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Comparative Assessment of Coastal Water Usage Supports Using Water Quality Indices and Fuzzy Synthetic Evaluation Methods: A Case Study of Ondo State Estuary, Nigeria

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ABSTRACT

The ability of water quality indices and fuzzy synthetic evaluation methods to combine large and technical water quality data into a single value that could help understand and communicate the status of water bodies and their usage supports for policy formulation is revealed by this study. Three water quality indices and two fuzzy synthetic evaluation methods were used to assess the usage support of Ondo estuarine water and the results compared. The indices revealed that the sites distant to the estuarine discharge point improved in quality and support uses than the ones nearer. Desalination of such will further improve is usage support. Anthropogenic activities are negatively affecting the quality of the environment and need to be managed if good quality water will be made available for economic uses and the vast aquatic life resources in the estuary and the neighbouring Atlantic Ocean will not be adversely affected.

Keywords: fuzzy synthetic evaluation, estuary, usage supports, water quality indices
Abbreviations: FSE, fuzzy synthetic evaluation; **FSM**, fuzzy similarity method; **SFC**, simple fuzzy classification; **WQI**, water quality index

INTRODUCTION

The availability of good quality water for various human uses is being limited by the distribution of water in the hydrosphere and serious effects of pollution of the water bodies by both natural and anthropogenic activities (van Loon and Duffy 2004). Lean *et al.* (1990) reported that the distribution of water across the hydrosphere is 97% in the ocean and 3% freshwater, making the coastal water of much significance to water supply. Of the 3% freshwater, only 1% is accessible surface water. The rest are: groundwater 20% of the freshwater; polar ice caps and glaciers (79%). Thus, man is limited in access to portable water by the distribution of water on earth beside the availability problem caused by the contamination of the water bodies. Discharge of waste products from human activities and the multiplier effects have lead to water scarcity, human health problems, extinction of biodiversity species, environmental degradation, hunger and poverty.

There is therefore a growing scarcity and increasing competition for water across sectors. Water, the most abundant resource on earth, is very important for the economic development of a nation and non-availability of good quality water is the cause of 80% of all diseases reported reducing human productivity and development (UNESCO 1983; Keating 1993; De Carlo 2004; Ilyina *et al.* 2006). It has also been reported that over three-quarter of the total population in the developing countries lack assess to clean and safe water (UNESCO 1983; UNEP 1993; Ilyina *et al.* 2006; Loos *et al.* 2010).

The various identified uses of water by man are drinking and other domestic uses; irrigation and livestock farming; industrial and recreation uses among others. Likewise, there are lots of resources in the water bodies (e.g. aquatic lives) which are of high importance and economic value to man. These identified uses and valuable resources are negatively affected by various pollutants used by man and discharged into the environment. The environment being made up of complex compartments interact leading to transport of these pollutants from one compartment of the environment to the other. The transportation of pollutants into the aquatic environment compromises its quality and creates risk of accumulation or magnification of these pollutants in living tissues or organisms in the food web increasing health risk in human.

Thus, evaluation of the extent of impairment of water system and effective communication of such to avoid unnecessary alarm to the public on the state of the environment is imperative. However, traditional reports presented on qualities of water from monitoring and research activities are too technical and detailed for this purpose, for the general public to understand, and for formulation of policies. They present monitoring data on individual concentration of substances, without providing a whole and interpreted picture of water quality. Thus, water quality index was designed by US National Sanitation Foundation using the Delphi technique as assessment tool to bridge this gap (Chang *et al.* 2001). Subsequently, various modified indices have been developed to integrate water quality variables worldwide (Dojlido *et al.* 1994; Heinonen and Herve 1994; SAFE 1995; Suvarna and Somashekar 1997; Cude 2001; Liou *et al.* 2004; Said *et al.* 2004; Debels *et al.* 2005; Sánchez *et al.* 2007) but with disputing acceptability.

Water Quality Index (WQI) was an important and promising tool for summarizing large data on water quality for effective communication with the public and agencies for actions. Though, no single WQI is found to have general acceptance, it is useful in comparing between water bodies, studying trends in water quality at different points in a water body; pinpointing the area with significant impairment in quality which could then be further investigated; and evaluating the usage support of the water from water

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body (Bhargava 1983; Costa *et al.* 1985).

However, discrepancies often arise in the use of WQI for lack of clear distinctions between each mode, diversity in the quality parameter employed for each usage and the imprecision, vagueness, or fuzziness of output values for decision-making (Chang *et al.* 2001). WQI and other similar indices exhibit a number of weak points like assignments of a quality values based on the use of limited number of parameters and crisp set. Most indices were proposed without consideration for parameters like heavy metals, hydrocarbons, or pesticides while some parameters in the index equations can significantly affect the final score with false justification using a rather elementary and limited number of variables. Moreover, another critical deficiency of these indices is the lack of dealing with fuzziness at boundaries of regulatory standards, inability to handle uncertainty and subjectivity present by complex environmental problems (Silvert 2000; Chang *et al.* 2001; Mpimpas *et al.* 2001; Ocampo-Duque *et al.* 2006; Agunbiade *et al.* 2012). Hence, there is a need for more appropriated techniques to manage water quality variables, for interpretations of parameters among others. Thus, some alternative methodologies are emerging from artificial intelligence. These methodologies: fuzzy logic and fuzzy sets, conceived and reported by Zadeh (1965) and are being applied to environmental problems with the aim of reducing the uncertainty and imprecision in quality criteria employed in decision-making tools (Chang *et al.* 2001; McKone and Deshpande 2005; Icaga 2007).

Therefore, the objective of this study was to comparatively assess the usage supports of coastal waters with the use of water quality indices and fuzzy synthetic evaluation (FSE) methods using Ondo estuary area as the case study. The choice of the usage support studies in the water body is based on the economic activities of the area and the perceived usage to which coastal waters could be subjected to generally. The results will indicate usage supports of the coastal water, the variations of water quality among sites as a measure of level of impairment and indicate area for attentions. Also, the appropriateness and effectiveness of the tools employed will be compared with each other.

THEORETICAL PRINCIPLES

Water quality indices principle

Generally, WQI index is calculated from 9 parameters: dissolved oxygen (0.17), faecal coliforms (0.16), biochemical oxygen demand (0.11), pH (0.11), temperature change (0.1), phosphates (0.10), nitrates (0.10), turbidity (0.08), and total solids (0.07) with the weight factors given in parentheses according to the importance of the parameters (Ocampo-Duque *et al.* 2006). Important requirement considerations for the WQI proposal were reported by Bhargava (1983) and Dinus (1987). The methods we have adopted to compute WQI are the Arithmetic Index (Landwehr and Deininger 1976; Bolton *et al.* 1978; Costa *et al.* 1985), the Solway Index (Bolton *et al.* 1978) and the Geometric Index (Landwehr and Deininger 1976; Bolton *et al.* 1978).

Several modifications have been made to the choice of parameters included in the formulation of WQI based on uses to which the index is proposed and the effect of such parameters on the uses. The choice of parameters, the weight factors, and the modifications to the general parameters used in index formulation were based on the widely reported effects of these parameters on uses and observed activities on the field. The parameters used in formulating WQI and the revised weight factors used in this study are presented in **Table 1**. The weight of total solids is significantly reviewed upward because of uses to which the coastal water is considered for and the impacts that tidal wave incursion of saline water have on dissolved solids and suspension of bottom sediment which thus increase the suspended solids both measured as total solids.

Table 1 Weight used for water quality index.

Parameter	Weight (NSF)	Revised weight (this study)
DO	0.17	0.20
BOD_5	0.11	0.15
pH	0.11	0.15
Temperature	0.10	0.10
Total phosphate	0.10	0.10
Nitrate	0.10	0.10
FC	0.16	-
Turbidity	0.08	-
Total solids	0.07	0.20

The expressions for the calculations were:

$$\text{ArithmeticIndex (AI)} \quad WQI = \sum_{i=1}^{n} q_i w_i \qquad (1)$$

$$\text{Solway Index (SI)} \quad WQI = \frac{1}{100}\left[\sum_{i=1}^{n} q_i w_i\right]^2 \qquad (2)$$

where w_i is the weight factor ($0 < w_i < 1$); q_i is the rating ($0 \le q_i \le 100$) given to the observed values of each i^{th} parameter measured per site, n is the total number of parameter, Σ denotes additive type of index. The weight factor w_i is expressed as $w_1 + w_2 + w_3 + \ldots + w_n = 1$. The Solway Index (equation 2) is the transformation of the Arithmetic Index (equation 1) by squaring it and dividing by a factor of 100. The Geometric Index (equation 3) was however determined by this expression:

$$\text{Geometric Index (GI)} \quad \prod_{i=1}^{n} q_i w_i \qquad (3)$$

The weight factor ranked as $0 < w_i < 1$ while q_i was ranked as $5 \le q_i \le 100$ and π is the multiplicative operator and the weight factor w_i summed up to 1 as in the case of AI and SI. The ratings of parameters (q) in the equations were done with strong consideration of WHO, USEPA, FEPA and others international standards for different water uses (USEPA 1993; WHO 2004). The limits used from regulatory standards are presented in **Table 2**.

Fuzzy synthetic evaluation principle

Fuzzy synthetic evaluation is based on fuzzy logic which deals with highly variable, linguistic, uncertain, and vague data or information and has been used to extract logical, reliable, systemic, and transparent information from such data collection for practical applications (Silvert 2000; McKone and Deshpande 2005). It is based on fuzzy set theory of Zadeh (1965) and expresses multiple level process between [0, 1] with a rule-based IF X AND Y THEN Z approach (Lu and Lo 2002; Ocampo-Duque *et al.* 2006; Icaga 2007). Fuzzy logic general approach to formulating environmental index can be carried out in six steps (**Fig. 1**).

The first step is the selection of the environmental media (i.e. soil, water sediment, plant, etc.) and the choice of relevant conventional parameters (e.g. dissolved oxygen - DO, biochemical oxygen demand - BOD, metals etc) need for the index formulation followed by the determination of the concentration of the parameters by chemical analysis to obtain the observed value. Second, the parameters are classified into i^{th} classes based on the observed values obtained from analysis and the limit set by regulatory bodies for each parameter (**Table 3**). The third step is to obtain membership function used to convert each parameter to fuzzy function. This involves that standardization of the natural measurement scale to the quality parameter based on the ith (which is five for this study) classifications earlier obtained using the equations (4 – 8) below. The limits used in the membership formulations (a, b, c, d, e) are based on the regulator standard limits in relation to the usage supports investigated (**Table 3**) where λ_a, λ_b, λ_c, λ_d, λ_e represent the membership function for the group classifications a, b, c, d, e, respectively; x represent the observed values from chemical analysis and a, b, c, d, e are the limits criteria for different classification in relation to usages based on regulatory standards for the parameters (**Table 3**).

Table 2 Water Quality Standards and Classification limits used to formulate WQI in this study based on WHO, EPA and FEPA standard for various usages.

Class Utility	Usages				
	I. Domestic	**II. Irrigation farming**	**III. Livestock farming**	**IV. Recreation**	**V. Aquatic life support**
DO (mg L^{-1})	> 6.5	> 5.0	> 3.0	> 6.5	> 5.0
BOD_5 (mg L^{-1})	< 10	< 20	< 10	< 10	< 20
pH	6.5 – 8.5	6.5 – 8.5	6.0 – 9.0	6.5 – 8.5	6.0 – 9.0
Temperature (°C)	25 – 30	25 – 30	25 – 30	27.5 – 30	20 – 30
Total Phosphate (mg L^{-1})	0.0 – 1.0	0.0 – 1.0	0.0 – 10.0	0.0 – 1.0	0.0 – 5.0
Nitrate (mg L^{-1})	0.0 – 0.5	0.0 – 2.0	0.0 – 2.0	0.0 – 1.0	0.0 – 5.0
Total solids (mg L^{-1})	< 500	< 1500	< 2500	< 2500	< 5000

DO – Dissolved oxygen, BOD – Biochemical oxygen demand

Table 3 Limit for each classification membership function used for fuzzy synthetic evaluation.

Parameters	Units	The parameter limits for the membership function classes*				
		High Support	**b. Moderate Support**	**c. Impacted**	**d. Highly Impacted**	**e. Non Support**
Temperature	°C	20	25	27.5	30	35
pH ≥ 7		7.0	7.5	8.0	8.5	9.0
pH < 7		7.0	6.5	6.0	5.5	5.0
T. Solids	mg L^{-1}	250	500	1000	1500	2000
DO*	mg L^{-1}	8.0	6.0	5.0	4.0	3.0
BOD	mg L^{-1}	2.0	5.0	10.0	15.0	20.0
Nitrate	mg L^{-1}	0.2	0.5	1.0	2.0	2.5
Phosphate	mg L^{-1}	0.2	0.5	1.0	2.0	2.5
Chloride	mg L^{-1}	100	250	500	750	1000
Sulphate	mg L^{-1}	100	250	500	750	1000
Mg	mg L^{-1}	100	250	500	750	1000
Ca	mg L^{-1}	50	100	250	500	750
As	µg L^{-1}	10	50	100	150	200
Pb	µg L^{-1}	10	50	100	500	1000
Co	µg L^{-1}	50	100	500	500	1000

* The limits of dissolved oxygen were in reverse order because high quantity of it is desirable for good water quality.

$$\lambda_a = \begin{cases} 1 & \text{when } 0 \le x \le a \\ \frac{(b - x)}{(b - a)} & \text{when } a < x < b \\ 0 & \text{when } x \ge b \end{cases} \qquad 4$$

$$\lambda_b = \begin{cases} 0 & \text{when } x \le a \text{ or } x \ge c \\ \frac{(x - a)}{(b - a)} & \text{when } a < x < b \\ 1 & \text{when } x = b \\ \frac{(c - x)}{(c - b)} & \text{when } b < x < c \end{cases} \qquad 5$$

$$\lambda_c = \begin{cases} 0 & \text{when } x \le b \text{ or } x \ge d \\ \frac{(x - b)}{(c - b)} & \text{when } b < x < c \\ 1 & \text{when } x = c \\ \frac{(d - x)}{(d - c)} & \text{when } c < x < d \end{cases} \qquad 6$$

$$\lambda_d = \begin{cases} 0 & \text{when } x \le c \text{ or } x \ge e \\ \frac{(x - c)}{(d - c)} & \text{when } c < x < d \\ 1 & \text{when } x = d \\ \frac{(e - x)}{(e - d)} & \text{when } d < x < e \end{cases} \qquad 7$$

$$\lambda_e = \begin{cases} 0 & \text{when } x \le d \\ \frac{(x - d)}{(e - d)} & \text{when } d < x < e \\ 1 & \text{when } x \ge e \end{cases} \qquad 8$$

The fourth step involves the arrangement of the membership function of the quality observed into evaluation matrix (R) and the application of fuzzy operators (Agunbiade *et al.* 2011):

$$R = \begin{bmatrix} \lambda_{11} & \lambda_{12} \cdots \lambda_{1m} \\ \lambda_{21} & \lambda_{22} \cdots \lambda_{2m} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \lambda_{n1} & \lambda_{n2} \cdots \lambda_{nm} \end{bmatrix} \qquad (9)$$

The operators in FSE are simple fuzzy classification (SFC), fuzzy similarity method (FSM), fuzzy comprehensive assessment (FCA), fuzzy information intensity and defuzzification (details in Chang *et al.* 2002; Lu and Lo 2002; Haiyan 2002; Onkal-Engin 2004). SFC and FSM are briefly described below for use in this case study.

Simple fuzzy classification (SFC)

This method utilises the development of membership functions according to water quality classifications using equations (4) – (8). From the membership function the possible overlap (fuzziness) is accounted for. The fuzzy membership is used to form a relationship between the observed data and the water quality index through an evaluation matrix R (equation 9). R is subjected to any fuzzy reasoning method. The fuzzy reasoning used in this study is the distance operator expressed by equations 10-12:

$$k_j = \left[\frac{\sum_{i=1}^{m} \left(w_i \lambda_{ij}\right)^2}{\sum_{i=1}^{m} \sum_{i=1}^{m} \left(w_i \lambda_{ij}\right)^2} \right]^{1/2} \qquad (10)$$

$$\sum_{i=n}^{n} w_i = 1 \qquad (11)$$

$$k_p = 100\, max\{k_j\} \qquad (12)$$

k_j are the corresponding support results obtained from the operator while k_p is the final class to which the environment belong. Equation 12 has a multiplication of the

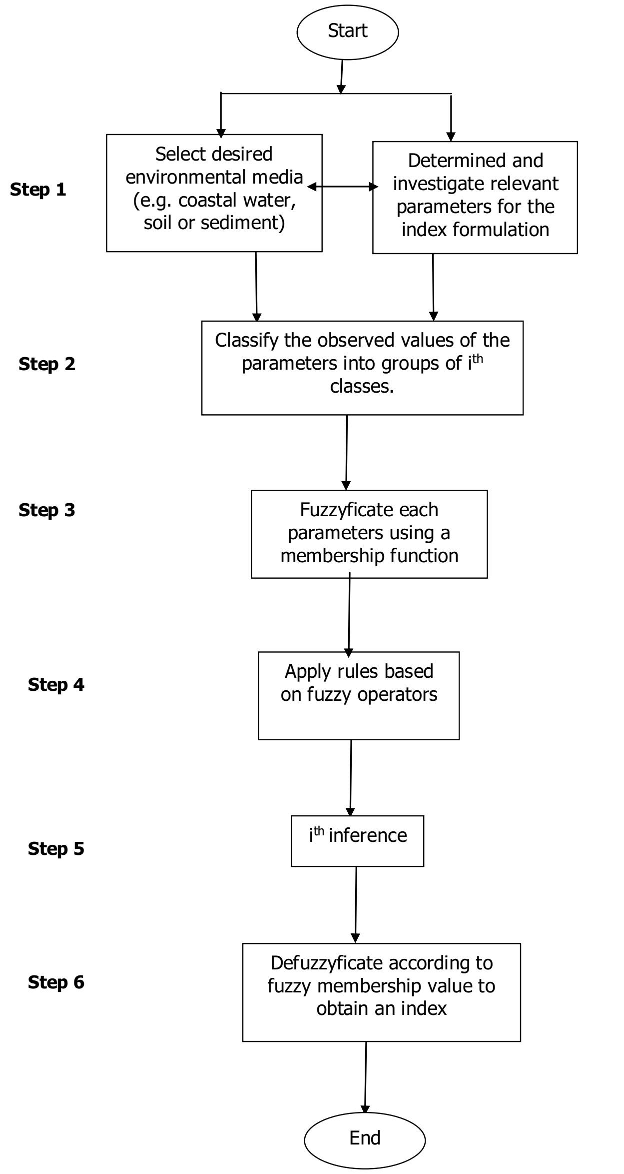

Fig. 1 Generalized analytical procedure for fuzzy logic evaluation of environmental media.

$\max\{k_j\}$ by a factor of 100 to get a crispy value comparable with the WQI.

The choice of appropriate weight (w_i) for the parameters which defines the importance of the parameter and its influence on the final output is made by varying methods. Analytical Hierarchy Process–Singular Value Decomposition (AHP-SVD) proposed by Gass and Rapesak (2004) was used in this study (see Ocampo-Duque *et al.* 2006). The resultant weights obtained for the 14 parameters used in the FSE evaluations are: {w_{DO} (0.173); w_{BOD} (0.111); w_{pH} (0.038); w_{temp} (0.033); w_{Phosp} (0.047); $w_{Nitrate}$ (0.066); w_{TS} (0.132); w_{Cl} (0.070); $w_{Sulphate}$ (0.070); w_{Mg} (0.055); w_{Ca} (0.068); w_{Co} (0.032); w_{As} (0.049); w_{Pb} (0.056)}.

Fuzzy similarity method (FSM)

Fuzzy similarity method employees the step of normalizing all quality criteria (**Table 3**) into independent membership function where the lowest criteria is appointed 0 and the highest is appointed 1 while the others in between are given membership function between 0 and 1. The independent membership function is then arranged into matrix R' (equation 13) corresponding to the arrangement of the evaluation matrix R (equation 9).

$$R' = \begin{bmatrix} \lambda'_{11} & \lambda'_{12} \cdots \lambda'_{1m} \\ \lambda'_{21} & \lambda'_{22} \cdots \lambda'_{2m} \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \\ \lambda'_{n1} & \lambda'_{n2} \cdots \lambda'_{nm} \end{bmatrix} \quad (13)$$

The relationship (similarity) between the two matrices is derived by any of Hamming, Euclid or Minkowski distance and their corresponding proximities or by fuzzy proximity (see Chang *et al.* 2001). The Euclidean distance method used in this study is expressed as:

$$e(A, A') = \left[\sum_{i=1}^{n} \left|\lambda_A(x_i) - \lambda'_A(x_i)\right|^2\right]^{1/2} \quad (14)$$

$$\varepsilon(A, A') = \frac{e(A, A')}{\sqrt{m}} \quad (15)$$

$$\text{Euclid proximity} = 100[1 - \varepsilon(A, A')] \quad (16)$$

The results obtained from the proximity with the maximum value among the several classes of usage support are multiplied by 100 to defuzzify and such define the usage supports and its degree for each usage

MATERIALS AND METHODS

Sample area, sampling and analysis

The coastal region of Ondo State (Lat. 5° 50′ N - 6° 09′ N and Long. 4° 30′ E - 5° 5′ E) was the site of study. It has a population size which is above 20% of the total population of the state. It is among the oil belt region of Nigeria (Niger-Delta region) where crude oil exploration is going on. It is between the Lagos coast with very high population density and industrial activities and the Delta coast where there is higher volume of crude oil exploration. There are several small settlements scattered around the coast making motorboat traffic of goods and persons intensive. The coast consists of rivers and streams which traverse over 110 km^2 of land space and different settlements and drain into the Ocean (Bright of Benin, Atlantic Ocean). Ten sampling points were selected for the study (**Fig. 2**). Samples were collected in the coast during the dry season in January 2007 because of the steady state condition during the season. The choice of sampling points was based on the economic activities in the area. All municipal and domestic wastes from the settlements are directly discharged into the sea. Site 1 (Ukua) host a crude oil exploration platform while site 2 (Awoye) is the estuary discharge point into the Atlantic Ocean which witnesses continual exchange of fresh and saline water into the coastal region. These two sites have been reported to contribute significantly to the introduction of metal contaminants into the coast (Adebowale *et al.* 2008a). Other sample sites are close to settlements at varying distances to the oil exploration and estuary discharge sites. Samples were collected in each of the sites for three classes of parameters. Samples for general parameters: total solids (TS), nitrate, phosphate, chloride and sulphate, were collected in plastic vessels and kept at 4°C prior to analysis while sample for metals (Mg, Ca, Co, As, Pb) analysis were also collected in plastic vessels and fixed with 1 ml conc. HNO_3 (Ultrex). The metals were analysed with Flame Atomic Absorption Spectrometer (AAS) Buck Scientific 205 Model (Buck Scientific Inc, East Norwalk, CT 06855) with direct air-acetylene flame method. Dissolved oxygen samples were taken into quick fit glass bottles and fixed with Winkler's reagents and analysed within 8 h from sample collection time. Temperature and pH were measured on the field while other parameters were analysed as specified by Standard Methods for Examination of Water and Wastewater (APHA 1995). All analyses were carried out in triplicate and the mean ± standard deviation presented.

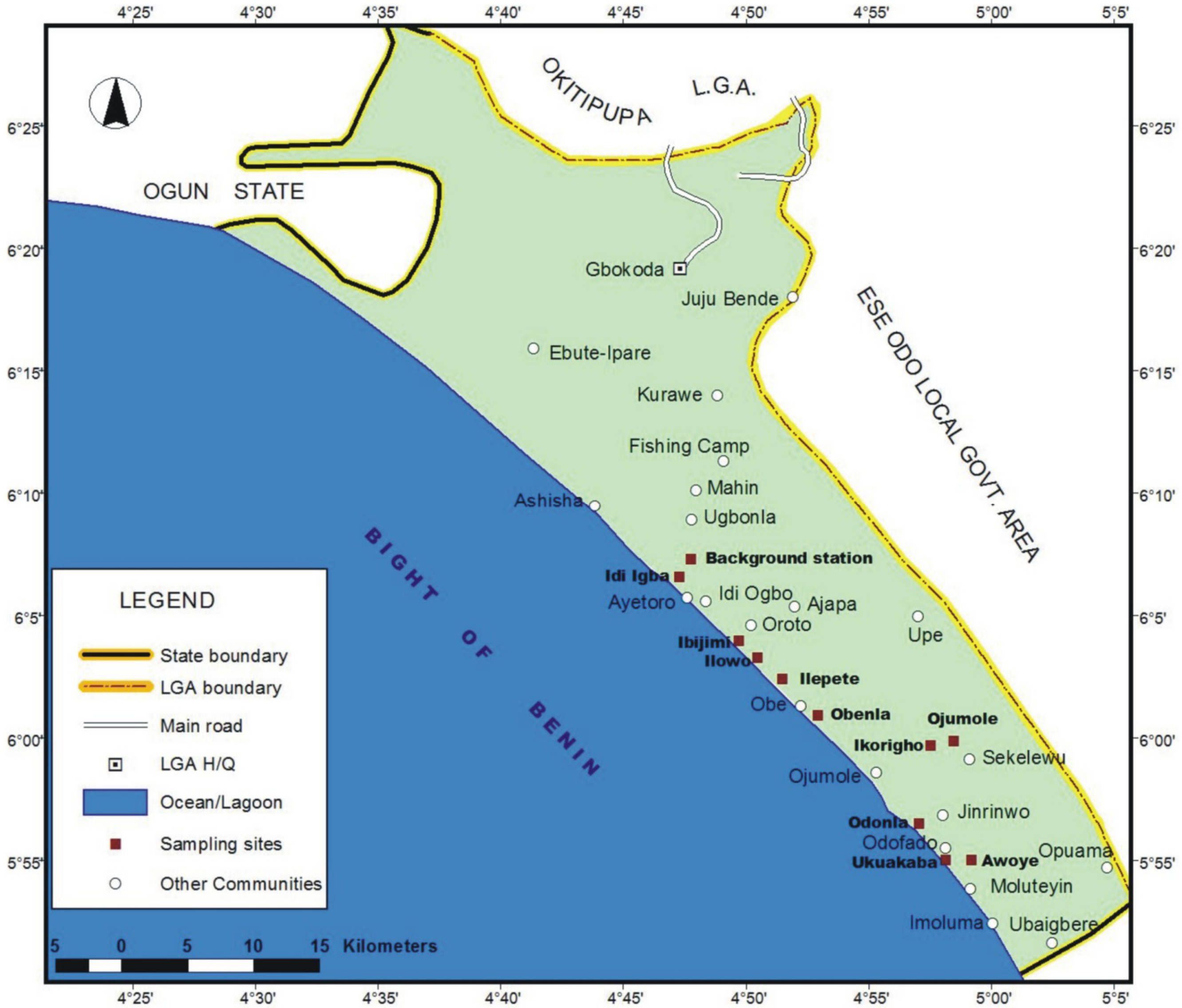

Fig. 2 Map of the Coastal Area of Ondo State and the sampling points.

Table 4 Outcome of sampling and chemical analysis of Ondo coastal water.

Sampling sites	DO (mgL^{-1})	BOD_5 (mgL^{-1})	pH	Temp (°C)	T. Phos. (μgL^{-1})	Nitrate (μgL^{-1})	T. solids (%)
Ukuakaba	6.5 ± 0.4	5.0 ± 0.4	5.0 ± 0.1	28.5	106 ± 1.5	383 ± 5.6	3.1 ± 0.05
Awoye	7.0 ± 0.6	12.5 ± 0.7	9.1 ± 0.2	29.0	155 ± 2.5	306 ± 6.7	3.4 ± 0.02
Odonla	5.0 ± 0.4	7.8 ± 0.5	8.5 ± 0.1	29.0	115 ± 3.5	306 ± 5.4	3.1 ± 0.02
Ikorigho	4.5 ± 0.3	3.8 ± 0.4	9.3 ± 0.3	29.5	88 ± 3.2	230 ± 4.2	3.1 ± 0.03
Ojumole	4.0 ± 0.4	1.3 ± 0.2	9.7 ± 0.3	29.5	74 ± 2.6	383 ± 5.4	2.7 ± 0.04
Obenla	3.5 ± 0.3	5.7 ± 0.3	9.5 ± 0.2	29.0	81 ± 4.8	332 ± 4.9	1.9 ± 0.01
Ilepete	4.0 ± 0.2	6.3 ± 0.5	8.9 ± 0.3	29.5	66 ± 3.6	230 ± 5.8	1.5 ± 0.01
Ilowo	4.0 ± 0.5	14.5 ± 0.7	9.1 ± 0.4	29.5	71 ± 2.9	179 ± 8.7	1.1 ± 0.02
Ibijinmi	5.5 ± 0.7	10.0 ± 0.6	8.7 ± 0.1	29.0	55 ± 1.8	102 ± 5.1	0.7 ± 0.01
Idi Ogba	4.5 ± 0.5	5.0 ± 0.4	8.4 ± 0.2	28.5	59 ± 2.4	77 ± 4.2	0.1 ± 0.01

Sampling sites	Chloride (%)	Sulphate (mgL^{-1})	Mg (mgL^{-1})	Ca (mgL^{-1})	Co (mgL^{-1})	As (μgL^{-1})	Pb (mgL^{-1})
Ukuakaba	1.8 ± 0.01	4430 ± 10	1026 ± 6	354 ± 4.6	1.2 ± 0.04	28 ± 0.5	2.3 ± 0.02
Awoye	1.9 ± 0.02	6058 ± 12	969 ± 7	359 ± 3.8	1.0 ± 0.03	36 ± 0.8	1.9 ± 0.03
Odonla	1.7 ± 0.01	5334 ± 7	1004 ± 6	367 ± 2.8	1.1 ± 0.05	20 ± 0.9	2.3 ± 0.05
Ikorigho	1.5 ± 0.01	5244 ± 10	998 ± 5	377 ± 4.5	1.0 ± 0.03	28 ± 1.1	1.9 ± 0.07
Ojumole	1.3 ± 0.02	5628 ± 11	1011 ± 7	375 ± 4.9	0.9 ± 0.04	32 ± 0.8	1.9 ± 0.06
Obenla	0.9 ± 0.01	4521 ± 8	1017 ± 4	378 ± 5.2	1.2 ± 0.05	40 ± 1.2	1.5 ± 0.04
Ilepete	0.8 ± 0.01	3752 ± 9	1011 ± 8	370 ± 3.5	1.1 ± 0.04	36 ± 0.7	1.5 ± 0.03
Ilowo	0.6 ± 0.01	2486 ± 7	1001 ± 10	357 ± 2.8	1.0 ± 0.02	24 ± 0.5	1.9 ± 0.10
Ibijinmi	0.5 ± 0.01	1763 ± 7	995 ± 8	359 ± 5.1	1.0 ± 0.03	32 ± 0.9	1.5 ± 0.08
Idi Ogba	0.1 ± 0.00	362 ± 4	969 ± 6	362 ± 4.1	1.0 ± 0.05	42 ± 1.3	1.9 ± 0.11

RESULTS AND DISCUSSION

The outcomes of the chemical analysis of all investigated parameters in the coastal water are presented in **Table 4**. The coastal water's usage potential is negatively impacted by exchange of saline water from the Ocean which is indicated by the high values obtained for the total solids, chloride and sulphate. These values were highest at Awoye,

Table 5 Proposed classification ranges of Water Quality Index (WQI).

WQI Range	Classification	WQI Range	Classification
95.0 – 100	A+	55.0– 59.9	C-
90.0 – 94.9	A	50.0 – 54.9	D+
85.0 – 89.9	A-	45.0 – 49.9	D
80.0 – 84.9	B+	40.0 – 44.9	D-
75.0 – 79.9	B	35.0 – 39.9	E+
70.0 – 74.9	B-	30.0 – 34.9	E
65.0 – 69.9	C+	25.0 – 29.9	E-
60.0 – 64.9	C	< 25	F

Table 6 Results of Water Quality Indices obtained for domestic usages.

Site	WQI	Usages	Site	WQI	Usages
		Domestic			Domestic
Ukua	AI	C	Obenla	AI	D+
	SI	E+		SI	E-
	GI	D-		GI	D
	SFC	D+		SFC	D-
	FSM	C		FSM	C
Awoye	AI	C-	Ilepete	AI	C-
	SI	E		SI	E
	GI	D-		GI	D+
	SFC	D-		SFC	E+
	FSM	C		FSM	C-
Odonla	AI	C-	Ilowo	AI	C-
	SI	E		SI	E
	GI	D-		GI	C-
	SFC	E		SFC	E+
	FSM	C-		FSM	D+
Ikorigho	AI	C-	Ibijinmi	AI	C
	SI	E		SI	D-
	GI	D-		GI	C
	SFC	E		SFC	C-
	FSM	D+		FSM	C
Ojumole	AI	C-	Idi Ogba	AI	B-
	SI	E		SI	D+
	GI	D-		GI	B-
	SFC	D-		SFC	C-
	FSM	D+		FSM	B-

Abbreviations: Arithmetic index (AI), Fuzzy Similarity Method (FSM), Geometric Index (GI), Simple Fuzzy Classification (SFC), Solway Index (SI)

which is the discharge point into the Ocean and gradually decrease as the distance increases away from the discharge site until a sharp decrease observed at Idi Ogba, the farthest site to the estuary discharge point surveyed. Mouths of estuary have been widely reported to possess higher level of contaminants than any other parts of the estuary because of contaminants' deposition from runoffs, *trans*-boundary movement of contaminants and changes in environmental conditions which affect the water chemistry (Elbaz-Poulichet *et al.* 1984; Guieu *et al.* 1998; Ip *et al.* 2006). Thus, desalination of the water from the coast along with other management policies could improve on its quality and usages. The supports of the water for five usages are thus proposed and classified into ranges as presented in **Table 5**.

Domestic usage support

The evaluation of water for domestic usages support depicts a close relationship between AI and FSM evaluation methods (**Table 6**). The indices obtained for this usage by the two methods are relatively risk-loving ranging usage support between D+ and C classes for the first nine site while the tenth site (Idi Ogba) has B-. This result is comparable with that reported by Chang *et al*. (2001), who applied WQI and three different fuzzy logic-based indices (simple fuzzy classification, defuzzification and fizzy information intensity) to evaluate the water quality condition of Tseng-Wen River system in Taiwan. The finding of their study was comparable to this study in that it revealed B+ to D classification except in Feng-Lee Bridge (during Autumn) where A class was observed. The consideration of the coastal water for domestic uses does not include human consumption because of the high salinity and suspended particle in the water. However, the water quality of site 10 best support domestic uses while the other sites require some considerable level of improvement and treatment to increase the suitability for this usage. Discharge of domestic waste and impacts from crude-oil exploration are reported to affect the quality of water and sediment from this coast and could be responsible for the low usage support of the water (Adebowale *et al.* 2008a). 70% (B-) consideration would be a better level of improvement target for policy formulation and management plan if the water from this coast will significantly support domestic use.

Furthermore, the water quality indices obtained from SI, GI and SFC (**Table 6**) were risk-averse. The results about the quality of the water indicate that the coastal water is being significantly impacted by pollutants reducing its quality. SI expressed the highest pessimism, ranking the water quality between E- to E+ for the first eight sites and site 9 and 10 as D- and D+ respectively. The positive and negative signs are indication of increase in improvement and impact of each classification respectively. The quality indices obtained from SI, GI and SFC indicate a need for positive policy focus that will manage the increase of pollutants in the coastal water to improve on its quality and use for domestic activities especially in sites 1 to 9 where combination of anthropogenic and natural activities have been reported to impact negatively on the sites (Adebowale *et al.* 2008b).

Irrigation farming usage support

The support of Ondo coastal water for irrigation farming activities is better revealed by the result of FSM evaluation approach (**Table 7**) which indicate that the quality of the water support irrigation purpose. Nitrate and phosphate in irrigation water play positive role being nutrients to plants thus improving their support for this use. However, increase in Na (from saline water) concentration relatively to Ca and Mg will reduce infiltration, permeability of water in the soil and soil aeration through its effects on sodium adsorption ratio which is a relationship of these cations in irrigation water (Wilcox and Durum 1967). This negatively affects the use of such water. Likewise, the high concentration of the associated ion (Cl^-) causes leaf burn and chlorosis (Environmental Canada 1987). Thus, increase in salinity will reduce estuarine water usage support for irrigation. The other indices obtained from AI, GI SI, and SFC are more risk-averse about the support of the coastal water for irrigation usage indicating the effect of the oceanic salty water incursion on this usage. The results of SI and SFC expressed lower results for usage supports about the water quality with gradual improvement from site 6 – 10 which indicate that any improvement policy targeted at remediation of water from site 6 – 10, where solids and chloride concentration are reducing, could significantly ensure their usage support for irrigation farming. The presence of *Eichornia crassipes* in this part of the coast and its reported potential to extract metals for phytoremediation purpose confirms this result (Agunbiade *et al*. 2009). Thus, the water from the estuary, especially as the distance increased from the discharge point demonstrate better potential for irrigation usage than domestic utility with remediation potential through the natural occurring seed weed which is improving the usage support.

Livestock farming usage support

Increase in parameters like sulphate induces deficiency of trace and essential elements in water and induces diarrhoea in young animals while nitrate reduces conception rate and excess dissolved solids cause physiological disorder (Environmental Canada 1987). Thus, increase in these parameters reduces the usage support of the water system for livestock watering. Therefore, the evaluation of the water quality was made considering the contributions of these parameters. The

Table 7 Results of Water Quality Indices obtained for irrigation farming.

Site	WQI	Usages Irrigation Farming	Site	WQI	Usages Irrigation Farming
Ukua	AI	C	Obenla	AI	D+
	SI	E+		SI	E
	GI	D-		GI	D
	SFC	D		SFC	D-
	FSM	B-		FSM	C
Awoye	AI	C-	Ilepete	AI	D+
	SI	E		SI	E
	GI	D-		GI	D
	SFC	E+		SFC	D-
	FSM	B		FSM	C+
Odonla	AI	C-	Ilowo	AI	D+
	SI	E		SI	E
	GI	D-		GI	D
	SFC	E+		SFC	D
	FSM	C+		FSM	B-
Ikorigho	AI	D+	Ibijinmi	AI	C-
	SI	E-		SI	E+
	GI	E+		GI	C-
	SFC	D-		SFC	C-
	FSM	B-		FSM	B
Ojumole	AI	D+	Idi Ogba	AI	C+
	SI	E-		SI	D
	GI	D-		GI	C+
	SFC	E+		SFC	B-
	FSM	C+		FSM	B-

Abbreviation: Arithmetic index (AI), Fuzzy Similarity Method (FSM), Geometric Index (GI)
Simple Fuzzy Classification (SFC), Solway Index (SI)

Table 8 Results of Water Quality Indices obtained for Livestock farming.

Site	WQI	Usages Livestock Farming	Site	WQI	Usages Livestock Farming
Ukua	AI	D+	Obenla	AI	D+
	SI	E-		SI	E-
	GI	D-		GI	D
	SFC	E		SFC	E+
	FSM	C-		FSM	C-
Awoye	AI	D+	Ilepete	AI	D+
	SI	E-		SI	E
	GI	E+		GI	D+
	SFC	E-		SFC	E+
	FSM	C-		FSM	C-
Odonla	AI	D+	Ilowo	AI	D+
	SI	E-		SI	E-
	GI	D-		GI	D+
	SFC	C-		SFC	D
	FSM	C-		FSM	C-
Ikorigho	AI	D+	Ibijinmi	AI	C
	SI	E-		SI	E+
	GI	D-		GI	C-
	SFC	E		SFC	D+
	FSM	C-		FSM	C
Ojumole	AI	D+	Idi Ogba	AI	B-
	SI	E		SI	D
	GI	D		GI	C+
	SFC	E		SFC	C
	FSM	C-		FSM	C+

Abbreviation: Arithmetic index (AI), Fuzzy Similarity Method (FSM), Geometric Index (GI), Simple Fuzzy Classification (SFC), Solway Index (SI)

results obtained from FSM and AI correlate with each other and show a higher degree of support that other methods. FSM ranked water from sites 1 to 8 as C- while AI ranked the same as D+ with improvement at sites 9 and 10 (**Table 8**). The increased distance of site 9 and 10 from the contamination sources and the positive biogeochemical reactions there improve their support for most uses. This improvements witnessed at sites 9 and 10 were similar to earlier observations and other reported studies (Adebowale *et al*. 2008a, 2008b, 2009). These indices however show lower level of supports than the earlier two usages reported. The increase in sulphate concentration plays a significant role in reducing the support of the water for this usage while the nitrate concentration plays a relatively moderate role. The sulphate and solids are at the extreme and need to be managed to support livestock farming.

Table 9 Results of Water Quality Indices obtained for Recreational usages.

Site	WQI	Usages Recreation	Site	WQI	Usages Recreation
Ukua	AI	C+	Obenla	AI	C
	SI	D		SI	D-
	GI	C+		GI	C
	SFC	F		SFC	E+
	FSM	E		FSM	E+
Awoye	AI	C+	Ilepete	AI	C+
	SI	D		SI	D
	GI	C+		GI	C+
	SFC	F		SFC	C
	FSM	E+		FSM	E
Odonla	AI	C+	Ilowo	AI	C+
	SI	D		SI	D-
	GI	C+		GI	C
	SFC	F		SFC	C-
	FSM	E		FSM	E
Ikorigho	AI	C+	Ibijinmi	AI	B-
	SI	D		SI	D+
	GI	C+		GI	B-
	SFC	E		SFC	E+
	FSM	E+		FSM	C
Ojumole	AI	C+	Idi Ogba	AI	B
	SI	D-		SI	C
	GI	C		GI	B
	SFC	C		SFC	C
	FSM	E+		FSM	C-

Abbreviation: Arithmetic index (AI), Fuzzy Similarity Method (FSM), Geometric Index (GI), Simple Fuzzy Classification (SFC), Solway Index (SI)

Overall, the evaluation results for livestock watering application obtained from SI, GI and SFC depicts a worse situation than the earlier methods except in rare situations. It could be concluded that the results of these latter methods with considered the weight, the effects of far distant parameters' concentrations on the quality index and are geometrically based are preferred especially SFC which considered along side others the fuzziness in boundaries. Therefore, this coastal water is not supporting usage for livestock watering in the present state and will require more detailed pollutant source(s) identification, control and significant water management efforts to improve on its uses.

Recreational usage support

USEPA (1993) classified recreational uses as primary and secondary contact recreations. The primary contacts are swimming, skin-driving and other uses involving immersion while the secondary contacts do not involve immersion. The least supported usage of all the investigated usages of the water from this estuary was found to be recreational usage based on the results of SI, SFC and FSM which correlated better that the others. The recreational uses considered were the human contact ones like swimming, etc. because of effects on human life Gerba (2000). The fuzzy based indices were very risk-averse about the quality of the water for recreational usage (**Table 9**). This is a departure from the findings of Chang *et al*. (2001) where fuzzy-based indices expressed better usage support for the site studied compared to WQI. The indices obtained ranked the water quality for this usage from site 1 to 9 as between E and F with some significant variations where C or C- were obtained. The results strongly indicate a non-support of the water for recreational use particularly swimming and other human contact game because of the poor quality of the water (Uttah *et al*. 2008). Thus, the water is not suitable for

Table 10 Results of Water Quality Indices obtained for aquatic life support.

Site	WQI	Usages Aquatic Life Support	Site	WQI	Usages Aquatic Life Support
Ukua	AI	B-	Obenla	AI	B-
	SI	C-		SI	D+
	GI	B-		GI	B-
	SFC	C+		SFC	B
	FSM	C+		FSM	C+
Awoye	AI	B-	Ilepete	AI	B-
	SI	C-		SI	C-
	GI	B-		GI	B-
	SFC	B-		SFC	C+
	FSM	C+		FSM	C+
Odonla	AI	B	Ilowo	AI	B-
	SI	C-		SI	D+
	GI	B		GI	B-
	SFC	C-		SFC	C
	FSM	C+		FSM	C+
Ikorigho	AI	B	Ibijinmi	AI	B
	SI	C-		SI	C
	GI	B-		GI	B
	SFC	B-		SFC	C+
	FSM	C+		FSM	C+
Ojumole	AI	B	Idi	AI	B+
	SI	C-	Ogba	SI	C+
	GI	B-		GI	B+
	SFC	C		SFC	B
	FSM	C+		FSM	B+

Abbreviation: Arithmetic index (AI), Fuzzy Similarity Method (FSM), Geometric Index (GI), Simple Fuzzy Classification (SFC), Solway Index (SI)

human contact immersion related uses in its present state except major quality improvement programmes are implemented most especially towards the estuary discharge mouth into the Atlantic Ocean. A consistent and targeted management of the sources of pollutants to improve on the uses of the water from the coast and to reduce their potential adverse effects on the neighbouring coastal ocean is recommended.

The risk-loving results expressed by AI and GI are indications of the shortfall of WQI in effectively evaluating the fuzziness in real world situation which put some measures of doubt on the reliability of indices thus generated when compared with fuzzy-based indices. Hence, the non-support of the water from this estuary for recreational usage and potential effects of such on the neighbouring ocean is expressed by this study and require monitoring, control and management.

Aquatic-life support

Despite the non-support status obtained for the present quality of the water from Ondo estuary to most of the uses investigated, there are significant, positive indications that the water system is in support of aquatic life habitation (Jinturkar *et al.* 2010; Monson and Monson 2010). All the indices used expressed better results about the aquatic life support of the water than any other uses (**Table 10**). Though the SI expressed the most risk-averse results, it is yet more optimistic about its aquatic life support than other uses investigated. The results of AI and GI correlate better with each other on this while those of FSM and SFC are better related. A range of B- to B+ was obtained for the water quality index for aquatic life support from AI and GI methods while a range of C- to B+ was obtained based on FSM and SFC for the same usage. It thus implies that relatively the quality of the water from the estuary is suitable for aquatic life habitation than other uses but could be improved upon for other uses (Bilotta and Brazier 2008). The present anthropogenic activities are not having any marked effect on biodiversity of the organisms nor are fish kill or other adverse aquatic life destruction activities witnessed (Mebane 2006). The results however, being in the in the boundary of limit between supporting and non-supporting conditions imply that continuous monitoring and water quality maintenance policies must be ensured and enforced to forestall against degrading the quality of the water further and adversely affecting the aquatic life resources in the estuary and the neighbouring Atlantic Ocean.

CONCLUSIONS

The quality of the water in the estuary and its usage supports evaluated by WQI and FSE revealed that index formulation is an effective approach to evaluating water quality, communicating such and arriving at sound conclusion for policy formulation on the water. There will be a considerable need for improvement on the present quality of the estuarine water used as case study if it will support domestic and irrigation uses while livestock and recreational uses are the least supported usage. Aquatic life habitation is well supported. The fuzzy based indices were more effective methodology of assessing usage supports and had revealed that adverse anthropogenic activities around the estuary are compromising the quality and the usages supports of the water and needs to be controlled because of its resultant effects on the neighbouring ocean.

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