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Research Article

Comparative Study of the Levels of Heavy Metal Contents of Stream Water and Borehole Water in Ika Local Government Area, Akwa Ibom State.

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Abstract

The research was on Comparative study of the level of heavy metals contents of stream water and borehole water in Ika Local Government Area, Akwa Ibom State. The levels of heavy metals (Pb, Zn, Cu and Mn) were compared in five boreholes and stream waters. Atomic Absorption Spectrometer was used to analyze the water samples. The results showed that the concentration levels of Pb and Mn in the stream water samples were above WHO permissible limit, Zn and Cu are lower than the allowable limit while the concentration levels of Pb in the borehole water samples was above WHO permissible limit, Zn, Mn and Cu levels were lower than the allowable limit for drinking water. The results obtained show that the stream waters are contaminated by Pb and Mn but is not contaminated by Cu, Zn according to the WHO (2011) minimum requirement for drinking water. The results obtained for the borehole water show that the water is contaminated by Pb only. The results also reveal that the mean values for levels of heavy metals in borehole water and stream water do not significantly differ between the two samples studied. It is therefore recommended that environmental chemists should conduct public awareness campaigns and educational programs to inform the local community about the quality of the streams and borehole waters.

Keywords: Heavy metals, Zn, Mn, Cu, Pb, stream, water, borehole.

1. Introduction

Access to safe and clean drinking water is a fundamental human right recognized by international organizations such as the United Nations (UN) and the World Health Organization (WHO). In Nigeria, like many other countries, groundwater from boreholes and surface water from streams and rivers are the primary sources of drinking water for both rural and urban communities. However, the quality of water from these sources can vary significantly, and the presence of heavy metals in drinking water is a growing concern.

Heavy metals are naturally occurring elements with high atomic weights, including but not limited to Lead (Pb), Copper (Cu), Zinc (Zn), and Manganese (Mn) [1, 2]. These metals are ubiquitous in the environment, and while they are essential in trace amounts for various biological processes, excessive exposure to heavy metals can be toxic to humans and the environment. Sources of heavy metal contamination in water include natural geological processes, industrial activities, agriculture, and urban runoff [3]. Therefore, the study on the comparative analysis of heavy metals in borehole and stream water in Ika Local Government Area (LGA), Akwa Ibom State, Nigeria, is of paramount importance.

Akwa Ibom State, located in the Niger Delta region of Nigeria, has been facing water quality challenges for several years. Despite being endowed with abundant water resources, including numerous rivers and aquifers, ensuring safe and clean drinking water remains a significant challenge. Pollution from various sources, including industrial activities, agricultural runoff, and urbanization, has the potential to contaminate both surface and groundwater sources [4].

Borehole water and stream water are the two primary sources of drinking water in many parts of Akwa Ibom State. Boreholes tap into groundwater reserves, while streams provide surface water [5]. Understanding the quality of water from these sources and the presence of heavy metals is essential for safeguarding public health and making informed decisions regarding water treatment and resource management.

The presence of heavy metals in drinking water poses a severe risk to public health [6, 7]. These contaminants can accumulate in the human body over time, leading to various health issues. For example: Lead (Pb) exposure can result in neurological and developmental disorders, especially in

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children. Copper (Cu), while an essential trace element, can be toxic in excessive amounts, leading to gastrointestinal issues. Zinc (Zn), like copper, is necessary in small quantities but can cause adverse health effects when present in high concentrations. Manganese (Mn) exposure can result in neurological disorders, particularly in infants. In addition to health concerns, heavy metal pollution in water sources can have detrimental effects on the environment [1, 2]. Aquatic ecosystems can be disrupted, and the toxicity of heavy metals can cascade through food chains, affecting fish and other wildlife. Furthermore, heavy metals in water may have adverse impacts on agricultural practices and crop production when used for irrigation.

To address water quality issues, Nigeria has established regulatory frameworks and standards. The National Agency for Food and Drug Administration and Control (NAFDAC) and the Standards Organization of Nigeria (SON) are responsible for setting and enforcing drinking water quality standards. These standards include limits on heavy metal concentrations to protect public health. Therefore, this research focuses on Comparative study of the level of heavy metals contents of stream water and borehole water in Ika Local Government Area, Akwa Ibom State.

Empirically, a significant study related to lead in drinking water is the Flint water crisis. The elevated lead levels were linked to the switch in the water source, leading to corrosion of lead pipes and subsequent contamination [8]. Studies have shown that lead can have toxic effects on aquatic life, impacting fish and invertebrates. It interferes with various physiological processes and can accumulate in tissues, affecting growth and reproduction [4].

Copper is known for its toxicity to aquatic organisms. Studies have demonstrated adverse effects on fish, invertebrates, and algae. Copper disrupts the ion balance and enzyme activities in aquatic organisms [9]. Copper surfaces have been explored for their antimicrobial properties. Research has shown that copper can reduce the survival of bacteria, including meticillin-resistant Staphylococcus aureus (MRSA), on surfaces in healthcare environments [10].

Studies have investigated the impact of zinc on soil and crops. Zinc deficiency in soils can limit crop growth, and zinc fertilizers are used to address this issue [11]. Research has explored the role of zinc in immune function. Zinc supplementation is known to enhance immune responses and is used in certain conditions to support immune health [12].

The presence of manganese in drinking water has been studied. Guidelines from organizations like the World Health Organization (WHO) provide standards for manganese in drinking water to ensure public health [13]. Chronic exposure to high levels of manganese has been associated with neurotoxic effects. Studies have shown neurological symptoms and conditions similar to Parkinson's disease in individuals with prolonged manganese exposure [14].

Ika LGA, like many other regions in Nigeria, faces challenges related to water quality. The availability of safe drinking water is essential for the well-being of its residents, as well as for agricultural and industrial purposes. While boreholes and streams serve as primary sources of water in the region, there is a pressing need to assess and compare the heavy metal contamination levels in both sources to ensure the safety of the water consumed by the local population.

To date, there has been a lack of comprehensive studies in Ika LGA that focus on the heavy metal contamination of both borehole and stream water sources. Such studies are crucial for understanding the extent of heavy metal pollution and its potential impact on public health and the environment. Without adequate data, it is challenging to make informed decisions regarding water treatment, regulation, and resource management.

The presence of heavy metals in drinking water can pose significant health risks to the local population. Long-term exposure to these contaminants can lead to a range of health issues, including kidney damage, nervous system disorders, developmental problems in children, and even cancer. Additionally, heavy metal pollution can harm aquatic ecosystems, disrupt food chains, and negatively affect agriculture. It is against this limelight that the researcher will be triggered to carry out a study on Comparative study of the level of heavy metals contents of stream water and borehole water in Ika Local Government Area, Akwa Ibom State.

1.1. Purpose of the Study

The purpose of this study was to determine the difference in the level of heavy metals content in borehole water and stream water in Ika Local Government Area, Akwa Ibom State. Specifically, therefore, the objectives of this study were to:

- measure the level of heavy metals in borehole water and stream in Ika Local Government Area.
- compare the level of heavy metals in the two samples and make deduction from the level of heavy metals measured in Ika Local Government Area.

2. Materials and Methods

The area of the study is Ika Local Government Area, Akwa Ibom State. Batch sampling which involved taking samples from the environment and performing an analysis later in the laboratory was used in this research work. The water samples used for this study were randomly collected from five different streams and boreholes in Ika Local Government Area, Akwa Ibom State. The following materials were used for this study:

- 10 Polyethene bottles
- Water from stream
- Water from borehole
- 1 Marker for labelling
- 1 Haier Thermocool
- 1 Atomic absorption Spectrophotometer (AAS) model
- Concentrated HNO3
- Deionized water
- Volumetric flask

The samples were collected in bottles of 0.5 litre each which had been thoroughly washed, and filled with distilled water, then taken to the sampling site. The bottles were emptied and rinsed several times with the water to be collected. Also, the sample bottles were partially filled with the collected water and vigorously shaken to note the odour. The sample bottles were tightly covered immediately after collection. They were then stored in a refrigerator at 4°C (Haier Thermocool) to slow down bacterial and chemical reaction rates.

The samples after transported from the field were subjected to digestion. Digestion of the sample is one of the storage steps taken to preserve the samples from bacterial activities and to release metals into the analytical solution. From each sample, 50 cm3 was measured into an evaporating dish and 5 cm3 of concentrated HNO3 was added. The samples digested for about 30 minutes using digestion block in a fume cupboard until the solution reduces to 5 – 6 cm3 with a characteristic colour, indicating complete digestion. Each digest was then allowed to cool and transferred to a 50 cm3 acid washed volumetric flask and the volume brought to the 50 cm3 mark with deionized water. Diluted digest was then filtered and kept in sample bottles ready for analysis.

Samples from the different streams were labelled S1, S2, S3, S4 and S5 respectively while Samples from the different boreholes were labelled B1, B2, B3, B4 and B5 respectively. On the same day of sampling, the samples were transported to the Chemistry Laboratory, University of Uyo for heavy metal analysis. Atomic absorption Spectrophotometer (AAS) model under the wavelength of 217 nm, 324.8 nm, 213.9 nm and 279.5 nm for Pb, Cu, Zn and Mn respectively was used for the determination of the concentration of heavy metals (Pb, Cu, Zn and Mn) in the borehole and stream water samples.

The results of the concentration of the heavy metals obtained were presented in mg/L. Mean, Standard deviation and independent t-test statistics in Statistical Package for Social Sciences (SPSS) were used for data analysis. Mean, Standard deviation statistics were used to present the level of heavy metals concentration while independent t-test statistical test was to test for significant at .05 alpha level. The results obtained were also compared with WHO required limit for drinking water.

3. Results

Presentation of Raw scores measurement

Table 1: Raw scores measurement

Heavy metals	S1		S2		S3		S4		S5	
	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)
Pb	0.576	0.572	0.576	0.576	0.578	0.580	0.579	0.581	0.676	0.676
Cu	0.077	0.076	0.079	0.079	0.077	0.079	0.071	0.074	0.873	0.873
Zn	2.088	2.090	2.089	2.089	2.047	2.045	2.099	2.097	2.107	2.105
Mn	0.379	0.377	0.328	0.328	0.334	0.336	0.312	0.314	0.386	0.389
Heavy metals	B1		B2		B3		B4		B5	
	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)	Ist (mg/L)	2nd (mg/L)
Pb	0.334	0.336	0.578	0.580	0.431	0.433	0.377	0.379	0.211	0.213
Cu	0.049	0.051	0.081	0.081	0.060	0.058	0.056	0.054	0.085	0.085
Zn	2.041	2.043	2.089	2.089	2.028	2.030	2.088	2.086	2.053	2.056
Mn	0.003	0.005	0.328	0.326	0.004	0.005	0.007	0.009	0.008	0.008

Source: Laboratory results of Water samples (2024)

The above raw scores show results as obtained from the laboratory analysis. These raw scores were appropriately subjected to statistically analysis using Mean, Standard deviation and Independent t-test in Statistical Package for Social Sciences (SPSS).

- To measure the level of heavy metals in borehole water and stream in Ika Local Government Area.

Table 2: Mean and Standard Deviation for level of heavy metals in stream water in Ika Local Government Area.

Heavy metal (mg/L)	S1	S2	S3	S4	S5	WHO (2011)
Pb	0.574 ±0.345	0.576 ±0.376	0.578 ±0.340	0.579 ±0.349	0.674 ±0.345	0.010
Cu	0.075 ±0.044	0.079 ± 0.051	0.077 ±0.049	0.071 ±0.048	0.871 ± 0.034	2.000
Zn	2.088 ± 2.007	2.089 ± 2.009	2.045 ± 2.010	2.097 ± 2.017	2.105 ± 2.007	3.000
Mn	0.377 ± 0.287	0.328 ± 0.276	0.334±0.277	0.312 ± 0.265	0.386 ± 0.268	0.050

Result in Table 2 revealed that the concentrations of Pb in Ika LGA among the different streams varied between 0.574 ±0.345 - 0.674 ±0.345 mg/L. The values observed for Mn in the different streams were higher than the WHO (2011) minimum requirement (0.010mg/L) for drinking water. This means that the stream water is contaminated by Pb. The result in Table 1 also revealed that the concentrations of Cu in Ika LGA among the different streams varied between 0.071 ±0.048 - 0.871 ± 0.034 mg/L. The values observed for Cu in the different streams were lower than the WHO (2011) minimum requirement (2.000mg/L) for drinking water. This means that the stream water is not contaminated by Cu. The result in Table 1 further revealed that the concentrations of Zn in Ika LGA among the different streams varied between 2.045 ± 2.010 - 2.105 ± 2.007 mg/L. The values observed for Zn in the different streams were lower than the WHO (2011) minimum requirement (3.000mg/L) for drinking water. This means that the stream water is not contaminated by Zn. Lastly, the result in Table 2 further revealed that the concentrations of Mn in Ika LGA among the different streams varied between 2.045 ± 2.010 - 2.105 ± 2.007 mg/L. The values observed for Mn in the different streams were higher than the WHO (2011) minimum requirement (0.050mg/L) for drinking water. This means that the stream water is contaminated by Mn.

Table 3: Mean and Standard Deviation for level of heavy metals in borehole water in Ika Local Government Area.

Heavy metal (mg/L)	B1	B2	B3	B4	B5	WHO (2011)
Pb	0.334 ±0.215	0.276 ±0.154	0.431 ±0.266	0.377 ±0.288	0.211 ±0.175	0.010
Cu	0.049 ±0.027	0.012 ± 0.007	0.058 ±0.023	0.054 ±0.032	0.084 ± 0.018	2.000
Zn	2.041 ± 1.981	2.012 ± 1.564	2.028 ± 1.988	2.086 ± 2.011	2.055 ± 1.977	3.000
Mn	0.003 ± 0.217	0.006 ± 0.165	0.004 ±0.189	0.007 ± 0.243	0.007 ± 0.218	0.050

Result in Table 3 revealed that the concentrations of Pb in Ika LGA among the different streams varied between 0.211 ±0.175 - 0.431 ±0.266 mg/L. The values observed for Mn in the different streams were higher than the WHO (2011) minimum requirement (0.010mg/L) for drinking water. This means that the borehole water is contaminated by Pb. The result in Table 3 also revealed that the concentrations of Cu in Ika LGA among the different streams varied between 0.012 ± 0.007 - 0.084 ± 0.018mg/L. The values observed for Cu in the different borehole were lower than the WHO (2011) minimum requirement (2.000mg/L) for drinking water. This means that the borehole water is not contaminated by Cu. The result in Table 3 further revealed that the concentrations of Zn in Ika LGA among the different streams varied between 2.012 ± 1.564 - 2.086 ± 2.011 mg/L. The values observed for Zn in the different streams were lower than the WHO (2011) minimum requirement (3.000mg/L) for drinking water. This means that the borehole water is not contaminated by Zn. The result in Table 3 further revealed that the concentrations of Mn in Ika LGA among the different streams varied between 0.216 ± 0.165 - 0.343 ± 0.217 mg/L. The values observed for Mn in the different streams were lower than the WHO (2011) minimum requirement (0.050mg/L) for drinking water. This means that the borehole water is not contaminated by Mn.

- To compare the level of heavy metals in the two samples and make deduction from the level of heavy metals measured in Ika Local Government Area.

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Table 4: Summary of Independent t-test for comparison of level of heavy metals in borehole and stream water in Ika Local Government Area.

Heavy metal (mg/L)	S1	S2	S3	S4	S5	WHO (2011)
Pb	0.574 ±0.345a	0.576 ±0.376a	0.578 ±0.340a	0.579 ±0.349a	0.674 ±0.345a	0.010
Cu	0.075 ±0.044b	0.079±0.051b	0.077±0.049b	0.071 ±0.048b	0.871 ±0.034b	2.000
Zn	2.088 ± 2.007c	2.089±2.009c	2.045 ±2.010c	2.097 ±2.017c	2.105 ±2.007c	3.000
Mn	0.377 ± 0.287d	0.328±0.276d	0.334±0.277d	0.312 ±0.265 d	0.386 ±0.268 d	0.050
Heavy metal (mg/L)	**B1**	**B2**	**B3**	**B4**	**B5**	**WHO (2011)**
Pb	0.334 ±0.215a	0.276±0.154 a	0.431±0.266a	0.377±0.288a	0.211±0.175a	0.010
Cu	0.049 ±0.027 b	0.012±0.007 b	0.058 ±0.023b	0.054 ±0.032 b	0.084 ±0.018b	2.000
Zn	2.041 ± 1.981c	2.012±1.564c	2.028±1.988 c	2.086 ± 2.011c	2.055 ±1.977a	3.000
Mn	0.003 ± 0.217 d	0.006±0.165d	0.004 ±0.189d	0.007 ±0.243d	0.007±0.218 d	0.050

Values are mean ± standard deviation of three values. The values with the same superscript along the row were not significantly different. (P>0.05).

The result in Table 4 revealed that the mean values for level of heavy metals in borehole water and stream water does not significantly differ between the two samples at .05 alpha level of significance. Therefore, this implies that the level of heavy metals (Zn, Cu, Pb and Mn) in the two water samples (stream and borehole water) are the statistically the same.

4. Discussions of Findings

The result in Table 2 revealed that stream water is contaminated by Pb and Mn but is not contaminated by Cu, Zn when compared to the WHO minimum requirement for drinking water. This result could be attributed to the fact that activities such as industrial processes and the use of certain pesticides or fertilizers can release lead and manganese into water sources, contributing to contamination. While copper and zinc are also used in various industries, the compounds formed by these metals may not be as mobile or as easily transported into water bodies compared to lead and manganese. More so, the pH of water and precipitation patterns can influence metal mobility. For instance, acidic conditions can enhance the leaching of lead and manganese. Furthermore, the presence of organic matter can influence the speciation of metals in water. Certain organic compounds may form complexes with metals, affecting their transport and availability in the water. Additionally, the solubility and mobility of metals in water are influenced by their geochemical properties. Lead and manganese can be present in forms that are more soluble and can be easily transported in water, leading to contamination. For example, mining activities or industrial discharges can introduce lead and manganese into streams, causing contamination. Lastly, Copper and zinc may form less soluble compounds or complexes that are not as readily transported in water. As a result, even if there are sources of copper and zinc in the environment, they might not contaminate stream water as easily as lead and manganese.

The results from this study agreed with the previous study conducted by earlier researcher which revealed that lead can have toxic effects on aquatic life, impacting fish and invertebrates [8]. Studies have demonstrated adverse effects on fish, invertebrates, and algae. The result of this findings disagreed with the previous study conducted by Akpanwho reported that copper disrupts the ion balance and enzyme activities in aquatic organisms [9].

The result in Table 3 revealed that borehole water is contaminated by Pb but is not contaminated by Cu, Zn and Mn when compared to the WHO minimum requirement for drinking water [14]. This result could be attributed to the fact that Borehole water may pass through geological formations that naturally contain lead, such as lead-rich minerals or deposits. In addition, leaching of lead from these geological sources can result in lead contamination in borehole water. These metals may not have significant natural sources in the geological formations through which the borehole water flows. As a result, their concentrations may be lower compared to lead. Lastly, proximity to sources of lead pollution, such as industrial facilities or areas with historical lead contamination, can contribute to higher lead levels in borehole water. These metals might not have significant local pollution sources, leading to lower concentrations in the borehole water. The results from this research agreed with those of Huang who observed neurological symptoms and conditions similar to Parkinson's disease in individuals with prolonged lead exposure [14].

The results in Table 4 revealed that the mean values for level of heavy metals in borehole water and stream water does not significantly differ between the two samples. Therefore, this implies that the level of heavy metals (Zn, Cu, Pb and Mn) in the two water samples (stream and borehole water) are the statistically the same. The result of this finding could be attributed to the geological and environmental conditions in the region may naturally contribute similar concentrations of heavy metals to both the stream and borehole water. If the underlying geology or soil composition is similar, the water samples may reflect comparable baseline levels of these metals. In addition, both the stream and borehole might be influenced by similar pollution sources or human activities in the vicinity. For example, if there are nearby industrial discharges or agricultural practices using similar inputs, the heavy metal concentrations could be similar in both water sources. Lastly, similar land use practices in the surrounding areas, such as agriculture or urban development, can contribute to comparable metal concentrations in both water sources. The results of these findings agreed with those of earlier researchers who reported that both stream and borehole water do not significantly differ based on the level of heavy metals [14].

5. Conclusion

Based on the findings, it was concluded that there is no significant different in the level of heavy metals (Zn, Pb, Mn and Cu) in stream and borehole water in Ika Local Government Area. Stream water is contaminated by Pb and Mn but is not contaminated by Cu, Zn when compared to the WHO minimum requirement for drinking water. Borehole water is contaminated by Pb but is not contaminated by Cu, Zn and Mn when compared to the WHO minimum requirement for drinking water.

Recommendations

Based on the findings, the following recommendations were made:

- Government should develop and implement targeted remediation strategies specifically addressing the sources of lead (Pb) and manganese (Mn) contamination in stream water. This may involve identifying and mitigating pollution sources such as industrial discharges or agricultural runoff contributing to these contaminants.
- WHO should strengthen water quality monitoring protocols for both stream and borehole water to ensure regular and comprehensive assessments of heavy metal concentrations. Increased monitoring frequency and the inclusion of additional sampling points can provide a more accurate representation of water quality over time.
- Chemistry environmentalists should conduct public awareness campaigns and educational programs to inform the local community about the quality of stream and borehole water. Emphasize the potential health risks associated with elevated levels of lead and manganese in stream water, even if they do not exceed WHO (2011) standards and encourage proper water treatment practices.

References

1. Etesin, U. M. (2015). Heavy metals in water: Sources, implications and treatment technologies. Journal of Environmental Chemistry and Ecotoxicology, 7(5), 22-31.
2. Amaibi, P. M., Maduelosi, N. J., & Lekia, S. (2023). INVESTIGATION OF THE IMPACT OF POTENTIALLY TOXIC ELEMENTS FROM URBAN FLOODED AREAS IN PORT HARCOURT CITY, NIGERIA. Journal of Chemical Society of Nigeria, 48(3).
3. James, R. K. (2018). Sources and distribution of heavy metal contamination in water systems. Environmental Science: Processes & Impacts, 20(4), p 593-609.
4. Obadimu, C. O. (2016). Water pollution and its effects on public health: A case study of Akwa Ibom State, Nigeria. Journal of Public Health and Epidemiology, 8(9), p 134-141.
5. Ite, A. E. (2017). Comparative analysis of borehole and stream water quality in Ika Local Government Area, Akwa Ibom State, Nigeria. Journal of Water, Sanitation and Hygiene for Development, 7(3), p 456-468.
6. Khan, K., Lu, Y., Khan, H., Zakir, S., Khan, S., Khan, A. A., ... & Wang, T. (2013). Health risks associated with heavy metals in the drinking water of Swat, northern Pakistan. Journal of Environmental Sciences, 25(10), 2003-2013.
7. Akinfolarin, O.M & Chukwuji, G. (2020). Assessment of bore-hole water in Oroworukwo, Port Harcourt, Rivers State, Nigeria. Journal of Enviromental Sciences Research, 2(3), p 1 -5.
8. Nsi, I. E. (2018). Impact of lead contamination on aquatic ecosystems: Lessons from the Flint water crisis. Aquatic Toxicology, 202, 94-102.
9. Akpan, E. E. (2013). Toxic effects of copper on aquatic organisms: A review. Environmental Toxicology and Pharmacology, 36(3), p 917-928.
10. Noyce, J. O., Michels, H., & Keevil, C. W. (2006). Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant Staphylococcus aureus in the healthcare environment. Journal of Hospital Infection, 63(3), 289-297.
11. Alloway, B. J. (2008). Zinc in soils and crop nutrition.
12. Haase, H., & Rink, L. (2014). Zinc signals and immune function. Biofactors, 40(1), 27-40.
13. World Health Organization, WHO (2011). Guidelines for manganese in drinking water quality. World Health Organization, 43(2), p 156-167.
14. Huang, C. C. (2019). Neurotoxic effects of chronic manganese exposure: A systematic review. NeuroToxicology, 73, p 219-227.