A GEO-STATISTICAL APPROACH TO EVALUATE KEPA WATER QUALITY SAMPLING STATIONS NETWORK OF KUWAIT BAY

Nawaf B. KH. Al-Mutairi, Asma Ali Abahussain and Ali El-Battay

Arabian Gulf University (Bahrain)
alieb@agu.edu.bh, elbattay@yahoo.com

Abstract

This study aimed to evaluate the current Kuwait Environment Public Authority (KEPA) water quality monitoring stations of Kuwait Bay and to propose a systematic mechanism to develop an optimal network of sampling stations. Three years of monthly data were used over six existing stations and a fieldwork campaign was conducted over twenty sampling sites (December 2011). Field sampling locations were selected based on stratified random sampling scheme oriented by existing classification Map of Kuwait Bay. Dataset was initially examined using statistical methods and then ArcGIS was used for the spatial assessment. Generated distribution maps of main water quality parameters (e.g. DO, pH, nitrate) coupled with Cluster Analysis showed that the current six KEPA stations might be statistically represented by two only. Furthermore, the existing sampling network is not adequate to highlight the relatively polluted *Sulaibikhat* area of Kuwait bay. The Geo-statistical approach was proven to be highly relevant to propose any future modification of KEPA's sampling network at Kuwait Bay, meanwhile assuring the temporal continuity with data acquired since 1985 and enhancing the spatial significance by including hotspot zones such as *Sulaibikhat* area.

Keywords: KEPA, Water Quality, Kuwait Bay, Cluster Analysis, Kriging distribution maps.

1 INTRODUCTION

Kuwait Bay is a unique ecosystem in Kuwait's territorial waters. It is known for its large shallows and tidal flats formed by mud, sand and rock, which include various ecosystems (Al-Sarawi *et al*., 1985; Hasegawa *et al*., 2002). The intertidal mudflats in Kuwait Bay are important feeding areas for shore birds, which either stop in Kuwait on their migratory route or overwinter, and it provides habitat for several invertebrates including microfauna, meiofauna and macrofauna (Al-Yamani *et al*., 2004). During the last few decades, Kuwait's marine environment experienced adverse incidents on regional and local scale threading the quality of water. The state of Kuwait unexpectedly witnessed a steady growth in population, doubling in 30 years. As a consequence of meeting the population's needs, many governmental and private sector facilities, such as desalination plants, power plants, recreational facilities, hospitals and other urban and industrial facilities, have been constructed along Kuwait Bay's coastal area which represents 54% of all developed coastline in Kuwait (Al-Mutairi, 2010). Most of these facilities discharge their effluent directly into the Bay. These discharges have been found to cause deleterious effects on the biota of Kuwait's marine environment (Bu-Olayan and Thomas, 2006). Hence, as Kuwait Bay is suffering from serious pollution from point and non-point sources (Al-Yamani *et al*., 2001) it is crucial to adequately monitor its water quality. In fact, Kuwait Environment Public Authority (KEPA) has been monitoring and collecting water samples from marine and coastal water of Kuwait, including those of Kuwait bay, since 1985. Although anthropogenic activities have increased dramatically after that date, KEPA monitoring stations number and locations have not been reviewed to monitor the effects of new activities along the coast. Therefore, the main objective of this study is to use a geo-statistical approach to evaluate KEPA's water quality Sampling Stations Network at Kuwait Bay.

2 METHODOLOGY

Water quality index (WQI) provides a simple and understandable tool for managers and decision makers regarding the quality and potential uses of a given body of water (Bordalo *et al*., 2001). Due to the importance of using WQI, many international institutes and agencies that are concerned about environmental issues officially approve the usage of WQI in their reports (Walsh and wheeler, 2013). In current research, weighted arithmetic WQI developed by Brown *et al*. (1970) will be used. Three years water quality data of Kuwait Bay (figure 1.a) obtained from six monitoring stations of KEPA were used to calculate the WQI and then subject to statistically analysed via clustering to assess the relevancy of their spatial distribution. Meanwhile, a fieldwork was conducted on 20 locations distributed over Kuwait bay, including the six locations of KEPA (figure 1-d). Sampling–site selection depended completely on the classification map of Kuwait Bay (Figure 1-b) produced by (Hasegawa *et al.* 2002) and anthropogenic influences (Figure 1-c) produced by (Al-Mutairi, 2010). Hasegawa *et al* (2002) classified Kuwait Bay into six zones based on geomorphology, water exchange, water use, and human activities on the coast.

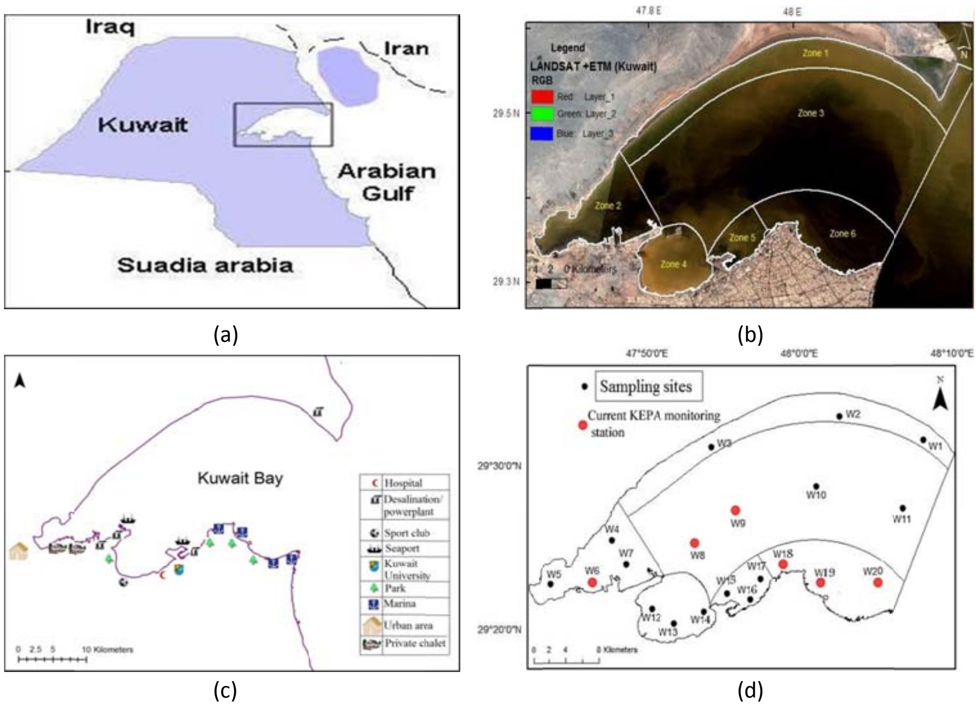

Figure 1: (a) Location of Kuwait Bay, (b) Kuwait Bay's classification by Hasegawa *et al.* (2002), (c) Kuwait Bay's anthropogenic influences by Al-Mutairi (2010) and (d) Sampling sites including KEPA monitoring stations

In-situ measurements were conducted including seawater temperature and pH. The others parameters were measured in two different laboratories. The required parameters for this study are water temperature, pH, dissolved oxygen, biochemical oxygen demand (BOD), total phosphorus, nitrate, fecal coliform, turbidity and total suspended solids. All samples were analyzed in KISR laboratories and in Subbiya Testing Laboratory according to American Public Health Association (APHA) 1998 methods. Figure 2 depicts the general flowchart methodology used in this study, where both historical water quality parameters (data) from KEPA and those obtained from the fieldwork were converted first into WQI. The second step was to submit the WQI obtained from KEPA's station into

Comment [nn1]: Do you think it's better to include WQI descriptor words!

cluster analysis and compare its result with (i) cluster analysis of fieldwork stations and (ii) distribution map(s) of fieldwork based WQI obtained via kriging technique (to reveal hotspots of any).

Multivariate analysis has been commonly used in water quality assessment. In particular, cluster analysis renders complex data matrices usable for ecosystem management (Astel et al., 2007; Pejman et al., 2009). Geostatistics as a class of statistics was used to analyze and predict the values associated with spatial measuring fieldwork network. ArcGIS 10.1 package is equipped with a Geostatistical Analyst tool, which provides many methods to production continuous surface from measured sample points. In this study Kriging was used as an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Semivariogram model was used to determine the best fit model that passes through the points. The reliability of the model for each water-quality parameter is examined using the cross-validation in the ArcGIS geostatistical analyst tool. Cross validation removes one data location and predicts the associated data using the data at of the remaining locations.

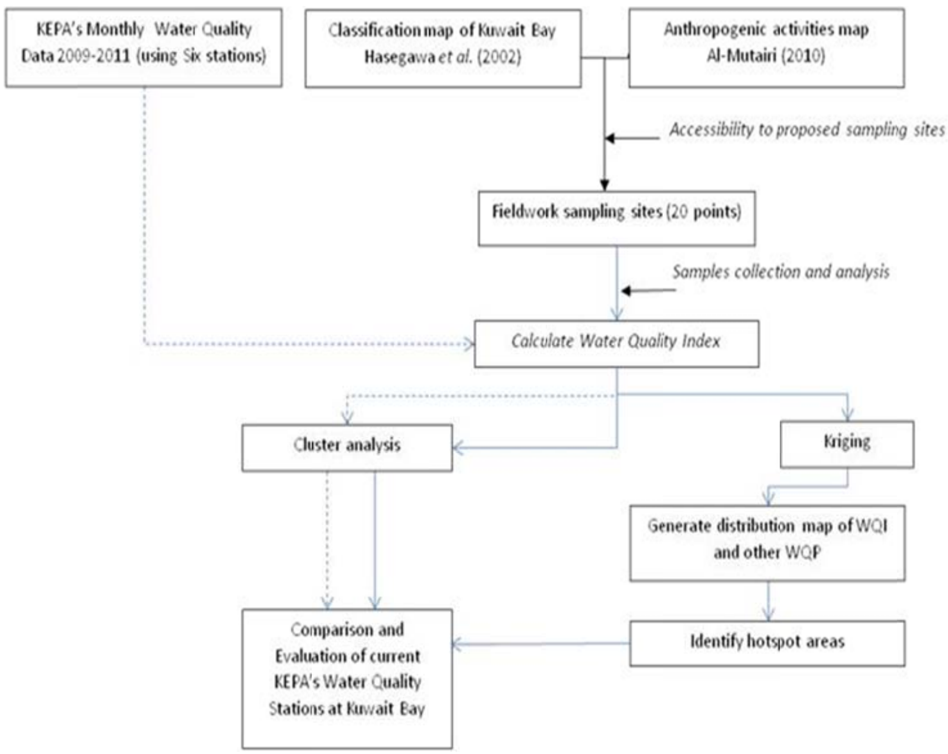

Figure 2: General methodology flowchart

3 RESULTS AND DISCUSSION

Figure 3-a presents the result of WQI obtained from the six KEPA's stations at Kuwait Bay for years 2009, 2010 and 2011. In 2009, 39.1% of Kuwait Bay's water samples were classified as excellent according to the WQI used; this percentage decreased to only 1.5% in 2010, most likely due to the breakdown of the Mishref sewage pumping station in late 2009. The water quality returned to excellent in 37.7% of samples in 2011. However, it clear that for the three years analyzed, the percentage of samples classified as Medium is very low (3.1% in 2009 and 2.3% in 2011). Knowing that *Sulaibikhat* area is a polluted area the shown WQI results may not reflect what is happening at Kuwait Bay.

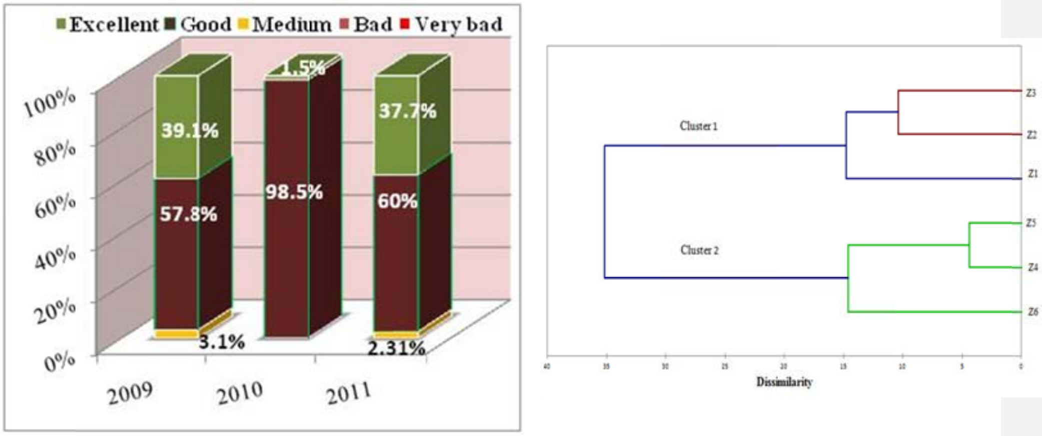

Figure 3: (a) Annual WQI for KEPA's samples at Kuwait Bay from 2009 to 2010, (b) Dendrogram showing clustering of KEPA's monitoring stations using WQI

The monitoring stations of Kuwait Bay were classified into two main clusters based on WQI data using hierarchical cluster analysis (figure 3-b). The first group consisted of stations Z01, Z02 and Z03, which are located in the western part of Kuwait Bay. This area is characterized by shallow and turbid water and slow seawater circulation. Most anthropogenic activities (e.g., desalination, power plants, emergency outlets and a marine-based recreational area) are densely concentrated along the coast. The stations of the second group (Z04, Z05 and Z06) are located in the eastern side of Kuwait Bay. The seawater in this area is exchanged with fresh seawater from the Arabian Gulf at a high rate. Recreational activities and development through reclamation and dredging along the beach are the major types of anthropogenic pressures, along with emergency outfalls. The water quality in the second group is slightly better than that in the first one in term of the type and quantity of anthropogenic activities and natural setting. The results of the cluster analysis combines with the distribution map of WQI from fieldwork reveal that actual KEPA's stations at Kuwait bay are poorly representative of water-quality in Kuwait Bay. In fact, figure 4 shows that none of KEPA's station is covering the *sulaibikhat* area (red in figure) characterized by a medium water quality according to the used WQI.

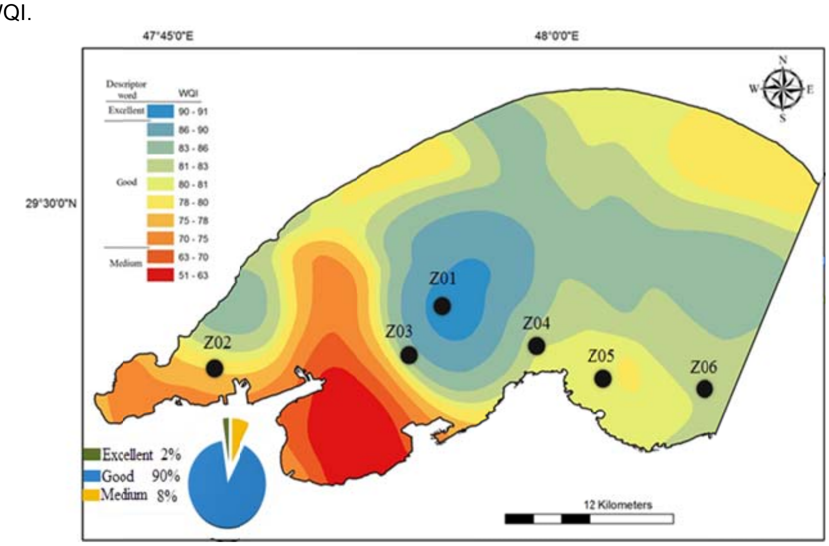

Figure 4: Distribution map of WQI using fieldwork stations (20 points)

The result of cluster analysis of proposed sampling stations based on WQI and other water quality parameters as variables is shown in Figure 5. The dendrogram shows that the 20 sampling stations grouped into three clusters. The first cluster contains points W5, W19, W2, W3, W1, W6, W16 and W7. Sampling sites in this cluster are completely located near the Kuwait Bay coasts. Several land-based pollution points representing in emergency outlets, desalination and powerplant discharges and recreational activities have influenced the water-quality in these stations. The water-quality in northern of Kuwait Bay is impacted mainly from discharges of Shatt Al-Arab and Khor Al-Subiya. The water-quality in this cluster is considered moderately degraded. The second cluster includes stations W10, W11, W4, W17, W9, W18, W15, W20 and W8. Most stations in this cluster are located in central of the Bay and relatively far away from anthropogenic pressures on the coast. The water quality in this cluster is described fair comparing to other areas. The last cluster contains the stations in Sulaibikhat Bay (W12, W13 and W14). The water quality in Sulaibikhat Bay is the most degraded waters (Medium WQI and covering 8% of the area of Kuwait Bay). Concentrations of nutrients are very high due to wastewater discharged via emergency and storm outlets. This fact has been confirmed with high measurements of fecal coliform. Furthermore, the turbidity and TSS in Sulaibikhat recorded high values due to the presence of most extensive intertidal mudflats found in Kuwait Bay.

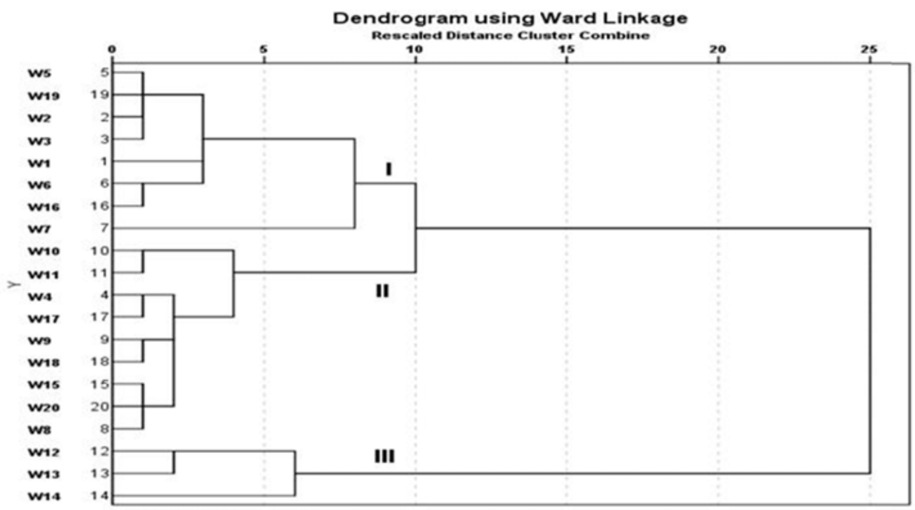

Figure 5: Dendrogram showing the cluster of sampling sites based on WQI and water quality parameters as variable.

4 CONCLUSIONS

Existing KEPA water quality monitoring stations at Kuwait Bay are not adequately spatially distributed. Indeed, there is no sampling site located in critical areas such as Sulaibikhat Bay and northern of Kuwait Bay. Only two stations of KEPA cover the water quality in cluster one while the cluster two there are four station. Thus, the distribution of the KEPA monitoring stations does not spatially reflect the water quality in Kuwait Bay. Beside global and regional stresses, various human activities have affected the marine environment in general and Kuwait Bay's ecosystem at particular. Good spatial monitoring is required to conserve and monitor one of the most vulnerable marine ecosystems in the region. The cluster analysis was a useful method to statistically analyze both existing KEPA's stations and fieldwork ones. However, using kriging as a geostatistical method was necessary to map spatially WQI from fieldwork and detect Sulaibikhat area as a hot spot. The proposed mechanism in this study relies on WQI, as a representative entity of various water quality parameters, statistically analyzed both with cluster analysis and using kriging to obtain distributed maps. KEPA might use this proposed mechanism to review its existing monitoring sites at Kuwait Bay however more samples should be taken over a longer period to get reliable and final locations.

ACKNOWLEGEMENT

The authors would like to acknowledge the contribution of Kuwait Environment Public Authority by sharing its water quality data and giving support for this study especially for fieldwork. A special thanks for KISR and Subbiya laboratories for analyzing water samples. Finally, sincere gratitude to Arabian Gulf University for providing the supporting environment to conduct this study.

AUTHORS INFORMATION

AL-MUTAIRI: M.Sc Student, Arabian Gulf University, geologest_04@hotmail.com. M. Nawaf got a Bachelor in Geology from Kuwait University in 2004. He then joined the state of Kuwait ministry of education. In 2010 he got a scholarship for Kuwait State to pursue his postgraduate studies at Arabian Gulf University- Desert and Arid Zone Program, Environment and Natural Resources specialization.

ABAHUSSAIN: Associate Professor- Geology/Geochemistry, Arabian Gulf University, asma@agu.edu.bh
Dr. Asma got her Geochemistry of sedimentary Rocks BSc. in 1980, Baghdad University. Earth Science MSc. In 1983, and PhD. In 1987. Currently, Dr. Asma is an associate professor of Geology, Geochemistry, Desert and arid Zones Sciences Program (DAZP), College of Graduate Studies, Arabian Gulf University (AGU). Since she joined AGU in 1988, She has supervised or co-supervised more than 40 Masters Theses, and has published more than 30 papers in refereed journals. Seven of her scientific research papers won awards at GCC and Arab Region. Dr. Abahussain served as a consultant and a resource person for Division of Early Warning & Assessment -West Asia UNEP/ROWA in the field of Integrated Environmental Assessment. Trainer in more than 25 IEA of UNEP Workshops on Environmental Indicators, Analysis of Environmental Policies, Dynamic modeling in support of Environmental Scenarios. She was selected by UNEP to be a member of two GEO-5 global working groups 2012 namely: Data and Indicators and Science and Policy Advisory Board. Locally in Bahrain, she was a member environment committee in the Bahrain National Planning Development Strategies 2030; editor of the first Bahrain SOE Report, head of Women and Environment Committee in the National Strategy for Bahraini women's; Bahrain Environmental Strategy, head of the Studies and Research Committee in the National Combating Desertification Committee and other specialized committees.

ELBATTAY: Assistant Professor-Remote Sensing, Arabian Gulf University, elbattay@yahoo.com
Dr. Ali Elbattay got his PhD (Environmental SAR specialization) from INRS-ete (Canada) in 2006. He joined Faculty of Geoinformation Science and Engineering at Universiti Teknologi Malaysia in 2007 as researcher then lecturer and subsequently senior lecturer. In 2011, Dr. Ali joined Arabian Gulf University as Assistant Professor (Remote Sensing) at College of Graduate Studies. His research interests are in Theoretical aspects of Proactive Remote Sensing as well as Remote Sensing applications for solar energy harnessing.

REFERENCES

Al-Mutairi, N. (2010). Proposal to Develop the Coastal Monitoring System of Kuwait Bay. Research Submitted to Graduated College of Arabian Gulf University in partial fulfillment of the requirement for the degree of high diploma. 2010

Al-Sarawi, M,. Gundladch E.R. and Boca B.J. (1985). Kuwait: An Atlas of Shoreline Types and Resources. Faculty of science, University of Kuwait, Kuwait.

Astel, A., Tsakovski, S., Barbieri, P., Simeonov, V. (2007). Comparison of self-organizing maps classification approach with cluster and principal components analysis for large environmental data sets. Water Research, 41(19): 4566–4578. [doi:10.1016/j.watres.2007.06.030].

Al-Yamani, F. Y., Bishop, J., al-Hussaini, M., Al-Ghadban, A. N., Behbehani, and M., Rao, S. (2001). A Strategic Plan for Sustainable Utilization of Kuwait's Marine Environment. Kuwait. Kuwait Foundation for Advancement of Sciences.

Al-Yamani, F. Y., Bishop, J., Ramadhan, E., Al-Husaini, M. and Al-ghadban, A. (2004). ceanographic Atlas of Kuwait's Waters. Environment Public Authority. Kuwait Institute for Scientific Research. Kuwait

Bordalo, A. A., Nilsumranchit and Chalermwat, K. (2001). Water-quality and Uses of the Bangpakong River (Eastern Thailand). Water Research, 35(15), 3635-3642.

Brown R. M., McClelland, N. I., Deininiger, R.A.and Tozer, R. G. (1970). A Water-quality Index– Do We Dare?. Water and Sewage Work. 117 (10), 339-343

Bu-Olayan, A.H. and Thomas, B.V. (2006). Assessment on biocides bioaccumulation in mullet Liza klunzingeri in Kuwaiti waters, off the Arabian Gulf. Am. J. Environ. Sci., 2: 109-113

Hasegawa, K., Tuchida, H. and Fuyumuro, M. (2002). Area Classification and Water-quality Management. Workshop Environmental rehabilitation of Kuwait Bay 16th Sep. 2002, Kuwait Sheraton. Kuwait.

Pejman, A. H., Bidhendi, G. R., Karbassi, A. R., Mehrdadi, N., and Bidhendi, M. E. (2009). Evaluation of Spatial and Seasonal Variations in Surface Water-quality Using Multivariate Statistical Techniques. Int. J. Rnviron. Tech., 6 (3), 467-476, Summer 2009

Walsh, P. & Wheeler, W. (2013). Water-quality Indices and Benefit-Cost Analysis. Journal of Benefit-Cost Analysis, 4(1), pp. 1-130.