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Statistical Analysis of Physico-chemical Properties of the Estuaries of KwaZulu-Natal, South Africa

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ABSTRACT: In general, estuaries may be classified variously according to inlet dynamics, geomorphology or whether they are tide or river dominated or, on a combination of all three factors. In KwaZulu-Natal (KZN), South Africa, the four recognised estuary types are temporary opened-closed estuaries (TOCEs), permanently opened estuaries, estuarine lakes and river mouths. Since physico-chemical parameters are important in defining the estuarine environment, multiple Pearson correlations were performed between summer datasets of five of these parameters: temperature (ºC), salinity (ppt), pH and turbidity (Nephelometric Turbidity Units (NTU)) according to clustered estuary types for all estuaries of KZN. It was found that very few significant relationships exist in all estuary types. These results are partly reflective of the sampling dataset. During summer, open mouth conditions commonly prevail for several estuaries following seasonal hinterland rainfall. Mixing of waters due to tidal influences and fluvial input from the upper catchment in KZN's shallow estuaries is known to inhibit stratification resulting in fewer pycnoclines and greater turbidity fluctuations. pH changes are closely linked to density changes (temperature and salinity) in water hence statistical relationships may not always be observable. It is clear that physico-chemical interactions are complex and long term sampling with seasonality and mouth state dynamics need to be taken into consideration. There is a need to develop a more holistic understanding of estuarine ecosystem functioning in this region.

Key words: Estuaries, statistical analysis, physico-chemical properties, KwaZulu-Natal

INTRODUCTION

Estuaries are dynamic, highly productive ecosystems (Pillay *et al.*, 2003) that are found at the interface of the ocean and the land (Day, 1981). Subsequently, there is much variation in the environmental conditions in estuaries. There are some 250 estuaries in South Africa (Perissinotto *et al.*, 2000). The province of KwaZulu-Natal is situated on the eastern seaboard of South Africa (Fig. 1) and has a coastline of approximately 500 kilometres (Chilli, 2009) with 52 estuaries of varying sizes. However, a significant proportion of these estuaries are less than 0.25 hectares in area and are consequently vulnerable to human impacts and consequent degradation (Ramm, 1990). Research on the ecology and physico-chemical characteristics of these estuaries began in the early 1950's (Day, 1981) but the most comprehensive survey was done about four decades ago by Begg (1978; 1984). Begg (1984) grouped the KZN estuaries into several classes using a cluster analysis technique which enabled him to define estuaries as *true estuaries* (with frequent and significant exchange with the sea); *Lagoons* (with infrequent and insignificant exchange with the sea) and, *river mouths* (open to the sea, but due to a perched bed, displayed no significant mixing of seawater with fresh water).

Whilst the basic principles of Begg's classification are still recognised, researchers have since refined it somewhat. For instance, a majority of South African estuaries (71-73%) are now regarded as temporary opened-closed estuaries (TOCE) (Perissinotto *et al.*, 2000; Thomas *et al.*, 2005; Perissinotto *et al.*, 2006; Anandraj *et al.*, 2007). Further, even though estuaries in South Africa are normally classified according to their mouth status, that is, whether they are open or closed; they may also be subdivided based on their sedimentary facies and geomorphology as well as whether they are river or tide-dominated (Cooper, 2001). Owing to the high runoff together with river channel properties and catchment topographic characteristics (Zietsman, 2004), KZN estuaries are mostly river-dominated (Cooper, 2001). Climate is also an important influencing factor on the physico-chemical parameters (Cooper, 2001). Physio-chemical parameters are fundamental in estuaries as they define the environment and hence the biological responses and biogeography of organisms (Harrison, 2004).

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Studies have rarely looked primarily at the interactions of physico-chemical parameters in different estuary types namely, TOCEs, permanently opened, river mouths and estuarine lakes. The aim of this study is to evaluate whether physico-chemical parameters interact differently in different estuary types and what could be the possible reasons for these interactions.

MATERIALS & METHODS

Few datasets exist that are homogeneous, harmonized and inclusive of all KZN estuaries. For this study, such a dataset sourced from Harrison (2004) and including survey data of physico-chemical parameters conducted at each KZN estuary were used (fig. 1). Parameters of this dataset include temperature (^{o}C), salinity (p.p.t), pH and turbidity (Nephelometric Turbidity Units (NTU)). Sampling was conducted over a five month period during the summer months (October – May from years 1993 to 1999) where most of the TOCEs, estuarine lakes and river mouths were in the open mouth state. The open mouth state is defined as one in which free interactions between marine water and estuarine waters occur at the mouth. Each estuary was classified as either TOCE, permanently opened, river mouth or as an estuarine lake (Harrison, 2004).

Statistical analysis was performed using SPSS version 15.0 for Windows®. Pearson multiple correlations run to evaluate interactions between physico-chemical parameters were clustered according to the estuary classification with each individual estuary constituting a replicate. Assumption tests for normality were significant if *p* (significant value) > 0.05 else variables were log transformed and the assumption test re-run. The assumption test for linearity was evaluated by visual inspection of scatterplots of each combination of tested physico-chemical parameters. If the assumption test for linearity was satisfied then only one of the physico-chemical parameters were transformed. Non-parametric Spearman's rank correlations were performed if any of the assumption tests were not satisfied. Analyses of variance (ANOVAs) of physico-chemical parameters in the four estuary types were analysed. The assumption tests

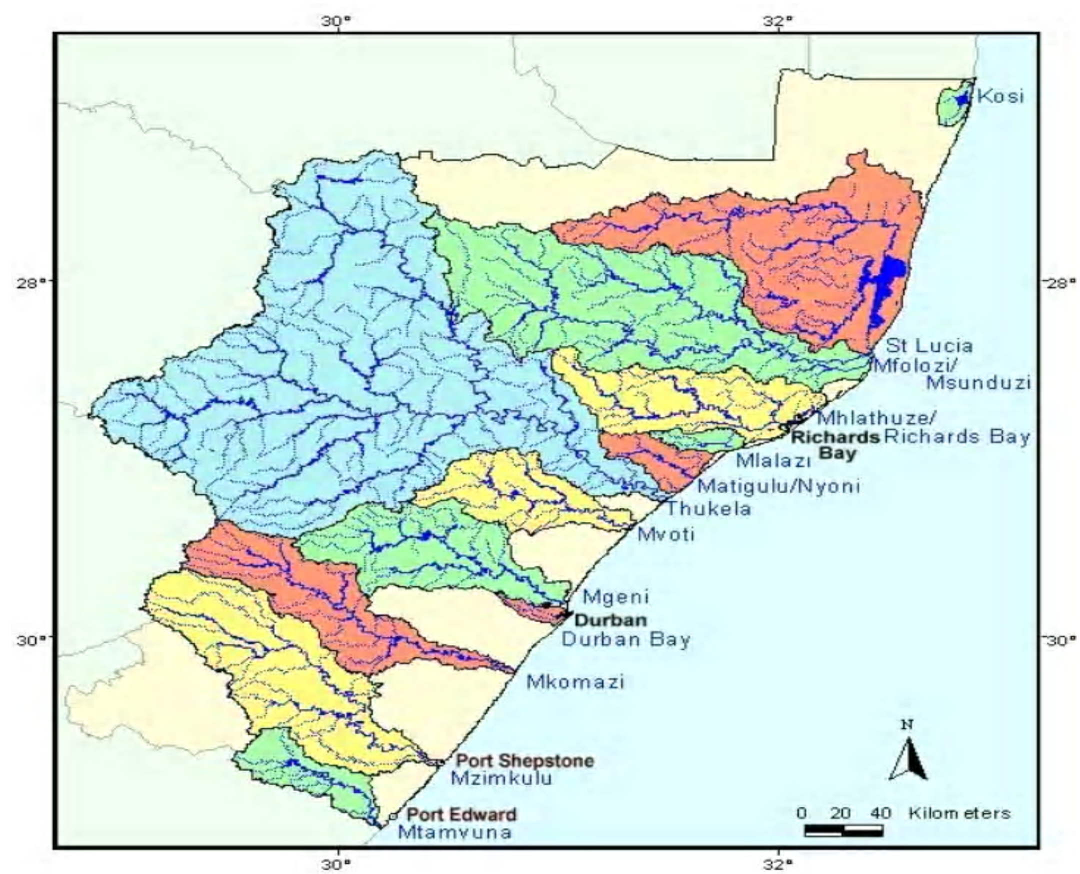

Fig. 1. The province of KwaZulu-Natal showing the major catchments and estuaries, labelled in blue. Numerous minor estuaries located between these major estuaries are also included in this study. Insert: South Africa, showing the location of KwaZulu-Natal. (Source: DEAT, 2001)

for normality and homoscedasticity were satisfied if *p* (significant value) > 0.05 else log transformations of the variables were performed and the assumption tests re-run. Non-parametric Kruskal-Wallis tests were performed if assumptions could not be satisfied.

RESULTS & DISCUSSION

Table 1 presents mean values of each physico-chemical parameter for each of the different estuary types. It is pertinent to note that there is a high degree of variability in turbidity in all estuary types. This is illustrated by the spread of this variable (Fig. 2) and the high standard deviations (Table 1). Fewer samples were taken for other estuary types besides TOCEs as few of these estuary types exist in the study area (permanently open (5), estuarine Lake (3) and river mouths (3)). This could be a confounding factor as to why certain relationships exist and vice versa.

According to the ANOVAs, pH is only significantly different between TOCEs and estuarine lakes (p= 0.02 < 0.05, F= 3.497, DF= 133). Turbidity is only significantly different between river mouths and all other estuarine types (p = 0.005 < 0.05, F= 36.64, DF= 133). Temperature is significantly different between estuarine lakes against TOCEs and permanently opened estuaries whilst there are also differences in temperature between river mouths against TOCEs and permanently opened estuaries (p = 0.005 < 0.05, F= 28.20, DF= 133). Salinity only differs significantly between estuarine lakes and all other estuarine types (p = 0.005 < 0.05, F= 19.77, DF= 133).

It is clear from Table 2, that TOCEs illustrate very few significant correlations between physico-chemical parameters. There is only a significant positive correlation present between salinity and pH. This is indicated by *rho* =0.354 (r^2 =0.089). There are no other significant correlations between other combinations of physico-chemical parameters present in TOCEs.

All correlations tested between physico-chemical parameters were not statistically significant. This was indicated by *p* (significant figure) > 0.05 for all correlations performed between parameters in estuarine lakes.

In permanently opened estuaries, there is only one significant correlation present which is the correlation between salinity and turbidity (Table 4). An *rho* = -0.673 indicates that the correlation is negative in nature.

Table 1. Mean values for each physico-chemical parameter in different estuary types

	N	pH	Turbidity (NTU)	Temperature (^{o}C)	Salinity (ppt)
TOCEs	95	7.70(0.34)	17.44(14.95)	24.33(2.42)	4.38(5.12)
Permanent Open	20	7.75(0.33)	140.45(241.76)	25.08(1.57)	3.04(4.18)
Estuarine Lake	11	8.06(0.43)	24.09(33.61)	29.59(1.92)	17.69(13.27)
River mouths	8	7.81(0.43)	1534.63(1651.61)	29.70(2.71)	0.06(0.12)

- Standard deviation is indicated in brackets

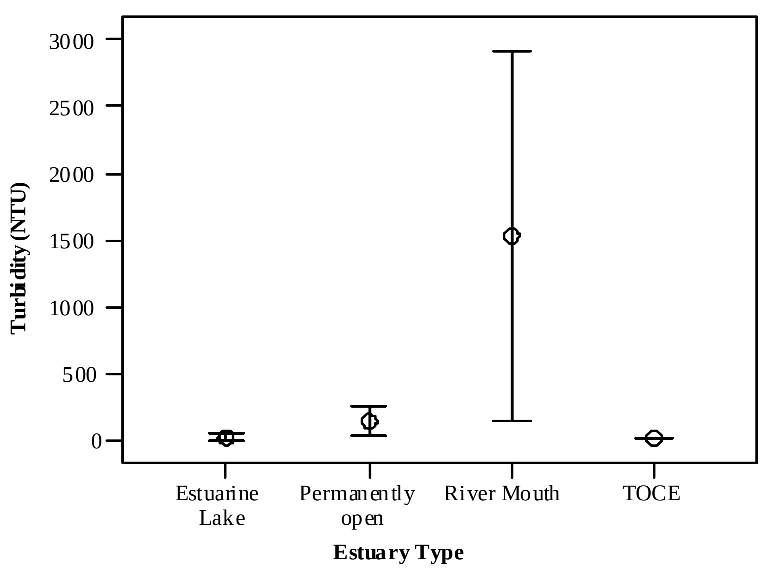

Fig. 2. Variance for turbidity against each of the estuary types with 95% confidence intervals

River mouths as an estuary type illustrate the most significant relationships between physico-chemical parameters (Table 5). pH is significantly correlated with both temperature and salinity. r = - 0.991 and *rho* = 0.802 for pH versus temperature and pH versus salinity respectively indicate that the correlations are strong.High rainfall across the province of KwaZulu-Natal (Zietsman, 2004) yields high run-off which contribute to appreciable breaching and scouring of estuaries (Anandraj *et al.*, 2007). Sampling was done during summer when estuaries were open. Subsequently, there would have been a lack of relationships present in physico-chemical parameters in TOCEs (Table 2) as constant breaching would change the environmental conditions constantly (Gattuso *et al.*, 1998; Zietsman, 2004). Haloclines and thermoclines may be present in marine systems owing to differences in salinity and temperatures between surface and deep waters (Trujillo & Thurman, 2005) however these relationships were not present. This could be due to the euphotic depth being the same as the total depth during the open phase (Cole *et al.*, 1992; Underwood & Kromkamp, 1999; Thomas *et al.*, 2005; Anandraj *et al.*, 2007) resulting in no temperature differences between surface and deep water. Breaching may also cause constant flushing of water out of the

Table 2. Correlations between four tested physico-chemical parameters in KZN TOCEs

	Statistic	pH	Turbidity ^(NTU)	Temperature (°C)	Salinity (ppt)
pH	*r*/***rho***		-.197	.051	**.354(**)**
	p		.055	.623	**.000**
Turbidity (NTU) ^	*r*/***rho***	-.197		-.134	**-.029**
	p	.055		.196	**.782**
Temperature (°C)	*r*/***rho***	.051	-.134		**.097**
	p	.623	.196		**.348**
Salinity (ppt)	*r*/***rho***	**.354(**)**	**-.029**	**.097**	
	p	**.000**	**.782**	**.348**	

^ - Log transformed variable
** - Relationship is significant
- Parameters in bold represent the use the Spearman's non-parametric test

Table 3. Correlations between four tested physico-chemical parameters in KZN estuarine lakes

	Statistic	pH	Turbidity (NTU)	Temperature (°C)	Salinity (ppt)
pH	*r*/***rho***		**.033**	**.579**	**.173**
	p		**.924**	**.062**	**.612**
Turbidity (NTU)	*r*/***rho***	**.033**		.419	.566
	p	**.924**		.199	.070
Temperature (°C)	*r*/***rho***	**.579**	.419		.395
	p	**.062**	.199		.229
Salinity (ppt)	*r*/***rho***	**.173**	.566	.395	
	p	**.612**	.070	.229	

** - Relationship is significant
- Parameters in bold represent the use the Spearman's non-parametric test

Table 4. Correlations between four tested physico-chemical parameters in KZN permanently opened estuaries

	Statistic	pH	Turbidity (NTU)	Temperature (°C)	Salinity (ppt)
pH	*r*/***rho***		**-.092**	.008	.225
	p		**.700**	.974	.341
Turbidity (NTU)	*r*/***rho***	**-.092**		**-.280**	**-.673(**)**
	p	**.700**		**.232**	**.001**
Temperature (°C)	*r*/***rho***	.008	**-.280**		.150
	p	.974	**.232**		.528
Salinity (ppt)	*r*/***rho***	.225	**-.673(**)**	.150	
	p	.341	**.001**	.528	

** - Relationship is significant
- Parameters in bold represent the use the Spearman's non-parametric test

estuary: the constant mixing of freshwater and seawater inhibits the formation of haloclines and make the water column homogeneous (Gattuso *et al.*, 1998; Trujillo & Thurman, 2005; Anandraj *et al.*, 2007).

Underlying water in deep estuaries may be less turbid owing to reduced interference by waves and subsequently less disturbance of the estuary bed (Underwood & Kromkamp, 1999). However, sediments such as clays in constant suspension will inherently result in turbid water (Underwood & Kromkamp, 1999; Trujillo & Thurman, 2005). High turbidity would normally cause less light penetration which would change the temperature to increase however no significant relationship exists. The significant relationship between salinity and pH is expected as salinity influences the amount of dissolved CO_2 which is involved in the buffering of seawater; an increase in salinity will cause changes in the solubility of CO_2 which will cause an initial increase in pH, buffering will cause the system to return to an equilibrium (Abril & Borges, 2004; García-Luque *et al.*, 2005 Trujillo & Thurman, 2005). Salinity and temperature not being related also suggests that the estuaries are well mixed owing to breaching of the sand barrier at the mouth (Gattuso *et al.*, 1998).

Estuarine lakes are those that have developed in coastal plains. There are only three in KZN located in the northern part of the province (Cooper, 2001). Results indicate that there are no significant relationships present between physico-chemical parameters in estuarine lakes. Estuarine lakes can be described as tide-dominated estuaries and this may account for their significantly higher salinity as compared to other estuary types, 17.69 ± 13.27 ($p < 0.05$, F= 19.77, DF = 133); this suggests that there is a high degree of intrusion by tides (Cooper, 2001). The constant ebb and flow of tides would cause more mixing (Grange *et al.*, 2000) and subsequently stops stratification by temperature or salinity. Hence it is logical that no relationship between salinity and temperature against other physico-chemical variables was detected. Since the water column is not stratified, no relationships between pH and other variables are expected.

An average depth of 126.75 ± 62.85 cm in permanently opened estuaries in KZN suggest that these estuaries are shallow and there is little to no differentiation between top and bottom water. Constant flushing of the estuary may inhibit the formation of haloclines and thermoclines (Trujillo & Thurman, 2005). pH not being related to salinity & temperature (García-Luque *et al.*, 2005; Trujillo & Thurman, 2005) is also probably due to constant vertical mixing in the water column and flushing as water will have a short residence time in estuaries (Gattuso *et al.*, 1998). The one significant relationship is negative, that is, turbidity against salinity (Table 4). This relationship seems implausible as it is more likely that a positive relationship may exist where an increase in turbidity as a result of more disturbances of sediments which could increase dissolved matter concentrations in the water column (Anandraj *et al.*, 2007).

Estuaries classified as river mouths are characterized by being river-dominated (Cooper, 2001). Higher turbidity (Table 1) in river mouths compared to all other estuary types ($p < 0.05$, F= 36.64, D.F. = 133) may contribute to less penetration of light into deeper waters hence contributing to the development of thermoclines (Underwood & Kromkamp, 1999). The relationship between pH against temperature and salinity is complex. The possibility of a thermocline suggests that less CO_2 would be able to dissolve in the water body which could cause the pH to fluctuate, in turn affecting buffering (Trujillo & Thurman, 2005). Also, fluctuations in salinity (owing to mixing) affects the density of water which affects the ability of water to hold CO_2 and this will also affect the pH (Abril & Borges, 2004; García-Luque *et al.*, 2005). It is important to note that caution must be taken when drawing conclusions about relationships in river mouths in KZN. Even though strong relationships exist, the sample size is only eight as there are only three classified river mouths present in KZN.

Table 5. Correlations between four tested physico-chemical parameters in KZN river mouths

	Statistic	pH	Turbidity (NTU)	Temperature (^{o}C)	Salinity (ppt)
pH	*r/rho*		**-.408**	-.991(**)	**.802(**)**
	p		**.364**	.000	**.030**
Turbidity (NTU)	*r/rho*	**-.408**		**.374**	-.603
	p	**.364**		**.409**	.152
Temperature (^{o}C)	*r/rho*	-.991(**)	**.374**		-.694
	p	.000	**.409**		.083
Salinity (ppt)	*r/rho*	**.802(**)**	-.603	-.694	
	p	**.030**	.152	.083	

** - Relationship is significant

- Items in bold represent the use the Spearman's non-parametric test

CONCLUSION

It is clear that the interactions between physico-chemical parameters are extremely complex. Due to the dearth in availability of complete, long term data, this study utilized available physico-chemical data for the summer season. However, sampling only during the summer months (October to February) during the open phase does not provide the complete suite of interrelationships present. During summer, estuaries breach much more frequently owing to higher hinterland rainfall which causes a reduction in the residence time in estuaries (Harrison, 2004; Zietsman, 2004; Trujillo & Thurman, 2005). Vertical mixing inhibits the formations of pycnoclines which may cause more interactions between parameters (Trujillo & Thurman, 2005). Also the fact that the euphotic depth may be the same as the total depth means that there is less stratification in the water column which aids in the formation of pycnoclines (Cole *et al.*, 1992; Underwood & Kromkamp, 1999; Thomas *et al.*, 2005; Anandraj *et al.*, 2007). It is clear that physico-chemical interactions are complex and long term sampling with seasonality and mouth state dynamics need to be taken into consideration to obtain a holistic understanding of these relations.

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