Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Ali Al-Maktoumi · Osman Abdalla · Anvar Kacimov · Slim Zekri · Mingjie Chen · Talal Al-Hosni · Kaveh Madani *Editors*

Water Resources in Arid Lands: Management and Sustainability

IEREK
RESEARCH & KNOWLEDGE ENRICHMENT

Springer

Advances in Science, Technology & Innovation

IEREK Interdisciplinary Series for Sustainable Development

Advances in Science, Technology & Innovation (ASTI) is a series of peer-reviewed books based on important emerging research that redefines the current disciplinary boundaries in science, technology and innovation (STI) in order to develop integrated concepts for sustainable development. It not only discusses the progress made towards securing more resources, allocating smarter solutions, and rebalancing the relationship between nature and people, but also provides in-depth insights from comprehensive research that addresses the **17 sustainable development goals (SDGs)** as set out by the UN for 2030.

The series draws on the best research papers from various IEREK and other international conferences to promote the creation and development of viable solutions for a **sustainable future and a positive societal** transformation with the help of integrated and innovative science-based approaches. Including interdisciplinary contributions, it presents innovative approaches and highlights how they can best support both economic and sustainable development, through better use of data, more effective institutions, and global, local and individual action, for the welfare of all societies.

The series particularly features conceptual and empirical contributions from various interrelated fields of science, technology and innovation, with an emphasis on digital transformation, that focus on providing practical solutions to **ensure food, water and energy security to achieve the SDGs.** It also presents new case studies offering concrete examples of how to resolve sustainable urbanization and environmental issues in different regions of the world.

The series is intended for professionals in research and teaching, consultancies and industry, and government and international organizations. Published in collaboration with IEREK, the Springer ASTI series will acquaint readers with essential new studies in STI for sustainable development.

ASTI series has now been accepted for Scopus (September 2020). All content published in this series will start appearing on the Scopus site in early 2021.

More information about this series at http://www.springer.com/series/15883

Ali Al-Maktoumi · Osman Abdalla ·
Anvar Kacimov · Slim Zekri ·
Mingjie Chen · Talal Al-Hosni ·
Kaveh Madani
Editors

Water Resources in Arid Lands: Management and Sustainability

Springer

Editors
Ali Al-Maktoumi
Water Research Center
Sultan Qaboos University
Al-Khod, Oman

Anvar Kacimov
Department of Soils, Water, and
Agricultural Engineering
College of Agricultural and Marine Sciences
Sultan Qaboos University
AlKhod, Oman

Mingjie Chen
Water Research Center
Sultan Qaboos University
Al-Khod, Oman

Kaveh Madani
Henry Hart Rice Senior Fellow
The MacMillan Center
Department of Political Science
Yale University
New Haven, CT, USA

Osman Abdalla
Department of Earth Sciences
College of Science
Sultan Qaboos University
Al-Khod, Oman

Slim Zekri
Department of Natural Resources Economics
College of Agricultural and Marine Sciences
Sultan Qaboos University
Al-Khod, Oman

Talal Al-Hosni
Department of Earth Sciences
College of Science
Sultan Qaboos University
Al-Khod, Oman

ISSN 2522-8714 ISSN 2522-8722 (electronic)
Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development
ISBN 978-3-030-67027-6 ISBN 978-3-030-67028-3 (eBook)
https://doi.org/10.1007/978-3-030-67028-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Editorial Board of Conference Proceedings

Reviewers List

Abdelaziz Hirich
Abdulrahim Al-Ismaili
Ahmed Douaik
Ahmed Hadidi
Alaba Boluwade
Alexander Osadchiev
Ali Sulaiman
Anwar Ahmed
Arash Malekian
Azizallah Izady
Balai Chandra Das
Elsayed Abu El Ella
Eman Hasan
Farhad Hosseinali
Furat Ahmed Mahmood Al-Faraj
Furat Al-Faraj
George Zaimes
Hamdan Al-Wahaibi
Ibrahim Al-Helal
Iswar Chandra Das
Khadija Semhi
Luminda Hewawasam
Mansour Al-Haddabi
Mohamed Chiban
Mohammad Mahdi Rajabi
Mohammed Farfour
Mushtaque Ahmed
Nalusamy Sivakumar
Narasimman Sundararajan
Pankaj Pathare
Peter Zavialov
Rashid Al-Yahyai
Rashid Umar
Rifaat Abdalla
Roohollah Noori
Said Al-Ismaily
Slim Zekri
Sundarajan Narasimman
Yaseen Al-Mulla
Yassine Charabi

Preface

The scarce freshwater resources in arid areas are under increasing pressure from population and economic growth, food demand, expanding irrigated agricultural areas, and climate change. The water deficit is especially drastic in arid areas characterized by low precipitation and high evaporation rates. In arid areas, groundwater is usually the only natural water resources and is endangered by excess agricultural extraction and seawater intrusions to coastal aquifers. Climate change leads to temperature increase and shifts of precipitation patterns, and likely increases the frequency of flooding and drought seasons. It is important to understand the impact of climate changes on irrigation, subsurface hydrology, flood risk, salinization, as well as mitigation approaches to cope with the above-mentioned challenges. Desalination of seawater is a popular way to supplement insufficient domestic water supply in urban areas. In recent years, desalination of brackish water and reuse of treated wastewater are also becoming popular as a non-conventional source of water for mainly for farming activities along with other feasible purposes. In addition, economical management and associated policy reforms are critical to induce water conservation and adoption of water-saving and reuse technologies.

This book entitled *Water Resources in Arid Land: Management and Sustainability* aims to address multiple water issues and challenges in arid land discussed above by selecting excellent studies presented at the 2nd International Conference on Water Resources in Arid Areas (WRAA2020) held online during November 9–11, 2020. This book consists of 6 parts with 31 chapters presenting contributions to a wide range of water sciences in arid regions. The following themes represent the six parts in the book ordered as:

Hydroinformatics
Water Desalination and Purification Technologies
Climate Change and Water Resources
Economics and Management of Wastewater
Urban Water
Subsurface Hydrology.

Hopefully, the most recent innovation, trends, and concerns, practical challenges encountered, and the solutions adopted in the field of water sciences presented in this book can enlighten water researchers and authorities in management of water resources in arid land.

Thanks!

Al-Khod, Oman — Ali Al-Maktoumi
Al-Khod, Oman — Osman Abdalla
Al-Khod, Oman — Anvar Kacimov
Al-Khod, Oman — Slim Zekri
Al-Khod, Oman — Mingjie Chen
Al-Khod, Oman — Talal Al-Hosni
New Haven, USA — Kaveh Medani

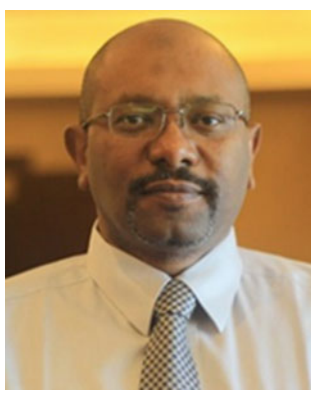
Acknowledgements

This book assembles selected papers presented at "the 2nd International Conference on Water Resources in Arid Areas" during November 9–11, 2020, in Muscat, Oman, jointly organized by Water Research Center, Sultan Qaboos University (SQU) and Ministry of Agriculture, Fisheries, and Water Resources in Oman. The highly appreciated generous support provided by SQU for the conference has paved the ground for this book. The review of papers conducted by a pool of experts in various fields of water science (names of reviewers are listed in the book) has significantly improved the quality and provided constructive criticism important for quality assurance. We would like to also express our deepest thanks and gratitude to the authors of the selected papers for their valuable contribution. We are also indebted to the office work and support of Ms. Maria Diana Austria, the WRC office coordinator.

Contents

About the Editors

Dr. Ali Al-Maktoumi is an associate professor of groundwater hydrology at the Department of Soil, Water, and Agriculture Engineering, and Director of Water Research Center, Sultan Qaboos University, Oman. His research focuses on water resources management in an arid area, which includes groundwater modeling/hydrology, the efficiency of recharge dams, and hydro-pedology. Through a number of awarded grants, he established scientific collaboration with Utrecht University, Delft University of Technology, UNESCO-IHE, California Institute of Technology, Jet Prolusion Laboratory-NASA, University of Nebraska-Lincoln, and University of Jordan. This international collaboration resulted in a number of excellent publications and professional scholarly activities.



Dr. Osman Abdalla holds B.Sc. (1988) and M.Sc. (1993) in geology from University of Khartoum and Ph.D. (2000) in hydrogeology from University of Technology, Berlin. He is Director of Water Research Center at Sultan Qaboos University since 2012 and Associate Professor of hydrogeology at the Department of Earth Sciences, College of Science. His research bridges several areas of physical and chemical hydrogeology in arid areas and intends to develop a solid platform for hydrogeological and environmental research and training of an international standard with emphasis on groundwater recharge and discharge. Dr. Abdalla has established many international and regional collaborations, been awarded over 10 major grants including His Majesty Trust Fund, and published several articles in reputable international journals.

Dr. Anvar Kacimov completed his B.Sc., M.Sc., Ph.D. (fluid mechanics) from Kazan University, USSR, 1982, 1987. He worked at Kazan University, Departments of Seepage and Mathematical Analysis for the period 1982–1998. Since 1998, he worked at SQU, Oman, as assistant–associate full professor, Department of Soils, Water and Agricultural Eng; administratively, HoD (2007–2012); director of Water Research Centre (2011–2012); and dean (2012–2015). His areas of interest include fluid, heat, and mass transfer through porous media (soils, aquifers, oil formations) and of applications in hydroecology, soil physics, irrigation and drainage, hydraulic and hydrologic engineering, groundwater hydrology, fluid mechanics, and reservoir engineering. He has published 128 papers in refereed journals (in English) and has co-authored two books (in Russian). He has been awarded Omani Green Research Award with a Special Commendation of Mitsubishi Corporation (2010) and Best Reviewer of *Vadose Zone Journal* (2005) and *Journal of Irrigation and Drainage Engineering*, ASCE (2013). Research and Innovation Award in Water Sciences, The Research Council, Oman (2018).

Dr. Slim Zekri is Professor and Head of the Department of Natural Resource Economics at Sultan Qaboos University (SQU) in Oman. He earned his Ph.D. in Agricultural Economics and Quantitative Methods from the University of Cordoba, Spain. He is Associate Editor of the *Journal of Water Economics and Policy*. Dr. Zekri has worked as a consultant for a range of national and international agencies on natural resource economics, policy and governance, agriculture, and water economics in the Middle East and North Africa. He is member of the Scientific Advisory Group of the FAO's Globally Interesting Agricultural Heritage Systems. His main research interests are in Water Economics and Policy and Environmental Economics. In 2017, he was awarded the Research and Innovation Award in Water Science from the Sultan Qaboos Higher Center for Culture and Science in the Scientific Publications Category.

Dr. Mingjie Chen holds a B.E. in Environmental Engineering (1997) from Tsinghua University China, a M.Sc. in Environmental Sciences (2000) from Peking University (China) and a Ph.D. degree in Hydrogeology (2005) from University of California, Santa Barbara (USA). After 10 years of research experiences in Los Alamos National Lab, Tufts University, Lawrence Livermore National Lab in USA, Dr. Chen joined Water Research Center, Sultan Qaboos University (Oman) in 2014 as a senior hydrogeologist. Dr. Chen's research focuses on using laboratory experiments, mathematical models, and numerical techniques to study multiple fluids (water, oil, gas) flow and contaminant transport in subsurface area. He has conducted more than 20 research projects on underground environment remediation, hydrocarbon reservoirs, CO_2utilization and sequestration, geothermal reservoir, groundwater modeling and management. At present, Dr. Chen serves as Associate Editor for *Arabian Journal of Geosciences*, *Hydrogeology Journal*, and *Journal of Hydrology*.

Dr. Talal Al-Hosni holds a B.Sc. in earth sciences (1999) from Sultan Qaboos University (Oman) and a M.Sc. in hydrogeology (2001) from Birmingham University (UK). He received a scholarship from Oman government in 2003 to continue with his Ph.D. study in chemical hydrogeology at Melbourne University (Australia). After his Ph.D. in 2007, Al-Hosni joined the Department of Earth Sciences at Sultan Qaboos University as an assistant professor in the area of hydrogeology and environmental geology. He worked as Theme Supervisor (Omani Land) in the Omani Encyclopedia for the period 2008–2009. Since 2012, he is a member of the scientific committee for the Oman Mountains Atlas Project. Talal is one of the Oman representatives in Group B of the CTBTO. He was the deputy director in the Center for Environmental Studies and Research at Sultan Qaboos University (2018–2019) and is now the head of Earth Sciences Department. He is a geology expert in the courts of Oman. Areas of interest include mainly hot springs, groundwater recharge, intra-aquifers mixing, and usage of bottled water and its impact. Al-Hosni contributed to teaching a number of courses including environmental geology and hydrogeology and developed a number of training courses in the area of EIA of mining and groundwater management.

Kaveh Madani is an environmental scientist, educator, and activist, working at the interface of science, policy, and society. He has previously served as the Deputy Vice President of Iran in his position as Deputy Head of Iran's Department of Environment, Vice President of the UN Environment Assembly Bureau, and Chief of Iran's Department of Environment's International Affairs and Conventions Center. He is currently a Henry Hart Rice Senior Fellow at the MacMillan Center for International and Area Studies of Yale University and a Visiting Professor at the Centre for Environmental Policy (CEP) of Imperial College London. He has received a number of awards for his research, teaching, as well as outreach and humanitarian activities, including the New Faces of Civil Engineering recognition in 2012, the Arne Richter Award for Outstanding Young Scientists in 2016, the Walter Huber Civil Engineering Research Prize in 2017, and the Hydrologic Sciences Early Career Scientist Award in 2019.

Hydroinformatics

Statistical Approach for Water Quality Evaluation of Irrigation Canals in Egypt

Eman A. Hasan, Marwa M. Aly, and A. M. I. Abd El Hamid

Abstract

Surface water quality is a vital issue worldwide due to increasing population and development plans. The objective of this study is to develop a statistical approach for assessing irrigation water canals through monitoring pollutant concentrations and a water quality index. Water samples were collected monthly for the two years 2012/2013 and 2013/2014, from fixed locations along the studied canals in Eastern Delta as a case study. The statistical approach used in this work includes weighted arithmetic water quality index (WAWQI), hierarchical clustering analysis (HCA) and principal component/factor analysis (PC/FA). The study revealed that according to the cluster analysis considering WAWQI, 61.11% of the monitoring locations were grouped under cluster A which has the best water quality among the cluster groups. Furthermore, the results of the principal component analysis identified five principal components which were responsible for 81.24% of water quality status in the studied locations. The results obtained from this study can assess the decision makers in applying water quality strategy to control the presence of pollutants from different sources.

Keywords

Water quality index • Cluster analysis • Principal component analysis • Factor analysis • Eastern Nile Delta canals

E. A. Hasan (✉)
Professor Irrigation and Hydraulics Engineering, Drainage Research Institute, National Water Research Center, Awal Shubra Al Kheimah, Egypt

M. M. Aly
Faculty of Engineering, Helwan University, Matareya, Egypt

A. M. I. Abd El Hamid
Hydraulic Research Institute, National Water Research Center, Awal Shubra Al Kheimah, Egypt

1 Introduction

In developing countries, millions of people die annually from water-related diseases (WHO, 2017); for this reason, protection of freshwater resources is an essential aspect. In Egypt, observing water quality of the Nile system began in 1980 using monitoring network (Abdel-Dayem, 2011). The purpose of monitoring network is to measure 34 water quality parameters such as physical, chemical, biological parameters, heavy metals and nutrients to be compared with Egyptian standards. Consequently, water quality index (WQI) is used to reduce the higher number of parameters, rate the health of a stream with a single number and assist in the development of water management strategies (Tyagi et al., 2013; Elshemy, 2016).

Several researchers worldwide assess the water quality of different canals and rivers using WQI (Goher et al., 2014; Manju et al., 2014). Meanwhile, Oketola et al. (2013) reported that hierarchical cluster analysis (HCA), principal component/factor analysis (PC/FA) and correlation matrix are used widely worldwide to illustrate the variations in the water quality as a statistical tool. In Bangladesh, the HCA and WQI were used to evaluate the water quality of an industrial area in Dinajpur (Howladar et al., 2017). FA was used to illustrate the water quality index parameters of the Nile River in Egypt (Yousry & El Gammal, 2015). In China, the water quality of the Tiaoxi River was evaluated by HCA and PCA for physicochemical and microbiological parameters (Vadde et al., 2018).

The research problem is the issue of water quality in the Eastern Nile Delta to support decision makers in taking the appropriate action regarding the protection of water resources. Several researchers assessed water quality of watercourses using different statistical analyses as mentioned before, but the objective of this research is to develop a statistical approach for assessing irrigation water canals through monitoring pollutant concentrations and water quality index.

A. Al-Maktoumi et al. (eds.), *Water Resources in Arid Lands: Management and Sustainability*,
Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-67028-3_1

2 Methodology

2.1 Study Area

The status of water quality for ten canals in the Eastern Delta region was evaluated. These canals are Tawfiki Rayah, Mansouria Canal, Sharkawiya Canal, Bahr Mois Canal, Daffan Canal, Ismailia Canal, Port Said Canal, Suez Canal, El-Wadi El-Sharky Canal and El-Salam Canal. The research gets to benefit from the GIS technique; the available database of the canals and drains of Egypt is generating a map for the study area using the ArcMap software as shown in Fig. 1. El Salam Canal is the backbone of an agriculture developing project in Egypt that aims at reclaiming more than six hundred thousand Feddans in the north-eastern part of the country. The water sources of El-Salam Canal are from mixing agricultural drainage water and freshwater from the River Nile (Damietta Branch) with variable mixing ratio through the year, up to 1:1.

2.2 Studied Locations and Parameters

Eighteen monitoring locations of water quality along the ten investigated canals in the Eastern Delta irrigation system are shown in Table 1. Seventeen water quality parameters were studied, namely dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO_3), ammonium (NH_4), total phosphorus (TP), total dissolved solid (TDS), sulfate (SO_4), the power of hydrogen (pH), boron (B), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), lead (Pb) and nickel (Ni).

Monthly water quality parameters for the two years 2012/2013 and 2013/2014 were obtained from the database

Fig. 1 Eastern Delta region and studied locations

Table 1 Studied locations in the Eastern Delta irrigation system

No	Location code	Canal name	Description
1	EI01	Tawfiki Rayah	Downstream of the built-up area of Banha city
2	EI02	Tawfiki Rayah	Downstream of the built-up area of Zifta/Mit Ghamr city
3	EI03	Mansouria Canal	Downstream of the built-up area of Mansoura city
4	EI04	Sharkawiya Canal	Upstream of the built-up area of Damietta city
5	EI05	Sharkawiya Canal	Upstream of the drinking water intake of Matariya city
6	EI06	Bahr Mois Canal	Upstream of the Zagazig drinking water intake
7	EI07	Bahr Mois Canal	Downstream built-up area of Zagazig city and inflow from East Wadi Irrigation Canal
8	EI08	Bahr Mois Canal	Upstream of drainage reuse PS* EH02
9	EI09	Daffan Canal	Upstream of drainage reuse PS EH12
10	EI10	Ismailia Canal	Ismailia Canal—at km 15
11	EI11	Ismailia Canal	Downstream of the built-up area of Bilbais city
12	EI12	Ismailia Canal	Upstream the branching and the built-up area of Ismailia city
13	EI13	Port Said Canal	Upstream the built-up area and the drinking water of Port Said city
14	EI14	Suez Canal	Upstream the built-up area and the drinking water intake of Suez city
15	EI15	El-Wadi El-Sharky Canal	Upstream of drainage reuse PS EB03
16	EI18	El-Salam Canal	Upstream of drainage reuse PS ESL02
17	EI19	El-Salam Canal	Upstream of drainage reuse PS ESL04
18	EI21	El-Salam Canal	El-Salam Canal intake from Damietta Branch of the River Nile

**PS* pump station

of the Drainage Research Institute and the Central Water Quality Unit in the Ministry of Water Resources and Irrigation (MWRI).

2.3 Statistical Approach

The statistical approach used in this study began with investigating water quality status using WAWQI and then applying statistical techniques (HCA and PC/FA).

2.3.1 Investigating Water Quality Status

The objective of this part is to investigate and evaluate the water quality status of each location along the studied canals using the WAWQI and taking into consideration the Egyptian guidelines (law 48 for 1982 and ministerial decree in 92/2013).

Over the years, several WQIs have been proposed and used appropriately by governmental agencies and researcher; Canadian Council of Ministers of Environment Water Quality Index—CCMEWQI (CCME, 2001), National Sanitation Foundation Water Quality Index—NSFWQI (Brown et al., 1972), Oregon Water Quality Index—OWQI (Dunnette, 1979) and Weighted Arithmetic Water Quality Index Method—WAWQIM are commonly used (Howladar et al., 2017).

The average WQI of the studied locations was computed by weighted arithmetic method, for the above-mentioned seventeen parameters during the two years. The weighted arithmetic water quality index (WAWQI) was used as it is considered a robust method in water quality analysis (Howladar et al., 2017; Chauhan & Singh, 2010; Chowdhury et al., 2012; Rao et al., 2010; Balan et al., 2012). After Rown et al. (1972), WAWQI was calculated according to Eq. (1).

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} QiWi}{\sum_{i=1}^{n} Wi} \quad (1)$$

where

Qi: the quality rating scale

WI: the unit weight

N: number of parameters.

Equation (2) is used to calculate the quality rating scale (Rown et al., 1972), while for calculating the unit weight for each parameter Eq. (3) is used.

.

$$Qi = 100[(Vi - Vo)/(Si - Vo)] \quad (2)$$

where

Vi: actual measured value of ith parameter in the analyzed water

Vo: the ideal value of the parameter in pure water, $Vo = 0$ except pH = 7 and

DO = 0.146 kg/m^3 (Tripathy & Sahu, 2005)

Si: the standard value of its parameter of Egyptian quality guidelines (MWRI, 2013).

$$Wi = \frac{K}{Si} \quad (3)$$

K is proportionally constant and is calculated from Eq. (4).

$$K = \frac{1}{\sum(1/Si)} \quad (4)$$

At the end of this part, the rating (status) of water quality for the studied locations can be obtained after using Table 2.

2.3.2 Hierarchical Cluster Analysis (HCA)

Cluster analysis (CA) is one of the large families of statistical techniques whose main purpose is to categorize sampling locations into distinct groups or clusters according to some criteria, such that the within-group similarity is maximized and among-group similarity is minimized. CA joins the most similar observations and successively the next most similar observations (Oketola et al., 2013).

In this study, CA was applied using the monthly values of the seventeen water quality parameters measured at eighteen monitoring locations along Eastern Delta canals for the two years 2012/2013 and 2013/2014 by means of Ward's method using squared Euclidean distance for similarity measurements (Singh et al., 2004). The data used were checked first to be normally distributed ensuring its validity to apply the multivariate statistical techniques (HCA and PC/FA). Kolmogorov–Smirnov and Shapiro–Wilk tests were used to examine the normality status.

2.3.3 Principal Component/Factor Analysis (PC/FA)

PCA is a powerful pattern recognition technique that attempts to explain the variance of a large dataset of intercorrelated variables with a smaller set independent variable (principal component) (Simeonov et al., 2003). Factor analysis (FA) generally helps to reduce and simplify the outcomes from the PCA.

For the purposes of this paper, PCA has been carried out upon seventeen parameters for identifying the most significant parameters for the assessment of the water quality of the Eastern Nile Delta canals. Through FA, varimax rotation was applied to determine the varimax factors (VFs) with strong positive loading that can account for high variability.

An eigenvalue gives a measure of the significance of factors with the highest eigenvalues, those are the most significant. Eigenvalues of 1.0 or greater are considered significant (Shrestha & Kazama, 2007). Classification of principal components is thus "strong," "moderate" and "weak," corresponding to absolute loading values of >0.75, 0.75–0.50 and 0.50–0.30, respectively (Liu et al., 2003).

It is worth to mention that the STATISTICA 10 software program was used to perform the statistical analysis (HCA and PC/FA) for the water quality parameters.

3 Results and Discussion

3.1 Investigating Water Quality Status

Table 3 shows the descriptive statistics of the measured parameters at the eighteen studied locations. The basic statistics are described, namely the mean, median, maximum, minimum, variance, standard deviation and variance coefficient of the selected water quality parameters. Regarding the Egyptian guidelines of law 48/1982 and its ministerial decree amendment 92/2013, it must be emphasized that the mean concentrations of some variables such as DO, BOD, COD, NO_3, NH_4, TDS, Cu and Pb are higher

Table 2 Water quality rating according to WAWQI (Brown et al., 1972)

WQI value	Rating of water quality	Grading
0–25	Excellent	A
26–50	Good	B
51–75	Poor	C
76–100	Very poor	D
Above 100	Need treatment	E

Table 3 Descriptive statistics for water quality parameters measured at Eastern Delta locations

Parameters	Mean*	Median	Min	Max	Variance	Std dev	Var coef	Standard values**
DO	6.490	5.990	3.240	8.020	2.020	1.420	21.879	6
BOD	9.093	6.583	6.000	17.250	16.180	4.022	44.233	6
COD	11.725	8.833	7.833	21.500	23.850	4.883	41.647	10
pH	7.858	7.870	7.770	7.930	0.00	0.041	0.525	6.5–8.5
NO_3	5.284	4.130	1.820	12.770	13.300	3.647	69.022	2
NH_4	1.777	1.590	0.950	4.770	0.850	0.920	51.791	0.500
TP	0.316	0.230	0.050	0.640	0.040	0.207	65.484	2
TDS	535	435	306	1172	751	274	51	500
SO_4	1.829	1.520	1.190	3.310	0.50	0.704	38.504	200
B	0.117	0.124	0.062	0.171	0.00	0.034	29.475	0.5
Cd	0.0004	0.000	0.000***	0.001	0.000	0.001	123.201	0.001
Cu	0.094	0.054	0.000	0.560	0.020	0.128	136.207	0.010
Fe	0.014	0.016	0.000	0.029	0.000	0.008	57.967	0.5
Mn	0.001	0.000	0.000	0.006	0.000	0.002	199.018	0.2
Zn	0.000	0.000	0.000	0.001	0.000	0.000	282.290	0.01
Ni	0.0001	0.000	0.000	0.001	0.000	0.0002	412.311	0.02
Pb	0.024	0.000	0.000	0.168	0.000	0.054	228.754	0.01

*All the parameters are in milligrams per liter except pH
**Law 48/1982 amended in 2013
***Number approximately equal to zero

than the standards; therefore, the water resource needs extensive monitoring process.

3.2 WAWQI

The method of calculation of WQI assigned unit weights for the considered parameters of the studied locations in the Eastern Delta. Table 4 shows an example of WAWQI calculation of the monitoring location (EI14) along the Suez Canal; the WAWQI for EII4 was 44.8. It is obvious from the table that the weighted value of copper affected mainly the calculation of WAWQI at EI14.

The results of WAWQI calculation ranged from 25.73 to 135.9 for all the monitoring locations as shown in Fig. 2. Its highest value was at location EI18 that represents water quality of El-Salam Canal after the mixing process of fresh and drainage water from the Nile River and Farsqur drain, respectively, resulting in high water salinity according to Shaban (2017). The lowest WAWQI was at monitoring location EI15 along El-Wadi El-Sharky Canal upstream of drainage reuse PS EB03. According to the calculated values of WAWQI, 30% of the considered locations fall under good quality, poor quality for another 30% and very poor for 20% and the rest 20% of the monitoring locations need more investigation and long-term monitoring to control any source of pollution in the future.

Figure 2 shows also that the three studied locations, namely E101, E106 and E118, have the extreme values of the WAWQI. Table 5 shows the percentages of compatible measurements with the Egyptian water quality guidelines for these locations. From these percentages for (DO, BOD, COD), (NO_3, NH_4, TDS) and (Cu) measured at EI01, EI06 and EI18, respectively, there was pollution resulted from domestic, agriculture and industrial activities. Meanwhile, it is clear that the location E118 has the least percentages of compatible for the above-mentioned water quality parameters according to its location on El-Salam Canal which is fed by reused water as previously explained.

3.3 HCA

Since HCA requires the examined data to be normally distributed, Kolmogorov–Smirnov and Shapiro–Wilk tests were used to check the normality status of the seventeen water quality parameters. The results showed that COD, BOD, Fe, B, TP and NO_3 were normally distributed while other studied parameters were transformed to be normally distributed. Then, all the seventeen water quality parameters were used for clustering process.

The relationships between the monitoring locations were resulted from the cluster analyses and were presented in the dendrogram plot, Fig. 3. It is obvious that the whole studied

Table 4 Calculation of WAWQI at monitoring location EI14 along Suez Canal

Parameters	*Actual measured values (*Vi*)	**Standard values (*Si*)	Unit weight (*Wi*)	Quality rating (*Qi*)	Weighted values (*QiWi*)
DO	4.480	6	0.0001	117.674	0.014
BOD	6.000	6	0.0001	100.000	0.012
COD	8.000	10	0.0004	80.000	0.006
pH	7.840	6.5–8.5	0.0015	168.000	0.016
NO_3	12.770	2	0.0004	638.500	0.234
NH_4	1.530	0.5	0.0000	306.000	0.449
TP	0.540	2	0.0000	27.000	0.010
TDS	946.000	500	0.0015	189.200	0.000
SO_4	2.820	200	0.7340	1.410	0.000
B	0.092	0.5	0.0734	18.400	0.027
Cd	0.000	0.001	0.0015	0.000	0.000
Cu	0.060	0.01	0.0037	600.000	44.034
Fe	0.014	0.500	0.073	2.800	0.004
Mn	0.000	0.200	0.037	0.000	0.000
Zn	0.000	0.010	0.073	0.000	0.000
Ni	0.000	0.020	0.0001	0.000	0.000
Pb	0.000	0.010	0.0001	0.000	0.000
					WAWQI = 44.88

*All the parameters are in milligrams per liter except pH, multiply all parameters except pH by 10^{-2} to convert and follow S.I units (kg/m^3)

**Law 48 for 1982 and ministerial decree in 92/2013

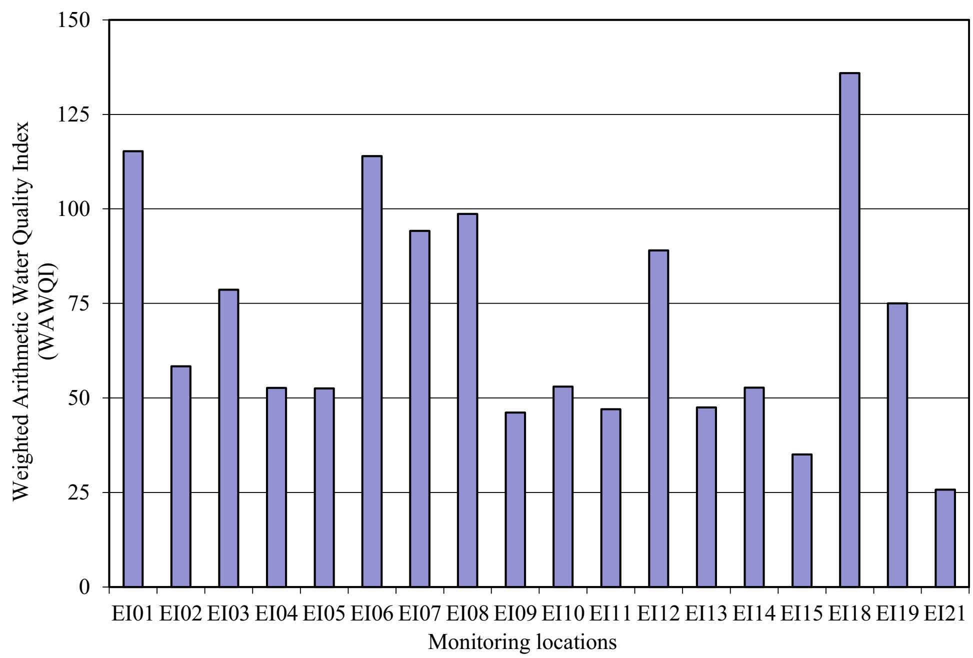


Fig. 2 Weighted arithmetic water quality index for monitoring locations

Table 5 Percentages of compatible measurements for water quality parameters measured at EI01, EI06 and EI18

Parameters	*Egyptian water quality guidelines	Percentage of compatible measurements		
		EI01	EI06	EI18
DO	6	0	0	0
BOD	6	84	75	17
COD	10	67	59	17
pH	6.5–8.5	100	100	100
NO_3	2	17	0	0
NH_4	0.50	59	100	0
TP	2	100	100	100
TDS	500	38.89	82	0
SO_4	200	100	100	100
B	0.50	100	100	100
Cd	0.001	100	100	100
Cu	0.01	12	17.50	0
Fe	0.50	100	100	100
Mn	0.20	100	100	100
Zn	0.01	100	100	100
Ni	0.02	100	100	100
Pb	0.01	100	100	100

*Law 48 for 1982 and ministerial decree in 92/2013

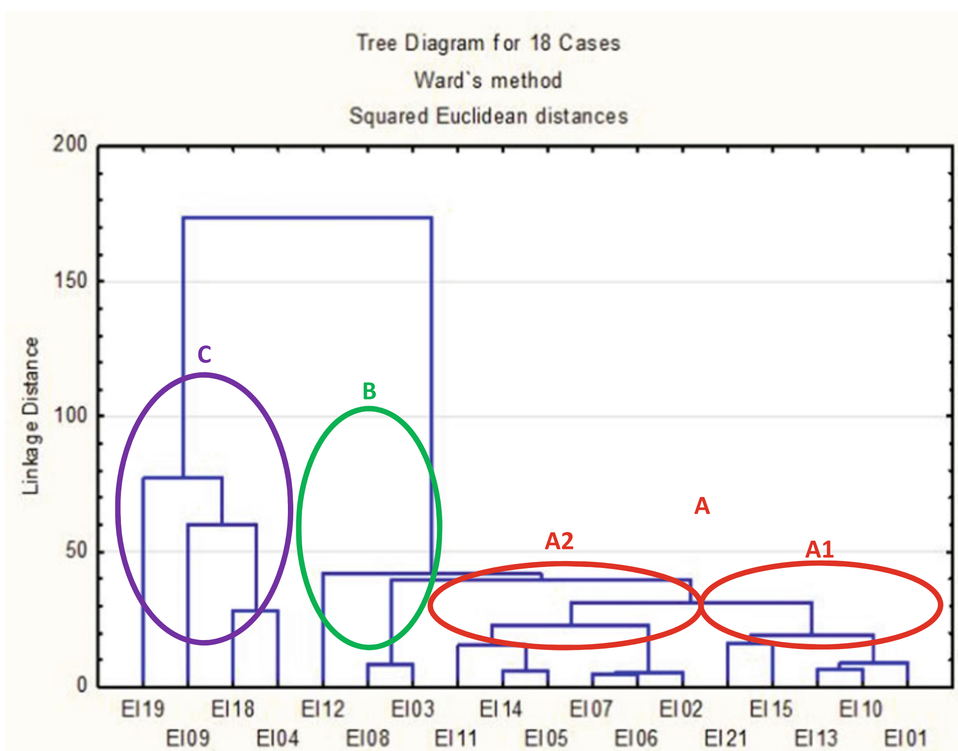


Fig. 3 Dendrogram shows the relationship between monitoring locations in Eastern Delta

Table 6 Cluster analysis of monitoring locations

Group	Location code	Cluster	Cluster percentage	Water quality status
A1	EI01, EI10, EI13, EI15, EI21	Cluster A	61.11	Poor
A2	EI02, EI06, EI07, EI05, EI14, EI11			
B	EI03, EI08, EI12	Cluster B	16.67	Very poor
C	EI04, EI18, EI09, EI19	Cluster C	22.22	Very poor

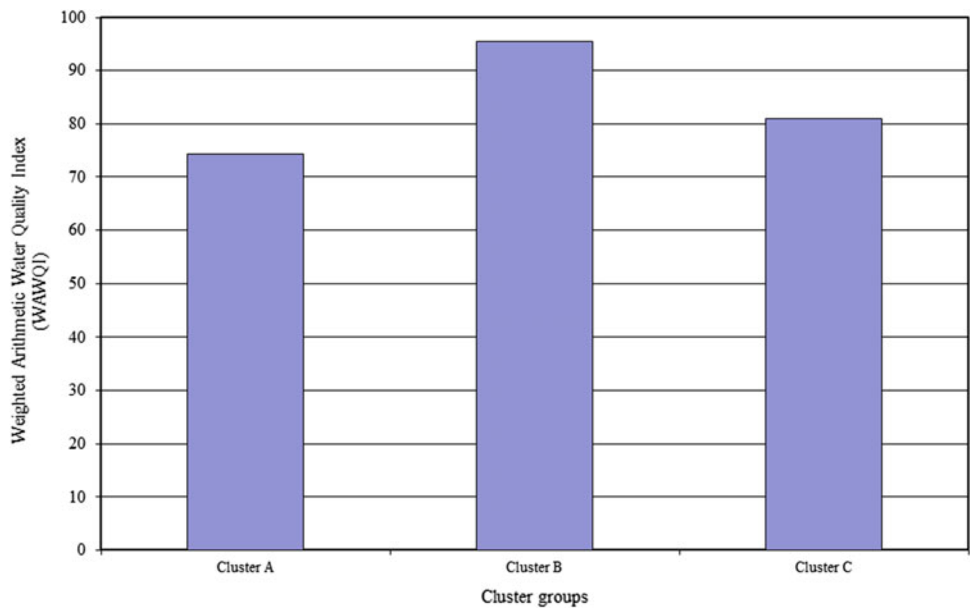


Fig. 4 Weighted arithmetic water quality index of cluster groups

locations formed three main groups of the cluster. Table 6 shows that cluster A groups 61.11% of the studied locations whereas cluster B represents 16.67% of locations and finally cluster C includes 22.22% of the total locations.

Figures 4 and 5 show the classifications of different studied locations according to their WAWQI and cluster group, and cluster group A has the best water quality among the cluster groups as it has the lowest value of the WAWQI. This result can assess the decision maker in management of water quality in the Eastern Delta.

3.4 PC/FA

According to PC/FA, five principal factors were detected to be responsible of 81.24 of the total variances in the water quality data. Table 7 shows that each of the five factors has eigenvalue greater than 1, and Factor1 (PC 1) is the most significant variables which explain 37.25% of the total variance and was strongly loaded with DO, NO_3, TP, TDS and SO_4, moderately loaded with BOD and COD and weakly loaded with B and Cu, while Factor2 (PC 2) contains 18.56% of the total variance which was strongly loaded with Cd and Cu, moderately loaded with BOD, COD and Pb and weakly loaded with DO, TP and Ni. Factor3 (PC 3) accounts 11.25% of the total variance and was strongly loaded with Zn and Ni and moderately loaded with B and Pb. Factor4 (PC 4) possesses 7.95 of the total variances and was strongly loaded with NH_4, moderately loaded with pH and weakly loaded with Cd, BOD and COD. Finally, Factor5 (PC 5) represents 6.23% of the total variance, weakly loaded with Fe, BOD and COD as shown in Table 8. The previous analysis proves the presence of organic contamination and wastewater from domestic, agricultural and industrial sources.

4 Conclusion

In this research, a comprehensive statistical approach was applied to classify, evaluate and identify the significant parameters in water quality of irrigation canals in Eastern

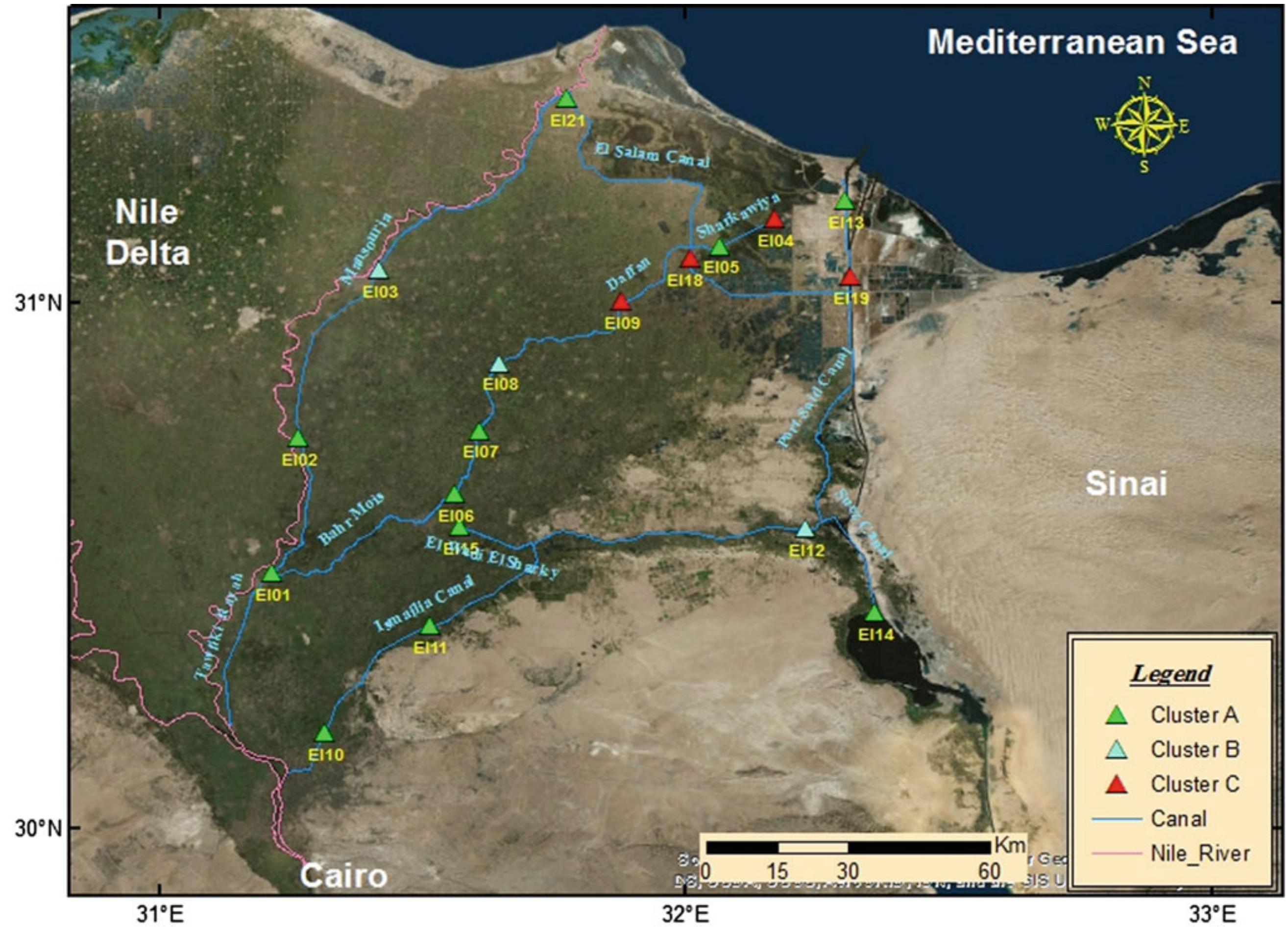


Fig. 5 Water quality clustering in Eastern Delta

Table 7 Eigenvalues and variance percentage

Principal components	Eigenvalue	% total variance	Cumulative eigenvalue	Cumulative percentage
1	6.3321	37.2479	6.3321	37.2479
2	3.1555	18.5618	9.4876	55.8097
3	1.9129	11.2523	11.4005	67.0620
4	1.3509	7.9461	12.7514	75.0081
5	1.0592	6.2305	13.8106	81.2386

Delta of Nile River taking into consideration the Egyptian guidelines of law 48/1982 and ministerial decree in 92/2013. The study revealed that the calculated WAWQI varied along the studied canals, according to the effect of each pollutant to the index calculation. This variation is due to organic pollution, nutrients and sometimes heavy metal concentration. According to the HCA, 61.11% of the studied locations were grouped under cluster A which has the best water quality among the cluster groups. Furthermore, the results of the PC/FA proved the presence of five principal components responsible for 81.24% of the variation in water quality. The results obtained from this study can assess the decision makers in applying water quality strategy to control the presence of pollutants from different sources.

Table 8 Factor loadings after varimax rotation

	Factor1	Factor2	Factor3	Factor4	Factor5
DO	−0.717	0.377	−0.295	0.157	−0.100
BOD	0.570	0.502	0.277	0.385	0.312
COD	0.547	0.559	0.265	0.348	0.311
pH	0.088	0.174	0.230	**0.675**	−0.279
NO_3	**0.955**	0.214	−0.007	−0.015	−0.029
NH_4	0.066	0.021	−0.016	**0.849**	0.166
TP	**0.841**	0.305	0.228	0.076	0.012
TDS	**0.933**	−0.185	0.075	0.053	−0.061
SO_4	**0.938**	−0.085	0.134	0.140	0.036
B	0.319	−0.170	**0.687**	−0.101	−0.327
Cd	0.068	**0.766**	0.197	0.336	0.013
Cu	0.455	**−0.724**	−0.005	0.262	−0.011
Fe	−0.024	0.079	**−0.622**	−0.012	0.311
Mn	−0.012	−0.068	−0.075	−0.001	**−0.933**
Zn	0.272	0.131	**0.895**	0.157	0.186
Ni	−0.014	0.434	**0.846**	0.055	0.119
Pb	0.250	**0.638**	0.473	−0.016	0.095

[*]Significant factor loadings are in bold

Acknowledgements The authors are grateful to the staff of the Drainage Research Institute (DRI), special thanks to Professor Dr. Esam Khalifa and Professor Dr. Hussein El Gammal Director of the institute for their continuous support and making all the required data available.

References

Abdel-Dayem, S. (2011). Water quality management in Egypt. *International Journal of Water Resources Development, 27*(1), 181–202. https://doi.org/10.1080/07900627.2010.531522.

Balan, I., Madan Kumar, P., & Shivakumar, M. (2012). An assessment of groundwater quality using water quality index in Chennai, Tamil Nadu, India. *Chronicles of Young Scientists, 3*(2), 146–150. https://doi.org/10.4103/2229-5186.98688.

Brown, R. M., McCleiland, N. J., Deininger, R. A., O'Connor, M. F. (1972). A water quality index—crossing the psychological barrier. In S. H. Jenkis (Ed.), *Proceedings of International Conference on Water*.

CCME. (2001). Canadian Environmental Quality Guidelines for the Protection of Aquatic Life, CCME Water Quality Index: technical report, 1.0.

Chauhan, A., & Singh, S. (2010). Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report Opinion, 2*(9), 53–61.

Chowdhury, R. M., Muntasir, S. Y., & Hossain, M. M. (2012). Water quality index of water bodies along Faridpur-Barisal road in Bangladesh. *Global Engineers and Techologists Review, 2*(3), 1–8.

Dunnette. (1979). A geographically variable water Quality Index used in Oregon. *Journal Water Pollution Control Federation, 51*(1), 53–61.

Elshemy, M. (2016). Water quality assessment of Lake Manzala, Egypt: a comparative study. *International Journal of Scientific Research in Environmental Sciences, 4*(6), 196–207. https://doi.org/10.12983/ijsres-2016-p0196-0207

Goher, M. E., Hassan, A. M., Abdel-Moniem, I. A., Fahmy, A. H., & El-Sayed, S. M. (2014). Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *Egyptian Journal of Aquatic Research, 40*(3), 225–233.

Howladar, M. F., Al Numanbakth, Md. A., & Faruque, M. O. (2017). An application of water quality index (WQI) and multivariate statistics to evaluate the water quality around Maddhapara Granite Mining Industrial Area, Dinajpur, Bangladesh. *Environmental Systems Research, 6*(1), 6–13. https://doi.org/10.1186/s40068-017-0090-9

Liu, C. W., Lin, K. H., & Kuo, Y. M. (2003). Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Science of the Total Environment, 313*(1–3), 77–89.

Manju, E. K., George, A. V., & Rekha, V. B. (2014). A comparative study of water quality index (Wqi) of Vagamon and peermade sub-watersheds of Meenachil and Pamba River basins of Western Ghats, Kerala, South India. *IOSR Journal of Environmental Science, Toxicology and Food Technology, 8*(1), 53–58. https://doi.org/10.9790/2402-08125358.

MWRI. (2013). Egyptian Ministry of Water Resources and irrigation, law 48/1982, Protection of the River Nile and Waterways from Pollution "Decree No. 49" (2013) in the amended executive regulations of the law by Minister Decision No. 92/2013. (Arabic Edition).

Oketola, A. A., Adekolurejo, S. M., & Osibanjo, O. (2013). Water quality assessment of river ogun using multivariate statistical techniques. *Journal of Environmental Protection, 4*(5), 466–479. https://doi.org/10.4236/jep.2013.45055.

Rao, C. S., Rao, B. S., Hariharan, A. V. L. N. S. H., & Bharathi, N. M. (2010). Determination of water quality index of some areas in Guntur district Andhra Pradesh. *International Journal of Applied Biology and Pharmaceutical Technology, I*(1), 79–86.

Rown, R. M., McCleiland, N. J., Deiniger, R. A., & O'Connor, M. F. A. (1972). Water quality index—Crossing the physical barrier. In S. H. Jenkis (Ed.), *Proceedings in International Conference on water pollution Research Jerusalem*, Vol. 6, pp. 787–797.

Shaban, M. (2017). Statistical framework to assess water quality for irrigation and drainage canals. *Irrigation and Drainage, 66*(1), 103–117. https://doi.org/10.1002/ird.2042.

Singh, K. P., Malik, A., Mohan, D., & Sinha, S. (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—A case study. *Water Research, 38*(18), 3980–3992.

Shrestha, S., & Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environmental Modelling and Software, 22*(4), 464–475.

Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., et al. (2003). Assessment of the surface water quality in Northern Greece. *Water Research, 37*(17), 4119–4124.

Tripathy, J. K., & Sahu, K. C. (2005). Seasonal hydrochemistry of groundwater in the barrier spit system of the Chilika Lagoon, India. *Journal of Environmental Hydrology, 13,* 1–9.

Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of Water Resources, 1*(3), 34–38. https://doi.org/10.12691/ajwr-1-3-3.

Vadde, K. K., Wang, J., Cao, L., Yuan, T., McCarthy, A. J., & Sekar, R. (2018). Assessment of water quality and identification of pollution risk locations in TiaoxiRiver(Taihu Watershed), China. *Water (Switzerland), 10*(2), 183. https://doi.org/10.3390/w10020183

WHO (World Health Organization). (2017). *World Water Day Report*. Available at: www.who.int/water_sanitation_health/takingchange.html

Yousry, M. M., & El Gammal, H. A. A. (2015). Factor analysis as a tool to identify water quality index parameters along the Nile River, Egypt. *Journal of American Science, 11*(2), 36–44. https://free-journal.umm.ac.id/files/file/005_27939am110215_36_44.pdf

Eutrophication Status and Control of Egyptian Northern Lakes

Eman A. Hasan

Abstract

Four coastal lakes fringe the north coast of the Nile Delta, Egypt: Manzala, Maruit, Edku and Burullus. These lakes receive huge amounts of direct and indirect drainage: agriculture, industrial and domestic. Eutrophication of these lakes can have significant negative ecological, social and economic impacts on human. The objective of this paper is to quantify and classify the Carlson trophic state index of the Egyptian northern lakes. Also, control actions to reduce deterioration of northern lakes will be recommended. Data of water quality variables of different lakes are taken from the formal reports of the Egyptian Environmental Affairs Agency (EEAA) Web site. The calculation and classification of Carlson trophic state index (CTSI) are made for the period from 2011 until 2015 according to Carlson method, United States Environmental Protection Agency (USEPA) classification and other variables associated with trophic levels in lakes. These variables are total phosphorus, total nitrogen, chlorophyll-a and Secchi depth. The study revealed that northern lakes suffer from different degrees of eutrophication. Regression analysis results showed that Carlson trophic state index trend is increasing which indicates deteriorating water quality in Lake Maruit, Burullus and Bardawil, declining or improving in Lake Edku and Lake Manzala.

Keywords

Carlson trophic state index • Eutrophication • Northern lakes • Regression analysis

E. A. Hasan (✉)
Professor, Irrigation and Hydraulics Engineering, National Water Research Center, Awal Shubra Al Kheimah, Egypt

1 Introduction

Carlson’s trophic state index (CTSI) is a common method for characterizing a lake’s trophic state or overall health. This method uses Secchi’s disk transparency, chlorophyll-a and phosphorus measurements (Carlson, 1977). The average values of CTSI of these three parameters will be considered in determining Carlson’s trophic state index.

Eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the mid-twentieth century. Since then, it has become more widespread. Surveys showed that 53% of lakes in Europe, 48% in North America and 41% in South America are found in eutrophic state (Colin et al., 2007).

The productivity of Kaw Lake, Oklahoma, USA, was evaluated through the interaction of nutrient concentration, mainly total phosphorous, chlorophyll-a and Secchi disk transparency as defined in Carlson trophic state index for the year 2013–2015. The results showed that the lake is eutrophic to hyper-eutrophic (Alemayehu & Francine, 2016).

Eutrophication problem in the Egyptian lakes (except Bardawil Lake) is attributed mainly to the large volumes of wastewaters discharged through land-based effluents to coastal lakes that are connected directly or indirectly to the Mediterranean coastal area. These effluents are loaded by variable amounts of nutrient salts, which promote intensive phytoplankton growth.

In this regard, the Egyptian government has taken action through preparing a comprehensive database for environmental parameters. This was done by implementing the periodic monitoring program of water quality of Egyptian lakes, starting with northern lakes (Maruit—Edku—Burullus—Manzala—Bardawil) with four seasons of field campaigns during each year (EEAA, 2015).

The research problem studied in this work is the deterioration of Egyptian northern lake's status as a result of dumping huge amounts of untreated wastewater into lakes

A. Al-Maktoumi et al. (eds.), *Water Resources in Arid Lands: Management and Sustainability*,
Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-67028-3_2