SPATIAL AND TEMPORAL VARIATIONS IN SURFACE WATER QUALITY: A CONTINENTAL REVIEW

Mary NGATIA [1], Shadrack M. KITHIIA [1], Mihai VODA [2,3]* and Ronald SSEMBAJWE [4,1]

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ABSTRACT

Surface water quality is a critical component of environmental health and sustainability. Its variations across space and time are influenced by numerous factors, including natural processes, human activities, and climate change. While the water quality is a critical issue, it is important to understand the spatial, temporal variations and the pollution sources that contribute to the variations. This review aims to provide a comprehensive overview of the spatial and temporal variations in surface water quality on a continental scale: Europe, Asia, North America, South America and Africa. This study used cluster analysis for a comparative approach based on papers published between 2002 and 2022. Our findings prove that domestic effluent discharges, agricultural runoffs and industrial discharges on the river basins represent the main contributors of water quality variations observed and consequently water pollution.

***Key-words**: Multivariate techniques, Cluster Analysis (CA), Water pollution*

1. INTRODUCTION

Water quality of rivers is a major global environmental concern because rivers are the most available fresh water resources for human consumption. However, rivers across different continents have been heavily polluted due to their easy accessibility to waste disposal.

Water pollution refers to the presence of toxic contaminants in the water bodies that render the water unfit for domestic, industrial and agricultural use. As such, water quality degradation owing to anthropogenic activities is a global concern resulting in significant water management challenges for both developed and developing countries (Hussein & Bomola, 2011; Voda et al., 2019). A plethora of authors have documented water quality related research (Daoji and Daler, 2004; Ismail and Robescu, 2019; Kithiia, 1992 and 2006; Voza, Vuković, et al., 2015). For Instance, Daoji and Daler. (2004), Hussein and Bomola (2011), Mehmood et al. (2017), Rodrigues et al. (2018) and recently Bhat et al. (2021) reported water quality degradation in Asian rivers especially within the Yangtze River basin (Yang et al., 2021), Euphrates and Tigris rivers (Hussein & Bomola, 2011) and Sukhnang river (Mehmood et al., 2017).

The huge pollution stresses affecting these rivers were attributed to human activities that discharge wastes rich in inorganic nitrogen, phosphate, oil hydrocarbons, organic matters and heavy metals. Excess nutrient loads cause eutrophication of the coastal waters and estuarine area often experiences red tides. The pollution of the Yangtze river basin for example consequently influences

[1] University of Nairobi, Department of Geography, P.O. Box 30197-00100 GPO, Nairobi, Kenya, maryngatia88@gmail.com, shadrack.mulei@uonbi.ac.ke
[2] Dimitrie Cantemir University, Geography Department, 540545 Targu Mures, Romania, mihaivoda@cantemir.ro (corresponding author)*
[3] Geography Doctoral School, Faculty of Geography, Tourism and Sport, University of Oradea, 410087 Oradea, Romania;
[4] College of Agricultural and Environmental Sciences, Makerere University, P.O. Box 7062 University Rd, Kampala, Uganda, ronaldnazirite@gmail.com

the marine environment of the East China Sea(ESC) (Daoji and Daler, 2004). Similar consequences have been reported in Europe especially in the Danube River. Europe's second longest river has remarkably been experiencing water quality degradation as a result of anthropogenic pressure. For example, Mănoiu and Crăciun (2021) have attributed this degradation to mainly organic pollution downstream of major cities and in some major tributaries. While, Georgescu et al. (2023) have further linked it to more factors such as changes in river flow patterns and sediment transport regimes.

In Africa, water pollution has been a longstanding issue (Chen et al., 2022). Studies including Elnazer et al., (2018) over the Nile river in the North, Madonsela et al., (2024) over river Mpumalanga in the south, Mustapha et al., (2014) over Kano river in the West and recently Chen et al., (2022) over east African Urban rivers have reported significant deteriorations in water quality owing to anthropogenic activities especially urbanization and agriculture. Other rivers source pollution from mining operations, oil spills and solid waste. Such rivers include Niger River, Zambezi River, Nile River and Congo River given their strategic location in mining Africa's mineral rich zones. The Zambezi River, known for its iconic Victoria Falls for example has been affected by pollution from both mining activities, agricultural runoff, and industrial waste. The same is true for Africa's second largest river: Congo river. The Nile River on the other hand has faced pollution issues due to industrial discharges, agricultural runoff, and domestic waste. While significant progress has been made, water pollution remains a challenge in many rivers across the globe. Continued efforts are needed to protect these vital ecosystems and ensure the health and well-being of future generations.

In East Africa, emphasis has been drawn to rivers whose basins are centered or bordered by major cities such as Nairobi, Jinja, Arusha among others, where, industrial waste, agricultural runoff, domestic sewage and deforestation are rampant and increasing over time (Voda et al., 2019). These issues have significant implications for public health, as contaminated water can lead to various diseases.

In Kenya, the earlier studies by Kithiia, (2007) within the Nairobi and Athi river basins indicated a downstream increase in water pollutants and water quality degradation. Sediments and heavy metals within the basins were observed to increase downstream the river courses which was attributed to industrialisation and urbanisation. Additionally, Njuguna et al. (2017) reported increased nutrient loads and heavy metal concentrations; Fe, Cr, Pb, Mn above the World Health Organization (WHO) macrophytes tolerable limits in the Nairobi River basin. In the same basin, Musyoki et al. (2013) reported high microbiological contamination of the river basin levels above the WHO standards for safe water for agriculture use and human consumption. As such, continuous monitoring of the surface water bodies and the pollution sources so as to minimise the observed pollution trends is recommended (Chen et al., 2022).

In North America especially Canada and the United States, improving water quality is one of the key focus of integrated water shed management project (Line, 2002; St-Hilaire et al., 2004) with water quality monitoring being a key component in water quality management. Similarly, various water quality management programmes have been initiated elsewhere to aid in assessing spatial and temporal variation which are important aspects of water management and pollution control (Melo et al., 2020). In Eastern Canada and especially New Brunswick province, the Sustainable Development program and the Water Classification program water quality management programs have been initiated with the Richibucto River being one of the focus of such program (St-Hilaire et al., 2004). Well planned and well managed water quality monitoring system is essential to signal, control or predict changes in water quality of a certain water body. This however cannot be achieved without continuous collection of water samples, analysis of the physico-chemical parameters and analysis of the water quality data. Oddly, long-term survey and monitoring programmes however produce large complex datasets which are difficult to analyse and interpret (Ismail and Robescu, 2019; Ngatia, 2022; Voza et al., 2015a; Zhang et al., 2011). Due to complexity of water quality data, application of multivariate statistics has proven useful in provision of meaningful information through reduction of data sets and interpreting various parameters in pollution monitoring.

Multivariate analysis techniques help in reducing the complexity of a large scale data set and are widely used in environmental impact studies (Voza et al., 2015a; Voda et al., 2018). Cluster analysis (CA) is one such technique used for classification of objects into clusters to indicate their intrinsic characteristics on the basis of their similarity or nearness (Bu et al., 2010). Cluster analysis is useful in solving classification problems by placing variables into groups such that the association level is strong between the same cluster members and weak between different cluster members (Bhat et al., 2014). Hierarchical clustering analysis (HCA) is the widely used approach that uses the Euclidean distances as a measure of similarity to form higher clusters. The cluster results is usually demonstrated using a dendrogram which gives a visual summary of clustering processes, showing high internal (or within cluster) homogeneity as well as high external (or between clusters) heterogeneity (Bu et al., 2010). Several successful applications of CA to water quality assessments have been reported in recent studies (Bhat *et al.*, 2014; Bu *et al.*, 2010; Voza *et al.*, 2015). The analytical results in this study indicate that this technique is useful in offering reliable classification of surface waters. The present findings are consistent with the recent studies on Hindawi River, Jonshui and Marova river systems as reported by (Bhat *et al.*, 2014; Bu *et al.*, 2010; Voza *et al.*, 2015). The application of multivariate techniques helps in the interpretation of complex data matrices, provides a clear indication of water quality and ecological status of study areas (**Fig.1**), allows for identification of possible sources of pollution and eventually offers a rapid solution to the pollution problem thus an important tool to water quality monitoring managers.

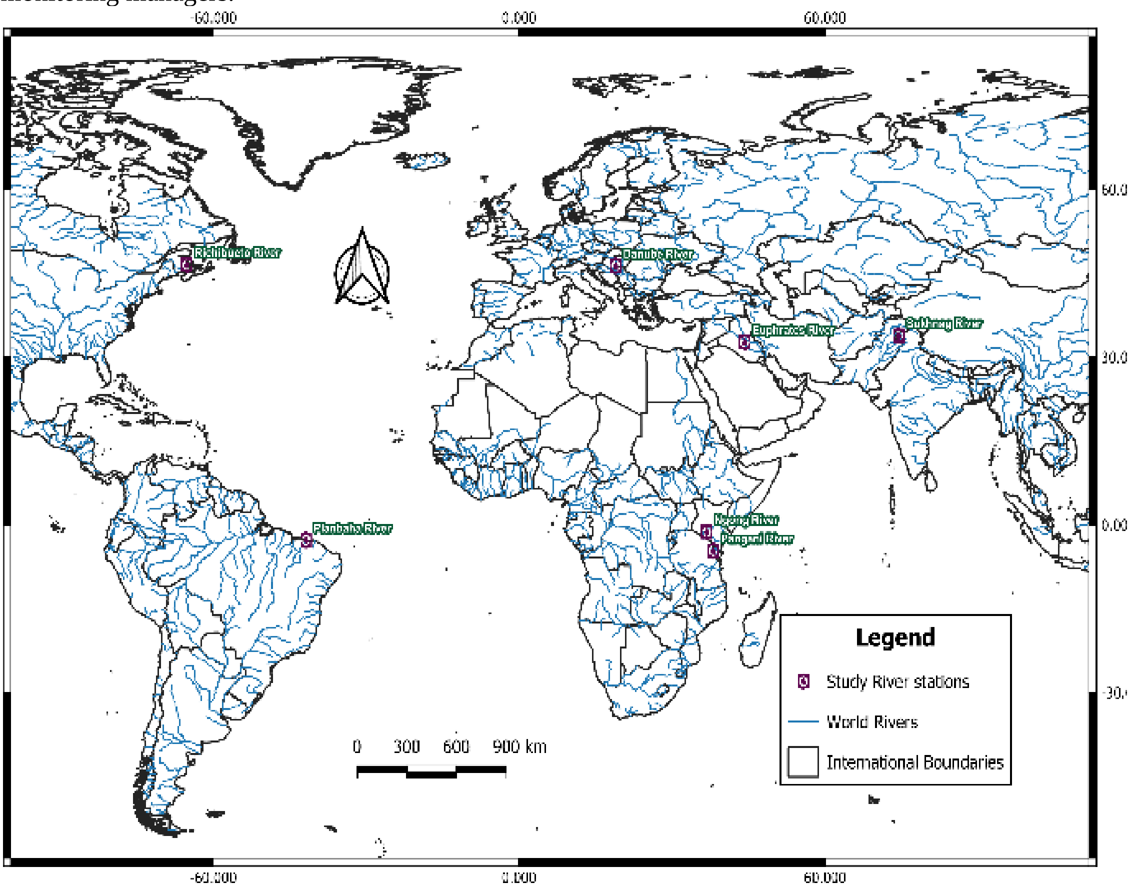

Fig. 1. Location of the study Rivers on the world map.

2. STUDY AREA

The study relied heavily on publications on Rivers in selected continents. In Europe, the study was conducted on Danube River which is Europe's second-longest river. Danube river flows through Romania for a significant distance and its a major transportation artery in Romania. The Danube also flows through Serbia, where it forms a natural border with Romania and Hungary. It's a vital source of water and supports a diverse ecosystem. Sukhnag a small stream located in the Indian state of Jammu and Kashmir also formed part of this study. This stream is known for its scenic beauty and is a popular destination for trekking and fishing. Elsewhere in Iraq, the Euphrates River which is one of the most important rivers in the Middle East, flowing through Iraq was studied. It's a vital source of water for agriculture and irrigation, and its basin has been a center of human civilization for millennia in Iraq. Richibucto River located in New Brunswick, Canada in North America was also studied. Richibucto flows into the Northumberland Strait and is known for its fishing and recreational opportunities. In South America Pianbaha River in Brazil located in the state of Mato Grosso also contributed in this research. It's a tributary of the Xingu River and flows through a region known for its biodiversity. In Africa, Ngong river in Kenya flows from the Ngong forest through Kibera slums and along the Nairobi city boundary and later traverses into the industrial area. Its a major tributary of the Nairobi River which drains Nairobi city and its environs. It's a vital source of water for wildlife and is known for its scenic beauty. The Pangani River is a major river in Tanzania and is important for agriculture, hydropower, and fisheries. Water quality is a significant concern in many river basins around the world, and monitoring and management are essential for protecting these valuable resources.

3. DATA AND METHODS

The present study was aimed at identifying and reviewing findings from research work published between 2002 to 2022, a period of 20 years, in which multivariate analytical techniques in "spatial and temporal variations of water quality in rivers" was used. The target research publications were based on different rivers in five continents: Africa, Europe, Asia, North America and South America. The research articles were chosen as case studies regarding water pollution as they revealed the benefits of application of multivariate techniques such as PCA and Cluster analysis in pollution monitoring of surface water quality in different continental contexts. Google scholar search engine was used to identify papers for inclusion and exclusion for this study. The reviewed papers were obtained using key words" multivariate analysis of water quality of rivers" in different combinations. The last search was conducted on 4th April, 2023. From the search, an inclusion and exclusion criteria were applied where by all papers published between 2002 and 2022 were selected. The second criteria was to obtain papers with open access, in English language and studies that used multivariate techniques in Water Quality (WQ) analysis were selected. Papers that did not have open access were excluded. Studies with no evidence of multivariate analysis were also excluded. Finally, eight papers were selected from Europe, Asia North and South America and Africa continents as case studies. Relevant studies from most recent publications whose research used Cluster Analysis were given priorities for inclusion.

The following eight papers were closely reviewed; WQ analysis of Danube River in Romania published in 2019, WQ of Danube River in Serbia published in 2015, WQ of Sukhnag stream in India published in 2014, WQ analysis of Euphrates River in Iraq published in 2012, WQ analysis of Richibucto River in Canada published in 2004, WQ in Pianbaha River in Brazil published in 2019, WQ analysis of Ngong River in Kenya published in 2022 and WQ in Pangani River Basin in Tanzania published in 2013. The full texts of the eight papers were retrieved and an in-depth review conducted. The review's results considering the scientific contribution in multivariate analytical techniques for water quality data of the rivers in various continents have been presented and discussed in this study (**Tab. 1**).

Table 1.

The google scholar review process on WQ analysis of Rivers using Multivariate techniques in different continents

River/Lake subjected to WQ analysis	Country	Continent	Reference
Danube River	Romania	Europe	(Ismail and Robescu, 2019)
Danube River	Serbia	Europe	(Voza et al., 2015b)
Sukhnag River	India	Asia	(Bhat et al., 2014)
Euphrates River	Iraq	Asia	(Emad AM et al., 2012)
Richibucto River	Canada	N.America	(St-Hilaire et al., 2004)
Pianbaha River	Brazil	S.America	(de Andrade Costa et al., 2020)
Ngong River	Kenya	Africa	(Ngatia, 2022)
Pangani River	Tanzania	Africa	(Hellar-Kihampa et al., 2013)

4. RESULTS AND DISCUSSION

Research papers by the nine authors (table 1) whose research work was in the five continents (Africa, Europe, Asia, North America and South America) selected for this study were reviewed and are presented below.

4.1. Multivariate statistical techniques and Water Quality (WQ) aspects of the reviewed rivers

Danube River is the second longest river in Europe with a length of 2860 km. It's a transboundary water body originating from Germany and draining into the Black Sea (Ismail and Robescu, 2019; Voza et al., 2015b). Over the decades, Danube River has been experiencing high pollution levels due to the agricultural, urban settlements and industrial establishments along its course thus attracting scientific research projects that look into its water quality (Ismail and Robescu, 2019; Radu et al., 2022; Voza et al., 2015b). A study conducted along a 13km stretch on Danube River in Romania from Gura Vaii, 2 km downstream of Iron Gate 1 up to Drabeta-Turnu Severin City revealed that the water quality of Danube River was influenced by both point and non-point sources of pollution (Ismail and Robescu, 2019). The study area is characterised by industrial effluent discharges coupled with human settlements that lack proper sewer treatment facilities (Andriţa, 2012). Water quality data sets from Danube river gathered for a period of 1 year were subjected to Multivariate Statistical methods Factor analysis and Cluster Analysis was applied to evaluate the spatial and temporal variations among the study sites and monitoring periods (Ismail and Robescu, 2019).

In this study Hierarchical agglomerative clustering using Ward's method of linkage and squares Euclidean distance determined the spatial similarity distance and results illustrated using a dendrogram.

In cluster analysis, locations within the same cluster infer similar characteristics hence for a rapid water quality assessment, only one site from each cluster acts as an indicator of the whole cluster Singh *et al.*, (2004); Voza, Vukovic, *et al.*, (2015) so the number of sampling sites can be reduced hence cost without losing any significance of the outcome (de Andrade Costa et al., 2020). The four sampling sites were clustered into two significant groups (Group A and B). Group A corresponded to less polluted sites which were located upstream of Drobeta Turnu Severin City whose pollution sources were attributed to non-point sources mainly agricultural. Group B sites were considered to be moderately polluted in comparison with Group A which was attributable to their location within the Drobeta Turnu Severin's city industrial area which contribute to industrial and domestic effluents to Danube River. CA further grouped the 12 months in to two groups indicating that temporal variation in the Danube WQ was not determined by local climate (spring, summer, winter, autumn) but rather the discharge (Q) was the main factor (Ismail and Robescu, 2019).

Similar to the Danube stretch in Romania, a recent study was also conducted on the same river in Serbia (Voza et al., 2015b). Danube River flows through Serbia over a distance of 588km stretching from Bezdan to Prahovo. The river in this stretch hosts two main cities located on its banks; Belgrade city with a population of 1.7 million people (3rd largest city on Danube River) and Novi sad with a population of 300,000 people. Several other smaller towns are also located in Danube Serbia basin. Similar to the Danube River in Romania's Drobeta Turnus Severin city, the settlements along the river banks lack adequate waste water treatment system contributing to water quality degradation of the River (Voza et al., 2015b). To evaluate the WQ in Danube River Serbia basin, 17 water quality monitoring stations were sampled and monitored for a duration of one year (January-December,2011) by Voza in 2011. Cluster Analysis was performed on the obtained data sets after performing basic statistics to determine similarities between sampling stations.

In reference to Voza, Vukovic 2015, cluster 1 consisted of 7 sampling stations on Danube Serbia River. These stations were; Apatin, Bezdan, Bogojevo, Centa, Backa, Palanka, and Novi sad while cluster 2 had two stations; Banatska Palanka and Pancevo. Cluster consisted of eight sampling stations; Belgrade-Vinča, Dobra, Zamun, Brza Palanka, Tekija, Smederevo, V. Gradište, and Radujevac. Cluster 1 consisted of sampling stations that are highly polluted while cluster 2 and cluster 3 had stations with moderate and low pollution, respectively. The observation on temporal similarities of Serbia's Danube by Voza, 2105 were similar to those of Ismail and Robescu 2019 whereby the temporal similarities were clustered into two groups; group 1 (January, February, March, April, November and December) and group 2 (May, June, July, August, September and October) inferring that the water quality in Danube River in Serbia is not influenced by the four seasons (Spring, Summer, Autumn and Winter) but by other factors such as discharge (Q).

Comparable to the Danube River in Romania and Serbia located in Europe, the Asian continent is also grappling with the issue of water pollution in various rivers. This clearly depicts the global challenge of water quality management that continuously need monitoring to evaluate pollution levels that occur due to continuous anthropogenic pressures. In India, water quality assessment of Sukhnag stream in Kashmir Himalaya was carried out in February 2011 to January 2022 on five sampling stations (Bhat et al., 2014). Sukhnag stream originates from Pir Panjal mountain range located in the southwest of Beerwah town (Bhat et al., 2014). The stream is 51 kms in length and drains in to lake Wular which is the second largest lake in the Indian Subcontinent and a Ramsar site (Bhat et al., 2014). The Sukhnag stream drains an area characterised by various economic activities of importance to North Kashmir (Bhat et al., 2014). The stream is an important source of water for both domestic and agricultural purposes. CA was applied on the WQ data set obtained from the five sampling sites and resulted to three clusters based on similarities and dissimilarities of the WQ parameters. Spatially, site IV and V revealed 96% and 94% similarity, respectively, while site II and III showing 94% similarity. Site I located on the upstream of Sukhnag, was the most dissimilar site indicating low influence by anthropogenic activities (Bhat et al., 2014).

Contrary to Ismail & Robescu, 2019 and Voza, Vukovic, *et al.*, (2015), the temporal variations in Sukhnag stream were due to higher inorganic and organic loads during spring and autumn season indicating that temporal variations are due to seasonal variations (Bhat *et al.*, 2014) as opposed to discharges (Q) as observed in Danube River in Romania and Serbia.

Furthermore, in the study on the WQ of the Euphrates River in Iraq, CA revealed that the temporal variations in the water quality was not influenced by the wet and dry seasons (Emad AM et al., 2012) but other factors. The month of April had the highest dissimilarity as compared to other months, which was attributed to high Total Dissolved Solids values (Emad AM et al., 2012). The study used cluster analysis to classify sampling sites based on standardized mean values of 16 measured parameters. The dendrogram produced from this analysis indicated two distinct clusters: Cluster I which Included only sampling site 7 (S7) and cluster 2 Comprised sampling sites 1-6 and 8-11. Further, the results suggested that sampling site 7 had the lowest pollution levels, while the other sites had higher levels of pollution. This was consistent with the observed variations in water quality parameters among the sites (Emad AM et al.,2012). The study concluded that cluster analysis is a valuable tool for classifying river water in the study region. It can help reduce the number of sampling sites and associated monitoring costs without sacrificing significant information. This finding aligns with the results of previous studies conducted in other rivers.

In the North American Continent, CA analysis applied on the WQ analysis of Richibucto River in Canada revealed that high phosphorus and nitrate concentrations were attributed to run offs from peats, tributaries receiving treated municipal effluent and lentic zones upstream of culverts (St-Hilaire et al., 2004). Moreover, peat runoff was found to be acidic whether from a harvested area or a natural bog which prompts continuous monitoring of the water quality of Richibucto River. In this study, 36 water quality stations were sampled during ice free periods from 1996-2001 which generated huge sets of data (St-Hilaire et al., 2004). The study used cluster analysis to identify distinct groups of freshwater and estuarine stations based on their water quality parameters. The results showed that Stations 31, 3, and 1, located in the upper reaches of tributaries, clustered together due to their high pH values and low TC concentrations. These stations formed the fresh water stations. Moreso, stations draining the St. Charles Plain formed two distinct clusters based on their pH values while Stations 18 and 16, located on tributaries of Mill Creek, were characterized by high P_{tot} and NO_3 concentrations and formed a separate cluster. On the other hand, estuarine stations located on the main Richibucto River and those in the downstream reaches of tributaries formed two distinct groups based on their physical parameters (SpCond, Q, and TC). Station 36, receiving treated sewage, was isolated due to its high P_{tot} and NO_2NO_3 concentrations. The remaining estuarine stations were clustered together based on their nutrient and DO levels. The most significant difference between freshwater and brackish water was the primary factor that accounted for the majority of variations in water quality within the Richibucto system. Overall, the cluster analysis provided valuable insights into the spatial variability of water quality parameters within the study area (St-Hilaire et al., 2004).

Over south America, similar studies were conducted in the Piabanha River basin in Brazil. This river basin forms a sub basin of the Paraiba do Sul river and is characterized by a combination of urban, industrial, rural characteristics together with large conserved fragments of the Atlantic forest (de Andrade Costa et al., 2020). In this study 40 years of monitoring were studied so as to provide an in-depth understanding of the water quality trends of the Piabanha River and support its steering committee in the application of public policies (de Andrade Costa et al., 2020). Due to the huge sets of data involved in this study, multivariate techniques were used to conduct an update diagnosis of the WQ of Piabanha River. The CA clustered Piabanha River into three clusters according to the stretches of the river with similar WQ. In cluster 1 (S1,S6,S4,S5) stations corresponded to Petropolis urban centre and the main sources of pollution were identified as industrial and sewer effluents (de Andrade Costa et al., 2020). Additionally, S6 traverses Teresopolis city also characterised by industrial and other economic activities such as mining which have an impact on its WQ. Similarly, station S4 and S5 also receive negative impacts from mines. S2 and S3 fall within the most urbanised section of the river however it is less polluted due to dilution effects from Araras River on the left bank and Poco do Ferreira River on the right bank. The third cluster also was low polluted due to its location near the mouth of the river (de Andrade Costa et al., 2020) study revealed that the pollution levels in some sections of the river are high comparable with class 4 of the Brazilian Regulation for coliforms and Biological Oxygen Demand parameters rendering the water not suitable for agriculture, human or animal consumption further recommending continuous monitoring.

In the African continent, Multivariate Analysis (Cluster Analysis) was applied to evaluate the effects of human activities on the WQ of Ngong River (Ngatia, 2022). CA clustered the river into three distinct clusters according to the levels of pollution (Low level, moderate level and high level of pollution) reflecting the different pollution levels for both wet and dry seasons. In the wet season, CA clustered the 12 sampling sites into three distinct clusters. The sampling sites of Cluster 1 (site 1, 5, 4, 9, 8, 7, 11, 12, 6 and 10) were located on the upstream, middle reaches and downstream of Ngong River basin. The sites showed a strong similarity, indicating the dilution effects on anthropogenic pollutants due to increased volume of water in the river as a result of surface runoff during the rainy season. The sampling site in cluster 2 (site 3) was less similar to the other sites probably due to the agricultural runoff from the farming activities carried out on the encroached part of the Nairobi dam. Contrary to these sites, Site 2 in Cluster 3 showed the maximum dissimilarity with other sites during the wet season. Site 2 (Lindi Mosque) is located downstream of site 1. This site receives sewer effluents and other forms of waste from the highly populated Kibera informal settlement. The dendrogram therefore, clearly indicates that the water quality degradation of site 2 is attributed to anthropogenic impacts including the sewer discharge which was revealed by the highest *Escherichia coli* Levels (214×106 MPN/100ml) recorded for the wet season. This also indicated that site 2 is highly polluted above the dilution capacity of the river during the wet season.

Contrary to other reviewed studies for Danube River in Romania and Serbia (Ismail and Robescu, 2019; Voza et al., 2015b), temporal variations on Ngong River +6 were found to be influenced by the wet and dry season. The CA for the dry season indicated a spatial and temporal variation of pollution factors suggesting the effects of human activities on water quality of Ngong River. The pollution levels were observed to be high during the dry season owing to high concentration of contaminants due to evaporation effect. The CA produced 3 distinct clusters. Sampling sites in Cluster 1 were site 6, 12, 3, 4, 8, 9, 2, 7, 10 and site 5. These sites are located in the middle and downstream stretch of Ngong River Basin. Site 2 which is Lindi Mosque in Kibera is located just after the forest and is highly populated, lacking basic sanitary provisions hence domestic effluent discharge into Ngong River and solid waste dumping. Sites 5, 6 and 7 (Enterprise Road, Likoni Road Bridge and Mukuru Kayaba) are all located within the Nairobi's industrial hub. These sites receive industrial waste, sewer discharge and other domestic effluents from the existing industries and the highly populated Mukuru slums. Dumpsites are also common on all the sites located along this stretch. Sites 4, 8 and 9 (Outering road, Embakasi and Kayole) are located downstream of the industrial area hence the impacts of industrial activities upstream and the existing human settlements along Ngong River in this section are revealed. Dump sites were also evident in these sampled sites while direct sewer discharge was evident at site 9-Kayole. Site 12 (Mong'etho) is located downstream of Ngong River just before confluence with the Nairobi River. The site also shows a similarity with the other middle stream sites indicating the impacts of anthropogenic activities in the downstream of the river. Small scale farming, informal settlements lacking proper domestic and sewer disposal, dumpsite and pig farming were evident in this site making it similar to the other sites due to pollution.

Contrary to these sites, Ngong Forest site 1 which formed Cluster 3 indicated maximum dissimilarity with the other sites during dry season as it's located on the headwater section of the stream. This indicates that anthropogenic activities on the Ngong River at site 1 is relatively low resulting to minimal pollution. The concentrations of all monitored pollutants were relatively low at the Ngong Forest boundary site as compared to other sites indicating less anthropogenic sources of pollution (**Fig. 2**).

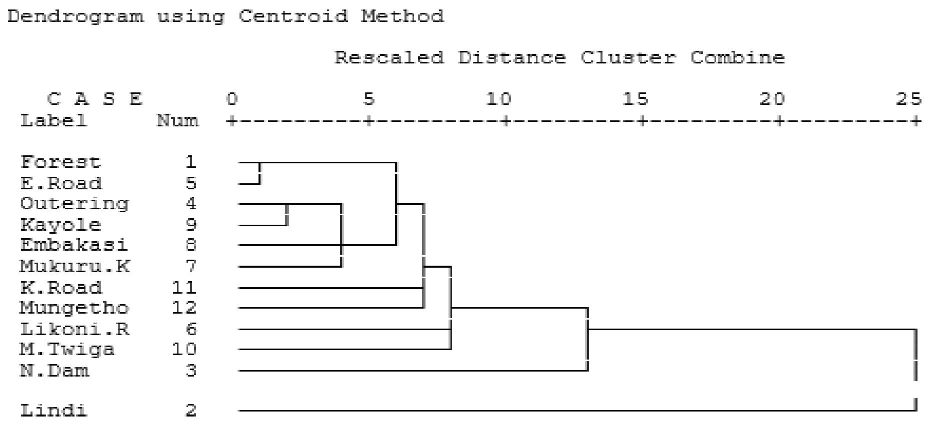

Fig. 2. Dendrogram of the cluster analysis for 12 sampling sites based on water quality parameters of Ngong River, Kenya for the wet season (The sample sites were represented as follows: Forest Boundary (1), Lindi Mosque (2), Nairobi dam (3), Outering bridge (4), Enterprise Road (5), Likoni road (6), Mukuru Kaiyaba (7), Embakasi bridge (8), Kayole (9), Matopeni Twiga (10), Kagundo Road bridge (11), and Mungetho-Njiru (12).

Source (Ngatia,2022).

In Tanzania, (Hellar-Kihampa et al., 2013) assessed using CA the natural and anthropogenic influences on the ions concentrations of Pangani River located in North Eastern part of Tanzania. Pangani River is one of the longest River basins in Tanzania and highly depended on for agricultural activities. CA applied in the analysis ions concentrations of this river revealed that the water quality is influenced by both natural and anthropogenic pressures which contributed to the variations in ionic concentrations of the river water.

5. CONCLUSION

The reviewed studies discussed here demonstrate the usefulness of multivariate statistical tools such as Cluster Analysis in investigating both the underlying processes and the spatial variation of water quality which are both critical aspects in developing the best river basins integrated management practices for water managers. Cluster analysis has proved to be a useful tool in obtaining maximum amount of information from a minimum number of sampling stations and consequent optimization of regional water quality sampling network which reduces on the costs that are usually incurred in water quality monitoring and evaluation programs. The present study analysed the spatial and temporal fluctuations of water quality in rivers from Europe, Asia, America and Africa. Our results show that industrial effluent discharges and agricultural runoffs constitute the principal influence on water quality variations.

Further studies on the application of multivariate techniques in water quality data management are recommended. These techniques are contributing to the identification of pollution sources as well as giving a comprehensive understanding of the spatial and temporal changes in surface water quality.

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