WEST VISAYAS STATE UNIVERSITY
COLLEGE OF ARTS AND SCIENCES
GRADUATE SCHOOL
Iloilo City

FECAL COLIFORM (MPN) AND WATER QUALITY PARAMETERS OF COASTAL WATERS IN BORACAY ISLAND: A CORRELATIONAL AND PREDICTIVE STUDY

A Master's Thesis

Presented to

the Faculty of the College of Arts and Sciences

In Partial Fulfillment

to the Degree

Masters of Science in Biology

(Microbioogy)

By

Althea Rowan-Horvidalla

July 2023

WEST VISAYAS STATE UNIVERSITY
COLLEGE OF ARTS AND SCIENCES
GRADUATE SCHOOL
Iloilo City

Approval Sheet

A Thesis for the Degree

Master of Science in Biology

(Microbiology)

By

Althea Rowan-Horvidalla

Approved by the Research Committee:

SATURNINO LUKE A. SOBREVEGA, MSc. Chairperson

CRISANTO S. LOPEZ, JR, Ph.D., Member

REY G. TANTIADO, Ph.D., Member

SHARON ANN P. MENDOZA, MSc., Member (External Expert)

JEANEMAR GENEVIVE YAP-FIGUERAS, Ph.D., Adviser

ALEXANDER J. BALSOMO, Ph.D.
OIC-Dean

July 2023

Rowan-Horvidalla, A. (2023). Fecal Coliform (Mpn) and Water Quality Parameters of Coastal Waters in Boracay Island: A Correlational and Predictive Study. A Thesis. College of Arts and Sciences Graduate School. West Visayas State Universuty, La Paz, Iloilo City

Abstract

Water quality monitoring is the basic reference in securing safe waters for either drinking or recreation. It is also serves as reference for successful coastal and land management. All water recreational sites are required to monitor the water quality if it is meeting its designated use. The water must maintain the guideline values for its classification, may it be safe for swimming. The water quality is used for the management plan of the concerned area and serve as a guide whether to institute management intervention to improve the water quality. Triplicates of water samples were collected monthly for six months in the three station of the Boracay Island. The water samples were analyzed for fecal coliform, pH, total suspended solids, phosphate, nitrate, and oil and grease. Dissolved Oxygen and Temperature were analyzed *in situ*. The sampling points where the water samples were gathered were geotagged for the development of the fecal coliform GIS density map. Tourist arrival and rainfall data was also gathered. Based on the regression analysis, there was a low correlation between fecal coliform and other water quality parameters such as oil and grease, phosphates, and nitrates. However, the model shows that with increasing oil and grease, phosphates, and nitrates, fecal coliform count is also increasing.

Table of Contents

Title Page	**Page**
Approval Sheet	ii
Acknowledgement	iii
Abstract	v
List of Tables	ix
List of Figures	xi
List of Appendices	xiii
Chapter	
1. Introduction to the Study	1
Background of the Study	2
Conceptual Framework of the Study	4
Statement of the Problem	7
Hypothesis of the Study	8
Definition of Terms	9
Delimitation of the Study	13
Significance of the Study	14
2 Review of Related Literature	15
Water quality in Recreational Waters	15
Correlation between Anthropogenic Activities and	16

	Physico-chemical Properties and Coliform Population in Coastal Waters	19
	Water Quality Monitoring in Recreational Coastal Waters	20
	Employing Geological Information System for Spatial Assessment of Water Quality	22
3	Research design and Methodology	25
	Research Design	25
	Samples	26
	Study Area	26
	Sampling Procedure	30
	Methodology	30
	Materials and Reagents	30
	Procedure	33
	Data Analysis	35
4	Results and Discussion	37
	Results	37
	Descriptive Data Analysis	37
	Inferential Data Analysis	48
5	Summary, Conclusion, Implications, and Recommendations	74
	Summary of the Problems, Methods, and Findings	74
	Conclusions	78

Implications 80

Recommendation 81

References 82

Appendices 96

LIST OF TABLES

Table		Page
1	Standard water quality values for Class SB water bodies (ecotourism and recreational activities) as per DENR Administrative Order No. 2016-08	38
2	Correlation of water parameters in Boracay Island.	48
3	Fecal coliform load in three stations of Boracay Island	49
4	Test between subjects effects of fecal coliform	50
5	Dissolve Oxygen levels from January to June using test of within subjects effects.	52
6	Dissolve oxygen level across three sampling stations	53
7	Significant difference of pH levels from January to June	54
8	pH level between three stations using Test of Between-Subjects Effects	55
9	Significant difference of temperature in the white beach area of Boracay Island.	57
10	Temperature level between three stations using the Test of Between-Subjects Effects.	58
11	Nitrate levels from January to June ($F = 1.755$; $p = .225$) using Test of Within Subjects Effects.	59
12	Nitrate level between the three stations of Boracay Island.	60

13	Phosphate level from January to June in the three stations of Boracay Island.	61
14	Phosphate level from January to June in the three stations of Boracay Island using Test of Between-Subjects Effects.	62
15	Total Suspended Solids level from January-June in the three stations of Boracay Island using Test of Within-Subjects Effects.	63
16	Total Suspended Solids level from January to June in the three stations of Boracay Island using Test of Between-Subjects Effects.	64
17	Oil and Grease level from January to June in the three stations of Boracay Island using the Test of Within-Subjects Effects.	65
18	Oil and Grease level from January to June in the three stations of Boracay Island using Tests of Between-Subjects Effects.	66
19	Precipitation level from January to June in Boracay Island using the Test of Within-Subjects Effects.	67
20	Regression model for fecal coliform load.	68

LIST OF FIGURES

Figure		Page
1	Schematic diagram of the process flow of the study.	6
2	Established sampling stations along the white beach area of Boracay Island, Malay, Aklan	28
3	Monthly fecal coliform load in the white beach area of Boracay Island for six months.	39
4	Monthly dissolve oxygen level in the three station along the white beach area of Boracay Island for six months.	40
5	Monthly pH level in the white beach area of Boracay Island for six months.	41
6	Monthly nitrate level in the three station along the white beach area of Boracay Island for six months.	42
7	Monthly phosphate level in the three station along the white beach area of Boracay Island for six months.	42
8	Monthly total suspended solid level in the three station along the white beach area of Boracay Island for six months.	43

9	Monthly oil and grease level in the three station along the white beach area of Boracay Island for six months.	44
10	Mean monthly precipitation (mm) in Boracay Island during the course of the study.	45
11	Monthly number of tourist arrival recorded within the six months period.	46
12	GIS- density map of fecal coliform load in white beach area in Boracay Island, Malay, Aklan	70

LIST OF APPENDICES

Appendix		Page
A	Multiple Tube Fermentation Method	96
B	Gravimetric Method	98
C	Automated Ascorbic Acid Method	99
D	Kjeldahl Digestion Method	100
E	Liquid-Liquid Partition Method	101
F	Water Sampling at the Front Beach of Boracay Island	103
G	pH level from January to June using Pairwise Comparison	105
H	A post-hoc pairwise comparison of temperature level using the Least Significant Difference	107
I	Communication Letter to Philippine Atmospheric, Geophysical and Astronomical Services Administration	109
J	Communication Letter to Environmental Management Bureau	110
K	Courtesy Call and Water Sampling	111

References

Addy, K., Green, L., and Herron, E. (2004). pH and Alkalinity. Cooperative Extension College of the Environment and Life Sciences (CELS) Department of Natural Resources Science (NRS) Coastal Institute in Kingston, 1 Greenhouse Road, Kingston, Rhode Island 02881-0804. Retrieved on July 20, 2023 from http://cels.uri.edu/docslink/ww/water-quality-factsheets/pH&alkalinity.pdf

Ajani, P., Gustaff, H., and Tim, P. (2001). Historic Overview of Algal Blooms in Marine and Estuarine Waters of South Wales, Australia. *Proceedings of the Linnean Society of New South Wales* 123, 1-22.

Alade, A., Alade, J., Suleyman, A., Mohamed, K., and M.D. Alam (2011). Removal of Oil and Grease as Emerging Pollutants of Concern (EPC) in Wastewater Stream. *IIUM Engineering Journal* 12(10).31436/iiumej.v12i4.218.

Almedia, C., Gonzalez, S.O., Mallea, M., and Gonzalez, P. (2012).A recreational water quality index using chemical, physical and microbiological parameters. *Environ Sci Pollut Res* (2012) 19:3400–3411. DOI 10.1007/s11356-012-0865-5.

An YJ, Breindenbach GP. 2005. Monitoring of *E. coli* and total coliforms in natural spring water as related to recreational mountain areas. Environmental Monitoring and Assessment, 102: 131-137.

Alp, E., and Mustapha, A. (2014). Prediction of Water Quality Parameters Using Statistical Methods: A Case Study in a Specially Protected Area, Ankara,

Turkey. Retrieved from https://ui.adsabs.harvard.edu/abs/2014AGUFM.H11A0837A on August 10, 2023.

Baudart,J., Grabulos, J., Barusseau, & J.P., Lebaron, P. (2000). Salmonella spp. and fecal coliform loads in coastal waters from a point vs. nonpoint source of pollution. *Journal of Environmental Quality 29: 241-250.*

Berglund, J., Mattila, J., Ronnberg, O., Heikkila, J. & Bonsdorff, E. (2003) Seasonal and inter-annual variation in occurrence and biomass of rooted macrophytes and drift algae in shallow bays. *Estuarine Coastal and Shelf Science* 56: 1167 1175.

Bharathi, Md., Sundaramoorthy, S., Patra, S., Perumal, M., & Sundaramanickam, Arumugam. (2018). Seasonal and spatial distribution of heterotrophic bacteria in relation to physico-chemical properties along Ennore coastal waters. *Indian Journal of Geo-Marine Sciences*. 47. 587-597.

Blaustein, R.A., Pachepsky, Y.A., Hill, R.L., & Shelton, D.R. (2015).Solid manure as a source of fecal indicator microorganisms: Release under simulated rainfall. Environmental Science and Technology. Retrieved from https://pubmed.ncbi.nlm.nih.gov/26011817/ on July 25, 2023

Borjarczuk, A., Jelonkiewicz, L., & Lenart-Boron, A. (2018). The effect of anthropogenic and natural factors on the prevalence of physicochemical

parameters of water and bacterial water quality indicators along the river Bialka, Southern Poland. *Environmental Science and Pollution Research*, 25: 10102-10114.

Boteva, Dimiitrina & Griffiths, Geoffrey & Dimopoulos, & Panayotis. (2004). Evaluation and mapping of the conservation significance of habitats using GIS: An example from Crete, Greece. *Journal for Nature Conservation*. 12:237-250. 10.1016/j.jnc.2004.09.002.

Burak, S., Dogan, E., & Gazioglu, C. (2004). Impact of urbanization and tourism on coastal environment. *Ocean and Coastal Management*, 47(9–10):515–527.

Ciupa T, Suligowski R. (2020). Impact of the city on the rapid increase in the runoff and transport of suspended and dissolved solids during rainfall – the example of the Silnica River (Kielce, Poland). *Water*, 12: 2693.

Cloern, J.E. (2001) Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* 210: 223– 253.

Colford, J.M., Wade, T.J., Schiff, K.C., Wright, C.C., Griffith, J.F., Sandhu, S.K., Burns, S., Sobsey, M., Lovelace, G., and Weisberg, S.B. (2007). Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. *Epidemiology. 18*(1):27-35. doi: 10.1097/01.ede.0000249425.32990.b9. PMID: 17149140.

Corbari C, Lassini F, Mancini M. (2016). Effect of intense short rainfall events on coastal water quality parameters from remote sensing data. *Continental Shelf Research*, 123: 18-28.

Cvetkovic, M., & Jovanovic, S. (2016). The Application of GIS Technology in Tourism. Quaestus; Timisoara, 8, 332–44.

de Souza, R.V., Campos, C.J.A., Garbossa, .LH.P., & Seiffert, W.Q. (2018). Developing, cross-validating and applying regression models to predict the concentrations of faecal indicator organisms in coastal waters under different environmental scenarios. *Science of the Total Environment*, 630: 20-31.

Demeya, C. & Dragozet, A. (2019). Employing GIS data for sustainable tourism: A review of the environmental impacts of marine tourism and how GIS data can be used to make marine tourism more sustainable in California. https://orcid.org/0000-0002-5320-7625.

Dumont E, Williams R, Keller V, Vor A, Tattari S. (2012). Modelling indicators of water security, water pollution, and aquaticbiodiversity in Europe. *Hydrological Sciences Journal*, 57: 1378-1403.

Dursun, S., Aysegul, T., Ethem, YM.G. (2002). Visualization and analyses of nutrient data in a coastal lagoon through GIS. Retrieved from https://www.researchgate.net/publication/228506451_Visualization_and_analyses_of_nutrient_data_in_a_coastal_lagoon_through_GIS on July 25, 2023.

Environmental Management Bureau (2018). Water Quality Monitoring Manual. *Manual on Ambient Water Quality Monitoring.1* 2-2.

Ershad, Mr & Ali, Ershad. (2020). Geographic Information System (GIS): Definition, Development, Applications & Components. Retrieved from https://www.researchgate.net/publication/340182760_Geographic_Information_System_GIS_Definition_Development_Applications_Components on July 25, 2023.

Exline, J., Levine, A., and Levine J. (2006). Meteorology: An Educator's Resource for Inquiry-Based Learning for Grades 5-9. Retrieved from www.nasa.gov on July 19, 2023.

Follett, R.F. and Hatfield, J.L. (2001). Nitrogen in the Environment: Sources, Problems, and Management. Research Article Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy. *The Scientific World* (2001) 1(S2), 920–926 ISSN 1532-2246; DOI 10.1100/tsw.2001.269.

Francy, D.S., Brady, A.M.G., Cravin, R., Corsi, S., Fuller, L., Harrison, J., Hayhurst, B., Nevers, M., Terrio, P., & Zimmerman, T. (2013). Developing and implementing the use of predictive models for estimating water quality at Great Lakes Beaches. *Scientific Investigations Report* 2013-5166. https://doi.org/10.3133/sir20135166.

Ghaly, A.E., & Ramakrishnan V.V. (2015). Nitrogen Sources and Cycling in the Ecosystem and its Role in Air, Water and Soil Pollution: A Critical Review. *Journal of Pollution Effects & Control.* DOI: 10.4172/2375-4397.1000136

Gokul, M.S., Dahms, H., Muthukumar, K., Kaviarasan, T., Henciya, S., Vignesh, S., Kumar, T., and James, R.A. (2019). Multimarker Pollution Studies Along the East Coast of Southern India,Coastal Zone Management. *Elsevier.* 331-346,ISBN 9780128143506,https://doi.org/10.1016/B978-0-12-814350-6.00013-6.

Gunawardena, N.K. (2014). Introduction to Geographic Information System. *The Bulletin of the Sri Lanka College of Microbiologists. 12.* 34-37.

Howarth, R.W. & Marino, R. (2006). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades. *Limnology and Oceanography* 51: 364–376.

Hoque, M.Z., Aziz, N.A.A., Salem, A., Mohamed, M., and Maruf, H. (2022). "Improving Water Quality Index Prediction Using Regression Learning Models" *International Journal of Environmental Research and Public Health* 19, no. 20: 13702. https://doi.org/10.3390/ijerph192013702

Jha, Dilip & Devi, Prashanthi & Rajendran, Vidyalakshmi & Brindha, Balan & Vinithkumar, N.V. & Kirubagaran, Ramalingam. (2015). Water quality assessment using water quality index and geographical information system

methods in the coastal waters of Andaman Sea, India. Marine Pollution Bulletin. 10.1016/j.marpolbul.2015.08.032.

Kale, V. (2016). Consequence of Temperature, pH, Turbidity and Dissolved Oxygen Water Quality Parameters. *International Advanced Research Journal in Science, Engineering and Technology.3*(8).187. doi 10.17148/iarjset.2016.3834

Kane K. (2016). Impacts of tourism on water quality in Quintana Roo, Mexico. Master's Thesis. Orthern Illinois University, Illinois.

Kumar, A., & Krishna, A. (2018). Groundwater vulnerability and contamination risk assessment using GIS-based modified DRASTIC-LU model in hard rock aquifer system in India. *Geocarto International.* 35. 1-66. Doi.10.1080/10106049.2018.1557259.

Lee, J.L., Kim, I.H., Yeon, Y.J., & Lee, J. (2017). Monitoring and analysis of bacterial communities during a summer season on Gyeongpo Beach. *The 2nd International Water Safety Symposium. Journal of Coastal Research, 79.*249–253.

Li D, Van De Werfhorst LC, Dunne T, Devarajan N, Ayala TG, Holden PA (2020). Surf zone microbiological water quality following emergency beach nourishment using sediments from a catastrophic debris flow. *Water Res. 176:*115733. doi: 10.1016/j.watres.2020.115733. Epub 2020 Mar 18. PMID: 32234606.

Liu L, Tang Z, Kong M, Chen X, Zhou C, Huang K, & Wang Z. (2019). Tracing the potential pollution sources of the coastal water in Hong Kong with statistical models combining APCS-MILR. *Journal of Environmental Management, 245*: 1443-150.

Losos, J.B., Mason, K.A. and Singer, S.R. (2007). *Biology, 8th edition,* McGraw-Hill ISBN 0073041106.

Manalo, J.J.P. (2017). Relevance of Sustainable Tourism in the Philippines: Case of Boracay Island and Puerto Princesa City. *International Journal of Information Research and Review.04(01),*3558-3562.

Martinez-Urtaza J, Saco M, de Novoa J, Perez-Piñeiro P, Peiteado J, Lozano-Leon A, & Garcia-Martin O. (2004). Influence of environmental factors and human activity on the presence of Salmonella serovars in a marine environment. *Appl Environ Microbiol.70(4)*:2089-97. doi: 10.1128/AEM.70.4.2089-2097.2004. PMID: 15066800; PMCID: PMC383045.

Mayorga E, Seitzinger SP, Harrison JA, Dumont E, Beusen AHW, Bouwman AF, Fekete BM, Kroeze C, & Van Drecht G. (2010). Global nutrient export from WaterSheds 2 (NEWS 2): *Model development and implementation. Environmental Modelling Software, 25:* 837-853.

McDonald AT. Chapman PJ. Fukasawa K. (2008). The microbial status of natural waters in a protected wilderness area. *Journal of Environmental Management 87*: 600608.

Mejia, R., N de. Ugarte, Molina, N. and Idiriago, J. Sigtur-Zulia (2000): An Aplication of the GIS Technologies for Tourism Planning.

Municipality of Malay. (n.d.). (2020) Tourist Arrival. http://malay.gov.ph. Retrieved December 2020.

Muyot, B. (2022). Quality of The Coastal Water Of Aroma Beach San Jose, Occidental Mindoro. *International Journal of Science, Technology & Management, 3*(3), 806-810. https://doi.org/10.46729/ijstm.v3i3.526

Noble, R.T., Moore, D.F., Leecaster, M.K., McGee, C.D., and Weisberg S.B. (2003). Comparison of total coliform, fecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing. *Water Res. Apr;37(7):*1637-43. doi: 10.1016/S0043-1354(02)00496-7. PMID: 12600392.

Pacheco AJ, Cabrera SA, Marin LE. (2000). Bacteriological contamination in the karstic aquifer of Yucatan, Mexico. *Geofisica Internacional, 39*: 285-291.

Paerl, H.W., Valdes, L.M., Peierls, B.L., Adolf, J.E. and Harding, L.W. (2006) Anthropogenic and climatic influences on the eutrophication of large estuarine ecosystems. *Limnology and Oceanography* 51: 448–462. /doi/abs/10.4319/lo.2006.51.1_part_2.0448

Pensatate Extension (2022). Coliform Bacteria. Retrieved from https://extension.psu.edu/coliform-

bacteria#:~:text=Coliform%20bacteria%20are%20often%20referred,water%20will%20cause%20an%20illness on August 15, 2023

Philippine Council for Agriculture and Aquatic and Natural Resources Research and Development. (2013). Planning and Developing Community-Based Ecotourism Projects in the Philippines. Los Banos, Laguna, PCAARRD-DOST, 181/2013.

Preißler, S.(2009). Evaluation of the quality of European coastal water by German tourists. *Coast. Chang. S. Balt. Sea Reg. Coastline Rep.* 2009, *12*, 177–186

Presidential Proclamation 475. (2018). Declaring a State of Calamity in the Barangays of Balbag, Manoc-manoc, and Yapak (Island of Boracay) in the Municipality of Malay, Aklan, and temporary Closure of the Island as a Tourist Destination.

Procopio NA, Atherholt TB, Goodrow SM, Lester LA. (2017). The likelihood of coliform bacteria in NJ domestic wells based on precipitation and other factors. Groundwater, 2017.

Ps, D., Jha, D.K., Vinithkumar, N.V., Ponmalar, A.A., Pitchiah, V., & Kirubagaran, R. (2014). Spatial variation of physicochemical and bacteriological parameters elucidation with GIS in Rangat Bay, Middle Andaman, India. Journal of Sea Research. 85. 534-541. 10.1016/j.seares.2013.09.001.

Raju, P.L.N. (2004). Fundamentals of Geographical Information System. In M. Sivakumar, K. Harmsen, P. Roy, and S. Saha, Satellite Remote Sensing and GIS Applications in Agricultural Meteorology.103-120.

Ranada, P. (2015). Gov't to crack down on water-polluting Boracay resorts. Retrieved from https://www.rappler.com/sciencenature/environment/92068 boracay-water-pollution-crackdown resorts.

Mylavarapu, R. (2008). Impact of Phosphorus on Water Quality. e Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Retrieved from http://edis.ifas.ufl.edu on July 25, 2023.

Rossi, L., Frankhauser, R., & Chevre, N. (2006). Water quality criteria for total suspended solids (TSS) in urban wet-weather discharges. Water Sci Technol (2006) 54 (6-7): 355–362.https://doi.org/10.2166/wst.2006.623

Schets, F.M., De Roda Husman, A.M., Havelaar, A.H. (2011). Disease outbreaks associated with untreated recreational water use. *Epidemiol Infect. 139(7):*1114-25. doi: 10.1017/S0950268810002347. Epub 2010 Nov 10. PMID: 21062530.

Simsek, C., Gunduz, O. (2007). IWQ Index: A GIS-Integrated Technique to Assess Irrigation Water Quality. *Environ Monit Assess* 128, 277–300. https://doi.org/10.1007/ s10661-006-9312-8

Sivri, N. & Seker, D. (2010). Investigation of Enteric Bacteria of Surface Waters in the Southwestern Coast of Istanbul by means of GIS. *Turkish Journal of Fisheries and Aquatic Sciences.* 10: 505-511. 10.4194/trjfas.2010.0410.

Sivri, N., Balci, M., Durmuş, T., Seker, D., and Balkis-Ozdelice, N. (2012). Analysis of enteric bacteria distribution in the Gulf of Gemlik (Marmara Sea) by means of GIS. *Fresenius Environmental Bulletin.* 21:3224-3232.

Shirodkar, P A., Mesquita, U.K., Pradhan, X.N., Verlekar, M.T., & Vethamony, B.P. (2011). Factors controlling physico-chemical characteristics in the coastal waters off Mangalore-A multivariate approach, *Environmental Research, 109(3).*

Smith JE Jr, & Perdeck JM. (2004). Assessment and management of watershed microbial contaminants. *Critical Reviews in Environmental Science and Technology, 34:* 109-139.

Smith, J.E., Runcie, J.W. & Smith, C.M. (2005) Characterization of a large-scale ephemeral bloom of the green alga Cladophora sericea on the coral reefs of West Maui, Hawai'i. *Marine Ecology-Progress Series 302:* 77–91.

Smith, V.H. (2006) Responses of estuarine and coastal marine phytoplankton to nitrogen and phosphorus enrichment. *Limnology and Oceanography 51*: 377–384.

Smith, V.H., Joye, S.B. & Howarth, R.W. (2006) Eutrophication of freshwater and marine ecosystems. *Limnology and Oceanography 51:* 351–355.

Sousa, R.C., Pereira, L.C., and Costa, R.M. (2013). Water quality at touristic beaches on the Amazon coast.

Steets, B.M., & Holden, P.A. (2003). A mechanistic model of runoff associated fecal coliform fate and transport through a coastal lagoon. *Water Research, 37*: 589-608.

Strokal, M., Spaier, E., Kroeze, C., Koelmans, A.A., Florke, M., Franssen, W.,Hofstra, N., Langan, S., Tang, T., van Vliet, T.H., Wada, Y., Wang, M., van Wijnen, J., & Williams, R. (2019). Global multi-pollutant modelling of water quality: scientific challenges and future directions. *Current Opinion on Environmental Sustainability, 36:* 116125.

Torres-Bejarano, F., González Márquez, L., Díaz-Solano, B., Torregroza, A., & Cantero Rodelo, R. (2018). Effects of beach tourists on bathing water and sand quality at Puerto Velero, Colombia. *Environment Development and Sustainability. 20.* 255-269. 10.1007/s10668-016-9880-x.

United State Environmental Protection Agency (2023). Indicators: Dissolved Oxygen. Retrieved from https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen on July 23, 2023.

Vaclav Smil, V. (2000). PHOSPHORUS IN THE ENVIRONMENT: Natural Flows and Human Interferences.Annu. Rev. *Energy Environ. 2000. 25*:53–88 Copyright c 2000 by Annual Reviews.doi: 10.1146/annurev.energy.25.1.53

van Vliet MTH, Florke M, Harrison JA, Hofstra N, Keller V, Ludwig F, Spanier JE, Strokal M, Wada Y, & Wen, Y. (2019). Model inter comparison design for large-

scale water quality models. *Current Opinion in Environmental Sustainability, 36:* 59-67.

Vermeulen, L.C., Benders, J., Medema, G., & Hofstra, N. (2017). Global cryptosporidium loads from livestock manure. *Environmental Science and Technology, 51:* 8663-8671.

Wang, J.H., Zhang, T.Y., & Dao, G.H. (2017). Microalgae-based advanced municipal wastewater treatment for reuse in water bodies. *Appl Microbiol Biotechnol 101*, 2659–2675. https://doi.org/10.1007/s00253-017-8184-x

World Health Organization (2001) In: L Fewtrell and J Bartram (eds). Water quality: guidelines, standards and health. IWA, London. ISBN: 1 900222 28