation of the parameter weighting values; and (4) computation of the final WQI score [1,2,4,5]. Most WQI models are region specific and only applicable in the areas for which they were designed [6], using local expert views and guidelines [1,2]. To avoid subjectivity and improve the implementation adjustability of WQIs, new techniques have been developed, placing emphasis on the weighting of parameters. A representative example is the use of the information entropy method. This has led to an improved WQI, the entropy-weighted water quality index (EWQI), which has been efficiently used in the evaluation of hydrogeochemical water quality [7,8].

However, while most of the indices identified in the literature (e.g., see [1]) include the steps of subindexing and weighting, the Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) [9,10] omitted these steps and performed the final aggregation function using the parameter measurements directly within fixed mathematical functions. This has made the CCME the most popular index. It is used for all types of water bodies, but primarily for rivers [1]. The index has various significant advantages compared to other indices, which include its broad applicability with respect to the number of water parameters included in its calculation steps, i.e., from only four to a huge number of parameters, its flexibility in selecting the water quality standards, and its tolerance in case of missing data. Moreover, the index is practically independent of a particular set of quality parameters; thus, it can apply to almost every combination of parameters, expressing a score that considers in combination: (a) the number of the parameters whose measured values deviate from predetermined target values at least once within a selected period of water quality monitoring; (b) the frequency that this happens within this period; and (c) the magnitude of the deviation occurring.

The flexibility of the CCME index has facilitated its implementation in several circumstances in Canada, among which are the evaluation of the quality of water used for drinking purposes [11,12] and the evaluation of the water quality status of several river basins [13–15]. In addition, the CCME WQI has been adopted in several other countries for water evaluation in river basins, such as Turkey [16], India [17], Chile [18], Iran [19], Indonesia [20], and it has been used for the water quality evaluation of the Danube river in Romania [21]. In Greece—the area of interest in the present paper—there are already many studies that have used the CCME WQI for water quality evaluation, including both surface (rivers and lakes) and groundwater resources [22–27]. In all these studies, the applicability of the CCME WQI was straightforward with the use of physicochemical datasets, and almost all concluded that the index is rather strict, giving estimates of water quality that mostly range between moderate and poor quality classes of the CCME classification system. It has to be noted, however, that each of these studies was based on monitored data from a single water body. Hence, even if their conclusions on the CCME WQI's conservative performance agree, this cannot be generalized to characterize water bodies at the regional or national level, where a variety of case studies exist with different climatic, geologic, and hydrological conditions and anthropogenic impacts. This remains a research concern and thus inspired the work presented in this paper.

Within the framework of the European water legislation [28], the Institute of Marine Biological Resources and Inland Waters (IMBRIW) of the Hellenic Centre for Marine Research (HCMR) is in charge of coordinating the national surface water monitoring program for rivers in Greece [29–31]. This is composed of systematic water sampling and laboratory analyses for assessing the ecological status. The personnel of IMBRIW have many years of experience in water sampling analysis but also in the use and maintenance of portable instruments for water monitoring, including systematic calibration before use in the field. To determine the physicochemical quality of river waters, the Institute developed and implements a classification system, which has been adopted by the Ministry of Environment and Energy and is being officially applied in the River Basin Management Plans (RBMPs) (termed from now on as Hellenic Water Quality Index, i.e., HWQI). The HWQI takes into account dissolved oxygen and nutrient concentrations, with the class boundaries of the latter being principally set on a rigorous basis according to respective boundaries of macroinvertebrate metrics [32,33]. The purpose of the present study is to apply the CCME WQI on a large dataset from Greek rivers for the determination of their generalized physicochemical water quality over a 3-year period and investigate its possible suitability through a comparative analysis of the results with the respective ones from the existing HWQI. To the best of our knowledge, this is a unique effort to provide a representative application of the CCME WQI on a national scale and investigate possible variations in its performance across a country with significant hydroclimatic, geomorphological, and anthropogenic impact variability. Moreover, the parallel implementation of the Canadian index and the Greek national index, developed for the needs of the European water legislation (the EU Water Framework Directive [28]), may attract the interest of both researchers and policy makers to the comparative results between a globally used WQI and an index developed by an EU Member State for the quality evaluation of its surface waters.

2. Materials and Methods

2.1. The Greek Monitoring Data for Rivers of the Period 2018–2020

Greek lotic systems predominately include highly fragmented, mountainous, small-to-medium-sized flashy rivers and streams, running through steep, narrow valleys and descending abruptly to the coast, most of which flow intermittently to episodically. A relatively small number of medium and large, high-runoff, low-gradient perennial rivers with extensive flood and deltaic plains flow through extended rift valleys [34,35]. The present study used chemical-physicochemical data from river sites distributed throughout the continental part of the country, which were investigated three-times seasonally (spring, summer/early autumn, and winter) in the frame of the Greek National Monitoring Program (NMP) (2nd round 2018–2023) coordinated by IMBRIW of HCMR. At the time of research, measured data from samplings collected until 2020 were available. Thus, we used the sampling results from the beginning of 2018 until the end of 2020, but we excluded those sites for which parts of the expected dataset on physicochemical parameters were empty for any reason (no flow conditions, no sampling available). Obviously, rivers of high intermittency were not included in the analysis. The final dataset consisted of data from 111 river sites (Figure 1) containing complete information on 10 physicochemical parameters, namely, five nutrient elements ($N\text{-}NO_2$, $N\text{-}NO_3$, $N\text{-}NH_4$, $P\text{-}PO_4$, Total P), water temperature (T), BOD, electrical conductivity (EC), pH, and dissolved oxygen (DO). Table 1 (Appendix A) provides useful information related to the 111 sampling sites, such as the exact location, elevation, upstream area, and median concentrations of nutrients and DO measured in each site within the period of analysis (2018–2020).

Temperature, DO, pH, and EC were measured in situ using a flow probe (FP111 Global Water Flow Probe, Global Water, College Station, TX, USA) and a waterproof portable logging multiparameter meter (HI-98194, Hanna Instruments, Leighton Buzzard, UK). Water samples were collected in polyethylene bottles (previously cleaned with diluted HCl), and 1 mL/L of 1% $HgCl_2$ solution was added as a preservative. Samples were transferred while frozen in the laboratory, through portable refrigerators (temperature 4 °C) with ice packs, filtered through 0.45 μm membrane filters, and analyzed for nutrients.

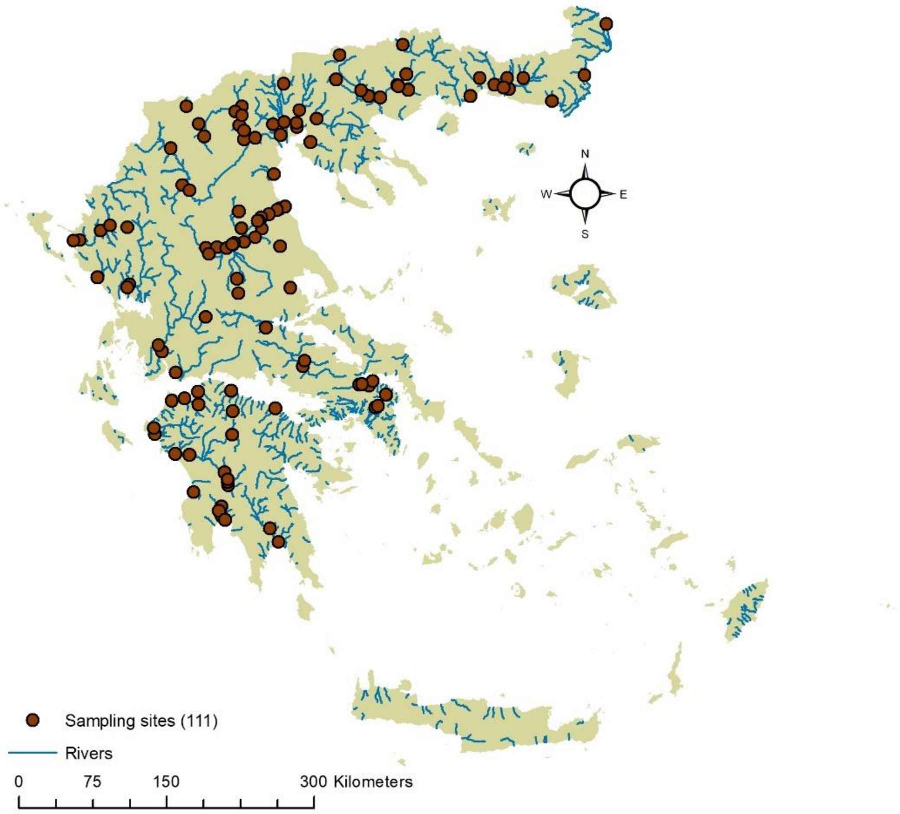

Figure 1. The 111 river sampling sites in continental Greece with full availability of 10 physicochemical parameters from spring, summer, and winter sampling campaigns in the period 2018–2020 used for the analysis in this study.

The data used in the current study are the official WFD monitoring data reported to the Hellenic Ministry of the Environment and Energy and to the EU WISE database, and they therefore follow all the necessary quality control procedures, according to the WFD provisions. Nutrients in water used in the present analysis were quantified/measured in HCMR labs that are certified according to international scientific standards. Labs also participate in intercalibration exercises on a regular basis to ensure the credibility of their chemical analyses output.

After filtration, nitrates, nitrites, ammonium, and orthophosphate were determined by a Skalar San++ Continuous Flow Analyzer according to standard methods: Kerouel and Aminot [36] for the ammonium, Boltz and Mellon [37] for the phosphates and Navone [38] for the nitrates and nitrites. The limits of quantitation (LOQs) were as follows: 1 μg/L for nitrites ($N\text{-}NO_2$), 2 μg/L for the nitrates ($N\text{-}NO_3$), 1 μg/L for the phosphates ($P\text{-}PO_4$), and 5 μg/L for the ammonium ($N\text{-}NH_4$). The determination of total phosphorus (TP) was performed using the wet chemical oxidation method (WCO) according to Raimbault et al. [39]. According to the method, after oxidation/digestion, all phosphorus organic compounds convert to inorganic salts. The assay mixture was analyzed for phosphates. The analysis was performed with a Skalar Auto analyzer as mentioned above. More technical details about field protocols and water chemistry analyses can be found in the Greek Government Gazette II 1635 of 9 June 2016 [40].

2.2. The Hellenic Water Quality Index (HWQI) Based on Nutrients and DO

The Directive 2000/60/EC established a framework for community action in the field of water policy to achieve and maintain the good status of waters by 2015 [28], which has been extended to 2027 [41], in the EU member states. Each national authority should set standards for each quality element (biological, hydromorphological, and physicochemical) most relevant to the pressures faced by the water body under its responsibility and classify waters into a 'High', 'Good', 'Moderate', 'Poor', and 'Bad' status. The IMBRIW-HCMR, being in charge of coordinating the monitoring program for rivers in Greece, set thresholds for water quality standards as far as nutrient elements are concerned (Skoulikidis et al., 2006). This is known as the Greek Nutrient-quality Classification System (NCS) for rivers [32], developed with data from the AQEM project (EVK1-CT-1999-00027; see [42]). NCS is based on a set of sampling sites with differing anthropogenic impacts (ranging from undisturbed to heavily disturbed) that are distributed throughout Greece, and it is based on a biological grounding. Class boundaries are principally set according to the respective boundaries of a biological quality classification system based on benthic macroinvertebrates [42]. Finally, Skoulikidis [33] modified the phosphorous ($P\text{-}PO_4^-$ and TP) high/good boundaries. For the physicochemical classification of a water body in five quality categories, both the NCS and an individual system for DO are applied for the HWQI. Table 1 presents the quality classes of the HWQI for the different nutrient species developed from the Greek NCS and those adopted for DO from the Norwegian classification system [43].

Table 1. Water quality classes of the HWQI based on nutrient species (according to NCS, [32]) and dissolved oxygen (according to [43]).

		High	Good	Moderate	Poor	Bad
$N\text{-}NO_3$	mg/L	<0.22	0.22–0.60	0.60–1.30	1.30–1.80	>1.80
$N\text{-}NH_4$	mg/L	<0.024	0.024–0.06	0.06–0.20	0.20–0.50	>0.50
$N\text{-}NO_2$	µg/L	<3	3–8	8–30	30–70	>70
$P\text{-}PO_4$	µg/L	<70	70–105	105–165	165–340	>340
TP	µg/L	<125	125–165	165–220	220–405	>405
DO	mg/L	>9	6.4–9	4–6.4	2–4	<2

By using DO and nutrient concentrations from each site, the physicochemical quality of water is assessed with the use of the two individual systems and a scoring system, which is summarized in Table 2.

Table 2. Scores of quality classes for the individual parameters [33].

Classes	Boundaries	Score
5 or H (High)	>4 and $\leq$5	(4.1 + 5)/2 = 4.55
4 or G (Good)	>3 and $\leq$4	(3.1 + 4)/2 = 3.55
3 or M (Moderate)	>2 and $\leq$3	(2.1 + 3)/2 = 2.55
2 or P (Poor)	>1 and $\leq$2	(1.1 + 2)/2 = 1.55
1 or B (Bad)	$\leq$1	1/2 = 0.5

For each class of the six parameters in Table 1, a corresponding numerical value (calculation score) is derived according to Table 2 (average of the lower- and upper-class boundaries). The individual scores (five for nutrient concentrations and one for oxygen), ranging between 0.5–4.55, are then averaged, and the resulting value (overall score) characterizes the physicochemical quality of the water, according to the respective class in Table 2. It has to be noted that the system is applied either to individual samplings or to groups of samplings of a river site within a certain period of time. In the case of multiple samplings at a site (various seasons of one calendar year or more years), following the prescriptions of Guidance Document 13 [44] and the Greek National Committee for Water [31], the median value for each of the six parameters is calculated first, and then the six medians are used in the scoring system and their average score is used to characterize the overall physicochemical quality of the river site for the respective monitoring period. The median values of the six parameters used by the HWQI are included in Table 1 for the 111 river sampling sites of the study for the monitoring period 2018–2020.

2.3. The CCME Water Quality Index (CCME WQI)

The Canadian Council of Ministers of the Environment CCME, represented by Canadian jurisdictions, modified the British Colombia WQI to create a CCME WQI, which could be applied by many water agencies in many different countries. The CCME WQI skips subindex generation for the variables, establishment of weights, and classical index aggregation [9]. According to the CCME [9], the CCME WQI uses a target value (objective or guideline) for each parameter that should not be exceeded and quantifies three essential elements (factors) for the calculation of a single unitless number that eventually indicates the overall water quality. The three factors are as follows: (a) scope, which refers to the number of variables of a dataset that were not meeting the objectives of water quality; (b) frequency, which refers to the number of times the objectives are not met; and (c) amplitude, which represents the amount by which the objectives are not met. The index's output ranges from 0, indicating the worst water quality, and 100, indicating the best quality. These numbers are divided into five classes to facilitate the presentation and are summarized in Table 3.

Table 3. CCME WQI classes [9].

Classes	Boundaries	Water Quality Description
Excellent	95–100	water quality is protected with a virtual absence of threat or impairment, conditions very close to natural or pristine levels.
Good	80–94	water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65–79	water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45–64	water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0–44	water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

The equations of the CCME WQI are as follows [10].

F_1 (Scope) represents the percentage of parameters that do not meet their guidelines at least once during the time period under consideration (failed parameters), relative to the total number of parameters measured. The term "guidelines" is equivalent to "objectives" or "target values".

$$F_1 = \left(\frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters}\right) \times 100 \tag{1}$$

F_2 (Frequency) represents the percentage of individual tests that do not meet guidelines (failed tests). A test is a single comparison of a parameter's value from a certain sampling campaign with the respective guideline for that parameter.

$$F_2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) \times 100 \tag{2}$$

F_3 (Amplitude) represents the amount by which failed test values do not meet their guidelines and is calculated in three steps.

The number of times an individual concentration is greater than (or less than, when the guideline is a minimum) the guideline is termed an excursion and is expressed as follows: When the i_{th} test value must not exceed the guideline (objective) of the j_{th} parameter:

$$excursion_i = \left(\frac{FailedTestValue_i}{Objective_j}\right) - 1 \tag{3}$$

For the cases in which the test value must not fall below the guideline (objective):

$$excursion_i = \left(\frac{Objective_j}{FailedTestValue_i}\right) - 1 \tag{4}$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their guidelines and dividing by the total number of tests (both those meeting guidelines and those not meeting guidelines). This parameter, referred to as the normalized sum of excursions, or *nse*, is calculated as

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ of\ tests} \tag{5}$$

F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from guidelines (*nse*) to yield a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) \tag{6}$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as follows:

$$CCME\ WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{7}$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the 'worst' water quality and 100 represents the 'best' water quality.

There are researchers who have criticized the aggregation formula of the index with the argument that the factor of scope (F_1) maintains a 'memory effect'. Thus, when this factor is high at a certain timing of the monitoring period, the CCME WQI cannot improve, with better measurements in the remaining period [45]. This leads to rather strict estimations of water quality. To eliminate such effects, a new formula was proposed for the aggregation score using multiplication and geometric mean. The new index is called the Modified Canadian Water Quality Index (MCWQI) [45] and takes into account the three factors (F_1, F_2, F_3) as different views of water quality but still behaves similarly to the CCME WQI. The MCWQI is considered to provide a fairer judgment status in cases where the statistical factors of the CCME WQI draw a skewed image. Therefore, Dao et al. [45] propose the following formula for calculating the index:

$$MCWQI = 100 - \sqrt[3]{F_1 \times F_2 \times F_3} \tag{8}$$

2.4. Building a Sound Basis for Comparing Indices

It is recommended that, at a minimum, four parameters should be used in the calculation of CCME WQI values; however, more consistent and reliable CCME WQI scores are usually obtained when more than the minimum number of parameters are applied [9,10]. In addition, the parameters and the guidelines were chosen to be based on relevant information about a particular site and express rational permissible limits in order for water to be suitable for a specific use. The established Greek NCS evaluates the suitability of the physicochemical quality of water as part of a healthy ecosystem and can directly indicate the least number of parameters for use with the CCME WQI along with the guidelines to be used in the calculations. On this basis, the least number of parameters to be incorporated into the CCME WQI are the six ones in Table 1, and the target values assigned in Equations (1)–(8) are the 'Good'/'Moderate' thresholds defined in Table 1. For example, the objective for N-NO_3 is set at the maximum of 0.60 mg/L according to Table 1, implying that every sample with an N-NO_3 concentration greater than that will increase the three factors of the CCME WQI from their ideal zero values, while the greater the deviation from the target value of 0.60 mg/L, the higher the value F_3. Similarly, the objectives for N-NH_4, N-NO_2, P-PO_4, and TP are the maximums (Table 1): 0.06 mg/L, 8 µg/L, 105 µg/L and 165 µg/L, respectively, while for DO, the objective is the value of 6.4 mg/L (minimum), which should be maintained in order for the three CCME WQI factors to remain at their optimal zero value.

The CCME WQI can be used to track changes at one site over time and compare values among sites [10]. If used for the latter purpose, care should be taken to ensure a valid basis for comparison. In the present dataset, the same parameters and guidelines (Table 1), along with the monitoring period, characterize each river site without any variation, ensuring that this prerequisite is fulfilled. Water quality was calculated for each of the 111 sampling sites using both the HWQI and the CCME WQI based on the methodologies explained in Sections 2.2 and 2.3, respectively. As mentioned earlier, for each site, spring, summer, and winter sampling campaigns were conducted, namely, values for each parameter from different years/seasons within 2018–2020. For the calculation of the HWQI, the median value of multiple samples for each parameter (DO and five nutrient species) was used in the calculations, while for the CCME WQI, all individual values for each of those six parameters were taken into account to evaluate the average physicochemical water quality of the three-year period 2018–2020. This offers a direct and sound comparison with the HWQI, which also calculates the physicochemical quality of water for the same period with the use of the medians. Finally, the MCWQI (Equation (8)) was also calculated, and its results were elaborated in the comparison analysis.

Except for the DO and nutrient species, which offer a reasonable and sound comparison of the two indices, a more extensive dataset, including the four additional physicochemical parameters that were available (T, pH, EC and BOD), was used to explore the behavior of the CCME WQI further. As guidelines for those four additional parameters, we used value ranges that are rarely exceeded in the aquatic environment of Greek rivers and are also suggested by the literature [46–49]: a permissible range of 6–9 for pH, a permissible range of 2–25 °C for T, and the maximum permissible values of 1500 µS/cm for EC and 4 mg/L for BOD. It has to be noted here that the EC dataset does not include records from sites very close to estuaries with significant mixing of fresh and saline water that could classify water quality at low levels without water pollution being the cause. In fact, the raw data of the measured EC (111 stations × almost 7–8 records per site within 2018–2020) contain less than 2% of records with EC > 1500 µS/cm, which cause penalties in the calculation of the CCME WQI.

For comparison purposes, it was also necessary to associate the classes of the HWQI with those of the CCME WQI. By ranking the five classes in the respective Tables 2 and 3, starting from the classes of the best quality and ending with the classes of the worst quality, a direct correspondence can be obtained, which is summarized in Table 4. Based on that, we can reasonably assume that despite the inherent subjectivities, the five classes from the two systems have quite similar titles and the descriptions of the CCME WQI classes (provided previously in Table 3) reasonably represent the five-class categorization of the HWQI. On the other hand, the numerical ranges of classes differ substantially between the two classification systems. A much better agreement could theoretically be achieved if the 'High' or best class of the HWQI with scores ranging between 4 and 5 corresponded with an 80–100 score range of the CCME WQI, the 'Good' class (range 3–4) with a 60–80 CCME WQI range, the 'Moderate' or intermediate class (range 2–3) with a 40–60 CCME WQI range, the 'Poor' class (range 1–2) with a 20–40 CCME WQI range, and the 'Bad' class (range 0–1) with values of the CCME WQI < 20. These ranges would fit well to the respective categorization of the HWQI, if each of the four best classes of the CCME WQI evaluation system (first four in Table 4) had the boundaries of the next or worse class. For example, the third 'Fair' class boundaries would be proportional with the numerical range of 2–3 of the HWQI 'Moderate' class if they were equal to the boundaries of the 'Marginal' class of the CCME WQI. This is the case with the 'Excellent' and 'Good' water quality classes of the CCME WQI, which would be in almost perfect numerical agreement with the 'High' and 'Good' classes of the HWQI if they had as ranges the less conservative ranges of the classes following them, namely, the ranges 80–94 and 65–79, respectively. Finally, the modified CCME WQI score classification would also require splitting the large range of 0–44 of the 'Poor' class into two scores. This empirical modification has also been incorporated in the last column of Table 4, which is later used for comparisons.

Table 4. Correspondence of water quality classes between the HWQI and the CCME WQI.

Classes Numbers	Classes HCMR WQI/ CCME WQI *	Class Boundaries HCMR WQI *	Class Boundaries CCME WQI *	Modified Boundaries CCME WQI **
5	High/Excellent	4–5	95–100	80–100
4	Good/Good	3–4	80–94	65–79
3	Moderate/Fair	2–3	65–79	45–64
2	Poor/Marginal	1–2	45–64	20–44
1	Bad/Poor	≤1	0–44	0–19

* From Tables 2 and 3 for HWQI and CCME WQI, respectively. ** This column does not contain data from the literature but data that were empirically created for later comparisons.

3. Results

Comparison of Water Quality with the HWQI and the CCME WQI

Water quality scores were calculated for all the 111 river sites with both the HWQI and the CCME WQI using the six conventional parameters (nutrients and DO), producing a dataset of 111 score pairs (scores can be found in Table 1). Our first attempt was to explore the correlation between those data and conclude whether or not the CCME WQI followed the physicochemical quality variation estimated by the HWQI. Indeed, the scattergram of Figure 2 shows a positive and relatively strong correlation between the scores obtained by the two indices. However, most of the scores were plotted above the red line (defined under a proportional correspondence of the two score ranges: 0–5 and 0–100). This implies that for most of the river sites, a better water quality was calculated with the HWQI compared to the CCME WQI, which produced more strict outputs.

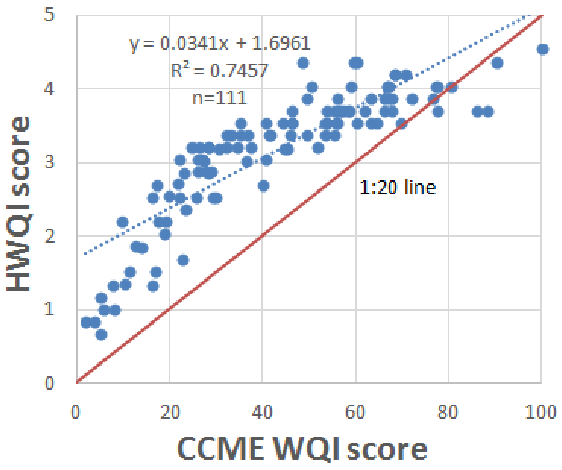

Figure 2. Scattergram of water quality scores obtained from implementing the HWQI and the CCME WQI on the physicochemical data (five nutrient species and DO, see Table 1) of the Greek rivers (2018–2020).

In Figure 3, the 111 quality classes assessed by the HWQI, the CCME WQI, and the MCWQI are presented. It is evident that the better water quality estimated by the HWQI was consistent throughout the study area. Specifically, for most of the 111 river sites, the water quality with the HWQI belonged to the fourth and fifth class ('Good' and 'High' physicochemical quality), while with the CCME WQI, most of the sites were at or below the class No. 3, namely, they belonged to the classes 'Fair', 'Marginal', or 'Poor' of the original CCME WQI classification system (Table 4).

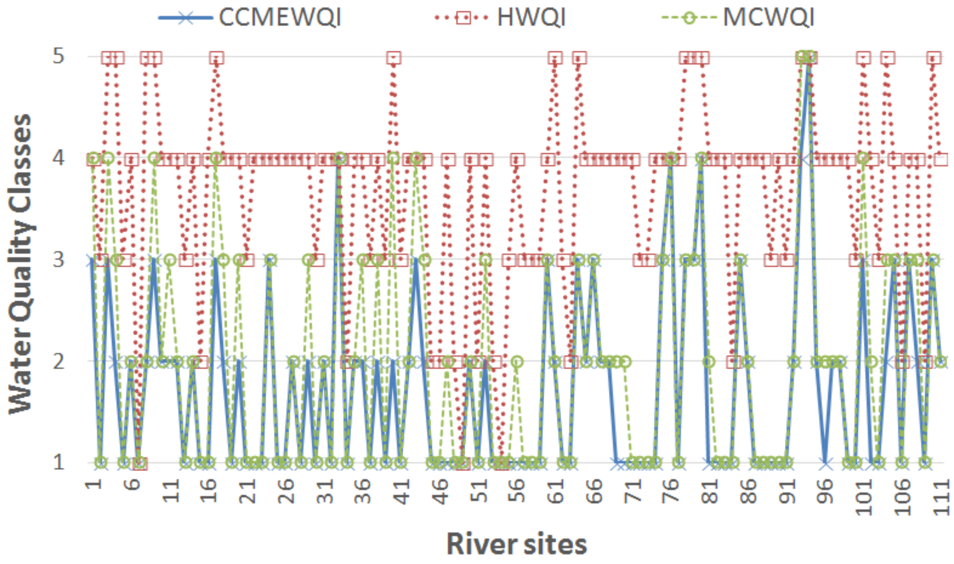

Figure 3. Graph showing the water quality class (1 = worst, 5 = best; see Table 4) that the 111 Greek river sites belong based on the HWQI, CCME WQI, and MCWQI, with the use of six physicochemical parameters (five nutrient species and DO) measured in the period 2018–2020.

A two-class difference seems to be the most typical deviation of the CCME WQI from the HWQI, with a three-class difference also appearing frequently. This indeed reveals the stricter character of the CCME WQI compared to the HWQI when used with the same physicochemical parameters (five nutrient species and DO). On the other hand, the score calculation of the MCWQI (summarized in Table 1) led to higher quality classes compared to the CCME WQI. For many river sites, the difference between the modified index and the HWQI was reduced to one class, mostly estimating one higher class than the traditional CCME WQI. Thus, the MCWQI (see Equation (8)) was still a strict estimator of physicochemical quality compared to the HWQI.

Figure 4 summarizes the number of river sites assigned to each water quality class. Apart from the three water quality class estimations shown above, two more class estimations were included in the analysis, namely, the class estimations derived by the recalculation of both the CCME WQI and the MCWQI from the addition of T, pH, EC, and BOD to the six typical ones. Their scores are also included in Table 1. The HWQI ranked almost 20 river sites at the 'High' quality class (No. 5) and more than 60 sites in the 'Good' quality class No. 4. From the remaining 30 sites, almost half were in the two worst classes. The CCME WQI, on the other hand, classified the majority of river sites into the worst classes (No. 1 and No. 2) with nearly 20 sites falling in the classes No. 3 and No. 4 and almost none of the sites in the best class (No. 5) with respect to the water quality classification of this index (Table 4).

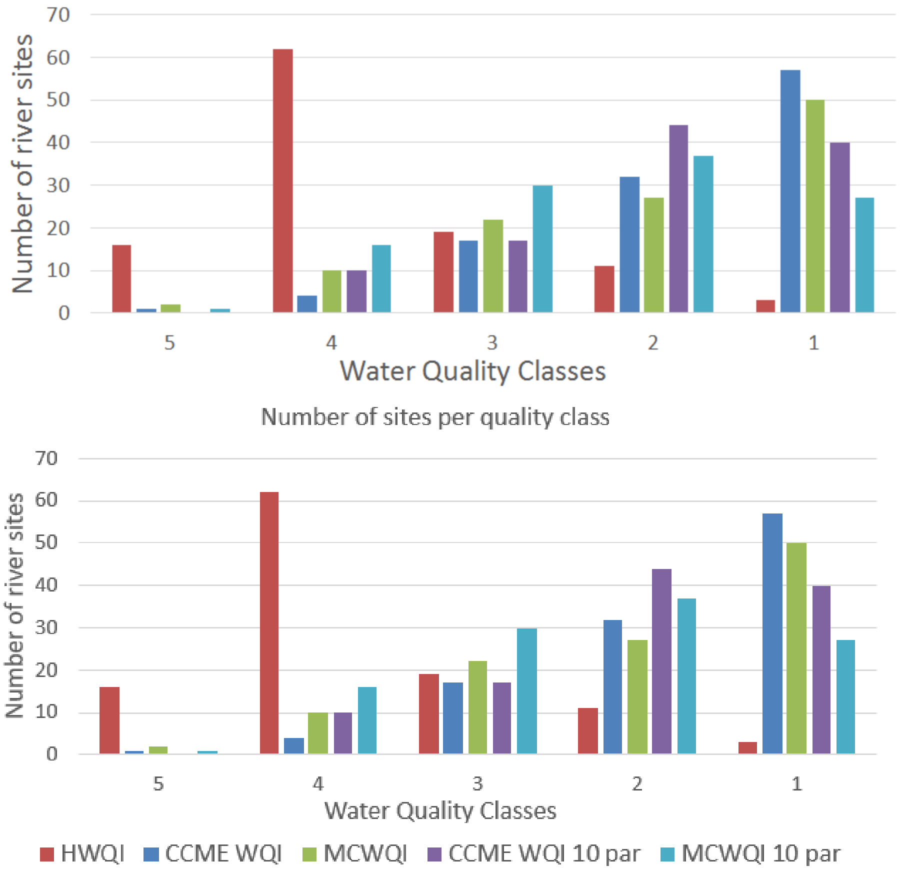

Figure 4. Bar chart showing the distribution of the 111 river sites among the five water quality classes of each classification system (5 = best class, 1 = worst class; see Table 4), with the calculation of the HWQI (traditionally with the use of six water parameters: five nutrient species and DO), the CCME WQI, and MCWQI with the same six parameters, and the last two indices with 10 parameters after the addition of T, pH, EC, and BOD in the dataset, measured all within the period 2018–2020.

The MCWQI is less strict, as shown by the larger number of river sites that belong to the classes No. 4 and No. 3 and the smaller number of sites that belong to the worst two classes No. 2 and No. 1 compared to the CCME WQI. However, the overall differences were not that high as to imply a clearly better agreement with the HWQI. The recalculated CCME WQI and MCWQI values with the use of the 10 available physicochemical parameters are shown in the last two bars above each class in Figure 4. The bars are, to some extent, taller than the respective bars of the same indices calculated with the use of only six typical physicochemical parameters for the classes No. 4 and No. 3, they are even more for class No. 2, and they are shorter than the respective bars of the worst class (No. 1). The use of more parameters in the CCME WQI analysis is, by definition, considered to increase the representativity of water quality assessment [9,10]. Indeed, in the present analysis, it reduced the initial large number of sites in the worst class (No. 1) by almost 20 when only six parameters were used and distributed these sites almost equally into the better classes (No. 2–No. 4) to the left (Figure 4). However, the HWQI remained the only metric that assigned most river sites to a 'Good' class of physicochemical quality.

Figure 5 shows the class differences estimated by the CCME WQI and MCWQI from the HWQI at the river sites used in the present analysis. These differences are summarized twice: once concerning the original quality class scores of the CCME WQI (Figure 5a) and once with the modified scores in the last column of Table 4 (Figure 5b), which are proportional to the numerical categorization of classes proposed by the HWQI (see Section 2.4). Both six and 10 parameters were used, so four alternative CCME/MCWQI indices were calculated. Under the original boundaries of classes, all indices assessed the largest number of sites to differ from the HWQI by two classes, except the MCWQI with the 10 parameters. The original CCME WQI with the six parameters gave a considerable number of sites (almost 30) with a three-class difference from the HWQI, which is a large difference in class categorization. The three alternatives reduced this three-class difference, with the MCWQI eliminating it when implemented with 10 physicochemical parameters. It is interesting, however, that all indices eliminated the three-class differences when the modified class boundaries were used (Figure 5b).

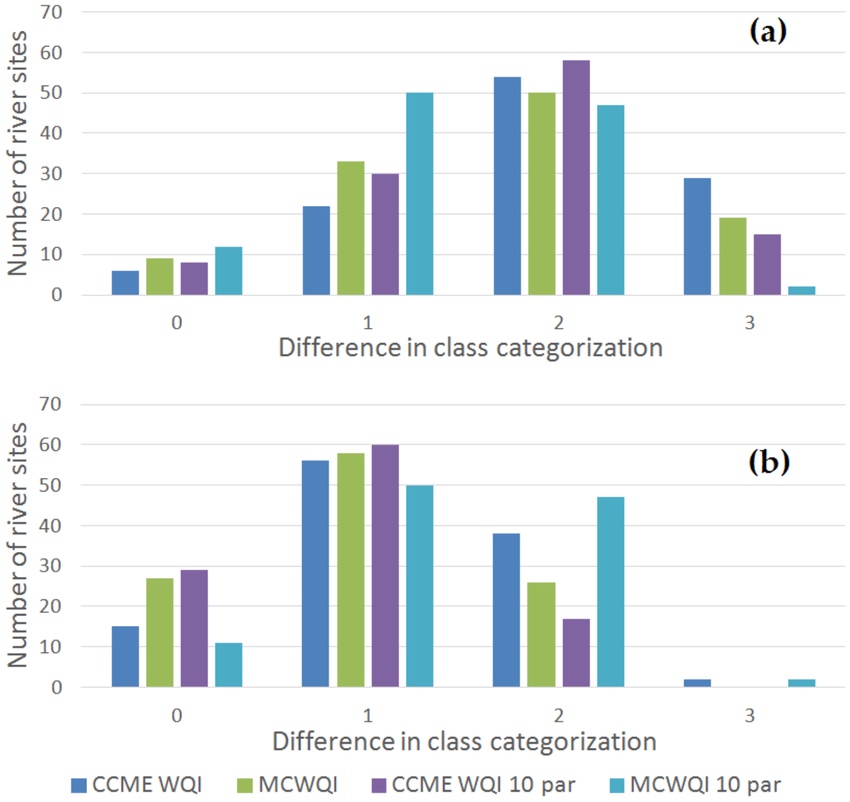

Figure 5. Distribution of differences in water quality classes from the HWQI classes assigned to the 111 river sites by the CCME WQI and the MCWQI with: (**a**) the original and (**b**) the modified CCME class boundaries of Table 4.

On the other hand, the dominance of the two-class differences characterized the majority of the CCME/MCWQI versions, with all assigning almost half of the total (111) river sites in this category to the original class boundaries. With the modified boundaries, which were closer to the HWQI, all indices assigned a quality class to most sites that differed by only one category from the class of the HWQI. It is also remarkable that the perfect agreement of classes (zero difference) between the indices was doubled with the modified boundaries. In almost all cases, more than 70 of the 111 river sites deviated by zero or one water quality class from the HWQI with the less conservative CCME WQI class boundaries.

A final intriguing result can be obtained with the depiction of class differences on the map of Greece. Due to space limitations, we decided to show the spatial distribution of the class differentiation estimated by the original CCME WQI with the six parameters only (nutrients and DO), which offers a more direct and sound comparison with the HWQI, as they were calculated on the same dataset. The purpose of Figure 6 is to explore whether or not high- and low-class deviations occurred homogeneously across the country both within the original CCME WQI boundaries (Figure 6a) and the modified ones (Figure 6b). Figure 6a reveals that high deviations of three and two classes, represented by red and orange dots, respectively, appeared all across the country, including the southern, central, and northern regions. With the modified boundaries of Table 4, these differences became smaller, as the red and orange dots were replaced by orange and yellow ones, respectively, demonstrating relative homogeneity across the country (Figure 6b). Thus, most sites changed by one level in the class difference scale, while a few sites, with zero difference (the light green dots on the map), were already in the category with the original and more strict class boundaries from Table 4 (Figure 6a).

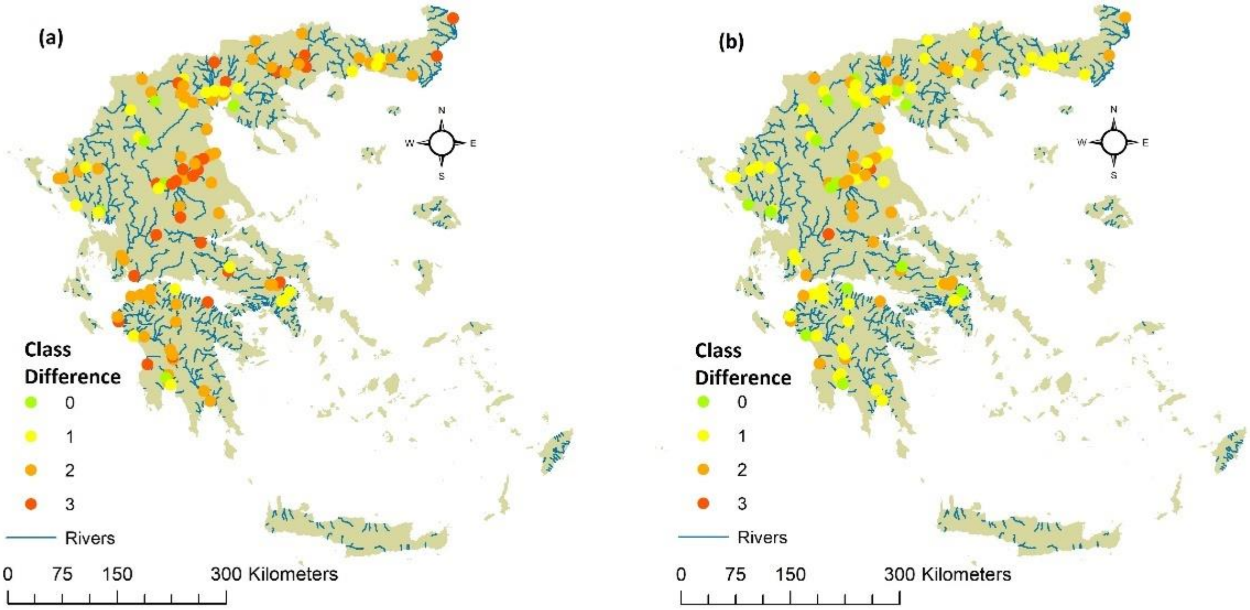

Figure 6. Spatial distribution of differences in water quality classes from the HWQI classes assigned to 111 river sites across continental Greece by the CCME WQI with (**a**) the original and (**b**) the modified class boundaries of the CCME WQI classification (see Table 4).

4. Discussion

In this work, we attempted to compare the WFD-oriented, biologically based HWQI, which has been officially used for almost a decade in the characterization of the physicochemical quality of rivers in Greece, with the globally applied Canadian Water Quality Index (CCME WQI), which can be easily adjusted to a large variety of available datasets due to its flexibility. The research question of whether the CCME WQI could provide reasonable estimates of the average physicochemical quality within the selected monitoring time period of 2018–2020 in Greek rivers led to a rather negative answer as for the majority of cases (river sites), i.e., quality on a 1–5 class scale was significantly inferior from that assessed by the HWQI, which has been extensively tested and officially used on a national basis. Even the scores from the less conservative MCWQI, which differs from the original CCME WQI in the mathematical expression of the total score, could not agree sufficiently with the HWQI scores. Moreover, even the classification of waters to water quality classes from the CCME WQI and its modified version, with the use of an extended dataset of physicochemical parameters in the calculations, could not closely converge with the respective classes of the HWQI, which characterized the majority of water bodies' status as 'Good'. At that point, we underline that the HWQI is among the strictest in Europe for the majority of its parameters [50].

Empirically modifying the rather strict class boundaries of the CCME WQI to bring them closer to the rationale of the HWQI boundaries increased the agreement between the results to some degree. The single test with boundary alterations in this work was solely a simplification for experimentation with numbers and the resulting classification for comparison with the classification determined by the HWQI. The acceptance of such a modification of class boundaries to almost equal increments, similar to the equal increments of the HWQI classes, would require further investigation and scientific evidence. This is the case for any kind of possible updates in the class boundary values of the CCME WQI, especially for a numerical/statistical fit that could possibly lead to a perfect or almost perfect agreement between the results. However, as already mentioned, in order for any modification of class boundaries to be scientifically sound, an investigation of the CCME background and data used for its development would be required, accompanied by communication and collaboration with water quality experts involved in CCME development, application, and results interpretation. It is assumed that the original class boundaries of the CCME WQI were developed based on extensive Canadian data, with their specific, uneven distribution between the five water quality classes representing the local knowledge about the actual status of the water appropriately, according to its quality variations. What is simply concluded here is that the particularities of the CCME WQI classification system, namely, the very large range of the worst class (No. 1) and the high boundary levels (upper and lower) of all the remaining classes (No. 2–No. 5), prevent the statuses assigned by the CCME to Greek rivers from being similar to those given by the national HWQI. Finally, this was further supported by the results produced from a manual adjustment of the CCME WQI class boundaries with the purpose of bringing them closer to the HWQI ones, by moving the value ranges of each CCME WQI original class to one class above (Table 4).

Another important reason for the rankings of all the CCME WQI versions tested in this article to be stricter than those of the HWQI is that, by definition, in the calculation of factors F_1, $F_{2,}$ and F_3, the CCME WQI used all the individual values of the parameters measured within the time period 2018–2020. In contrast, for assessing the average rivers' chemical-physicochemical quality for the same period, the HWQI only used the median value of each physicochemical parameter, resulting in the normalization of the values, which ultimately entered into the calculations. Outliers were disregarded and did not 'disturb' the estimation of the acceptable average quality conditions that predominated among the 111 river sites. To better understand this, Figure 7 was created, in which, for the 111 river sites, the three calculated CCME WQI factors are depicted. The Figure refers to the calculation of the CCME WQI with the six conventional parameters, which resulted in the highest deviation from the HWQI results. As shown, in most cases, F_1 received values greater than 70, resulting in a high penalty according to Equation (7). High values of F_1 could easily be caused by one single measurement of a certain parameter violating the guideline, resulting in the penalization of that parameter overall, which would have a considerable impact on Equation (1).

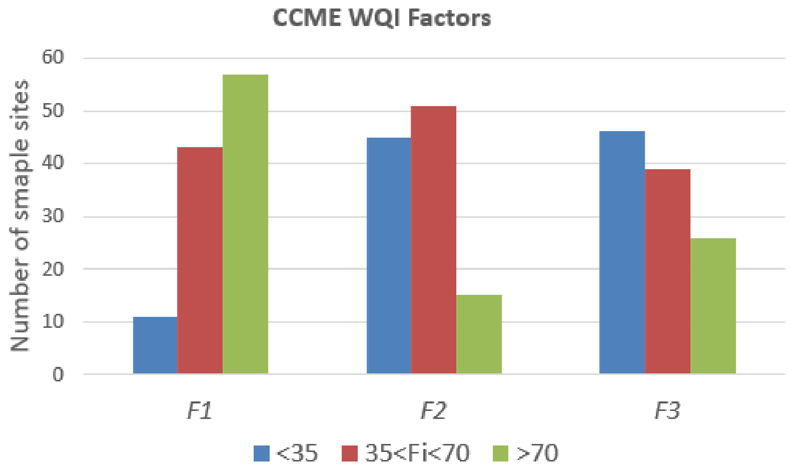

Figure 7. Distribution of F_1, $F_{2,}$ and F_3 values into three equally separated numerical classes, resulting from the implementation of the CCME WQI on the Greek rivers' physicochemical dataset of 2018–2020 (six parameters including five nutrient species and DO—see Table 1—from seven samplings at 111 river sites).

F_1 is known to not work appropriately when too few variables are considered or when too much covariance exists among them [3]. Therefore, for a specific date with bad measurements of many parameters, F_1 would move close to its maximum value (100) and inevitably result in a low CCME WQI score. In the dataset in the present study, there could be a strong correlation between P-PO_4 and TP [51] or between N constituents, which, in some cases, may have caused a double impact on the CCME WQI, increasing the F_1 value. A larger dataset used in the recalculation of the CCME WQI with the inclusion of four additional and quite independent physicochemical parameters reduced the importance of anyone parameter or pairs of dependent parameters, lowering the significance of this 'twice counting' effect. The proportion of sites ranked in extreme categories, especially the worst class, was reduced. However, the overall ranking did not improve much towards the HWQI ranking. On the other hand, F_2 and F_3 can be considered more representative factors in determining water quality since they aggregate all the deviations occurring from the guidelines, attributing a more objective magnitude to them (Equations (2)–(6)). For most river sites, these factors received lower/moderate values, within the range 0–100 (Figure 7), resulting in a CCME WQI score with Equation (7) that was penalized less. Thus, the effect of F_1 is the main factor responsible for the conservative nature of the CCME WQI. Even the implementation of the alternative MCWQI on our dataset seemed to be greatly influenced by the highly penalized F_1 values, resulting in them not being able to approach the HWQI assessments.

Thus, with the present dataset, it was determined that the contribution of the first term (F_1) to the final CCME WQI score was much greater than the contribution of the other two terms. A rather positive effect of this, however, could be in the case of a highly toxic compound existing in water, even only once within a certain period of time. With the use of the CCME WQI, the strictness of the F_1 parameter can prevent undesired water use due to a possibly dangerous concentration of a specific parameter. In this article, neither the erasure nor the replacement of F_1 with another component is suggested. What is recommended, at least for Greek rivers, is using the CCME WQI with caution, paying attention to the contribution of F_1 to the overall results produced in each circumstance. A deep investigation of the developmental background of the CCME WQI is highly recommended to encourage a successful adjustment of this flexible and easy-to-use index for the rivers of Greece and other countries.

5. Conclusions

This study attempted to evaluate the widely applied CCME WQI on a large dataset of physicochemical properties measured in the rivers of continental Greece. The CCME WQI has the advantage of integrating a variety of variables and different measurement units in a single number, offering great flexibility in the selection of input parameters and objectives, with tolerance to missing data. Only river sites with complete and good quality data were, however, used in this study, from monitoring locations spread evenly across the country, in order to create a homogeneous dataset that could maximize the reliability of estimations. Taking the Greek classification system and the associated HWQI for physicochemical water quality as a reference, this study concluded that the water quality assessments for the same time period 2018–2020 and the physicochemical water parameter dataset, attempted with the use of the CCME WQI, deviated significantly, assigning much worse quality statuses to the majority of the river monitoring sites included in the analysis, independently of the hydroclimatic, geomorphological, and anthropogenic impact variability across the country. In addition, the calculation of the MCWQI, a less strict modified version of the CCME WQI, and both indices with a larger dataset, including four additional water parameters, improved assessments, albeit slightly. Despite the non-agreement between the results, the article does not attempt to degrade the validity of the widely used CCME WQI and/or its modified version in assessing water status. However, incorporating dozens of river monitoring sites throughout Greece into the analysis confirmed the inferences of all previous Greek applications in individual water bodies regarding the conservativeness of the Canadian index in the evaluation of water quality. Thus, the use of the index should be treated with caution. Based on our analysis and results, the reasons for this are related to the mathematical structure of the index, especially the first calculation factor, and the numerical boundaries of the classification system, whose adjustment to another country's conditions seems necessary after a deeper investigation.

Author Contributions: Conceptualization, Y.P., D.E.A. and E.D.; Methodology, Y.P., D.E.A., N.T.S. and E.D.; software, Y.P., D.E.A. and S.L.; validation, Y.P. and S.L.; formal analysis, Y.P., D.E.A., N.T.S., A.P. and E.D.; investigation, Y.P., D.E.A., N.T.S. and S.L..; resources, Y.P., D.E.A., N.T.S., S.L., A.P. and E.D.; data curation, Y.P., D.E.A. and S.L.; writing—original draft preparation, Y.P. and N.T.S.; writing—review and editing, Y.P., D.E.A., N.T.S., S.L., A.P. and E.D.; visualization, Y.P. and S.L.; supervision, N.T.S., A.P. and E.D.; project administration, N.T.S., A.P. and E.D.; funding acquisition, N.T.S., A.P. and E.D. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data used in this study are available at IMBRIW-HCMR and to external parties they are available upon request either at IMBRIW-HCMR or at the Ministry of Environment and Energy: http://nmwn.ypeka.gr/?q=surface-stations (accessed on 25 May 2022).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table 1. Detailed information about the 111 sampling sites included in the analysis: site name, hydrologic basin to which each site belongs, location (lat, long), site elevation and catchment's upstream area, medians of measured data from the samplings within 2018–2020 and the numerical scores of the HWQI, CCME WQI and MCWQI based on the six parameters used conventionally by the HWQI and the scores of CCME WQI and MCWQI with the use of the extended dataset of 10 physicochemical parameters.

No.	Site Name	Hydrologic Basin	Lat	Long	Elev m	Area Km^2	DO mg/L	N-NO$_2$ mg/L	N-NO$_3$ mg/L	N-NH$_4$ mg/L	P-PO$_4$ mg/L	TP mg/L	HWQI 6par	CCME 6par	MCWQI 6par	CCME 10par	MCWQI 10par
1	DIMHKOS	Acheloos	38.57	21.29	17	711	8.31	0.007	0.773	0.024	0.015	0.024	3.72	58.17	73.35	69.19	81.58
2	GURIOTISA	Acheloos	38.63	21.25	26	225	5.42	0.005	0.206	0.033	0.054	0.073	3.88	49.27	69.36	63.75	79.03
3	PARK_KYKL	Acheloos	41.10	25.56	33	65	8.7	0.009	1.093	0.358	0.097	0.098	3.05	21.78	26.80	40.28	43.82
4	PENTALOFOS_ACHEL	Acheloos	40.94	23.69	4	5560	8.21	0.003	0.246	0.013	0.005	0.009	4.05	80.29	92.30	82.33	93.09
5	MAVROPOTAMO	Acherontas	39.23	20.50	5	791	9.27	0.004	0.738	0.031	0.013	0.019	3.88	67.08	78.01	68.41	78.66
6	AG_THOMAS	Agrilias	38.38	21.46	5	27	10	0.004	0.212	0.063	0.02	0.024	4.05	58.75	72.73	57.62	75.04
7	3POTAMO	Alfeios	37.36	22.09	375	8	8.53	0.079	1.685	0.635	0.048	0.053	2.53	15.99	20.21	29.33	35.00
8	APIDITSA	Alfeios	37.39	22.09	356	280	9.48	0.03	0.414	0.022	0.005	0.014	4.05	50.19	57.22	57.85	65.39
9	EPITALION	Alfeios	37.64	21.48	1	3404	10.9	0.01	0.72	0.018	0.003	0.006	3.88	65.97	73.82	74.13	81.94
10	KARYTAINA	Alfeios	37.48	22.05	324	884	8.56	0.083	2.287	0.108	0.005	0.007	2.70	39.79	44.25	46.89	53.20
11	OLYMPIA	Alfeios	37.63	21.64	22	3141	10.5	0.008	0.722	0.015	0.002	0.004	4.05	66.62	74.58	74.11	81.81
12	THOKNA	Alfeios	37.83	22.12	449	234	9.32	0.177	1.286	0.514	0.002	0.006	2.87	27.96	33.15	34.46	43.69
13	TIMIOS	Alfeios	39.79	22.38	58	291	7.89	0.001	0.909	0.012	0.006	0.009	4.05	77.32	82.58	75.25	85.14
14	3POTAM	Aliakmonas	40.53	22.20	101	198	11.37	0.004	1.007	0.028	0.015	0.027	3.88	76.37	80.58	80.05	85.22
15	AMYNTAS	Aliakmonas	40.66	21.65	593	220	7.06	0.03	0.798	0.084	0.023	0.036	3.38	45.88	48.51	55.35	60.01
16	ARAP_DW	Aliakmonas	40.66	22.13	55	165	11.38	0.022	1.308	0.068	0.067	0.077	3.38	55.16	55.51	61.99	64.29
17	GREVENIOT_VIOLOGIKOS	Aliakmonas	40.10	21.47	484	171	10.1	0.025	0.973	1.12	0.372	0.417	1.86	13.78	15.69	28.05	30.80
18	KOSTARAZI	Aliakmonas	40.44	21.32	614	309	8.26	0.07	2.746	0.723	0.307	0.328	1.53	16.74	16.91	29.44	30.68
19	PROFITIS_ILIAS	Aliakmonas	41.31	23.34	60	984	10.56	0.01	0.902	0.029	0.02	0.028	3.72	65.87	73.31	68.16	78.67
20	RIZARI	Aliakmonas	40.99	23.60	9	2424	10.04	0.057	1.126	0.154	0.051	0.061	3.38	31.91	33.81	46.41	49.50
21	SIMB_BEN	Aliakmonas	36.85	22.68	12	4197	9.31	0.001	0.034	0.017	0.001	0.004	4.55	100.00	100.00	82.36	94.50
22	T1	Aliakmonas	40.55	22.33	16	3724	11.2	0.016	1.006	0.183	0.034	0.055	3.55	46.02	47.91	54.59	57.39
23	T2	Aliakmonas	39.63	22.35	79	10767	10.31	0.021	1.116	0.154	0.041	0.041	3.55	55.40	55.77	61.49	63.48
24	ANTHEM_DW	Anthemountas	40.52	22.99	5	299	3.72	0.638	1.514	32.5	5.92	6.096	0.85	1.80	1.85	11.30	12.35
25	ASSOPOS_DW	Asopos Viotia	38.29	23.71	38	653	13.58	0.038	3.852	0.045	0.135	0.159	2.71	16.90	19.92	31.89	35.84
26	ASSOPOS_UP	Asopos Viotia	38.30	23.59	89	385	9.82	0.012	2.761	0.028	0.007	0.024	3.38	49.47	53.89	62.74	67.12
27	CHALKOUTSI	Asopos Viotia	38.33	23.75	2	690	11.77	0.037	3.391	0.032	0.046	0.07	3.21	30.49	33.93	37.67	43.02
28	INDUSTRY	Asopos Viotia	38.31	23.62	74	436	8.93	0.025	4.279	0.051	0.11	0.121	2.88	22.79	26.81	39.97	44.95
29	FLORINA	Axios	40.82	21.50	600	255	7.58	0.031	0.823	0.105	0.146	0.153	2.72	21.59	25.02	35.03	41.20
30	LOUDIAS_DW	Axios	40.58	22.63	1	1136	8	0.05	0.778	0.384	0.209	0.214	2.22	17.44	19.63	25.17	30.21
31	PSAR_DW	Axios	40.78	22.09	73	621	10.54	0.034	4.886	0.062	0.013	0.025	3.04	36.40	38.40	49.87	53.07
32	VARDAROV	Axios	38.21	23.90	302	306	5.12	0.077	1.211	0.254	0.524	0.566	1.36	10.11	10.72	27.44	28.31
33	VOZVOZ	Bospos	36.97	22.58	109	315	8.33	0.404	2.178	4.52	0.699	0.726	1.01	7.86	8.84	22.05	25.75

Table 1. *Cont.*

No.	Site Name	Hydrologic Basin	Lat	Long	Elev m	Area Km^2	DO mg/L	N-NO$_2$ mg/L	N-NO$_3$ mg/L	N-NH$_4$ mg/L	P-PO$_4$ mg/L	TP mg/L	HWQI 6par	CCME 6par	MCWQI 6par	CCME 10par	MCWQI 10par
34	APOKRIMNO_DW	Evros	40.88	25.90	23	228	9.44	0.006	0.797	0.02	0.01	0.01	4.05	77.04	81.24	80.76	86.24
35	EVROS_MD	Evros	41.57	26.59	28	35260	7.7	0.007	1.006	0.036	0.162	0.163	3.22	32.14	44.47	47.43	58.63
36	LYKOFOS	Evros	41.11	26.30	14	39264	8.69	0.009	1.482	0.019	0.129	0.154	3.05	40.36	47.37	47.23	57.93
37	DS_SKOURA	Evrotas	36.99	22.52	127	1202	8.39	0.007	0.765	0.027	0.024	0.028	3.72	56.47	66.03	61.11	69.95
38	SKALA	Evrotas	39.12	22.16	467	1680	9.07	0.009	0.45	0.024	0.015	0.026	3.88	55.96	64.44	60.92	69.34
39	VRODAMAS	Evrotas	41.09	23.29	25	1362	8.16	0.007	0.2	0.011	0.01	0.017	4.22	68.33	76.69	66.71	72.98
40	GALLIKOS_DW	Gallikos	40.65	22.83	6	935	8.92	0.012	0.937	0.034	0.008	0.013	3.55	55.75	63.77	61.58	70.89
41	GALLIKOS_MD	Gallikos	40.81	22.86	55	851	9.25	0.027	4.043	0.041	0.037	0.043	3.38	33.02	36.83	50.27	54.54
42	GRIBOVO	Kalamas	39.66	20.52	100	1569	10.29	0.043	0.982	0.129	0.071	0.075	3.22	51.59	51.91	59.18	60.86
43	KASTRI_(Kalamas)	Kalamas	39.56	20.28	47	1538	8.23	0.019	0.74	0.035	0.041	0.045	3.55	53.67	60.04	71.81	75.10
44	KESTRINI	Kalamas	39.56	20.21	3	2302	6.99	0.003	0.708	0.057	0.021	0.031	3.72	58.55	79.63	69.43	86.23
45	KLIMATIA	Kalamas	39.71	20.63	186	513	8.29	0.04	1.243	1.821	0.373	0.421	1.53	11.04	12.77	28.53	32.67
46	LAPSISTA	Kalamas	39.69	20.84	466	404	6.89	0.006	0.215	0.069	0.022	0.033	3.88	62.95	65.68	66.22	71.53
47	KIFISOS_MD	Kifisos Attiki	38.09	23.78	185	73	11.33	0.14	4.024	0.027	0.472	0.515	1.68	22.45	23.20	40.15	42.78
48	ERKYNA	Kifisos Viotia	38.46	22.93	107	88	8.52	0.03	0.962	0.16	0.058	0.074	3.38	34.93	38.34	47.68	52.28
49	ORXO	Kifisos Viotia	38.51	22.96	102	326	9.15	0.003	2.625	0.027	0.01	0.014	3.54	69.73	71.70	76.25	78.71
50	KIFISOS_UP	Lekanopedio Attikis	38.11	23.81	235	38	9.96	0.2342	4.456	0.375	0.955	0.987	1.35	15.99	16.24	33.73	36.81
51	PLATY	Loudias	40.83	22.16	36	590	4.95	0.059	0.746	0.462	0.302	0.322	1.88	12.35	13.80	27.11	29.35
52	GEF. KALOGIROU	Louros	39.18	20.89	8	471	8.48	0.003	0.837	0.032	0.017	0.027	3.72	85.79	87.46	80.97	87.91
53	KERASOUNTA	Louros	39.15	20.86	5	485	8.98	0.004	0.786	0.045	0.023	0.029	3.72	77.50	83.80	81.00	88.32
54	VARNAVAS	Marathonas (Lake)	37.87	21.22	6	17	9.47	0.002	3.048	0.009	0.001	0.004	3.88	71.73	77.16	80.28	85.40
55	MAVRONER	Mavroneri	40.22	22.56	7	636	9	0.052	0.54	2.087	0.295	0.32	2.04	18.61	21.05	23.82	28.77
56	DESPATI	Nestos	41.41	24.11	385	778	10.45	0.006	0.528	0.013	0.044	0.051	4.22	70.59	90.43	70.17	83.94
57	LASPO_DW	Nestos	40.94	24.92	2	203	6.76	0.162	1.732	2.246	0.663	0.692	1.18	5.04	5.21	24.93	26.93
58	AG_FLOROS	Pamisou-Nedontos-Neda	37.17	22.02	15	9	9.5	0	0.819	0.013	0.003	0.007	4.22	68.38	81.13	81.02	88.58
59	ARIS	Pamisou-Nedontos-Neda	37.08	22.03	7	129	6.85	0.003	0.988	0.024	0.018	0.02	3.72	57.10	67.46	62.85	75.01
60	PAMISSOS	Pamisou-Nedontos-Neda	39.26	21.41	365	564	8.76	0.003	0.627	0.035	0.012	0.022	3.72	88.14	93.18	87.42	94.38
61	TZIROREMA	Pamisou-Nedontos-Neda	40.70	22.68	6	155	8.45	0.005	0.765	0.038	0.017	0.023	3.72	67.51	74.50	63.19	75.93
62	FARAI	Peirou-Verga-Pineiou	38.10	21.73	122	138	9.53	0.008	0.583	0.023	0.152	0.197	3.55	46.09	58.48	55.74	68.27
63	K_AXAIA	Peirou-Verga-Pineiou	38.15	21.57	1	535	8.78	0.009	1.271	0.049	0.027	0.036	3.55	63.02	66.70	72.46	76.73
64	MANNA	Peirou-Verga-Pineiou	38.13	21.42	3	32	9.67	0.032	2.14	0.113	0.155	0.155	2.54	21.86	25.95	33.20	39.38

Table 1. *Cont.*

No.	Site Name	Hydrologic Basin	Lat	Long	Elev m	Area Km^2	DO mg/L	$N\text{-}NO_2$ mg/L	$N\text{-}NO_3$ mg/L	$N\text{-}NH_4$ mg/L	$P\text{-}PO_4$ mg/L	TP mg/L	HWQI 6par	CCME 6par	MCWQI 6par	CCME 10par	MCWQI 10par
65	VARTHOLOMIO_US	Peirou-Verga-Pineiou	41.01	25.32	13	12	6.61	0.006	1.104	0.038	0.029	0.033	3.72	56.34	66.79	61.67	72.19
66	KALONERO	Peristera	37.29	21.70	8	186	10.8	0.002	0.588	0.012	0.004	0.007	4.38	60.16	80.93	64.07	79.97
67	PINIOS	Pinios Peloponnisos	40.67	22.54	5	844	6.03	0.024	1.207	0.125	0.057	0.071	3.22	26.03	31.67	43.52	49.80
68	ELASSON_MD	Pinios Thessalia	39.87	22.15	245	247	4.92	0.015	0.083	0.094	1.342	1.427	2.20	9.46	10.97	17.35	20.30
69	ENIPEA	Pinios Thessalia	39.56	22.09	87	2640	8.01	0.038	1.436	0.126	0.064	0.083	3.05	25.75	31.11	41.84	46.94
70	KIT_TRIK	Pinios Thessalia	39.53	21.77	104	5	8.26	0.016	5.271	0.035	0.027	0.034	3.21	44.35	47.11	53.88	58.58
71	LITHEO_DW	Pinios Thessalia	39.54	21.90	96	148	3.91	0.203	2.368	0.928	0.633	0.652	0.68	4.83	5.01	18.88	20.08
72	MAKRY	Pinios Thessalia	39.26	22.15	119	41	7.6	0.013	2.604	0.037	0.171	0.181	2.38	23.27	27.45	41.00	45.60
73	MEGA	Pinios Thessalia	39.53	22.01	87	348	10.48	0.002	0.018	0.028	0.053	0.053	4.38	48.20	64.54	50.83	68.39
74	MELISSA	Pinios Thessalia	39.56	22.65	54	587	6.79	0.008	2.326	0.019	0.257	0.289	2.54	25.50	30.99	48.28	52.19
75	OMOLIO_DS	Pinios Thessalia	39.90	22.64	6	9731	9.62	0.016	1.327	0.036	0.076	0.091	3.38	53.30	59.89	60.98	70.01
76	P004	Pinios Thessalia	39.92	22.70	3	10721	9.85	0.014	1.166	0.03	0.082	0.089	3.55	53.14	60.71	49.10	63.33
77	P028	Pinios Thessalia	39.89	22.61	15	10610	9.96	0.015	1.243	0.022	0.073	0.085	3.72	53.45	60.31	61.06	70.31
78	P061	Pinios Thessalia	39.85	22.51	15	10389	9.82	0.02	1.63	0.025	0.083	0.1	3.38	41.59	48.56	48.08	59.32
79	P073	Pinios Thessalia	39.81	22.40	60	10332	10.15	0.018	1.612	0.037	0.089	0.098	3.38	41.21	48.09	47.05	57.36
80	P088	Pinios Thessalia	39.79	22.39	56	8425	9.81	0.019	1.541	0.097	0.092	0.099	3.22	37.31	41.35	44.68	51.91
81	P223	Pinios Thessalia	39.59	22.22	85	6333	8.92	0.02	1.256	0.088	0.122	0.14	2.88	25.71	31.86	38.27	47.15
82	P263	Pinios Thessalia	39.58	22.11	86	6012	8.72	0.024	1.266	0.091	0.113	0.14	2.88	27.32	34.14	38.82	48.07
83	P266	Pinios Thessalia	39.57	22.08	86	3370	9.26	0.023	1.587	0.07	0.109	0.115	3.05	26.90	33.29	38.47	47.42
84	PAMISOS	Pinios Thessalia	39.48	21.81	101	222	9.84	0.005	1.174	0.051	0.018	0.029	3.88	67.58	74.68	63.26	76.61
85	PIN_IND	Pinios Thessalia	37.81	21.23	1	8275	9.94	0.021	1.649	0.133	0.105	0.113	3.22	24.41	29.79	37.60	45.68
86	T_XINIADA	Pinios Thessalia	40.75	22.17	27	23	9.3	0.014	2.274	0.023	0.052	0.06	3.54	40.53	48.03	46.20	55.61
87	TERPSITHEA	Pinios Thessalia	37.42	22.09	361	6517	8.9	0.02	1.443	0.048	0.08	0.101	3.22	28.22	36.16	39.82	50.59
88	TITAR_DW	Pinios Thessalia	39.72	22.19	117	1884	10.67	0.017	0.313	0.047	0.1	0.131	3.55	34.89	48.97	43.84	60.83

Table 1. *Cont.*

No.	Site Name	Hydrologic Basin	Lat	Long	Elev m	Area Km^2	DO mg/L	N-NO$_2$ mg/L	N-NO$_3$ mg/L	N-NH$_4$ mg/L	P-PO$_4$ mg/L	TP mg/L	HWQI 6par	CCME 6par	MCWQI 6par	CCME 10par	MCWQI 10par
89	TITAR_MD	Pinios Thessalia	38.08	22.62	5	1566	10.31	0.025	1.975	0.066	0.162	0.189	2.54	29.21	30.52	44.40	46.60
90	FILIUR_DW	Rema Komotinis-Loutrou Evrou	41.00	25.39	8	1381	9.13	0.006	1.801	0.037	0.028	0.032	3.54	64.35	68.49	72.59	76.68
91	MESOHOR	Rema Komotinis-Loutrou Evrou	41.10	25.37	22	125	4.27	0.093	1.627	5.4	0.693	0.762	1.02	5.71	6.12	23.42	25.95
92	PASSOS	Rema Komotinis-Loutrou Evrou	38.21	21.72	2	311	12.17	0.002	1.468	0.009	0.004	0.007	4.05	66.51	72.26	68.55	77.33
93	ASPROPO	Rema Xanthis-Xirorema	41.04	25.21	3	114	8.74	0.004	1.22	0.039	0.051	0.063	3.72	45.97	58.09	50.55	66.93
94	KOSSYNTHOS_DW	Rema Xanthis-Xirorema	41.10	25.03	18	397	9.08	0.019	1.46	0.037	0.017	0.024	3.55	60.21	61.83	70.36	72.78
95	KALAVRITA	Remata Paralias Vor Peloponnisou	38.04	22.13	693	138	5.87	0.021	0.848	0.04	0.121	0.143	2.88	28.82	36.90	50.85	56.59
96	PATRA	Remata Paralias Vor Peloponnisou	38.49	21.24	6	100	10.02	0.002	0.627	0.024	0.008	0.012	4.05	67.07	73.63	74.65	81.50
97	TRIKALITIKOS	Remata Paralias Vor Peloponnisou	37.05	22.06	1	161	11.58	0.002	0.315	0.009	0.001	0.004	4.38	59.48	74.87	63.79	78.47
98	SELINOUS	Selinous	40.05	21.56	431	356	11.2	0.001	0.411	0.012	0.001	0.004	4.38	90.28	98.56	82.50	97.49
99	ELKE	Spercheios	38.81	22.49	13	1393	7.55	0.015	0.642	0.101	0.074	0.076	3.22	28.04	34.94	48.12	52.48
100	DRAMA	Strymonas	41.14	24.14	90	117	9.85	0.014	1.796	0.123	0.029	0.039	3.38	36.44	40.07	54.62	57.45
101	FILIPP	Strymonas	41.00	24.17	46	248	7.52	0.04	1.221	0.082	0.063	0.069	3.22	34.44	37.46	52.29	54.96
102	PETHELINO	Strymonas	39.71	22.43	64	14016	10.38	0.013	0.32	0.102	0.0963	0.116	3.55	44.06	53.32	54.63	64.55
103	PROMAXON	Strymonas	41.05	22.66	26	11090	9.57	0.015	0.755	0.035	0.053	0.057	3.72	55.12	63.39	61.95	72.71
104	S10	Strymonas	41.04	24.04	48	12570	7.47	0.026	0.834	0.159	0.1706	0.194	2.55	19.52	24.27	39.43	43.54
105	S12	Strymonas	41.03	24.05	50	495	9.1	0.0415	2.948	0.046	0.0962	0.11	3.04	27.24	33.75	43.25	49.97
106	S16	Strymonas	40.93	23.83	8	1349	8.81	0.08	1.816	0.147	0.086	0.1	2.53	29.61	31.59	42.75	45.89
107	S18	Strymonas	38.23	22.11	35	2148	10.04	0.036	2.114	0.052	0.066	0.069	3.21	45.05	46.80	59.82	62.11
108	ZEVGO	Strymonas	40.11	20.72	447	11949	9.85	0.0094	0.308	0.111	0.016	0.029	3.72	61.64	64.19	60.22	67.51
109	KOILADA	Vegoritida (Lake)	40.55	21.71	578	1005	5.46	0.264	2.856	2.19	0.402	0.421	0.84	3.75	3.84	16.22	17.31
110	BOGDANO	Volvi (Lake)	40.73	23.06	91	201	2.7	0.076	0.053	38	3.78	3.953	1.35	7.65	9.01	20.12	24.08
111	ALMYR_DW	Xirias (Almyros)	39.18	22.78	37	154	10.2	0.008	5.237	0.065	0.369	0.384	2.20	18.78	21.83	34.52	38.05

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