water

MDPI

Article

Development of a Universal Water Quality Index (UWQI) for South African River Catchments

Talent Diotrefe Banda * and **Muthukrishnavellaisamy Kumarasamy**

Department of Civil Engineering, School of Engineering, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Howard College, Durban 4041, South Africa; kumarasamy@ukzn.ac.za
* Correspondence: diotrefetb@yahoo.co.uk; Tel.: +27-15-291-1176

Received: 30 April 2020; Accepted: 26 May 2020; Published: 28 May 2020

Abstract: The assessment of water quality has turned to be an ultimate goal for most water resource and environmental stakeholders, with ever-increasing global consideration. Against this backdrop, various tools and water quality guidelines have been adopted worldwide to govern water quality deterioration and institute the sustainable use of water resources. Water quality impairment is mainly associated with a sudden increase in population and related proceedings, which include urbanization, industrialization and agricultural production, among others. Such socio-economic activities accelerate water contamination and cause pollution stress to the aquatic environment. Scientifically based water quality index (WQI) models are then essentially important to measure the degree of contamination and advise whether specific water resources require restoration and to what extent. Such comprehensive evaluations reflect the integrated impact of adverse parameter concentrations and assist in the prioritization of remedial actions. WQI is a simple, yet intelligible and systematically structured, indexing scale beneficial for communicating water quality data to non-technical individuals, policymakers and, more importantly, water scientists. The index number is normally presented as a relative scale ranging from zero (worst quality) to one hundred (best quality). WQIs simplify and streamline what would otherwise be impractical assignments, thus justifying the efforts of developing water quality indices (WQIs). Generally, WQIs are not designed for broad applications; they are customarily developed for specific watersheds and/or regions, unless different basins share similar attributes and test a comparable range of water quality parameters. Their design and formation are governed by their intended use together with the degree of accuracy required, and such technicalities ultimately define the application boundaries of WQIs. This is perhaps the most demanding scientific need—that is, to establish a universal water quality index (UWQI) that can function in most, if not all, the catchments in South Africa. In cognizance of such a need, this study attempts to provide an index that is not limited to certain application boundaries, with a contribution that is significant not only to the authors, but also to the nation at large. The proposed WQI is based on the weighted arithmetic sum method, with parameters, weight coefficients and sub-index rating curves established through expert opinion in the form of the participation-based Rand Corporation's Delphi Technique and extracts from the literature. UWQI functions with thirteen explanatory variables, which are NH_3, Ca, Cl, Chl-a, EC, F, $CaCO_3$, Mg, Mn, NO_3, pH, SO_4 and turbidity (NTU). Based on the model validation analysis, UWQI is considered robust and technically stable, with negligible variation from the ideal values. Moreover, the prediction pattern corresponds to the ideal graph with comparable index scores and identical classification grades, which signifies the readiness of the model to appraise water quality status across South African watersheds. The research article intends to substantiate the methods used and document the results achieved.

Keywords: universal water quality index (UWQI); water quality index (WQI); water quality indices (WQIs); weight coefficients; sub-index rating curves; sub-index functions; Delphi method

1. Introduction

The water quality index (WQI) is the most popular method of exhibiting the water quality of surface water bodies. WQI models are better known for delivering a comprehensive and explicit representation of water contamination for both surface water basins and groundwater reservoirs. The appraisal concept is concise and more straightforward, leading to wide acceptance across the water science community [1]. WQI provides a single numeric value that expresses the status of water quality through the integration of multiple microbiological and physico-chemical parameters [1,2]. Water quality index scores are classified using a diverse array of rating scales, but the frequently used grading system ranges from zero (bad quality) to one hundred (excellent quality) [2–5]. WQI scores are dimensionless [6], and can be further categorized using descriptive ranks associated with terms like "poor", "marginal", "fair", "good" and "excellent" [3–5,7]. Water quality indices (WQIs) are typically used by water authorities, water scientists, policymakers and the general public for decision-making, delineating spatial and temporal trends, tracing contamination sources, appraising regulatory guidelines and environmental policies and, most importantly, for suggesting future recommendations [6,8].

The main objective of WQIs is to convert multiple parameter data into information that is understandable by both technical and non-technical personnel. The ability of WQIs to synthesize complex scientific data into simple and easily understood formats makes them the most fundamental and indispensable elements of water quality monitoring agenda. Therefore, they are universally acknowledged as a "lifeline" for water quality studies, and their development continues as an ongoing affair [7]. Despite their range of applications and the variety of WQIs developed this far, there is still no definite and commonly acceptable methodology for developing water quality indices [6,9]. Instead, numerous techniques and approaches exist in WQI formation, but the conventionally employed method involves (a) the determination of relevant water quality variables, (b) the establishment of sub-indices, (c) the generation of significant weightage coefficients, (d) the aggregation of sub-indices and, lastly, (e) the attribution of a water classification schema [7,8,10–12]. Each step has alternative methods to consider, which mean that it is extremely important to decide the most suitable method for each scenario. Notwithstanding technical knowledge of WQIs, the developer should apply due diligence and avoid subjective judgements and bias in the process of establishing WQIs, otherwise the WQI will inherit abnormalities and be considered dysfunctional [7]. For the current study, an index model for water pollution control and river basin planning functions has been established using expert opinion in the form of the participation-based Rand Corporation's Delphi Technique and extracts from the existing literature. The process yielded thirteen input variables, namely NH_3, Ca, Cl, Chl-a, EC, F, $CaCO_3$, Mg, Mn, NO_3, pH, SO_4 and turbidity (NTU). In addition to the parameter selection, expert opinion was also applied to develop significant ratings and parameter weightage coefficients. The universal water quality index (UWQI) model is an increasing scale index founded on the weighted arithmetic sum method with resultant values ranging from zero (very bad quality) to one hundred (good quality). The overall classification is centered on five categories, with the Class 1 rank denoting "good water quality" and Class 5 rank representing very bad water quality. Following the review by Banda and Kumarasamy [7], it has been noted that most WQIs are designed for particular region and are source specific, thus creating a gap and ample scope to develop a universally acceptable WQI. However, it is a demanding task and is extremely difficult to develop a water quality model that is globally acceptable, and hence the current studies only focus on national boundaries—that is, they focus on a model only applicable to South African river catchments. Though this prospect is seemingly problematic to deal with, it is pertinent and recommended that water quality experts embark on developing a unified model that can be utilized across the globe. However, the immediate mission is to develop nationally acceptable water quality indices and break the barrier of region-specific models [7]. Moreover, this study attempts to break such barriers through the development of a universal index that is applicable to most river catchments in South Africa, thereby promoting a standardized way of monitoring and comparing the water quality of various watersheds at a national level, which might eventually assist in the prioritization of water resources across all nine provinces in South Africa.

Umgeni Water Board (UWB) provided the water quality dataset used to test the UWQI. The data are from six sampling stations located in four different catchments under the jurisdiction of Pongola-Mtamvuna Water Management Area (WMA) in KwaZulu-Natal Province, South Africa. The four watershed regions are Umgeni, Umdloti, Nungwane and Umzinto/uMuziwezinto River catchments. The UWQI is earmarked for national application, but it is far-reaching and beyond the scope of the study to test the model against data from all 148 catchment regions in South Africa. Nevertheless, the four catchments used are adequate to ascertain the functionality of the model and the process is a step towards the ultimate goal of testing the model against most, if not all, the catchment areas in South Africa. The model responded steadily to the variation in parameter values and managed to indicate spatial and temporal changes in water quality for the four catchment areas considered for the study. It should be noted that the UWQI is formed autonomously without being linked to a particular dataset or specific region. The methods used are exclusively independent from such associations and the UWB dataset is entirely for testing purposes, upon which tasks can be performed using any other available data.

2. Methods

2.1. Research Data

The water quality monitoring process demands substantial amount of resources; therefore, the current study could not collect samples specific to the research work. Alternatively, water quality data from Umgeni Water Board (UWB) assisted in testing the functionality of the model. The dataset was comprised of 416 samples, tested monthly for a period extending to four years. The water quality records are from six sampling stations located in four different catchment areas, namely Umgeni, Umdloti, Nungwane and Umzinto/uMuziwezinto River catchments.

The UWB data were sampled in accordance with standard methods prescribed by the Department of Water and Sanitation (DWS), and analyzed according to international standards in an ISO 9001 accredited laboratory owned and operated by UWB [13]. The research dataset from UWB satisfactorily provided all the required thirteen water quality parameters, and these are ammonia, calcium, chloride, chlorophyll-a, electrical conductivity, fluoride, hardness, magnesium, manganese, nitrate, pondus Hydrogenium, sulphate and turbidity. Testing the model with data from these four river catchments supports the objective of establishing a UWQI applicable to a greater part of the country, if not the whole of South Africa. More than the availability of data from UWB, the economic significance of KwaZulu-Natal Province [14,15], the distinctiveness of its inter-basin arrangements, the scope of the transfer schemes involved and the extensive water demand [16,17] encouraged the choice of the study area, which falls under Pongola-Mtamvuna water management area (WMA) [18,19]. The project data were adequate to examine the model and complement the objective of developing a universally acceptable water quality model.

2.2. Universal Water Quality Index (UWQI)

Various methods are documented in the literature and, among them, there is no one distinctive method regarded as the supreme and favorable method for developing water quality indices (WQIs). Each method has its own considerable problems and the universal water quality index (UWQI) was formulated using the conventional method of establishing water quality indices. Moreover, the technique involves four common steps, which are (1) selecting water quality variables, (2) establishing relative weightage coefficients (3) forming sub-index rating curves and sub-index functions and (4) deriving the appropriate aggregation or indexing model [8,10–12]. The methods employed for the development of the UWQI are selected based on a couple of reasons. Firstly, they eliminate individual bias through the incorporation of objective and subjective opinions from water quality scientists through appraisal questionnaires. Secondly, compared to other available techniques, the chosen methods are both practical, convenient and easy to implement in electing variables and generating weightage coefficients [20]. Lastly, the methods are proven and have been performed in various WQI studies [21–35].

2.2.1. Selection of Water Quality Variables

These steps and procedures were performed cautiously with cognizance of the fact that the model should widen its application boundaries and target to become a nationally accepted water quality monitoring tool. Based on this fact, a fixed set of parameters were established using expert opinions. The advantage of a fixed set of variables is that the model can be applied in various catchments without the possibility of altering the structure and functionality of the model [9], thereby permitting stakeholders to fairly compare the water quality of different sites and develop a more informed national prioritization schedule without prejudice. Further to this, expert opinion has the advantage of promoting the acceptability of the model, in the sense that most of the experts engaged are also the targeted end users of the model; therefore, the idea that they were involved in the process of developing the UWQI may eventually facilitate acceptance through a sense of ownership. Nevertheless, this alone does not warrant the usefulness of the model, the authors exercised enormous care and great attention to ensure that the most significant variables were incorporated in the UWQI. Importantly, the authors had to optimize the ideal number of parameters necessary to provide a meaningful water quality index value.

Following the Rand Corporation's Delphi Technique, a panel of thirty water specialists from government parastatals, the private sector and academia was established. Delphi Questionnaires were circulated to the participants and they were asked to consider twenty-one water quality parameters for their possible inclusion in the UWQI. The panelists were instructed to designate each variable as: "Include" and "Exclude" and further assign a relative significance rating against each variable elected as "Include." The rating scale ranged from one to five, whereby "scale 1" denoted the highest significance and "scale 5" represented a comparatively low significance. In addition to the prescribed twenty-one parameters, the experts were allowed to add, at most, five more variables if desired. A total of twenty-one questionnaires were returned out of the thirty questionnaires circulated. The Rand Corporation's Delphi Technique is described in detailed by Horton [21], Brown et al. [22] and Linstone and Turoff [36,37] and applied in several studies, which include those by Nagels et al. [33], Kumar and Alappat [34] and Almeida et al. [35].

Complementarily, the existing literature on WQIs was used to select the most significantly used water quality variables. Thirty-seven studies were considered and each variable was designated as "Include" if it corresponded to the twenty-one parameters considered for the Delphi Questionnaires; otherwise, it was designated as "Not Included." Furthermore, the formerly assigned significance rating was adopted as the relative significance rating for each parameter that was "Included" in the study in question. The rating was based on a scale ranging from one to five, with "Scale 1" representing the lowest significance and "Scale 5" for relatively high significance. If a different significance rating scale was used in the existing study, the original rating values were equivalently transformed to match the preferred rating scale using Equation (1), as follows:

$$y = \mathrm{a} + (\mathrm{b} - \mathrm{a})(x_i - x_{min})/(x_{max} - x_{min}) \quad (1)$$

where y is the new rating; a, b, are minimum and maximum values of the targeted significance scale rating; x_{min}, x_{max}, are minimum and maximum possible ratings in the specified significance scale; x_i is the ith rating value of the specified scale.

Finally, a holistic ranking order was derived from the combined effect of the two aforementioned methods, upon which a rejection rationale was employed to eliminate redundant variables that are not commonly monitored across South African river catchments [20].

2.2.2. Establishing Weight Coefficients

Each parameter has different effects on water classification; hence, weighting factors are used to reflect their influence on the index model. These mathematical tools are assigned to each water quality variable based on the level of significance of the overall index value [9,38]. Parameter significance ratings assigned on Delphi questionnaires and those extracted from the literature on WQI publications were considered as preliminary significance ratings (see Section 2.2.1). Parameter significance ratings (b_i) were then established by aggregating the preliminary ratings from the two methods. Relative weight coefficients (w_i) are directly proportional to the significance ratings and they were established from dividing the parameter significance rating value (b_i) by the sum of all ratings ($\sum b_i$) using Equation (2) [3]. The weight coefficients are presented as decimal figures with a total sum of unity, the reason being that the combined effect of the water quality parameters should not exceed one hundred percent [3]. If this does occur, the aggregation of sub-indices will be compromised, and the water quality index will be deemed dysfunctional. Expert opinion techniques were employed primarily to produce comparative weights which minimize prejudice and uphold the integrity of the index model.

$$w_i = \frac{b_i}{\sum_{i=1}^{n}(b_i)} \tag{2}$$

where b_i is the assigned significance rating of the ith water parameter (one being the lowest rating and five the highest rating); w_i is the final weight coefficient for the ith water parameter (decimal value); n is the total number of the rated water quality parameters.

2.2.3. Formation of Sub-Indices

Considering that water quality parameters are monitored in different scientific units, sub-indices are applied to convert the different units of measure into a single common non-dimensional scale [7]. This is a common practice and the conventional method involves sub-index rating curves which are later transformed into mathematical functions commonly known as sub-indices. For practical purposes, fixed key points of the rating curves were graphically established with reference to the permissible concentration limits. Straight-line graphs were used to converge the plotted points and produce a series of linear graphs, which were further converted into linear sub-index functions. Target Water Quality Ranges (TWQRs), as prescribed by DWAF [39–41], were consulted in the process.

2.2.4. Aggregation Formula

A scenario-based analysis was used to modified and align the model with local conditions to develop the final universal water quality index (UWQI), which is an improved version of the weighted sum method. The model equation integrates sub-index values of selected parameters in relation to the assigned weights and obtains the overall water quality status, which is presented as a unitless number ranging from 0 to 100. The rationale employed is based on solving multiple systems of equations [42], where key points of the rating curves were used to generate a series of m equations, with two unknown variables (x, z) and n water quality parameters in the form

$$\begin{aligned} \mathrm{WQI}_1 &= (1/x_1)(\mathrm{SI}_{11}w_1 + \mathrm{SI}_{12}w_2 + \mathrm{SI}_{13}w_3 + \ldots + \mathrm{SI}_{1n}w_n)^{z}{}_1 \\ \mathrm{WQI}_2 &= (1/x_2)(\mathrm{SI}_{21}w_1 + \mathrm{SI}_{22}w_2 + \mathrm{SI}_{23}w_3 + \ldots + \mathrm{SI}_{2n}w_n)^{z}{}_2 \\ &\ldots \\ \mathrm{WQI}_m &= (1/x_m)(\mathrm{SI}_{m1}w_1 + \mathrm{SI}_{m2}w_2 + \mathrm{SI}_{m3}w_3 + \ldots + \mathrm{SI}_{mn}w_n)^{z}{}_m \end{aligned} \tag{3}$$

where $\mathrm{WQI}_{1,\ldots,m}$ are the ideal water quality index values corresponding to the key points of the rating curves; $x_{1,\ldots,m}$ are the equation denominators (first unknown variable); $\mathrm{SI}_{m1,\ldots,mn}$ are the corresponding sub-indices; $w_{1,\ldots,n}$ are relative weight coefficients for the thirteen water quality parameters and $z_{1,\ldots,m}$ are the equation exponentials (second unknown variable).

The first step was to find the optimum values of x and z; thereafter, the closest *x-value* was rounded off and substituted into the same set of equations to find the corresponding optimum *z-value*, which becomes the final exponential factor of the UWQI.

Using the thirteen selected water quality variables, weightage coefficients and sub-indices, the improved weighted sum method proved to be the most appropriate and relevant method to develop a UWQI for assessing water quality in South African river catchments. Hypothetically, this advocates the readiness of the UWQI model and deems the study a success. Such a milestone provides a tool that can be adopted at the national level to help solve the challenges experienced by water quality professionals. The structure of the universal water quality index model is represented in Figure 1.

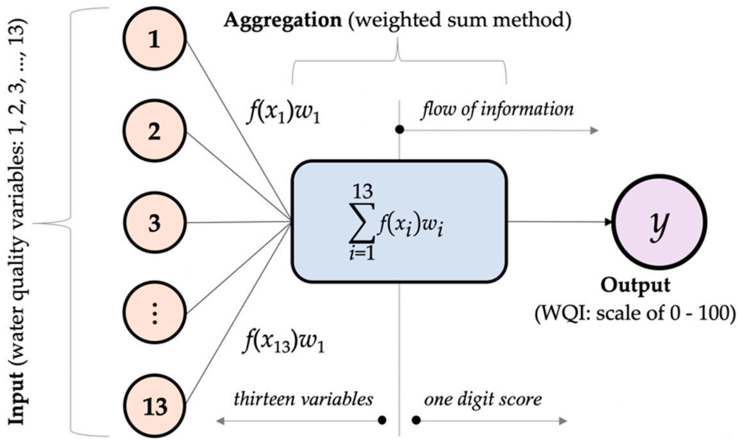

Figure 1. Design diagram indicating the framework and concept considered for the establishment of the universal water quality index (UWQI) model. A model framework showing the thirteen water quality input variables $x_1, x_2, x_3, \ldots, x_{13}$, their corresponding weights, w_1 to w_{13}, sub-index functions, $f(x_1)$ to $f(x_{13})$, and the aggregation function $\sum f(x_i)w_i$ applied to calculate the weighted influence of the input variables.

2.3. Water Classification

In the interest of simplifying the interpretation of water quality index (WQI) values, mostly to accommodate non-technical individuals, an index categorization schema was established. The classification mechanism is based on an increasing scale index and the advantage of this system is that it is identical to a normal percentage hierarchy [3]; therefore, the public can easily relate to its function and interpretation. The UWQI model yields WQI values between zero and one hundred. Accordingly, the WQI scores are categorized using classes ranging from one to five, with "Class 1" representing water of the highest degree of purity with a possible maximum score of one hundred and, vice versa, "Class 5" denotes water quality of the poorest degree with index scores nearing or equal to zero. In order to close gaps identified in some of the existing classification scales [7], appropriate mathematical functions with logical linguistic descriptors, which include, but are not limited to, "greater than", "less than", and "equal to" were used to appraise WQI scores and we respectively assigned them to the corresponding category.

3. Area of Study

3.1. Background and Specific Considerations

A substantial increase in population and improper disposal of wastewater have a significant influence on diminishing water quality in rivers and other surface water reservoirs. As a consequence, routine water quality assessment and pollution control measures are necessary to preserve and restore the healthiness of surface water bodies [43]. On the same basis, this study attempts to put forward a practical and standardized tool that can be used for monitoring surface water quality across all

South African river catchments. Despite the fact that the current study targets all South African river catchments, a specific dataset from a distinct Water Service Authority (WSA) was considered to ascertain the appropriateness of the proposed model. It would be a far-reaching and considerable effort to test the model against water quality data from all the Water Boards (WBs) in South Africa. On these grounds, water quality data from Umgeni Water Board (UWB) was deemed appropriate to establish the effectiveness of the developed water quality model. The selection of UWB does not devalue the purpose of the study, rather it is the beginning of a long-term undertaking to demonstrate that the developed model is indeed universal and applicable to most, if not all, South African river catchments.

Umgeni Water Board is a Water Service Authority responsible for the water and sanitation affairs of KwaZulu-Natal Province in South Africa [44,45]. UWB falls under the jurisdiction of Pongola-Mtamvuna Water Management Area (WMA) which has four primary drainage regions labelled T, U, V and W. Among the four regions, primary drainage basin U was considered for the current study. Further to this, only four secondary drainage regions were selected and these are Umgeni, Umdloti, Nungwane and Minto River catchments, which are identified by the Department of Water and Sanitation (DWS) as U20, U30, U70 and U80, respectively. Umgeni River catchment is the largest of the four; consequently, it is regarded as the primary study area, and henceforth it is considered more significant than the other three catchments.

3.2. Umgeni River Catchment

Umgeni River catchment is a sub-humid drainage basin located along the Indian Ocean coastline in KwaZulu-Natal Province in the Republic of South Africa [14,46,47]. Having a diversified land usage and multiple water supply systems, Umgeni basin is regarded as one of the most complex drainage regions in the country. The basin is subdivided into twelve quaternary drainage regions, also known as quaternary catchments (QCs). Seven of the QCs are situated in the upper most part of Umgeni basin, three are in the middle and two are in the lower part of the secondary drainage region [13,46]. Umgeni River catchment plays a major role in the economic development of the country; it serves South Africa's biggest trading port and the second largest province in terms of population and economic sizes [14]. This is why Umgeni is considered one of the most significant river catchments in South Africa.

Significantly, Umgeni basin addresses the water needs of the Durban–Pietermaritzburg business corridor and act as the primary source of water supplied to the Port of Durban, which is the biggest trading port in Africa and contributes significantly to the Gross Domestic Product (GDP) of South Africa [14,15]. Considering the social and economic activities in KwaZulu-Natal, the province is regarded to be a highly ecologically disturbed region [13], and this describes the motivation for the adoption of Umgeni catchment as the main study area. The current activities and projected developments in Umgeni River catchment have extraordinary effects on the national water resources and require a comprehensive water management monitoring model that focuses on protecting the water reserves. It is therefore important to develop a water quality index model that can be adopted to better understand the dynamics of water quality changes in Umgeni River catchment and South Africa as a whole. The model will provide institutional support in delineating water quality concerns across various river catchments and provide substantial information to water technocrats and decision-makers.

Umgeni River catchment has a surface area nearly 4432 km^2, with Umgeni River being the major water channel of the drainage basin [13,15,19,48]. The 232-kilometre-long river originates from the Drakensberg mountains and flows eastwards towards the Indian Ocean, with four main cardinal tributaries, namely Lions, Karkloof, Impolweni and Umsunduzi Rivers [19,47]. Lions River is the most contributing tributary in the upstream of Midmar Dam and it serves as the transfer channel, conveying water resources from the adjacent Mooi River Catchment [13]. The basin land cover is characterized as heterogeneous, mostly consisting of urban areas, natural forest, commercial sugarcane plantations, small-scale and commercial agricultural farms and the Port City of Durban [13–15,46]. Notably, Umgeni River supports the livelihood of informal settlers residing along the river course. They rely on the river for various household activities, irrigation and livestock production [49].

The rainfall pattern of Umgeni basin is seasonal, with rains concentrated in the summer months (October to March). The amount of precipitation is highly variable, increasing from the western side to the eastern part of the river catchment. Highest rainfall occurs in coastal areas with a range of 1000 mm/y to 1500 mm/y [15,47]. The inland parts of Umgeni basin generally receive rainfall ranging from 800 mm/y to 1000 mm/y [15,46,50]. The average annual temperature ranges from 12 °C to 22 °C; leading to evaporation rates between 1567 mm/y and 1737 mm/y [13]. Four major dams are used to regulate and reserve the water resources in Umgeni drainage region, and these are Midmar, Albert Falls, Nagle and Inanda [13,16]. Midmar Dam supplies Pietermaritzburg and some portions of Durban, whereas Albert Falls, Nagle and Inanda Dams cater for the greater part of the Durban metropolitan area [19,46,47]. In addition to the four major dams, there is also Henley Dam, situated south of Midmar Dam along the Msunduzi River, a tributary of the Umgeni River. Apart from that, there are about 300 farm dams utilized for irrigating nearly 185 km^2 of commercial farms in the Umgeni catchment area [46].

3.3. Umdloti River Catchment

Umdloti catchment is situated north-east of Umgeni basin, adjacent to Nagle and Inanda Dams. The catchment has an estimated area of 597 km^2 with Umdloti River as the main watercourse of the basin [51]. The river source is found in the Noodberg area and stretches for nearly 88 km, flowing eastwards toward the Indian Ocean. The river estuary is approximately 25 km northeast of central Durban [48,52]. A considerable portion of the catchment is utilized for commercial farming, dominated by sugarcane and banana plantations with minimal vegetable and citrus farming. Apart from these, other establishments include residential areas, Verulam Town, game reserves, Hazelmere Dam and Hazelmere wastewater treatment plant [52]. In a similar manner to Umgeni basin, the catchment experiences summer rainfall, with mean annual precipitation ranging between 800 mm and 1125 mm. Temperatures vary from 9 °C in winter to 38 °C in summer [52]. Hazelmere Dam is the major water impoundment in Umdloti catchment [51]. The dam was established to service the domestic, industrial and agricultural needs of the Durban area, including the new Durban International Airport [48,52].

3.4. Nungwane River Catchment

Located southwest of Umgeni drainage region, Nungwane River catchment has mean annual precipitation of 938 mm/y and annual evaporation close to 1200 mm/y. The significant impoundment in the quaternary catchment is the Nungwane Dam, situated along the Nungwane River, which is a tributary of Lovu River [53]. The impoundment was built in 1977, with a catchment area of 58 km^2, and raw water from Nungwane Dam is treated at Amazimtoti water treatment plant and then supplies eThekwini Municipality [53].

3.5. Umzinto/uMuziwezinto River Catchment

Umzinto River catchment, also known as uMuziwezinto River catchment, lies further south of Nungwane Dam. According to Umgeni Water [53], the river basin receives rainfall averaging 985 mm/y, with an evaporation rate of 1200 mm/y. In 1983, Umzinto Dam was constructed along Umzinto/uMuziwezinto River, with a catchment area of about 52 km^2. Together with EJ Smith Dam, raw water from Umzinto Dam is treated at Umzinto water treatment plant (WTP) and distributed to Ugu District Municipality [53,54]. Both dams, EJ Smith and Umzinto, supply raw water to the operation of Umzinto WTP [53,54].

3.6. Sampling Locations

Umgeni Water Board (UWB) established water sampling stations to enhance water quality monitoring and the stations are strategically positioned to provide a holistic understanding of water affairs within the service area of KwaZulu-Natal Province. Instead of establishing new research-based sampling stations, the current studies utilized water quality data collected by UWB. At least one or more stations were considered for each of the four drainage basins discussed in the preceding sections. Further details of the selected sampling stations are included in Table 1 and Figure 2.

Table 1. Details of sampling stations relevant to the study.

Sampling Station Identity		Identity Codes		Sampling Location Coordinates (DMS)*	
		Station	Catchment	Latitude	Longitude
1	Henley Dam	DHL003	U20	S 29°37′25.734″	E 30°14′49.754″
2	Hazelmere Dam	DHM003	U30	S 29°35′53.722″	E 31°02′32.121″
3	Inanda Dam 0.3 km	DIN003	U20	S 29°42′27.403″	E 30°52′03.352″
4	Midmar Dam	DMM003	U20	S 29°29′47.332″	E 30°12′05.655″
5	Umzinto Dam	DMZ009	U80	S 30°18′40.676″	E 30°35′34.580″
6	Nungwane Dam	DNW003	U70	S 30°00′24.473″	E 30°44′36.150″

Source: Umgeni Water Board. Notes: * location coordinates are based on the World Geodetic System 84 (WGS 84); degrees, minutes and seconds (DMS). Although Umgeni Water Board has more water quality monitoring stations, Table 1 shows only the six water quality monitoring stations considered in this study.

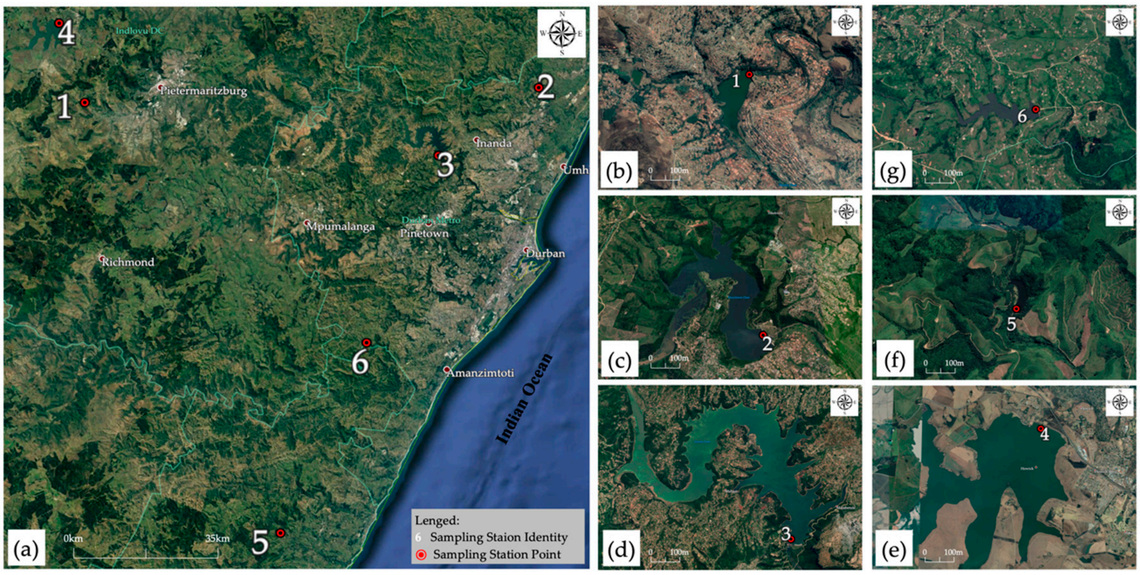

Figure 2. Locality map for sampling stations: (**a**) all six sampling stations, (**b**) Henley Dam, (**c**) Hazelmere Dam, (**d**) Inanda Dam, (**e**) Midmar Dam, (**f**) Umzinto Dam, and (**g**) Nungwane Dam.

Source: The underlying map of Figure 2 was downloaded from Google Earth and station coordinates are from Umgeni Water Board (UWB) (Table 1). Sampling station identification numbers: (1) Henley Dam DHL003, (2) Hazelmere Dam DHM003, (3) Inanda Dam DIN003, (4) Midmar Dam DMM003, (5) Umzinto Dam DMZ009, and (6) Nungwane Dam DNW003.

The economic importance of the Umgeni Basin, the uniqueness of its inter-basin arrangements, the magnitude of the transfer schemes involved and the extensive water demand require comprehensive water resource management. All of these factors distinctively motivated the identification and selection of the Umgeni River catchment as the main study area. Beyond that, three additional catchments were incorporated into the study in order to further examine the model and complement the objective of developing a universally acceptable water quality model.

4. Results and Discussion

4.1. Research Dataset

Regular water quality sampling and analysis is a costly and demanding task, hence acquiring large volumes of water quality data is often a challenge and requires significant amount of financial resources [55,56]. Given that the authors could not gather their own samples, water quality data from Umgeni Water Board (UWB) were used to attest the functionality of the model. The dataset from UWB is for six sampling stations that fall under the jurisdiction of four different catchment areas. It contains 416 monthly samples for a period of four years, ranging from June 2014 to July 2018 and the dataset statistics are presented in Table 2. Hardness ($CaCO_3$) tests were recorded on a quarterly basis and, where possible, using the measured values of calcium (Ca) and magnesium (Mg); alternatively, the estimation of missing $CaCO_3$ values was achieved through Equation (4).

$$CaCO_3 = 2.497Ca + 4.118Mg \tag{4}$$

where all parameter concentration levels are in mg/L. The method is common practice and is prescribed in the literature [3,39,40,57,58].

Table 2. Descriptive statistics for observed water quality data for UWB for a period ranging from 2014 to 2018.

S.No.[1]	Statistics	Water Quality Variables [7]												
		NH_3	Ca	Cl	Chl-a	EC	F	$CaCO^3$	Mg	Mn	NO_3	pH	SO_4	Turb
1	Min. [2]	0.04	4.32	3.16	0.14	6.84	0.10	21.29	2.55	0.01	0.41	7.20	0.16	3.90
	Mean [3]	0.12	6.90	8.67	6.33	11.13	0.11	34.59	4.21	0.07	1.27	7.78	2.13	36.64
	Max. [4]	0.56	14.20	21.40	68.31	21.80	0.54	69.55	8.28	0.59	2.27	8.60	3.46	367.00
	Std. Dev.[5]	0.09	1.61	2.30	11.67	2.17	0.06	7.55	0.91	0.12	0.50	0.28	0.71	61.57
	CoV [6] (%)	72.68	23.37	26.56	184.30	19.47	56.76	21.83	21.59	166.03	39.19	3.55	33.45	168.05
2	Min.	0.04	3.80	19.40	0.14	15.80	0.10	27.69	3.27	0.01	0.10	6.80	1.56	1.20
	Mean	0.09	5.45	28.87	6.23	18.18	0.12	34.15	4.99	0.03	0.37	7.90	6.38	31.62
	Max.	0.16	18.80	40.50	92.22	22.30	0.20	81.45	8.38	0.14	3.54	9.10	13.40	293.00
	Std. Dev.	0.02	1.67	3.82	13.62	1.23	0.02	6.41	0.61	0.03	0.41	0.47	2.13	38.95
	CoV (%)	24.83	30.58	13.25	218.73	6.78	19.01	18.77	12.26	90.51	111.39	5.89	33.35	123.20
3	Min.	0.04	7.35	18.70	0.14	7.85	0.13	31.16	3.11	0.01	0.05	0.00	11.50	0.60
	Mean	0.10	15.87	32.80	4.66	28.64	0.16	71.20	7.67	0.03	0.71	7.59	16.51	2.25
	Max.	0.27	30.50	43.90	19.50	33.60	0.22	128.46	12.70	0.29	9.58	8.80	24.20	19.30
	Std. Dev.	0.03	4.70	4.36	3.70	2.53	0.02	18.32	1.78	0.05	0.90	0.76	2.27	2.00
	CoV (%)	30.18	29.64	13.30	79.33	8.84	12.11	25.74	23.17	157.57	125.59	10.02	13.75	88.90
4	Min.	0.04	1.00	1.82	0.18	6.99	0.10	6.67	1.00	0.01	0.10	6.00	0.95	1.10
	Mean	0.11	5.93	4.35	4.70	7.67	0.10	27.91	3.14	0.01	0.32	7.87	1.86	5.23
	Max.	0.61	18.50	7.88	25.62	8.93	0.21	79.00	8.08	0.08	4.50	8.50	2.64	19.10
	Std. Dev.	0.08	2.58	0.92	4.84	0.38	0.02	10.90	1.07	0.01	0.61	0.39	0.35	3.78
	CoV (%)	75.45	43.57	21.08	103.00	4.89	17.35	39.06	34.08	86.38	189.44	4.91	18.99	72.24
5	Min.	0.04	1.91	31.90	0.14	18.80	0.11	11.07	1.53	0.01	0.05	6.80	1.72	1.24
	Mean	0.12	10.34	50.83	3.72	31.95	0.22	61.44	8.65	0.18	0.32	7.81	10.33	9.43
	Max.	0.99	17.00	79.00	30.39	48.00	0.39	102.57	14.60	1.21	2.18	8.40	23.10	75.40
	Std. Dev.	0.13	2.98	12.00	4.95	6.53	0.07	17.09	2.53	0.22	0.39	0.35	4.70	12.61
	CoV (%)	110.62	28.79	23.60	133.02	20.43	30.67	27.82	29.30	126.21	120.10	4.45	45.52	133.83
6	Min.	0.04	1.00	12.00	0.14	13.20	0.10	6.62	1.00	0.01	0.10	7.30	0.16	2.00
	Mean	0.12	3.76	24.49	4.13	14.84	0.10	25.62	3.94	0.02	0.45	7.87	3.14	8.63
	Max.	0.68	7.91	37.10	11.92	16.60	0.10	36.39	5.02	0.15	1.77	8.70	7.16	29.20
	Std. Dev.	0.09	1.12	3.55	2.45	0.99	0.00	6.40	0.96	0.03	0.36	0.31	1.30	5.69
	CoV (%)	71.12	29.83	14.51	59.51	6.66	0.00	24.98	24.31	120.12	78.90	3.99	41.52	65.87

Source: Umgeni Water Board. Notes: [1] sampling station identification number, [2] minimum measured water quality values, [3] mean/average of measured water quality values, [4] maximum measured water quality values, [5] standard deviation, [6] coefficient of variation as a percentage, and [7] water quality variables measured in mg/L, except for chlorophyll-a (µg/L), electrical conductivity (µS/m), pondus Hydrogenium (unitless), and turbidity (NTU).

The samples obtained from UWB were adequate and contributed significantly towards the success of the current study. Umgeni water quality data were considered based on availability; other than being a priority and limiting the number of WBs used for testing, the models do not devalue the significance of the study. The rationale used in developing the universal water quality index is completely independent of the dataset used for testing the functionality of the model; nevertheless, as an ongoing project and in support of the current studies, it is recommended that additional data from other WBs, if not all, be considered and documented separately.

4.2. Water Quality Variables and their Relative Weightage Coefficients

With the aid of the Delphi method and the existing literature, a fixed set of thirteen physico-chemical parameters were found to be adequate and appropriate to analyze and compare water quality status among different sites. A fixed system requires enormous care, attention, experience and proficiency to ensure that the most significant variables are incorporated in the WQI. Expertise is required to delineate what might be regarded as too few or too many variables, the ability to optimize the ideal number of parameters necessary or just enough to calculate a meaningful water quality index value [7]. Therefore, the study involved expert opinions through a group of selected professionals and extracts from similar studies. Accordingly, the most appropriate variables considered for inclusion in the UWQI are ammonia (NH_3), calcium (Ca), chloride (Cl), chlorophyll-a (Chl-a), electrical conductivity (EC), fluoride (F), hardness ($CaCO_3$), magnesium (Mg), manganese (Mn), nitrate (NO_3), pondus Hydrogenium (pH), sulphate (SO_4) and turbidity (Turb).

Considering that, in the current study, water quality parameters are viewed to have different influences on the overall classification of water, some variables are considered greater than others; therefore, weights were established to appropriately reflect the diversity of each parameter. The comparative scale used is biased towards the level of influence and significance towards the overall index value [9,38]. As represented in Table 3, two sets of parameter significance ratings obtained from the participation-based Delphi method and extraction from the existing literature are used to derive the weight ratings based on a common scale of influence, ranging from one (lowly rated) to five (highly rated). Given the Delphi significance rating (c_i) and the literature significance rating (d_i), the parameter weight rating (b_i) is given by $(c_i + d_i)/2$, whereas the final weight coefficient (w_i) is transformed by dividing the relevant parameter weight rating (b_i) by the sum of all weight ratings ($w_i = b_i / \sum b_i$) and the index weight coefficients are represented as a decimal number with a sum equal to one ($w_1 + w_2 + w_3 + \ldots + w_n = 1$). In principle, this theory governs the model from computing index values in excess of one hundred percent, otherwise the aggregation process will be compromised and will jeopardize the scientific steadiness of the model [3].

Table 3. Parameters of consideration and their weight coefficients.

Variable Identity and Name		Impact Weight Ratings and Weightage Coefficients			
		Delphi Rating (c_i)	**Literature Rating (d_i)**	**Weight Rating (b_i)**	**Weight Coefficient (w_i)**
1	Ammonia	4.3684	3.5033	3.9358	0.1035
2	Calcium	3.5263	1.9961	2.7612	0.0726
3	Chloride	3.7143	1.9249	2.8196	0.0742
4	Chlorophyll a	1.7222	1.0000	1.3611	0.0358
5	Electrical Conductivity	2.9474	2.3136	2.6305	0.0692
6	Fluoride	3.7500	3.4619	3.6059	0.0949
7	Hardness	2.5714	1.8943	2.2329	0.0587
8	Magnesium	3.4667	1.9334	2.7000	0.0710
9	Manganese	3.8125	3.1093	3.4609	0.0910
10	Nitrate	3.9048	3.0072	3.4560	0.0909
11	pondus Hydrogenium	4.3333	2.5949	3.4641	0.0911
12	Sulphate	2.9167	2.9712	2.9439	0.0774
13	Turbidity	2.6667	2.6226	2.6446	0.0696
			Totals	**38.0167**	**1.0000**

Notes: parameters are listed alphabetically. Using final weight coefficients in Table 3, the following order of importance is achieved: NH_3 > F > pH > Mn > NO_3 > SO_4> Cl > Ca> Mg > Turb > EC > $CaCO_3$ > Chl-a.

4.3. Formation of Parameter Sub-Index Rating Curves and Sub-Index Functions

Given the fact that the identified model input variables are assessed using different units of measurement, sub-indices were then developed to transform the measurement units into a common unitless scale. Moreover, the adopted indexing model can only aggregate parameters with a common scale, which became more necessary in order to harmonize the parameter values using a standardized non-dimensional scale. In relation to the permissible water quality parameter concentrations prescribed by DWAF [39–41], fixed key points of the rating curves were established (see Table 4) and converged with straight-line graphs. Thereafter, the linear equations associated to the straight-line graphs were collectively transformed into linear sub-index functions. The advantage with this technique is that sub-index functions are able to interpolate the limits in between water classification categories using the linear regression method. Examples of the final sub-index curves are included in Figure 3, whereas examples of sub-index functions are represented mathematically from Equation (5) to Equation (7).

$$\mathrm{SI}_a = \begin{cases} -56.627x_a + 97.609, \text{ if } x_a \leq 1.4 \\ -140x_a + 216, \text{ if } 1.4 < x_a \leq 1.5 \\ -12x_a + 24, \text{ if } 1.5 < x_a \leq 2.0 \\ 0, \text{ otherwise} \end{cases} \tag{5}$$

$$\mathrm{SI_b} = \begin{cases} -1.0707x_b + 100, \text{ if } x_b \leq 46.70 \\ -2.0301x_b + 144.08, \text{ if } 46.70 < x_b \leq 60 \\ -0.7667x_b + 69, \text{ if } 60 < x_b \leq 90 \\ 0, \text{ otherwise} \end{cases} \tag{6}$$

$$\mathrm{SI_c} = \begin{cases} 100, \text{ if } x_c \leq 50 \\ -0.4x_c + 110, \text{ if } 50 < x_c \leq 150 \\ -0.1286x_c + 69.286, \text{ if } 150 < x_c \leq 500 \\ 5, \text{ if } 500 < x_c \leq 600 \\ 0, \text{ otherwise} \end{cases} \tag{7}$$

where $\mathrm{SI}_{a,b,\ \ldots,c}$ are sub-index functions for (a) ammonia, (b) calcium, (c) chloride; $x_{a,b,\ \ldots,c}$ are the observed water quality reading of the respective water quality parameter. Due to the nature of the article, only sub-index rating curves and mathematical functions for NH_3, Ca and Cl are presented herein; the rest are documented elsewhere.

Table 4. Range of water quality parameters and their key points defined for sub-index rating curves.

	Variable	Unit	Key Points of the Sub-Index Graph ($\mathrm{SI}_{0,\ldots,100}$ = Sub-Index Zero to Sub-Index One Hundred)										
			Class 5				Class 4		Class 3		Class 2		Class 1
			SI_0	SI_5	SI_{10}	SI_{25}	SI_{45}	SI_{50}	SI_{55}	SI_{75}	SI_{90}	SI_{95}	SI_{100}
1	NH_3	mg/L	2.00	1.58	1.47	1.28	0.93	0.84	0.75	0.40	0.13	0.05	0.00
2	Ca	mg/L	90.00	83.47	76.95	59.01	49.16	46.70	42.03	23.35	9.34	4.67	0.00
3	Cl	mg/L	601.00	501.00	461.01	344.37	188.85	150.00	137.50	87.50	50.00	50.00	50.00
4	Chl-a	µg/L	29.00	24.00	20.00	17.00	13.00	12.00	11.00	5.50	1.00	1.00	1.00
5	EC	µS/m	492.86	471.44	450.00	385.77	300.00	278.58	257.15	171.45	70.00	70.00	70.00
6	F	mg/L	1.51	1.38	1.27	0.92	0.46	0.35	0.33	0.27	0.05	0.05	0.05
7	$CaCO_3$	mg/L	300.00	280.00	260.00	200.00	180.00	175.00	170.00	150.00	75.00	50.00	0.00
8	Mg	mg/L	91.00	82.00	74.00	50.00	46.00	45.00	44.00	40.00	32.50	30.00	0.00
9	Mn	mg/L	1.54	1.43	1.33	1.03	0.63	0.53	0.49	0.34	0.05	0.05	0.05
10	NO_3	mg/L	2.00	1.75	1.50	0.95	0.75	0.70	0.65	0.37	0.07	0.03	0.00
11	pH [a]	Unitless	4.00	4.00	4.00	4.19	4.94	5.12	5.31	6.06	6.62	6.81	7.00
	pH [b]	Unitless	11.00	11.00	11.00	10.81	10.06	9.87	9.69	8.94	9.37	8.19	8.00
12	SO_4	mg/L	350.00	310.00	270.00	150.00	113.98	104.99	95.99	60.00	37.50	30.00	0.00
13	Turb	NTU	45.00	27.50	10.00	8.75	7.08	6.67	6.25	4.60	3.40	3.00	0.00

[a] pondus Hydrogenium lower limits (pH [a]), [b] pondus Hydrogenium upper limits (pH [b]). The key points are based on Target Water Quality Ranges (TWQRs) as prescribed by DWAF [39–41].

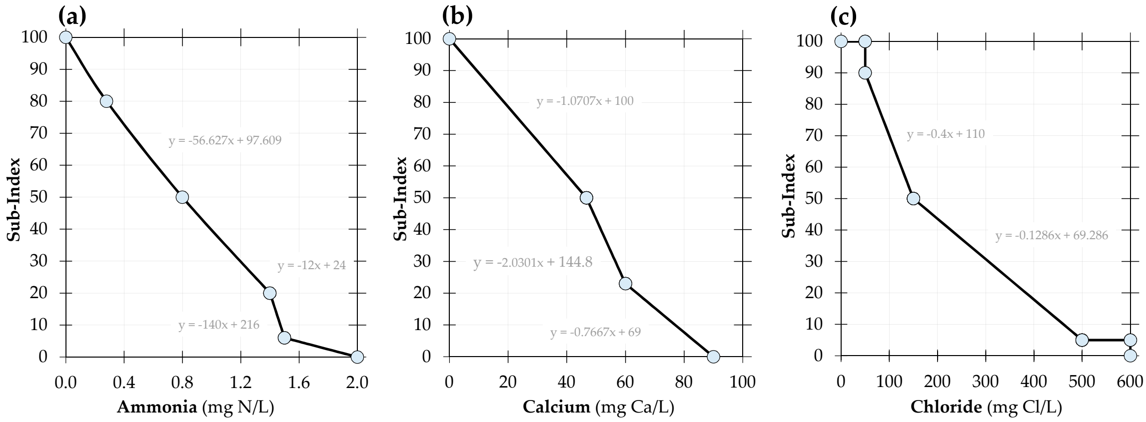

Figure 3. Examples of the graphically established parameter sub-index rating curves for the selected water quality parameters (**a**) NH_3, (**b**) Ca and (**c**) Cl.

4.4. Weighted Indexing Model (UWQI)

The mathematical structure and application of indexing models is normally governed by the degree of accuracy perceived and the type of weightage coefficients, which might be equally or unequally defined. Various aggregation methods exist, and each technique has its own formidable challenges; thus, the index developer has to decisively select the most appropriate and relevant indexing model, preferably one with fewer complications that might adversely influence the final index value. Otherwise, defining the best and absolute aggregation model is close to impossible. Since there is no supreme and favorable technique of formulating water quality indices (WQIs), various aggregation methods were tried and tested. The modified weighted sum (additive) method was found to be the most appropriate for the development of a universal water quality index for monitoring South African watersheds. The modified weighted sum (additive) method is represented in Equation (8) [26–28].

$$\mathrm{WQI} = \frac{1}{100}\left(\sum_{i=1}^{n} s_i w_i\right)^2 \tag{8}$$

Upon conducting a scenario-based analysis, the modified weighted sum equation has been further improved to align it with local conditions and the developed final universal water quality (UWQI) model is presented in Equation (9):

$$\mathrm{WQI} = \frac{2}{3}\left(\sum_{i=1}^{n} s_i w_i\right)^{1.0880563} \tag{9}$$

where UWQI is the aggregated index value ranging from zero to hundred, with zero representing water of poor quality and hundred denoting water of the highest quality; s_i is the sub-index value of the ith water quality parameter obtained from the sub-index linear functions and the values range from zero to hundred, similar to WQI values; w_i is the weight coefficient value for the ith parameter represented as decimal number and the sum of all coefficients is one, ($w_1 + w_2 + w_3 + \ldots + w_n = 1$); n is the total number of sub-indices—in this case, $n = 13$.

4.5. Scenario-Based Model Validation Analysis

Scenario-based analysis helps to identify potential data-processing gaps, which, in turn, enlighten us as to the necessary precautions that are imperative in order to minimize the impact, or perhaps eliminate the problem completely. To determine such precautions, ideal sets of predictive variables have been established under a variety of scenarios to calculate specific water quality variables. Considering increments of five scores, nine probable scenarios have been examined to demonstrate the model's ability to predict scores of all ranges, from class one (excellent) to class five (the worst). The nine forecasts use three-level grading, comprised of (i) worst-case scenario, $0 \leq$ Index ≤ 10, (ii) base-case scenario, $45 \leq$ Index ≤ 55 and, lastly, (iii) best-case scenario, $90 \leq$ Index ≤ 100. Purposefully, the groupings provided a complete change of circumstances with each scenario, thereby widening the range of analysis and including a considerable array of possibilities. With reference to permissible concentration limits and developed linear sub-index functions, definite assumptions about all nine cases have been carefully considered. Accordingly, parameter values corresponding to each scenario have been established and applied to perform the analysis. The results of the scenario-based analysis are presented in Table 5 and Figure 4.

Table 5. Comparison of modified weighted arithmetic water quality index and the developed universal water quality index using scenario-based analysis to establish the functionality and predictive capacity of the models.

Sample Identity	Water Quality Index Results from Scenario-Based Analysis					
	Ideal WQI Results		Modified Weighted WQI Results		Developed UWQI Results	
	Index Score	WQI Class	Index Score	WQI Class	Index Score	WQI Class
Maximum	100.00	1.00	99.51	1.00	99.74	1.00
Average	50.00	4.00	39.39	4.00	48.83	4.00
1	0.00	5.00	0.00	5.00	0.00	5.00
2	5.00	5.00	0.18	5.00	3.18	5.00
3	10.00	5.00	0.83	5.00	7.38	5.00
4	45.00	4.00	20.25	5.00	41.95	4.00
5	50.00	4.00	25.03	4.00	47.07	4.00
6	55.00	3.00	30.27	4.00	52.20	3.00
7	90.00	2.00	84.67	2.00	91.35	2.00
8	95.00	2.00	93.76	2.00	96.56	1.00
9	100.00	1.00	99.51	1.00	99.74	1.00

Notes: samples used for scenario analysis are predictive values ideal for establishing specific sets of results, as demonstrated with the ideal water quality index (WQI) results columns. With increments of five scores, nine probable scenarios have been considered to demonstrate the model's ability to predict scores of all ranges, from Class 1 (good) to Class 5 (bad).

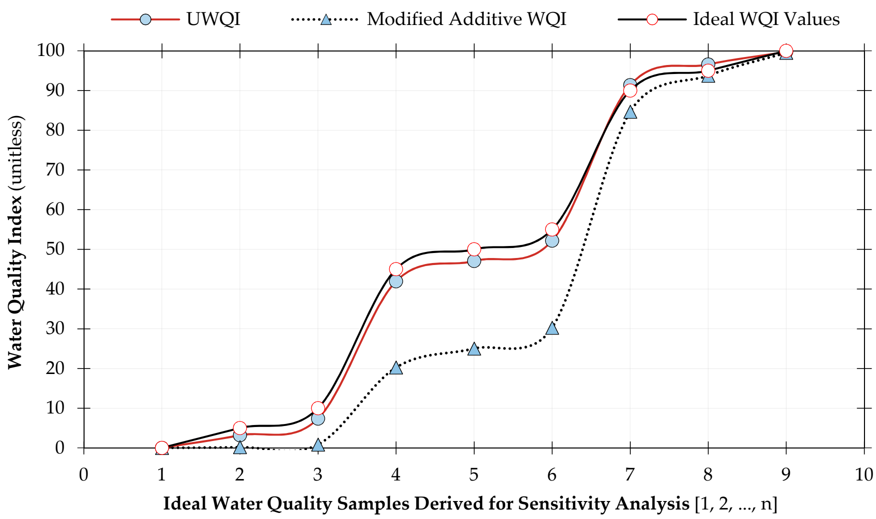

Figure 4. Plot diagram showing the results of the scenario-based analysis of the developed universal water quality index (UWQI) model and the modified additive water quality model against ideal water quality values derived from nine probable scenarios. The nine cases were represented as samples 1, 2, . . . , n, which correspond, respectively, to water quality index (WQI) values of 0, 5 and 10 (worst-cases), 45, 50 and 55 (base cases) and 90, 95 and 100 (best cases).

While we do not wish to devalue the efforts by House [26–28], the modified weighted arithmetic model could not sufficiently satisfy the expected analytical results. Although the predictive pattern is recommended, there is a significant lag between the calculated results and the ideal case, especially with the base-case scenarios ($45 \leq$ Index ≤ 55). Henceforth, the model was further improved to suit our local conditions. In view of the analysis results, it is evident that the proposed UWQI is robust and technically stable. The degree of variation from the ideal values is negligible; the prediction pattern followed the ideal graph with corresponding values in terms of both WQI scores and classification. This, therefore, pronounces the competence of the UWQI to be used as an evaluation tool for monitoring South African river catchments.

Good water quality index scores nearing or equal to one hundred are achieved when the surface water shows the virtual absence of threats or impairments, conditions very close to pristine (natural) levels. On the other hand, index values close or equal to zero are recorded when almost all the water quality parameters depart from desirable concentration levels. Ideal parameter concentrations for each possible level of contamination are documented in Tables 4 and 6.

Table 6. Calculation of water quality index scores using universal water quality index (UWQI) model.

Key Point [a]	Calculation of WQI Using the Parameter Values Corresponding to the Key Points of the Rating Curves														
	Water Quality Parameters [c]													WQI Results	
	NH_3	Ca	Cl	Chl-a	EC	F	$CaCO^3$	Mg	Mn	NO_3	pH	SO_4	Turb	Score	Class
KP_1	2.00	90.00	601.00	29.00	492.86	1.51	301.00	91.00	1.54	2.10	4.00	351.00	46.00	0.00	5
KP_2	1.58	83.47	501.00	24.00	471.44	1.38	280.00	82.00	1.43	1.75	4.00	310.00	27.50	3.18	5
KP_3	1.47	76.95	461.01	20.00	450.00	1.27	260.00	74.00	1.33	1.50	4.00	270.00	10.00	7.36	5
KP_4	1.28	59.01	344.37	17.00	385.77	0.92	200.00	50.00	1.03	0.95	4.19	150.00	8.75	22.13	5
KP_5	0.93	49.16	188.85	13.00	300.00	0.46	180.00	46.00	0.63	0.75	4.94	113.98	7.08	41.95	4
KP_6	0.84	46.70	150.00	12.00	278.58	0.35	175.00	45.00	0.53	0.70	5.12	104.99	6.67	47.07	4
KP_7	0.75	42.03	137.50	11.00	257.15	0.33	170.00	44.00	0.49	0.65	5.31	95.99	6.25	52.20	3
KP_8	0.40	23.35	87.50	5.50	171.45	0.27	150.00	40.00	0.34	0.37	6.06	60.00	4.60	73.13	3
KP_9	0.13	9.34	50.10	1.01	70.01	0.05	75.00	32.50	0.05	0.07	6.62	37.50	3.40	89.16	2
KP_{10}	0.05	4.67	50.00	0.99	70.00	0.05	50.00	30.00	0.05	0.03	6.81	30.00	3.00	96.55	1
KP_{11}	0.00	0.00	50.00	0.99	70.00	0.05	0.00	0.00	0.05	0.00	7.00	0.00	0.00	99.74	1
S.No. [b]	Calculation of WQI Using the Parameter Values from Umgeni Water Board for Six Different Sampling Stations														
	Water Quality Parameters [c]													WQI Results [d]	
	NH_3	Ca	Cl	Chl-a	EC	F	$CaCO^3$	Mg	Mn	NO_3	pH	SO_4	Turb	Score	Class
1	0.27	5.92	3.16	5.71	9.71	0.54	29.77	3.64	0.26	0.51	7.40	1.11	97.20	77.98	2
	0.13	8.47	7.23	5.65	14.20	0.10	42.89	5.28	0.02	0.45	8.20	2.53	7.10	88.08	2
2	0.10	5.64	29.50	20.49	19.20	0.17	35.66	5.24	0.01	0.99	7.70	7.70	66.70	77.87	2
	0.10	6.36	22.20	0.14	20.10	0.10	38.86	5.58	0.01	0.10	7.30	5.81	1.90	95.15	1
3	0.10	16.50	36.40	19.50	31.40	0.20	82.36	10.00	0.01	1.31	7.90	20.05	5.80	80.01	2
	0.10	13.30	35.30	1.71	28.90	0.16	61.79	6.94	0.03	0.10	7.90	19.40	1.00	93.45	2
4	0.36	5.19	5.54	1.28	8.40	0.10	24.80	2.83	0.01	4.50	7.90	2.26	4.70	83.30	2
	0.04	1.00	4.79	1.87	7.85	0.10	6.67	1.00	0.01	0.34	7.80	1.89	1.90	94.92	2
5	0.09	13.36	59.33	5.91	42.60	0.23	80.59	11.47	1.05	0.43	7.60	16.20	13.20	75.99	2
	0.04	10.70	56.80	1.08	34.90	0.27	66.87	9.75	0.03	0.05	7.80	12.50	1.90	92.64	2
6	0.10	3.30	23.70	2.96	14.20	0.10	24.84	4.03	0.01	1.77	8.00	2.66	13.30	80.48	2
	0.10	4.28	26.10	2.63	16.50	0.10	29.14	4.48	0.01	0.10	7.80	3.60	3.80	93.95	2

[a] Key point identification number, [b] sampling station identity number, [c] water quality variables in mg/L, except for chlorophyll-a (μg/L), electrical conductivity (μS/m), pondus Hydrogenium (unitless) and turbidity (NTU). [d] WQI scores representing the minimum and maximum index values calculated for each sampling station (2014 to 2018).

4.6. Evaluation of Water Quality

Umgeni water quality data have been evaluated using the proposed universal water quality index (UWQI) model documented in Equation (9). Based on the UWQI, Tables 6 and 7 and Figure 5 indicate spatial and temporal water quality variations among the six sampling sites. In order to demonstrate further the ability of the suggested UWQI, Table 6 also includes WQI scores calculated using the ideal values derived from the key points of the rating curves.

Table 7. Water quality index matrix for the six sampling stations.

Year	Month	Sampling Stations					
		Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
2014	July	80.45	91.97	88.40	91.20	89.42	90.71
	October	83.80	86.98	90.32	83.30	87.04	85.62
	Seasonal Average [1]	82.13	89.48	89.36	87.25	88.23	88.16
	Annual Average [2]	80.94	87.49	89.63	91.42	84.78	88.35
2015	January	79.09	84.19	92.35	94.92	86.73	90.70
	April	80.40	82.48	92.89	90.79	90.38	92.20
	July	79.68	84.04	87.13	87.72	78.32	89.61
	October	87.13	84.70	91.75	94.05	90.04	93.95
	Seasonal Average [1]	81.58	83.85	91.03	91.87	86.37	91.61
	Annual Average [2]	82.74	83.99	91.32	90.99	86.48	91.60
2016	January	78.38	84.37	93.28	94.08	85.27	88.38
	April	81.52	86.61	93.45	92.54	91.89	93.68
	July	86.51	90.73	83.93	86.76	81.37	91.55
	October	85.12	90.07	91.65	86.99	89.27	90.27
	Seasonal Average [1]	82.89	87.94	90.58	90.09	86.95	90.97
	Annual Average [2]	81.72	88.80	89.20	89.88	87.80	90.03
2017	January	82.43	95.15	83.69	92.86	86.03	92.02
	April	82.42	92.63	91.91	94.35	91.79	91.21
	July	85.16	91.87	86.30	91.05	91.31	81.90
	October	81.21	94.46	90.95	93.90	85.21	86.03
	Seasonal Average [1]	82.81	93.53	88.21	93.04	88.59	87.79
	Annual Average [2]	81.86	92.32	88.73	92.93	85.66	85.72
2018	January	80.47	87.50	84.12	92.96	85.16	87.46
	April	80.63	94.71	90.52	94.06	88.00	87.90
	July	83.14	91.40	84.65	91.41	82.55	87.35
	Seasonal Average [1]	81.41	91.20	86.43	92.81	85.24	87.57
	Annual Average [2]	81.26	90.80	86.76	92.83	86.71	87.58
Station Minimum WQI [3]		77.98	77.87	80.01	83.30	75.99	80.48
Station Maximum WQI [4]		88.08	95.15	93.45	94.92	92.64	93.95
Station Average WQI [5]		81.81	87.39	89.05	91.52	86.39	88.74

Notes: [1] seasonal average considering WQI scores for January, April, July and October only, [2] snnual average considering WQI values for the entire year from January to December, and [3,4,5] overall station WQI scores, taking into account the entire period of water quality evaluation—that is, from June 2014 to July 2018.

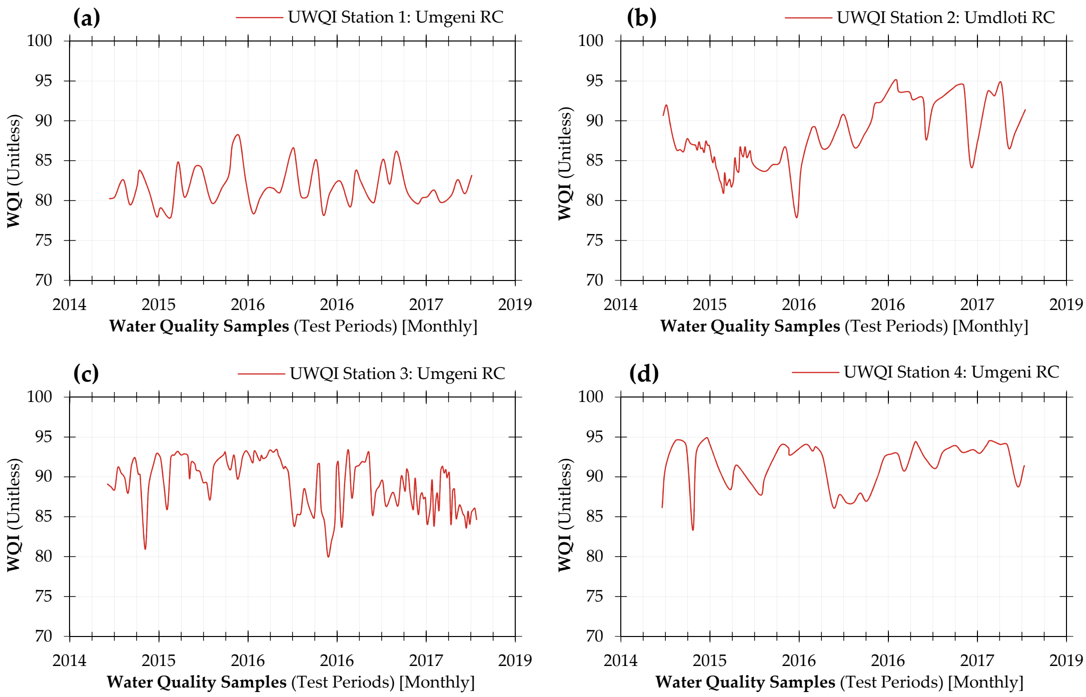

Figure 5. *Cont.*

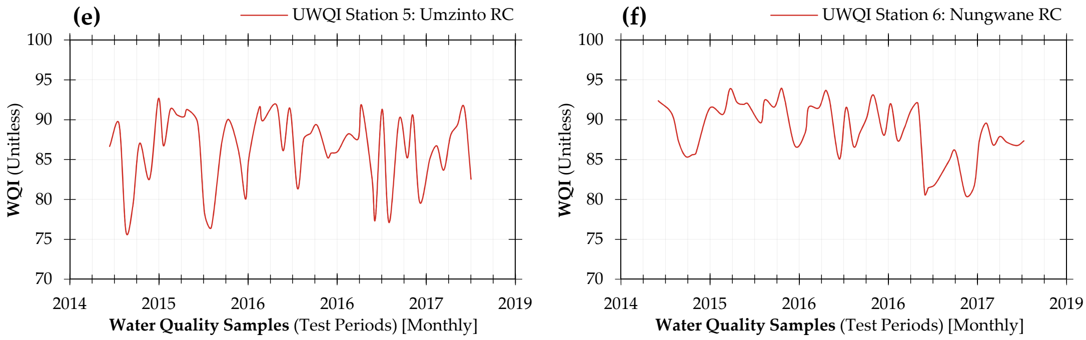

Figure 5. Water quality index results calculated using the developed universal water quality index (UWQI) for Umgeni water quality data for a period of four years from June 2014 to July 2018 (**a**) Umgeni River catchment for Henley Dams, (**b**) Umdloti River catchment for Hazelmere Dam, (**c**) Umgeni River catchment for Inanda Dams, (**d**) Umgeni River catchment for Midmar Dam, (**e**) Umzinto/uMuziwezinto River catchment for Umzinto Dam, and (**f**) Nungwane River catchment for Nungwane Dam.

The results show that water quality in the region can be categorized as "acceptable water quality", with the lowest WQI score of 75.99 (class two) recorded at station 5 (Umzinto Dam). In this case, turbidity and Mn are the main contributors to the deterioration of the water quality, with concentration levels of 13.20 NTU and 1.05 mg/L, respectively. Sampling station 2 recorded the highest surface water quality with an index of 95.15 (class one) during the summer of 2017. NO_3 is the principal pollutant factor responsible for the minimum WQI scores for stations 2, 3, 4 and 6, with NO_3 concentrations of 0.99, 1.31, 4.50 and 1.77 mg/L, respectively (see Table 6).

High levels of NO_3 are recorded during the summer periods and, considering the socio-economic developments surrounding the sampling stations (Figure 2), the source of contamination might be anthropogenic activities, especially wastewater discharge, among others. NO_3 is a naturally occurring ion [59,60] that is widespread and is regarded as the most significant contaminant in water [61,62]. Nitrate itself is a low-toxicity compound, but when endogenously converted to nitrite (NO_2), it becomes toxic to human health and the aquatic environment [59,60], thus exemplifying the need for regular water quality monitoring to identify water quality trends over time and space [63].

High levels of turbidity are evident during the summer seasons at stations 1, 2, 5 and 6, with corresponding values of 97.20, 66.70, 13.20 and 13.30 NTU. Together with NO_3, turbidity contributes significantly towards the deterioration of water quality among these sites. Sources of turbidity are diverse and include, but are not limited to, reservoir drawdown flushing, algal blooms (eutrophication), wastewater discharge, industrial effluent, exceptional rainfall events, soil erosion and decomposition of organic matter [64,65]. Chl-a concentrations at stations 2 and 3 exceed targeted water quality levels in summer, with values of 20.49 and 19.50 µg/L, respectively. Soluble nutrients, especially phosphorus and nitrogen, are the key determinants promoting algae blooms (eutrophication), which contribute significantly towards increased levels of chlorophyll-a [66,67]. Such enriching nutrients often originate from anthropogenic activities, which include wastewater discharge and fertilizer runoff [3,68,69].

Narrow variations in WQI are observed for stations 1 (77.98–88.08) and 4 (83.30–94.92). The two stations are located upstream of the catchment and the rest of the sampling sites are situated downstream of the drainage region, towards Durban–Pietermaritzburg business corridor. WQI results indicate that surface water quality varies more with the increase in socio-economic activities along the river's watercourse, with station 2 having the largest variation (77.87–95.15).

Testing the model with data from various river catchments promotes the objective of establishing a universal water quality index suitable for use across the catchment areas in South Africa. Noticeably, the UWQI model responded steadily to the highs and lows of each water quality parameter value, with the index output graphs showing the variations. This advocates the readiness of the UWQI to interpret water quality data and provide a simple non-dimensional score that is justifiable and repeatable. Such success fulfils the objective of developing a universal WQI and, more importantly, presents a "yardstick" that can be applied in most, if not all, of the distinct watersheds in South Africa. This accomplishment is a critical milestone not only to the authors, but also to most of the stakeholders directly or indirectly involved in water quality science.

4.7. Index Categorisation Schema

A five-class WQI categorization schema has been adopted for this study (Table 8). The schema is an increasing scale that is identical to normal percentage hierarchy, offering a better understanding of water classification scales. The ranking mechanism is similar to WQI classifications suggested for the Boyacioğlu Index (Turkey) and Vaal WQI (South Africa) [3,5].

Table 8. Index score classification for the universal water quality index for south african river catchments.

ID	Water Quality Classification	
	Description of Rank and Classification	Index Score
1	Class 1—Good water quality Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels	$95 < \text{Index} \leq 100$
2	Class 2—Acceptable water quality Water quality is usually protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels	$75 < \text{Index} \leq 95$
3	Class 3—Regular water quality Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels	$50 < \text{Index} \leq 75$
4	Class 4—Bad water quality Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels	$25 < \text{Index} \leq 50$
5	Class 5—Very bad water quality Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels	$0 < \text{Index} \leq 25$

Source: a modified version of theWQI categorisation schema suggested by Banda [3]. Notes: Class 1 index values (good water quality) can only be obtained if all measurements are within the objective values virtually all the time.

In a similar manner to the methods used by and Sutadian et al. [20], Abrahão et al. [70], Rabee et al. [71] and Rubio-Arias et al. [72], appropriate mathematical functions with logical linguistic descriptors such as less than, equal to and greater than have been assigned to each categorization class. In this way, the categorization schema can accommodate all possible index scores regardless of the decimal value. More importantly, the established categorization schema aids in closing gaps identified in the literature and presents a progressive approach that will contribute significantly towards water quality index development. Such an academic contribution reflects on the efficiency of the model and can be attributed to the success of the current study.

5. Conclusion and Future Directions

Over four hundred water quality samples from six sampling stations located in four different river catchments are evaluated using UWQI, and Table 7, together with Figure 5, provides a summary of the trend analysis. The spatial and temporal changes in water quality for Umgeni Water Board are evident over a period of four years, with a varying sequence comprising of index scores as high as 95.15 (class one), with an average of 87.78 (class two) and the lowest score being 75.99 (class two) across the six sites. The best surface water quality was recorded at station 2 during the summer period of 2017, whereas the lowest water quality was recorded at station 5 during the month of August 2014. The main pollution contributors are NO_3 (station 2, 3, 4 and 6), turbidity (station 1, 2, 5 and 6), Chl-a (station 2 and 3) and, lastly, Mn at station 5. The sources of pollution may be associated with anthropogenic activities, considering the socio-economic developments surrounding the affected sampling stations. Otherwise, the rest of the water quality parameters are virtually within permissible levels. There is the need for regular water quality appraisal to monitor concentration levels against pollution control regulations and record the variation in trends, especially for sampling stations located within the Durban–Pietermaritzburg business corridor. The application of UWQI can perform sustainable water resource functions for river basin management.

The study opens a path for unified WQIs to be considered in South Africa. As this is the first attempt to demonstrate the use of nationally applicable indices, it is highly expected that the study will have an impact on methods of developing future water quality indices, contributing to our understanding of index models and supplementing our knowledge of water quality science. It is important to conduct research into unified WQIs formed based on multivariate statistical approaches. Further research is required to better understand the performance of objective methods on nationally applicable indices and address the effects of subjectivity on traditional methods of establishing WQIs. As an ongoing study, additional data from other river catchments should be considered and evaluated using the suggested UWQI. This will further demonstrate the universality of the model and perhaps provide guidance on necessary modification requirements. Nevertheless, an initial step towards the ultimate goal has been achieved, which is the development of a universal water quality index (UWQI).

Author Contributions: Conceptualization, T.D.B. and M.K.; methodology, T.D.B.; software, T.D.B.; validation, T.D.B. and M.K.; formal analysis, T.D.B.; investigation, T.D.B.; resources, T.D.B. and M.K.; data curation, T.D.B.; writing—original draft preparation, T.D.B.; writing—review and editing, T.D.B. and M.K.; visualization, T.D.B.; supervision, M.K.; project administration, T.D.B.; funding acquisition, T.D.B. and M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by ZAKUMI Consulting Engineers (Pty) Ltd., grant number ST2017/BANDA/PhD-Eng/UKZN and the research was supported by the University of KwaZulu-Natal.

Acknowledgments: Our utmost gratitude is extended to the staff members of the Research Office of the University of KwaZulu-Natal for supporting this research publication.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the preparation of this paper; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the paper.

References

1. Tripathi, M.; Singal, S.K. Use of Principal Component Analysis for parameter selection for development of a novel Water Quality Index: A case study of river Ganga India. *Ecol. Indic.* **2019**, *96*, 430–436. [CrossRef]
2. Paca, J.M.; Santos, F.M.; Pires, J.C.M.; Leitão, A.A.; Boaventura, R.A.R. Quality assessment of water intended for human consumption from Kwanza, Dande and Bengo rivers (Angola). *Environ. Pollut.* **2019**, *254*, 113037–113044. [CrossRef]
3. Banda, D.T. Developing an Equitable Raw Water Pricing Model: The Vaal Case Study. Ph.D. Thesis, Tshwane University of Technology, Pretoria, Republic of South Africa, 2015.
4. Carvalho, L.; Cortes, R.; Bordalo, A.A. Evaluation of the ecological status of an impaired watershed by using a multi-index approach. *Environ. Monit. Assess.* **2011**, *174*, 493–508. [CrossRef] [PubMed]
5. Boyacioğlu, H. Development of a water quality index based on a European classification scheme. *Water Sa* **2007**, 33. [CrossRef]
6. Unda-Calvo, J.; Ruiz-Romera, E.; Martínez-Santos, M.; Vidal, M.; Antigüedad, I. Multivariate statistical analyses for water and sediment quality index development: A study of susceptibility in an urban river. *Sci. Total Environ.* **2019**, *711*, 135026. [CrossRef] [PubMed]
7. Banda, D.T.; Kumarasamy, M.V. Development of Water Quality Indices (WQIs): A Review. *Pol. J. Environ. Stud.* **2020**, *29*, 2011–2021. [CrossRef]
8. Poonam, T.; Tanushree, B.; Sukalyan, C. Water quality indices - important tools for water quality assessment: A review. *Int. J. Adv. Chem.* **2015**, *1*, 15–28.
9. Sutadian, A.D.; Muttil, N.; Yilmaz, A.G.; Perera, B. Development of river water quality indices-A review. *Environ. Monit. Assess.* **2016**, *188*, 58–90. [CrossRef]
10. Paun, I.; Cruceru, L.V.; Chiriac, L.F.; Niculescu, M.; Vasile, G.G.; Marin, N.M. Water Quality Indices-methods for evaluating the quality of drinking water. In Proceedings of the 19th INCD ECOIND International Symposium-SIMI 2016, "The Environment and the Industry", Bucharest, Romania, 13–14 October 2016; pp. 395–402.

11. Tyagi, S.; Sharma, B.; Singh, P.; Dobhal, R. Water quality assessment in terms of water quality index. *Am. J. Water Resour.* **2013**, *1*, 34–38. [CrossRef]
12. Abbasi, T.; Abbasi, S.A. *Water Quality Indices*. 2012, p. 353. Available online: https://doi.org/10.1016/C2010-0-69472-7 (accessed on 14 October 2015).
13. Namugize, J.N.; Jewitt, G.; Graham, M. Effects of land use and land cover changes on water quality in the uMngeni river catchment, South Africa. *Phys. Chem. Earthparts A/B/C* **2018**, *105*, 247–264. [CrossRef]
14. Hughes, C.; de Winnaar, G.; Schulze, R.; Mander, M.; Jewitt, G. Mapping of water-related ecosystem services in the uMngeni catchment using a daily time-step hydrological model for prioritisation of ecological infrastructure investment–Part 1: Context and modelling approach. *Water Sa* **2018**, *44*, 577–589. [CrossRef]
15. Shoko, C. The Effect of Spatial Resolution in Remote Sensing Estimates of Total Evaporation in the uMgeni Catchment. Ph.D. Thesis, University of KwaZulu-Natal, Pietermaritzburg, Republic of South Africa, 2014.
16. Umgeni Water. *Infrastructure Master Plan 2019/2020-2049/2050, Volume 2: Mgeni System*; Umgeni Water: Pietermaritzburg, South Africa, 2019; p. 185.
17. Umgeni Water. *Infrastructure Master Plan 2019/2020-2049/2050, Volume 3: uMkhomazi System*; Umgeni Water: Pietermaritzburg, South Africa, 2019; p. 35.
18. Republic of South Africa. Proposed new nine (9) water management areas of South Africa. In *Government Gazette No. 35517, Notice No. 547*; Department of Water and Environmental Affairs, Ed.; Republic of South Africa: Pretoria, South Africa, 2012; Volume 565, p. 72.
19. Chiluwe, Q.W. Assessing the Role of Property Rights in Managing Water Demand: The Case of uMgeni River Catchment. Ph.D. Thesis, Monash South Africa, Johannesburg, Republic of South Africa, 2014.
20. Sutadian, A.D.; Muttil, N.; Yilmaz, A.G.; Perera, B.J.C. Development of a water quality index for rivers in West Java Province, Indonesia. *Ecol. Indic.* **2018**, *85*, 966–982. [CrossRef]
21. Horton, R.K. An Index-Number System for Rating Water Quality. *J. Water Pollut. Control Fed.* **1965**, *37*, 300–306.
22. Brown, R.M.; McClelland, N.I.; Deininger, R.A.; Tozer, R.G. A water quality index-Do we dare? *Water Sew. Work.* **1970**, *117*, 339–343.
23. Brown, R.; McClelland, N.; Deininger, R.; Landwehr, J. Validating the WQI. In Proceedings of the Paper Presented at National Meeting of American Society of Civil Engineers on Water Resources Engineering, Washington, DC, USA, 30 January 1973.
24. SRDD. Development of a water quality index. In *Applied Research & Development Report Number ARD3*; Scottish Research Development Department Engineering Division, Ed.; Scottish Research Development Department Engineering Division: Edinburg, UK, 1976; Volume ARD3, p. 61.
25. Ross, S. An index system for classifying river water quality. *Water Pollut. Control* **1977**, *76*, 113–122.
26. House, M.A. *Water Quality Indices*; Middlesex Polytechnic: London, UK, 1986.
27. House, M.A. A water quality index for river management. *Water Environ. J.* **1989**, *3*, 336–344. [CrossRef]
28. House, M.A. Water quality indices as indicators of ecosystem change. *Environ. Monit. Assess.* **1990**, *15*, 255–263. [CrossRef] [PubMed]
29. Dinius, S. Design of an index of water quality. *Jawra J. Am. Water Resour. Assoc.* **1987**, *23*, 833–843. [CrossRef]
30. Smith, D.G. *Water Quality Indexes for Use in New Zealand's Rivers and Streams*; National Water and Soil Conservation Authority of New Zealand, Water Quality Centre Publication: Hamilton, New Zealand, 1987; Available online: http://docs.niwa.co.nz/library/public/WQCpub12.pdf (accessed on 16 October 2015).
31. Smith, D.G. A better water quality indexing system for rivers and streams. *Water Res.* **1990**, *24*, 1237–1244. [CrossRef]
32. Tyson, J.; House, M. The application of a water quality index to river management. *Water Sci. Technol.* **1989**, *21*, 1149–1159. [CrossRef]
33. Nagels, J.; Davies-Colley, R.; Smith, D. A water quality index for contact recreation in New Zealand. *Water Sci. Technol.* **2001**, *43*, 285–292. [CrossRef]
34. Kumar, D.; Alappat, B.J. NSF-Water Quality Index: Does It Represent the Experts' Opinion? *Pract. Period. Hazard. Toxicand Radioact. Waste Manag.* **2009**, *13*, 75–79. [CrossRef]
35. Almeida, C.; González, S.O.; Mallea, M.; González, P. A recreational water quality index using chemical, physical and microbiological parameters. *Environ. Sci. Pollut. Res.* **2012**, *19*, 3400–3411. [CrossRef] [PubMed]
36. Linstone, H.A.; Turoff, M. *The Delphi Method: Techniques and Applications*; Addison-Wesley: Reading, MA, USA, 1975; Volume 29.

37. Linstone, H.A.; Turoff, M. *The Delphi Method: Techniques and Applications*; Addison-Wesley Publishing Company, Advanced Book Program: Newark, NJ, USA, 2002; Volume 18.
38. Sharma, P.; Meher, P.K.; Kumar, A.; Gautam, Y.P.; Mishra, K.P. Changes in water quality index of Ganges river at different locations in Allahabad. *Sustain. Water Qual. Ecol.* **2014**, *3*, 67–76. [CrossRef]
39. DWAF. *South African Water Quality Guidelines: Volume 1: Domestic Water Use*; Department of Water Affairs and Forestry: Pretoria, South Africa, 1996; p. 190.
40. DWAF. *South African Water Quality Guidelines: Volume 3: Industrial Use*; Department of Water Affairs and Forestry: Pretoria, South Africa, 1996.
41. DWAF. *South African Water Quality Guidelines: Volume 7: Aquatic Ecosystems*; Department of Water Affairs and Forestry: Pretoria, South Africa, 1996.
42. Wang, P.; Mou, S.; Lian, J.; Ren, W. Solving a system of linear equations: From centralized to distributed algorithms. *Annu. Rev. Control* **2019**, *47*, 306–322. [CrossRef]
43. Low, K.H.; Koki, I.B.; Juahir, H.; Azid, A.; Behkami, S.; Ikram, R.; Mohammed, H.A.; Zain, S.M. Evaluation of water quality variation in lakes, rivers, and ex-mining ponds in Malaysia (review). *Desalin. Water Treat.* **2016**, *57*, 28215–28239. [CrossRef]
44. Nozaic, D.; Freese, S.; Thompson, P. Longterm experience in the use of polymeric coagulants at Umgeni Water. *Water Sci. Technol. Water Supply* **2001**, *1*, 43–50. [CrossRef]
45. Manickum, T.; John, W.; Terry, S.; Hodgson, K. Preliminary study on the radiological and physicochemical quality of the Umgeni Water catchments and drinking water sources in KwaZulu-Natal, South Africa. *J. Environ. Radioact.* **2014**, *137*, 227–240. [CrossRef]
46. Warburton, M.L.; Schulze, R.E.; Jewitt, G.P.W. Hydrological impacts of land use change in three diverse South African catchments. *J. Hydrol.* **2012**, *414–415*, 118–135. [CrossRef]
47. Rangeti, I. Determinants of Key Drivers for Potable Water Treatment cost in uMngeni Basin. Ph.D. Thesis, Durban University of Technology, Durban, Republic of South Africa, 2015.
48. Olaniran, A.O.; Naicker, K.; Pillay, B. Assessment of physico-chemical qualities and heavy metal concentrations of Umgeni and Umdloti Rivers in Durban, South Africa. *Environ. Monit. Assess.* **2014**, *186*, 2629–2639. [CrossRef]
49. Gakuba, E.; Moodley, B.; Ndungu, P.; Birungi, G. Occurrence and significance of polychlorinated biphenyls in water, sediment pore water and surface sediments of Umgeni River, KwaZulu-Natal, South Africa. *Environ. Monit. Assess.* **2015**, *187*, 568. [CrossRef] [PubMed]
50. Namugize, J.N.; Jewitt, G.P.W. Sensitivity analysis for water quality monitoring frequency in the application of a water quality index for the uMngeni River and its tributaries, KwaZulu-Natal, South Africa. *Water Sa* **2018**, *44*, 516–527. [CrossRef]
51. Umgeni Water. *Infrastructure Master Plan 2019/2020 - 2049/2050, Volume 5: North Coast System*; Umgeni Water: Pietermaritzburg, South Africa, 2019; p. 116.
52. Govender, S. An Investigation of the Natural and Human Induced Impacts on the Umdloti Catchment. Ph.D. Thesis, University of KwaZulu, Durban, South Africa, 2009.
53. Umgeni Water. *Infrastructure Master Plan 2019/2020-2049/2050, Volume 4: South Coast System*; Umgeni Water: Pietermaritzburg, South Africa, 2019; p. 116.
54. Mwelase, L.T. Non-Revenue Water: Most Suitable Business Model for Water Services Authorities in South Africa: Ugu District Municipality. Ph.D. Thesis, Durban University of Technology, Durban, Republic of South Africa, 2016.
55. Pegram, G.; Görgens, A. *A Guide to Non-Point Source Assessment: To Support Water Quality Management of Surface Water Resources in South Africa (WRC Project No. 696/2/01)*; Water Research Commission: Cape Town, Republic of South Africa, 2001; p. 127.
56. Ochieng, G.M. Hydrological and water quality modelling of the Upper Vaal water management areas using a stochastic mechanistic approach. Ph.D. Thesis, Tshwane University of Technology, Pretoria, South Africa, 2007.
57. Bogart, S.J.; Woodman, S.; Steinkey, D.; Meays, C.; Pyle, G.G. Rapid changes in water hardness and alkalinity: Calcite formation is lethal to Daphnia magna. *Sci. Total Environ.* **2016**, *559*, 182–191. [CrossRef]
58. Beyene, G.; Aberra, D.; Fufa, F. Evaluation of the suitability of groundwater for drinking and irrigation purposes in Jimma Zone of Oromia, Ethiopia. *Groundw. Sustain. Dev.* **2019**, *9*, 100216. [CrossRef]

59. Fan, A.M. Nitrate and Nitrite in Drinking Water: A Toxicological Review. *Encycl. Environ. Health* **2011**, 137–145. [CrossRef]
60. Serio, F.; Miglietta, P.P.; Lamastra, L.; Ficocelli, S.; Intini, F.; De Leo, F.; De Donno, A. Groundwater nitrate contamination and agricultural land use: A grey water footprint perspective in Southern Apulia Region (Italy). *Sci. Total Environ.* **2018**, *645*, 1425–1431. [CrossRef] [PubMed]
61. Espejo-Herrera, N.; Cantor, K.P.; Malats, N.; Silverman, D.T.; Tardón, A.; García-Closas, R.; Serra, C.; Kogevinas, M.; Villanueva, C.M. Nitrate in drinking water and bladder cancer risk in Spain. *Environ. Res.* **2015**, *137*, 299–307. [CrossRef]
62. Sadler, R.; Maetam, B.; Edokpolo, B.; Connell, D.; Yu, J.; Stewart, D.; Park, M.J.; Gray, D.; Laksono, B. Health risk assessment for exposure to nitrate in drinking water from village wells in Semarang, Indonesia. *Environ. Pollut.* **2016**, *216*, 738–745. [CrossRef]
63. Shah, K.A.; Joshi, G.S. Evaluation of water quality index for River Sabarmati, Gujarat, India. *Appl. Water Sci.* **2017**, *7*, 1349–1358. [CrossRef]
64. Robert, E.; Grippa, M.; Kergoat, L.; Pinet, S.; Gal, L.; Cochonneau, G.; Martinez, J.-M. Monitoring water turbidity and surface suspended sediment concentration of the Bagre Reservoir (Burkina Faso) using MODIS and field reflectance data. *Int. J. Appl. Earth Obs. Geoinf.* **2016**, *52*, 243–251. [CrossRef]
65. Uncles, R.J.; Hooper, T.; Stephens, J.A.; Harris, C. Seasonal variability of turbidity, salinity, temperature and suspended chlorophyll in a strongly tidal sub-estuary: The Lynher Marine Conservation Zone. *Estuar. Coast. Shelf Sci.* **2018**, *212*, 253–264. [CrossRef]
66. Andrade, C.; Alcântara, E.; Bernardo, N.; Kampel, M. An assessment of semi-analytical models based on the absorption coefficient in retrieving the chlorophyll-a concentration from a reservoir. *Adv. Space Res.* **2019**, *63*, 2175–2188. [CrossRef]
67. Hashim, K.S.; Al Khaddar, R.; Jasim, N.; Shaw, A.; Phipps, D.; Kot, P.; Pedrola, M.O.; Alattabi, A.W.; Abdulredha, M.; Alawsh, R. Electrocoagulation as a green technology for phosphate removal from river water. *Sep. Purif. Technol.* **2019**, *210*, 135–144. [CrossRef]
68. Omwene, P.I.; Kobya, M.; Can, O.T. Phosphorus removal from domestic wastewater in electrocoagulation reactor using aluminium and iron plate hybrid anodes. *Ecol. Eng.* **2018**, *123*, 65–73. [CrossRef]
69. Rankinen, K.; Cano Bernal, J.E.; Holmberg, M.; Vuorio, K.; Granlund, K. Identifying multiple stressors that influence eutrophication in a Finnish agricultural river. *Sci. Total Environ.* **2019**, *658*, 1278–1292. [CrossRef]
70. Abrahão, R.; Carvalho, M.; da Silva, W., Jr.; Machado, T.; Gadelha, C.; Hernandez, M. Use of index analysis to evaluate the water quality of a stream receiving industrial effluents. *Water Sa* **2007**, 33. [CrossRef]
71. Rabee, A.M.; Al-Fatlawy, Y.F.; Nameer, M. Using pollution load index (PLI) and geoaccumulation index (I-Geo) for the assessment of heavy metals pollution in Tigris river sediment in Baghdad Region. *Al-Nahrain J. Sci.* **2011**, *14*, 108–114. [CrossRef]
72. Rubio-Arias, H.; Contreras-Caraveo, M.; Quintana, R.M.; Saucedo-Teran, R.A.; Pinales-Munguia, A. An overall water quality index (WQI) for a man-made aquatic reservoir in Mexico. *Int. J. Environ. Res. Public Health* **2012**, *9*, 1687–1698. [CrossRef]