Analysis of existing water information for the applicability of Water Quality Indices in the fluvial-littoral area of Turia and Jucar Rivers, Valencia, Spain.

Highlights

- First study analysing water quality information of Turia and Jucar River basins.
- Applicability of 42 Water Quality Indices (WQIs) in 67 stations was studied.
- About 283,023 records of water physicochemical parameters were evaluated.
- Assessment and comparison of 7 WQIs at 21 stations from 1990 to 2016.

Abstract

For the first time, all the water quality information gathered by an European Union water district authority between 1990 and 2016 (the Spanish Jucar River Management Authority, *Confederación Hidrográfica del Júcar*, CHJ) was analysed and discussed. The main goal is to evaluate the applicability of this existing physicochemical information as potential data sources for continuous evaluation with Water Quality Indices (WQIs). Specifically, the spatial and temporal representativity of available data is assessed together with the applicability of WQIs both in time and space. A list of 42 existing WQIs with type and number of variables used was compiled after literature review. The study was carried out in the fluvial-littoral area of Turia and Jucar Rivers, Valencia, Spain, which was divided into six Landscape Functional Areas (LFAs), based on the outer continental perimeter zone, the irrigation areas of main channels crossing the flood plain, and the Albufera Lake.

Input information consisted of a database, provided by the CHJ, of 67 sampling points with 401 physicochemical variables from 1990 to 2016, (about 283,023 records). This information was cross-analysed using descriptive statistics to evaluate the CHJ database information, the possibility of using WQIs, and the performance of target WQIs once their possible use both in time (27 years) and space (6 LFA) was established. Finally, a map representing the six LFAs was digitised, including the 67 sampling points and their water physicochemical characteristics.

Results demonstrate that, out of 42 WQIs selected, seven can be used whenever all variables required are present. None of them can be calculated simultaneously at all stations and for all years. About 31% (21) of stations provided data that can be used in some years, and only 10% (27,430 values) of the database information is required for

WQIs calculation. Indices that estimate repetitiveness (constant measure of water parameters over time) and consistency (coincidence of parameters measured at the 21 sampling points) show great disparity both in time and in parameters between sampling points. These results suggest that not only is it essential to obtain information on different compounds that may alter the water quality (to fulfil basin management authority policies), but also to establish a set of mandatory physicochemical parameters based on suitable application of some indices allowing temporary monitoring and comparison between them, in an accessible and repeatable manner.

Keywords: Water quality index, landscape units, agricultural systems, Mediterranean rivers, connectivity.

1. Introduction

Water quality is an issue of pressing concern. Future perspectives for water availability on a global scale show increased water scarcity or fragility due to a combination of both global climate change and human activities (Luo et al., 2015; Vörösmarty et al., 2000).

The constant rise in water demand may be partially overcome by re-using water to supply different sectorial activities (Bdour et al., 2009). However, water flow is related to its circulation through different environmental compartments with specific connectivity processes known as landscape functional areas (LFAs) (Foltête and Vuidel, 2017). The hydrological connectivity between systems can transport contaminants that may ultimately affect water quality (Pascual Aguilar et al., 2015), as agricultural and natural ecosystems are most affected whenever water comes from urban areas.

One of the major concerns of environmental agencies worldwide is establishing procedures and criteria to evaluate the status of the water bodies under their control (e.g. ITFM, 1995; WMO, 2013). In the European Union, the Water Framework Directive (WFD) has drawn up guidelines to maintain the acceptable environmental conditions of the member states' waters (European Commission, 2000). Water quality as pursued by the WFD refers to thresholds assigned to specific physicochemical and biological indices, and to different potential pollutants.

The constant increase in demand for water to meet its multiple uses, makes it necessary to obtain optimal benefits from this resource. Water is considered an environmental service, essential to different human activities and environmental systems. This multiple use of water requires measures to prevent undesirable substances from being transmitted through multiple landscapes (Pringle, 2003), as potential pressures on environmental compartments may occur (Pascual Aguilar et al., 2015). A systematic

71 permanent evaluation of the quality and durability of the services provided by the
72 ecosystem, including the quality (Arthington et al., 2010) and quantity (Liu et al. 2018)
73 of water flows, is of utmost importance to maintain acceptable water quality (Acreman
74 and Ferguson, 2010).

75 New approaches incorporating ecosystem services in order to enhance water quality
76 and prevent its deterioration will need a precise evaluation of water quality, taking both
77 space (Sener et al., 2017) and time dimensions (Sun et al., 2016) in consideration.
78 Constant temporal analysis of contaminants related to different LFAs is a priority.

79 Evaluation methods with few parameters may be used in addition to those of the water
80 authorities. Such water quality indices (WQIs) (Tirkey et al., 2013) are among the
81 simplest and yet most useful methods, providing they can be understood by water
82 quality managers and the public.

83 Implementing this strategy will require data. Existing multiple sampling points in
84 different landscapes provide an important source of data. Historical series of data
85 collected by official agencies help evaluate the quality of the waters under their
86 management. Nonetheless, having numerous data on different water quality
87 parameters of surface water without a proper interpretation is not useful for water
88 quality management. So, exploratory data analysis is required to identify the suitability
89 of the data for the systematic application of WQIs.

90 WQIs express in a synthetic way the quality of water in a particular place (Tyagi et al.,
91 2013), proposing corrective measures in poor water quality situations, and even
92 assessing the effectiveness of such quality improvement measures (Cude, 2001). Since
93 the mid-twentieth century, indexes have been developed (Poonam et al., 2013) that
94 combine a limited number of the most well-known parameters in water quality

assessment and pollution control. Some of these indices have been widely accepted around the world, such as the Canadian Council of Ministers Environment Water Quality Index (CCMEWQI) (Feng et al., 2018), Oregon Water Quality Index (OWQI) (Darvishi et al., 2016), National Sanitation Foundation Water Quality Index (NSFWQI) (Mirzaei et al., 2016) and British Columbia Water Quality Index (BCWQI) (Perrin et al., 2018).

WQI calculations use the most common measured parameters such as dissolved oxygen, turbidity, total phosphates, nitrates and faecal coliform bacteria, etc. (Lumb, et al. 2011). However, the number of parameters, the weights assigned to sub-indices to establish the total value of the WQI applied and the final objective of quality assessment vary (Sutadian et al., 2016). Some indexes are used for the overall assessment of water quality by displaying ranges adapted to different uses (House, 1989), while others can be developed with specific targets such as establishing water quality for human consumption (Ramesh et al., 2010), or for agricultural use (Misaghi et al., 2017).

Quality analysis using WQIs has been expanded to incorporate detailed territorial and historical information through the use of multiple time series of water quality data and applying spatial analysis techniques (Nabizadeh et al., 2013; Puri et al. 2015; Yan et al., 2015).

While research on the application of WQIs has been carried out consistently and systematically for decades (Ott, 1978), very little progress has been made on the study of the characteristics of the information used and, in particular, of the applicability of the already existing data collected worldwide by the different environmental agencies in charge of water management. The large amount of information generated requires an analysis strategy to determine whether the established sampling networks can guarantee the monitoring of water quality over time (temporal definition of the

network) and of the territory (spatial dimension of the network). This evaluation makes it possible to set out criteria for the applicability of WQIs, as it determines the need for information to be measured and used.

The novelty of this work lies in being the first one that makes a detailed analysis of the data collected by a water authority as set forth in the Water Framework Directive of the European Union. Exploratory techniques of time series of multi-point water quality data are used for this purpose. The significance of this analysis refers to the need for assessments that could give more detailed knowledge on the quality status of waters within a framework of ecosystem services provided by different areas at the local level.

Therefore, all the information gathered for a Spanish Mediterranean area between 1990 and 2016 by water authorities, mainly the Júcar River Management Authority (*Confederación Hidrográfica del Júcar*, CHJ) was analysed. The significance of this analysis and its contribution to the water resource management, and to geography in general, refers to the need for assessments that could give more detailed knowledge on the quality status of waters within a context of ecosystem services provision by different areas at the local level.

The main objective of this research is to analyse the feasibility of using existing water physicochemical information as a long-term water quality predictor for different landscape areas and general quality purposes. Specifically, the study aims (i) to assess the spatial and (ii) temporal representativity of available data together with the (iii) applicability of WQIs both in time and space, in order (iv) to compare the quality of water calculated with the different WQIs at the fluvial-littoral area of Turia and Júcar Rivers in Valencia (Spain)

2. Material and methods

2.1. Study area

The study was conducted in the region between the rivers Turia (to the north) and Júcar (to the south) in Eastern Spain (Figure 1). It is an area with great water demand due to the presence of the city of Valencia and its surrounding metropolitan area (totalling more than 1.5 million inhabitants) and the necessary supply for irrigated agriculture. One of the area's main features is that the water comes from both rivers and, once it has been used, is to some extent returned to the Albufera Lake, located in the protected Natural Park of "Albufera de Valencia", through an intricate system of irrigation channels.

The area was selected because it has a large number of sampling points as well as measured parameters. The area can also be divided into LFAs due to the different characteristics of land uses and, above all, water circulation that occurs in them that may be related to the sampling points. In response to this particular feature involving water uptake and use, the study area was divided into six LFAs.

The LFA 1 is defined as the area supplied by water from the Turia River. The origin of this historic irrigation system goes back to Muslim times (Hermosilla Pla, 2007). In recent decades, the steady expansion of the city of Valencia and its metropolitan surroundings has considerably reduced the surface area dedicated to crops. Owing to the multiple demands on water, part of the water for the urban system is subsequently treated and reused for farming, and finally carried through the irrigation channel system to the LFA 3, the Albufera Lake.

The LFA 2 is characterised by a large area devoted to crops. Irrigation water is supplied by the "*Acequia Real del Júcar*", the main irrigation channel. The water of this historic

166 irrigation system comes from the upper part of the Jucar River (Hermosilla Pla, 2006).
167 Rice crops are predominant in the eastern part, with mainly citrus orchards in the west.
168 Once the surplus water has been channelled across the area, much of it is discharged
169 into the LFA 3.

170 The LFA 3, the Albufera Lake, the major natural water body of the zone, is the remains
171 of a larger coastal marshland that has been converted into rice fields through a long
172 history of human intervention (Soria et al., 2002). The hydrology of the lagoon combines
173 human management system and natural contributions, water coming from the historic
174 irrigation system being the main inflow source of water. These water contributions,
175 particularly those from rice fields, make up almost 70% of the total water draining into
176 the Albufera Lake (Soria and Vicente, 2002).

177 The LFA 4 is a small irrigated area cultivated with the water from the Magro River, a
178 tributary of the Jucar River. This area is mainly occupied by citrus orchards and, to a
179 lesser extent, other types of land cover, such as urban artificial surfaces and vegetables
180 crops. The irrigation system drains part of the water surplus into the "*Acequia Real del*
181 *Júcar*" in the LFA 2 (Hermosilla Pla, 2006).

182 The LFA 5 is located in the southeast of the study area. Water supplies are obtained from
183 the lower part of the Jucar River (Hermosilla Pla, 2006). The water is sourced for
184 irrigation of a large area devoted to rice crops, while citrus plantations are less prevalent
185 here. Most of the main channels that structure the complex irrigation systems drain
186 their remaining waters into the LFA 3.

187 The LFA 6 occupies the western lands of the study area. Until 1979, the zone was mainly
188 devoted to rainfed crops (Pascual Aguilar, 2002). In this area, the small natural *ramblas*
189 and *barrancos* (ephemeral streams) drain into the Albufera Lake and surrounding lands,

the main water course being the Rambla de Torrent. This area is crossed from south to north by the Jucar-Turia Canal, which was designed in 1964 and finally put into operation in 1979 (Marco Segura, 2012). The canal transports water from the Jucar to the Turia River. It was designed for urban water supplies of Valencia and its metropolitan area, and for farming supplies to new (and existing) irrigated fields on both sides of the canal, thus transforming old rainfed plots into irrigated ones, where citrus crops predominate (Gil Olcina and Rico Amorós, 2007).

2.2. Data characteristics

The Jucar and Turia rivers basin authority, the CHJ, takes measurements of a number of physical and chemical water parameters to monitor surface water quality within the river basins. In this study, a total of 283,023 available records provided by CHJ were analysed, containing 401 parameters corresponding to 67 sampling points or stations. These data were collected by the CHJ over 27 years, from 1990 to 2016. It is important to highlight that not all the stations measured the same parameters, and that these parameters were not gathered in all the years included in this study, as some stations have incomplete series with different start and end dates.

The database is a historical compendium of surface water parameters related to the different water quality monitoring strategies of the CHJ (CHJ, 2016). All information is distributed according to sampling point location given in Universal Transversal Mercator (UTM) coordinates. In the study area, the spatial distribution of sampling points is not only related to natural surface waters but also to the major artificial water system used both for urban-industrial supply and agricultural irrigation (Figure 1).

2.3. Methodology

2.3.1 Selection of potential WQIs

A preliminary analysis of existing physicochemical WQIs was carried out. To determine some of the more relevant indices, a literature review was conducted using the two main world databases for scientific references: Web of Science, owned by Clarivate Analytics, and Scopus, owned by Elsevier. All references identified were filtered and organised according to the type of index classified as physicochemical (Abbasi and Abbasi, 2012) and the type and the number of parameters used.

Incorporated data were also filtered to match coincidence of parameters with the information requirements of the previously selected WQIs. To determine whether it was possible to apply the indices initially selected, a confusion matrix was created which relates the total number of parameters to the variables required by each WQI. In this way, data incorporated into the database were filtered to match coincidence of parameters with the information requirements of the previously selected WQIs. In this way, from the previously established maximum number of WQIs, a feasible number of WQIs is obtained, which can be applied at the points of the study area.

A filter was applied to the database with the parameters, sampling points and years with information to determine the applicability of the indices. For this purpose, new fields were created in the database for each WQI that could also be used. Filters were then applied for each parameter identified as being part of an index, and a binary code-number was assigned to the parameter when required for the calculation of WQIs. For each new WQI field created, code 1 meaning that the parameter was necessary, and 0 that the parameter was not used in the selected WQI. A WQI was chosen for further analysis whenever its required parameters were present, and the WQI could be

calculated at least at one sampling point and for one year, regardless of the absence of data in the remaining measuring points and/or years.

2.3.2. Analysis sampling stations and LFAs

All sampling points of the study area found in the CHJ database were assigned to one of the six LFAs. To this end, a GIS database was created using the ARCGIS (10.5) software. A digital LFAs map was delimited according to surface waters distribution, combining natural and irrigation networks. Data from the original CHJ database were filtered to draw up a synthetic spreadsheet including the point ID code and the location of X/Y coordinates. Assignment of respective LFAs to sampling points was performed by applying overlay GIS procedures after converting the spreadsheet to digital vector layers. All GIS covers were integrated in an analytical structure following national (Spanish) and European criteria for spatial data infrastructures (Vandenbroucke and Biliouris, 2011) using UTM projection (Zone 30N) and the ETRS89 Datum.

2.3.3. Database applicability and LFAs representativity

The aim was to analyse spatial and temporal applicability of the information contained in the database, as well as to determine the number of WQIs that can be applied at one specific sampling point. The applicability of the information at one point is complete when all selected WQIs can be applied over the 27 years of the time series. A set of metrics was produced to measure water quality information consistency as in Rangeti et al. (2015). Other studies used similar metrics as Monteiro and Costa, (2018), based on time series analysis, and Sprague et al. (2017), on the analysis of missing data.

a) Time General Index (TI_{gen})

258 This is defined as the ratio between the number of years in which a sampling point may
259 be characterised by at least one WQI and the total number of years in the common time
260 series (for all sampling points):

$$261 \quad Tl_{gen} = N_{med}/N_y$$

262 Where:

263 Tl_{gen} : This allows comparing measurement stations within the same time interval. If for
264 a given point Tl_{gen} equals 1, the index can be applied in the 27 years of the time series
265 analysed (1990-2016). Conversely, the closer it gets to zero, the lower the applicability
266 of the index.

267 N_{med} : Number of years in which an index can be applied. All parameters required to
268 calculate a specific WQI are present.

269 N_y : Number of years common to all sampling points (shared measured time).

270 b) Time Specific Applicability (A_{sp})

271 This is defined as the relation between the time span of measurements presented at a
272 sampling point and the number of years in which an index can be applied at this point:

$$273 \quad A_{sp} = N_{med}/n_y$$

274 Where:

275 N_{med} : Number of years in which an index can be applied.

276 n_y : Number of years of the period of measurements at sampling point, which is
277 obtained as follows:

$$278 \quad n_y = Y_{end} - Y_{in} + 1$$

279

280 Y_{end} : Last year of measured time.

281 Y_{in} : Initial year of measured time.

c) Data availability for LFA analysis

An analysis of data availability for each LFA was calculated. In first instance, a general percentage of data available (including all points within a given LFA) to calculate a WQI in relation to the number of parameters measured in one year was obtained. A second value was also calculated, which can be considered as a refinement of the first general percentage. This is a weighted value that divides the first percentage by the number of stations providing data in one particular year.

2.3.4. Water quality assessment

All sampling points and years that presented sufficient data for the application of WQIs were further analysed. It is important to highlight that each WQI assigns a different weight to each parameter in the calculation, according to its importance in relation to the other parameters and to the type of water analysed. Information was organised to facilitate calculations from the database. WQIs were calculated for each target sampling point and each year of the time series to which the index can be applied. WQI values were calculated, taking into consideration annual average values of the variables. The results of the WQIs calculation were compared to a scale (from 0 to 100), which increases when the quality of water improves. However, the thresholds used to characterise the quality of the water vary from one WQIs to another, as explained later.

3. Results

3.1. Data characteristics: completeness and representativity

Out of the 67 stations studied, 21 presented sufficient data to permit WQI calculations (Table 1). There is an uneven distribution of sampling points and data representing LFAs (Table A2 and Table A3 in Supplementary Material 2). LFAs 1, 2 and 5 had 6, 7 and 4

sampling points respectively, whereas the LFA 6 had two and both LFAs 3 and 4 were represented by 1 station. Only LFAs 1, 2 and 5 had constant temporal measurements from 1990 to 2016 (Table A2 in SM2). Also, the number of stations attributed to each LFA with records to calculate WQIs may fluctuate with time, although since 1996 there has been an increasing trend towards more data availability, which facilitates calculation of the indices (Table A3 in SM2). However, from 2012 a decrease in the stations with available information has also been observed.

LFA 1 exhibits a trend to incorporate more sampling points, starting with three at the beginning of the time series and ending with six in 2016. A similar trend may be observed for LFAs 2 and 5, which started with only one station in 1990 (Table A2 in SM2). In the LFA 2, a total of six sampling points of a maximum of seven was reached between 2007 and 2011, while in the LFA 5 the maximum number of measuring points (4) was also reached during this period. The LFA 6, with a maximum of two stations located in the area, has had permanent measurements in one of them (I603) since 1994. The other station (I629) had records for the period 2009-2012 and in 2016.

The spatial representativity of LFAs 3 and 4 is very inconsistent, with only one station located in each zone. In LFA 3, only two years, 2005 and 2006, provided data that could be used for WQIs calculation, whereas LFA 4 supplied 14 year measurements, from years 2000-2001, in addition to a continuous record over 12 years of the time series (2005-2016).

Trends in the total number of measurements taken in each LFA per year also vary with time (Table A2 in SM2). Although most information is located in the LFA 1, where there is a great fluctuation of measurements over the period of time, with the minimum of 145 values recorded in 2005 and the maximum of 648 in 2010. LFAs 2 and 5 showed

similar trends with big differences between their maximum (LFA 2: 400 in 2010, LFA 5: 475 in 2011) and minimum (LFA 2: 47, LFA 5: 33, both in 2005) number of measurements.

The comparison of LFAs, using percentages rather than absolute values, shows temporal representativity with regard to the total number of parameters recorded per year in each LFA and the measurements taken at all 21 stations (Figure 2a). LFAs 1, 2, 5 and 6 had higher percentages of records with fluctuations. The LFA 1 has always been the area with the greatest number of measurements, in most years producing over 30% of the total study area measurements. LFAs 2, 5 and 6 showed percentages around 10%, with LFA 5 reaching up more than 20% at the end of the study period.

Figure 2b shows some details of the trends depicted in Figure 2a. It displays the percentages calculated in Figure 2a divided by the number of stations that had records for each year. In this case, LFAs 5 and 6 took more measurements in most years, over 10%, indicating a greater regularity in records and consistency of the temporal series. LFA 1 presented more data during the first years but this trend has changed since 2006. With regard to completeness, Table 2 presents summary values related to the possibility of applying a WQI to each sampling station, and the corresponding years that register sufficient information to apply a WQI. Summary values in Table 2 represent the number of years in which an index can be applied (N_{med}), the year in which measurements are initiated (Y_{ini}), the last year with records (Y_{end}) and the interval of time between the initial and last year with data. From these values, descriptors that analyse time series homogeneity and WQIs consistency in applicability, Time General Index (T_{Igen}) and Specific Applicability (A_{sp}) were calculated.

Only one station (H602) has a complete 27-year time series of measurements with a T_{Igen} of 1. The stations I601 and I607 had measurements with the lowest T_{Igen} 0.07 (only two consecutive years were considered, 2006 and 2007). The rest of the sampling points have incomplete records for the 27 years, with T_{Igen} trending from 0.19 to 0.85. Four stations had five years of records which did not coincide in the time interval or the continuity of measurement, as shown by the A_{sp} metric (0.63) for sampling point I629. The rest of the stations had, in general, more regular measurements with ten or more years of records, most of them ending in 2016.

3.2. Applicability of the WQIs

After a thorough analysis of the available literature, 42 WQIs were initially included in the present study (Table A1 in Supplementary Material 1, SM1). From these, only seven could be applied to evaluate the data collected by the CHJ. The other 35 WQIs were discarded because the set of parameters needed were not available in the database.

The selected WQIs are presented in Table 3 together with the water physicochemical characteristics used for their calculation (equations of the different sub-indices and of the WQI are displayed in SM1). WQIs used in this study are:

1. Oregon Water Quality Index (OWQI) (Cude, 2001): This index characterises the quality of water with no specific use. It uses eight variables to calculate different sub-indices. The scale, where 0 is the lowest quality and 100 the highest, is decreasing. The OWQI uses 8 variables to calculate different sub-indices.

2. The Ganga River WQI (Bharti and Katyal, 2011): Based on the National Sanitation Foundation's WQI (NSF-WQI) proposed by Brown et al. (1970). The four parameters used in this index were selected by Delphi method (Hsu and Sandford, 2007); the

weights are a modified version of those of the NSF-WQI, and the values of each sub-index can be obtained from the equations proposed by Abbasi and Abbasi (2012).

3. Universal Water Quality Index (UWQI) (Boyacioglu, 2007): Created using the water quality standards established by the 75/440/EEC set out by the Council of the European Communities (European Council, 1991) and the Turkish water pollution control regulation (Official Gazette, 1988). The UWQI needs 12 parameters to be calculated and its qualitative scale is also decreasing, with values from 0 to 100.

4. Dinius WQI (Dinius, 1972): Based on 11 variables chosen by the Delphi method (Hsu and Sandford, 2007) and on a qualitative decreasing scale (0 to 100). The water quality is classified according to five different uses; one of them (industrial and agricultural purposes) is shown in the SM1.

5. Dinius' second WQI (Dinius, 1987): This index includes some modifications with respect to the previous Dinius WQI: nitrate measurements are added to the 11 variables already selected for the Dinius WQI (see the SM1). Additionally, the weights assigned to the parameters to calculate sub-indices are different, and the final equation for the WQI calculation is multiplicative (compared to Dinius WQI, which is additive). The quality of the water in this index (decreasing scale, from 0 to 100) is classified according to six different uses, the agricultural one having been chosen for the present study.

6. Idaho WQI (Brandt, 2002; IWRRI, 2003): Initially designed to study the correct use of water courses for their protection. This index includes five variables and simplifies the calculations as it eliminates the sub-index equations, and the assessment is performed through a single formula (as shown in SM1).

7. Said Water Quality Index: Said et al. (2004) created an index with less parameters than the NSF-WQI (Brown et al., 1970). As in the case of the Idaho WQI, this index needs five

parameters and does not establish sub-index equations, as all the calculations are present in the final equation (see the SM1).

3.3. Water Quality evaluation and WQI performance

For each WQI used in this study, two tables summarising the main results are presented in the SM1. The first one shows the years and stations to which the index could be applied, along with their final values. The second table displays some statistical parameters calculated by zones, which include the minimum and maximum values for each index, the difference between them, the average, the standard deviation, etc. In addition, in all of these tables, the qualitative assessment of the results was illustrated by colours, according to the different scale tables shown in the SM1. The zones with no measurements are shown as ND (No Data).

The OWQI was applied at 20 stations (Table A2 in SM1) and all of them present OWQI values lower than 60. Accordingly, water quality in all zones is considered to be “very poor” (Figures 3 and 4). LFA 1 is the only one in which water quality has been analysed for 26 years out of the total of 27 and, based on these results, its water quality has not improved from 1990 to 2016 (Table A3 in SM1).

The Ganga River WQI was also applied at 20 stations (Table A4 in SM1), with a wide range of results, most of them indicating a "good to excellent" quality of water (Figures 3 and 4). In LFA 1, the initial indices correspond to the minimum values, meaning “bad to very bad” (Table A5 in SM1). However, in the last year measured (2016), this zone showed a WQI above 63, which is “good to excellent”. Accordingly, water quality of this zone has increased over the years. LFA 2 showed some variability, with an initial water

423 quality “medium to good”, which went down to “bad to very bad” and finished as "good
424 to excellent".

425 There were six stations in which it was possible to apply the UWQI (Table A6 in SM1).
426 They presented, in general, index values between 75 and 94, except the stations I602
427 and J604 in which the UWQIs were lower in most of the years. Accordingly, when
428 grouping them by zones (Table A7 in SM1), the mean water quality of LFAs 1, 4 and 6
429 was "good" (Figure 3). Only in the LFA 2 was it “fair” (this LFA showed some values within
430 the “marginal” quality range). No stations were available in LFAs 3 and 5 and the UWQI
431 was not calculated (Figure 4).

432 The results of applying the first Dinius index are shown in Table A8 in SM1, by stations
433 and years. This index could be applied at 16 sampling points, in which this WQI
434 presented values between 51 and 70 but also between 31 and 50. Consequently, water
435 quality was classified, in general, as "no treatment necessary for normal
436 industry/agriculture" (Figure 4). The LFA 2 showed the lowest index, classified as "rough
437 industry/agriculture use only", and in LFA 3 was not possible to calculate it (Table A9 in
438 SM1). Increased water quality was observed in all LFAs, but only LFA 6 finished the study
439 period with “minor purification necessary” (Figure 3).

440 Despite that the Dinius’ second WQI calculation includes one more parameter (nitrates),
441 it was also able to be applied at 16 stations (Table A10 in SM1). As in the first Dinius
442 index, most of the values ranged from 51 to 70, with some of them between 41 and 50.
443 As the quality ranges of the second Dinius WQI are more restrictive than those of the
444 first one (SM1), water quality was classified as "water treatment necessary" or "doubtful
445 consumption without purification" (Figure 3). When pooled together, all LFAs presented
446 a water quality classed as "necessary water treatment" (Figure 4 and Table A11 in SM1).

The Idaho WQI could only be applied in one station located in the LFA 5 (Tables A12 and A13 in SM1). The water quality of the first year analysed (1999) was considered “clean water”, but in the following years it was reduced to the extent that it was considered as needing “average treatment” (Figures 3 and 4). On the other hand, the WQI proposed by Said et al. (2004) applied at the same station (Table A14 in SM1), and LFA (Table A15 in SM1), showed a water quality classified as “good” from 1999 to 2016 (Figures 3 and 4), except in 2010 when it was “marginal”.

4. Discussion

Despite having a large number of stations measuring physicochemical water characteristics in the study area (67), only about the 30% (21) could be used for the calculation of the different WQIs. Even though numerous parameters were determined at the 21 stations used, the applicability of WQIs is considered to be scarce, although not insufficient, as seven of them have been determined out of a total of 42.

Bearing in mind the maximum number of variables (22) required by these seven WQIs (Table 3), related to the measurements undertaken over the 27 years of the time series (1990-2016), there is a vast number of records available (27,430). Consequently, a great applicability of the indices by stations and years should be expected. However, this was not the case. This relative contradiction arises from the fact that the measurement strategies of the river basin district authorities, under the requirements established by the basin management plans (Boeuf and Fritsch, 2016; Nixdorf et al., 2008), do not systematically and consistently measure the parameters. That is because sampling designs (Madrid and Pedrero Zayas, 2007) are oriented to the assessment of the quality of water bodies, instead of relating them with the surrounding landscapes (Xia et al., 2012). As the number of parameters needed to apply WQIs is not too demanding, it

would be worth carrying out specific data analysis and sampling designs (Ouyang, 2005) to adjust the needs of water authorities and the application of WQIs in order to conduct other types of water quality evaluations that integrate landscape and consider spatial variations influencing water flows.

While a temporal and spatial water quality characterisation could be carried out in almost all the LFAs of the study area, this would only be possible if more than one WQI were used in different years, with the added difficulty of interpreting quality categories created by each WQI. A WQI strategy should be adapted (Lumb et al., 2011; Torres et al., 2010) to present more homogeneous and comparable results between WQIs, as well as allowing the correlation of the results between the landscape zones (LFAs) and their temporal monitoring to evaluate trends and patterns of change over time (Sener et al., 2017; Sun et al., 2016).

The coherence or temporal consistency of the measurements and, consequently, of the applicability of the indices is relatively low in the first ten years of this study. This improves thereafter, although in the final period, after 2010, it tends to decline again (Figure 2). Such fluctuations can be determined by the intrinsic needs of the water management authorities to implement water management plans (Boeuf and Fritsch, 2016), for example, by taking fewer measurements when the quality of water is good enough, following their standards. However, it should also be considered that, regardless of this water quality, the decrease in measurements can be due to external factors, such as the reduction of budget allocation for measurement campaigns to monitor water quality (Boeuf et al., 2016). Nevertheless, in order to guarantee consistency of data applicability, it would be advisable to maintain the constant measurement of a minimum set of parameters.

Of the total of 21 parameters (Table 3), 13 are the most frequently used by the various WQIs analysed (alkalinity, BOD, chlorides, colour, conductivity, DOS, faecal coliforms, hardness, pH, temperature, total coliforms, total phosphorus and turbidity), which were required by four indices (Dinius, Ganga River, Idaho, and Said) or five if we include the Dinius' Second WQI. The list could be reduced to 7 when taking into consideration only the most demanded parameters: DOS, faecal coliforms, pH, BOD, conductivity and total phosphorous (used in 7, 6, 5, 5, 4, and 4 WQIs, respectively), together with turbidity (used in two indices), which are required to calculate 3 WQIs (Ganga River, Idaho and Said). Additionally, it is also important to highlight that the variables that have most weight in the calculation of the different WQIs are DOS, faecal coliforms, total coliforms, total phosphorous, hardness and colour (Supplementary Material 1).

For optimum use of the vast amount of data gathered by water authorities, the number of stations required for water quality assessment could be reduced by using a measurement strategy based on the determination of areas of potential homogeneous environmental characteristics (Foltête and Vuidel, 2017), similar to the LFAs established here.

It is considered that most of the indices are sensitive to the number of variables they use (Davies, 2006). However, some of the indices used in this work that require few parameters such as Ganga River, Idaho and Said show results to a certain extent comparable to those with a greater number of variables such as Dinius, Dinius' Second and UWQI. Therefore, the differences may be found in the way of calculating the sub-indices that each WQI use and in the criteria established in the determination of quality ranges.

Therefore, water quality assessment may be dependent on the WQI selected. It can be stated that the quality of the water in the different LFAs defined in the fluvial-littoral area of the Jucar and Turia rivers can be classified as “very poor” or “necessary water treatment” even “medium to good”; although “no treatment necessary for normal industry/agriculture” or “good to excellent” classes were also determined in some LFAs (Figure 3). Although there may be a good characterisation for all LFAs with indices such as OWQI and Ganga WQI (Figure 4), using average values of the whole time series, it is important to bear in mind that these indices were rarely calculated in some LFAs, as in LFA 3, in which they were obtained only for the years 2005 and 2006. Consequently, the number of samples would also be reduced. For this purpose, an optimised sampling design with a minimum but sufficient number of sampling points should be drawn up (Asadollahfardi, 2015). Likewise, the determination of a minimum set of parameters ensuring the calculation of some WQIs would help to optimise the permanent assessment of water quality for different uses. Summarising, the study area sub-division into LFAs has been made considering aspects of water circulation and functional structures of irrigated areas, in addition to the land covers found in them. Although they have served to perform the spatial analysis of the existing sampling stations representativeness, other criteria may be established to define LFAs (Foltête and Vuidel, 2017) since the concept of landscape multifunctionality is present in the landscape areas (Bolliger et al., 2011). When comparing the quality values obtained with the seven WQIs studied, it is observed a certain disparity in the ranges obtained. This is because not all the indices weight and classify in the same way (Hamlat et al., 2017). Therefore, the search for a general

application should be an objective, since the rating system of any WQI facilitates the understanding by a large number of users.

The scope of this work is limited to WQIs applicability using existing water quality information. Further work should be done to search for an optimal WQI that can be applied in a generalized way in other places. However, the results obtained suggest the use of a limited number of parameters that can be used for the continuous evaluation of the water quality of the landscape areas.

Towards this aim, it should be advisable that water agencies establish a set of common pollutants related to different water uses (USEPA, 2008) that were measured consistently in time and space. These parameters are often measured by the different European environmental agencies, which could facilitate the development of some type of WQI for the entire European Union, or even participate in a greater effort to establish WQIs of general applicability in the rest of the countries of the world.

The benefits would be the simplification of an index that would be understood by a broad sector of the population, the simplification in the measurement of some parameters and the robustness of water governance (Akhmouch and Correia, 2016) by being able to simplify and contribute to participatory processes.

5. Conclusions

Out of the 42 WQIs selected, seven could be used in the fluvial-littoral area of the Júcar and Turia rivers whenever all variables required are present. None of the WQIs can be calculated simultaneously at all stations and for all the years. Only 31% (21 out of 67) of the stations provided data that could be used in some years, and almost 10% (27,430 values) of the database information was required for the WQIs calculation. Indicators that estimate repetitiveness (constant measure of water parameters over time) and

consistency (coincidence of parameters measured in the sampling points) are quite weak, with a great disparity both in time and in parameters between sampling points. WQIs could be applied to represent the water quality of stations and most of the proposed LFAs. Nevertheless, due to the different calculations and, in particular, the classification rankings of water quality proposed by each index, there are different results at any one sampling point and for any single year. For this reason, harmonisation criteria should be pursued to further integrate results of various indices in an understandable way.

The results of the study suggest that not only it is essential to obtain information on different compounds that may alter the water quality (to fulfil basin management authority policies), but also to establish a set of mandatory physicochemical parameters to be measured, which should be based on suitable application of some water quality indices allowing temporary monitoring and comparison between them, in an accessible and repeatable manner.

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References

Abbasi, T., Abbasi, S.A. 2012. Water Quality Indices. Elsevier. Amsterdam.

588 Acreman, M.C., Ferguson, A.J.D. 2010. Environmental flows and the European Water
589 Framework Directive. *Freshwater Biol* 55, 32-48.

590 Akhmouch, A., Correia, F.N. 2016. The 12 OECD principles on water governance – when
591 science meets policy. *Util. Policy*, 43, 14-20.

592 Arthington, A.H., Naiman, R.J., McClain, M.E., Nilsson, C. 2010. Preserving the
593 biodiversity and ecological services of rivers: new challenges and research
594 opportunities. *Freshwater Biol* 55, 1-16.

595 Asadollahfardi, G. 2015. *Water Quality Management, Assessment and Interpretation*.
596 Springer, London.

597 Bdour, A., Hamdi, M., Tarawneh, Z. 2009. Perspectives on sustainable wastewater
598 treatment technologies and reuse options in the urban areas of the Mediterranean
599 region. *Desalination* 237, 1621-1674.

600 Bharti N., Katyal, D. 2011. Water quality indices used for surface water vulnerability
601 assessment. *International Journal of Environmental Sciences* 2, 154-173.

602 Boeuf, B., Fritsch, O. 2016. Studying the implementation of the Water Framework
603 Directive in Europe: a meta-analysis of 89 journal articles. *Ecology and Society* 21(2):
604 19.

605 Boeuf, B., Fritsch, O., Martin-Ortega, J. 2016. Undermining European Environmental
606 Policy Goals? The EU Water Framework Directive and the Politics of Exemptions.
607 *Water* 8(9), 388.

608 Bolliger, J., Bättig M., Gallati, J., Kläy, A., Stauffacher, M., Kienast, F. 2011. Landscape
609 multifunctionality: a powerful concept to identify effects of environmental change.
610 *Reg. Environ. Change*. 11, 203-206.

611 Boyacioglu, H. 2007. Development of a water quality index based on a European
612 classification scheme. *Water SA* 33 (1), 101-106.

613 Brandt, D. 2002. River Physiochemical Index. Idaho Department of Environmental
614 Quality, Idaho.

615 Brown, R.M., McClelland, N.I., Deininger, R.A., Tozer, R.G. 1970. Water quality index-do
616 we dare? *Water Sewage Works* 117(10), 339-343.

617 Büttner, G. Kosztra, B. 2011. CLC2012 Addendum to CLC2006 Technical Guidelines.
618 European Environment Agency/European Topic Centre for Spatial Information and
619 Analysis, working document.

620 CHJ. 2016. Memoria 2016. Confederación Hidrográfica del Júcar. Valencia.

621 Cude, C.G. 2001. Oregon water quality index: A tool for evaluating water quality
622 management effectiveness. *J Am Water Resour As* 37 (1), 125–137.

623 Darvishi, G., Kootenaei, F.g., Ramezani, M., Lotfi, E., Asgharnia, H. 2016. Comparative
624 Investigation of River Water Quality by OWQI, NSFQI and Wilcox Indexes (Case
625 study: The Talar River–IRAN). *Arch. Environ. Prot.* 42 (1), 41-48.

626 Davies, J.M. 2006. Application and Tests of the Canadian Water Quality Index for
627 Assessing Changes in Water Quality in Lakes and Rivers of Central North America. *Lake*
628 *Reserv Manage* 22, 308-320.

629 Dinius, S.H. 1972. Social accounting system for evaluating water. *Water Resour Res* 8 (5),
630 1159-1177.

631 Dinius, S.H. 1987. Design of an index of water quality. *Water Resour Bull* 23 (5), 833-843.

632 European Commission. 2000. Directive 2000/60/EC of the European Parliament and of
633 the Council Establishing a Framework for Community Action in the Field of Water
634 Policy. Official Journal (L327/1) of 23 October 2000.-

635 European Council. 1991. Consolidated Text Produced by the CONSLEG System of the
 636 Office for Official Publications of the European Communities. Council Directive of 16
 637 June 1975 Concerning the Quality Required of Surface Water Intended for the
 638 Abstraction of Drinking Water in the Member States (75/440/EEC). Office for Official
 639 Publications of the European Communities. CONSLEG: 1975L0440 31/12/1991.

640 Feng, Y., Bao, Q., Chenglin, L., Bowen, W., Zhang, Y. 2018. Introducing Biological
 641 Indicators into CCME WQI Using Variable Fuzzy Set Method. Water. Resour. Manage.
 642 32, 2901-2915.

643 Foltête, J. C., Vuidel, G. 2017. Using landscape graphs to delineate ecologically functional
 644 areas. Landscape Ecol 32, 249-263.

645 Gil Olcina, A., Rico Amorós, A.M. 2007. El problema del agua en la Comunidad
 646 Valenciana. Fundación de la Comunidad Valenciana Agua y Progreso. Valencia.

647 Hamlat, A., Guidoum, A., Koulala, I. 2017. Status and trends of water quality in the Tafna
 648 catchment: a comparative study using water quality indices. Journal of Water Reuse
 649 and Desalination. 7 (2), 228-245.

650 Hermosilla Pla, J. 2006. Las Riberas del Xúquer: Paisaje y Patrimonio Valencianos.
 651 Generalitat Valenciana. Valencia.

652 Hermosilla Pla, J. 2007. El patrimonio hidráulico del Bajo Turia: L'Horta de València.
 653 Generalitat Valenciana. Valencia.

654 House, M.A. 1989. A water quality index for river management. Journal of the Institution
 655 of Water and Environmental Management. 3, 336-344.

656 Hsu, C. C., Sandford, B. A. 2007. The Delphi Technique: Making Sense of Consensus.
 657 Pract. assess., res. eval. 12, 1-8.

658 ITFM. 1995. The strategy for improving water-quality monitoring in the United States.
 659 Final report of the intergovernmental task force on monitoring water quality.
 660 USEPA/USGS. United States.

661 IWRRI. 2003. Idaho Stream walk: Learning how to monitor our streams. Idaho Water
 662 Resources Research Institute. Idaho.

663 Liu, L., Parkinson, S., Gidden, M., Byers, E., Satoh, Y., Riahi, K., Forman, B. 2018.
 664 Quantifying the potential for reservoirs to secure future surface water yields in the
 665 world's largest river basins. *Environmental Research Letters* 13 (4): e044026.

666 Lumb A., Sharma T.C., Bibeault, J.F. 2011. A Review of Genesis and Evolution of Water
 667 Quality Index (WQI) and Some Future Directions. *Water Qual Expo Health* 3, 11–24.

668 Luo, T., Young, R., Reig, P. 2015. Aqueduct Projected Water Stress Country Rankings.
 669 Technical Note. World Resources Institute. Washington, D.C.

670 Madrid, Y. Pedrero Zayas, Z. 2007. Water sampling: Traditional methods and new
 671 approaches in water sampling strategy. *Trac-Trends Anal. Chem.* 26 (4), 293-299.

672 Marco Segura, J.B. 2012. Los proyectos de regulación de los ríos Júcar y Turia (1928-
 673 1964). *Una nueva lectura. Cuad. De Geogr.* 91-92, 73-94.

674 Mirzaei, M., Solgi, E., Salman-Mahiny, A. 2016. Evaluation of Surface Water Quality by
 675 NSFQI Index and Pollution Risk Assessment, Using WRASTIC Index in 2015. *Arch.*
 676 *Hyg. Sci.* 5(4), 264-277.

677 Misaghi, F., Delgosha, F., Razzaghmanesh, M., Myers, B. 2017. Introducing a water
 678 quality index for assessing water for irrigation purposes: A case study of the Ghezel
 679 Ozan River. *Sci. Total Environ.* 589, 107-116.

680 Monteiro, M., Costa, M. 2018. A Time Series Model Comparison for Monitoring and
 681 Forecasting Water Quality Variables. *Hydrology*, 5, 37.

682 Nabizadeh, R., Amin, M.V., Alimohammadi, M., Naddafi, K., Mahvi, A.H., Yousefzadeh,
683 S. 2013. Development of innovative computer software to facilitate the setup and
684 computation of water quality index. *J. Environ. Health Sci. Eng.* 11, 1.

685 Nixdorf, B., Rektins, A., Mischke, U. 2008. Standards and Thresholds of the EU Water
686 Framework Directive (WFD) – Phytoplankton and Lakes. Chapter 26, p. 301-314, In:
687 Schmidt, M., Glasson, J., Emmelin, L., Helbron, H. (Eds.) Standards and Thresholds for
688 Impact Assessment Series: Environmental Protection in the European Union, Vol. 3.
689 Springer, Berlin.

690 Official Gazette. 1988. Turkish Water Pollution Control Regulation, No. 19919. 4
691 September 1988, Ankara.

692 Ott, W.R. 1978. Water Quality Index, A Survey of Indices used in the United States,
693 Environmental Protection Agency, Washington D.C, EPA-600/478-005.

694 Ouyang, Y. 2005. Evaluation of river water quality monitoring stations by principal
695 component analysis. *Water Res* 39, 2621–2635.

696 Pascual Aguilar, J.A. 2002. Cambios de usos del suelo y régimen hídrico en la rambla de
697 Poyo y el barranc de Carraixet. Universitat de València. Valencia.

698 Pascual Aguilar, J., Andreu, V., Gimeno-García, E., Picó, Y. 2015. Current anthropogenic
699 pressures on agro-ecological protected coastal wetlands. *Sci. Total Environ.* 503-504,
700 190-199.

701 Perrin, J.L., Salles, C., Bancon-Montigny, C., Raïs, N., Chahinian, N., Dowse, L., Rodier, C.,
702 Tournoud, M.G. 2018. Comparison of index systems for rating water quality in
703 intermittent rivers. *Environ. Monit. Assess.* 190, 70.

704 Poonam, T., Tanushree, B., Sukalyan, C. 2013. Water quality indices-important tools for
705 water quality assessment: a review. *Int. J. Adv. Chem.* 1 (1), 15-28.

706 Puri, P.J., Yenkie, M.K.N., Rana, D.B., Meshram, S.U., Awale, L S. 2015. Surface water
 707 (Futala Lake) quality and its pollution load in terms of water quality index (WQI). Adv.
 708 Appl. Sci. Res. 6(1), 15-26.

709 Pringle, C. 2003. What is hydrologic connectivity and why is it ecologically important?
 710 Hydrol. Process. 17, 2685-2689.

711 Ramesh, S., Sukumaran, N. Murugesan, A.G., Rajan, M.P. 2010. An innovative approach
 712 of Drinking Water Quality Index-A case study from Southern Tamil Nadu, India. Ecol.
 713 Indic. 10, 857-868.

714 Rangeti, I., Dzwauro, B., Barratt G.J., Otieno, F.A. 2015. Validity and Errors in Water
 715 Quality Data-A Review. Chapter 6p. 95-112, In Lee, T.S. (Ed.) Research and Practices
 716 in Water Quality, INTECH Europe, Rijeka, Croatia.

717 Said, A., Stevens, D.K., Sehlke, G. 2004. An innovative index for evaluating water quality
 718 in streams. Environ Manage 34 (3), 406–414.

719 Şener, Ş., Şener, E., Davraz, A. 2017. Evaluation of water quality using water quality index
 720 (WQI) method and GIS in Aksu River (SW-Turkey). Sci. Total Environ. 131-144, 584–
 721 585.

722 Soria, J.M., Miracle, M.R., Vicente, E. 2002.Relations between physic-chemical and
 723 biological variables in aquatic ecosystems of the Albufera Natural Park (Valencia,
 724 Spain). Verh. Internat. Verein. Limnol. 28, 564-568.

725 Soria, J.M., Vicente, E. 2002. Estudio de los aportes hídricos al parque natural de la
 726 Albufera de Valencia. Limnetica 21, 105-115.

727 Sprague, L. A., Oelsner, G. P., Argue, D. M. 2017. Challenges with secondary use of multi-
 728 source water-quality data in the United States, Water Res., 110, 252-261,
 729 doi:10.1016/j.watres.2016.12.024.

730 Sun, W., Xia, C., Xu, M., Guo, J., Sun, G. 2016. Application of modified water quality
731 indices as indicators to assess the spatial and temporal trends of water quality in the
732 Dongjiang River. *Ecol. Indic.* 66, 306-312.

733 Sutadian, A.D., Muttill, N., Yilmaz, A. G., Perera, B. J. C. 2016. Development of river water
734 quality indices-a review. *Environ. Monit. Assess.* 188, 58.

735 Tirkey, P., Bhattacharya, T., Chakraborty, S. 2013. Water quality indices- important tools
736 for water quality assessment: a review. *Int J AdvChem* 1(1): 15-28.

737 Torres, P., Cruz, C.H., Patiño, P., Escobar, J.C. Pérez, A. 2010. Applying water quality
738 indexes (WQI) to the use of water sources for human consumption. *Ing. Inv.* 30 (3),
739 86-95.

740 Tyagi, S., Sharma, B., Singh, P., Dobhal, R. 2013. Water Quality Assessment in Terms of
741 water quality. *Am. J. Water Res.* 1 (3), 34-38.

742 USEPA. 2008. Handbook for Developing Watershed Plans to Restore and Protect Our
743 Waters. United States Environmental Protection Agency, Washington, D.C.

744 Vandenbroucke, D., Biliouris, D. 2011. Spatial Data Infrastructures in Spain: State of
745 Spain: State of play 2011. Leuven, Belgium, K.U. Leuven (SADL + ICRI).

746 Vörösmarty, C.J., Green, P., Salisbury, J., Lammers, R.B. 2000. Global water resources:
747 vulnerability from climate change and population growth. *Science* 289, 284-288.

748 WMO. 2013. Planning of water-quality monitoring systems. Technical Report Series No.
749 3. World Meteorological Organization. Geneva.

750 Xia, L.L., Liu, R.Z., Zao, Y.W. 2012. Correlation Analysis of Landscape Pattern and Water
751 Quality in Baiyangdian Watershed. *Procedia Environ. Sci.* 13, 2188-2196.

752 Yan, C.A., Zhang, W, Zhang, Z., Liu, Y., Deng, C., Nie, N. 2015. Assessment of Water
753 Quality and Identification of Polluted Risky Regions Based on Field Observations &
754 GIS in the Honghe River Watershed, China. PLoS ONE 10 (3): e0119130.