

HEAVY METAL BIOACCUMULATION AND HUMAN HEALTH RISK IN CLARIAS GARIEPINUS AND OREOCHROMIS NILOTICUS FROM KPATA, LOWER RIVER NIGER, NIGERIA

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Abstract

Fish taken from waters contaminated with heavy metals are a recognised route by which those metals enter the human diet. This study assessed heavy metal bioaccumulation and the associated human health risk in *Clarias gariepinus* and *Oreochromis niloticus* from the Kpata reach of the Lower River Niger at Lokoja, Nigeria. Forty specimens of each species were collected in each of two hydrological periods, January to March 2025 representing the dry season and June to August 2025 representing the wet season. Liver tissue was digested and analysed for cadmium, lead, chromium, zinc, mercury, copper and arsenic. Bioaccumulation factors were computed relative to ambient water and sediment, and human health risk was evaluated through the estimated daily intake, the target hazard quotient, the hazard index and the margin of exposure. All seven metals were detected in both species in both seasons. Chromium recorded the highest liver concentration in both species, at 1.110 and 1.090 mg per kg in the dry season and 1.163 and 1.127 mg per kg in the wet season, followed by zinc and copper. Concentrations were significantly higher in *C. gariepinus* than in *O. niloticus* for most metals, which is consistent with the benthic and opportunistic feeding habit of the former. With the exception of mercury, concentrations were higher in the wet season than in the dry season. Bioaccumulation factors were below unity for every metal in both species relative to both water and sediment, indicating that liver concentrations did not exceed those of the surrounding matrices. Target hazard quotients were below unity for every metal, and the hazard index reached 0.443 for *C. gariepinus* and 0.430 for *O. niloticus*, both below the threshold of concern. Chromium contributed 61.2 and 62.1 percent of the respective hazard indices and is therefore the risk determining metal. The study concludes that consumption of fish from this reach does not at present pose a cumulative non carcinogenic risk at the intake rate modelled, but that chromium warrants continued monitoring.

Keywords: heavy metal bioaccumulation; *Clarias gariepinus*; *Oreochromis niloticus*; human health risk; River Niger; Nigeria

1. Introduction

Fish supplies high quality protein and essential micronutrients to more than three billion people worldwide, and is particularly important in low and middle income tropical countries where alternative animal protein is costly. The same characteristic that makes fish nutritionally valuable, namely its position in aquatic food webs, also makes it a route by which contaminants reach people.

Heavy metals are persistent, non biodegradable contaminants that partition between water, sediment and biota. Fish absorb them through gill respiration, dermal contact and dietary ingestion, and because the metals are not metabolised they accumulate in tissue over the life of the animal. The liver is of particular interest in this context because it is the principal site of detoxification and storage, and liver concentrations therefore integrate exposure over longer periods than muscle does (Akan et al., 2015; Chale, 2016).

The Kpata reach of the Lower River Niger at Lokoja lies at the Niger and Benue confluence and supports an active artisanal fishery serving local and regional markets, while receiving industrial, domestic and agricultural discharge from the surrounding catchment. The combination of a working fishery and multiple contaminant sources makes it a setting in which the relationship between environmental contamination and dietary exposure can be examined directly.

This study therefore assessed heavy metal concentrations in the liver of two commercially important species from this reach, *Clarias gariepinus* and *Oreochromis niloticus*, across two hydrological seasons, and evaluated the resulting human health risk. The two species were chosen deliberately because they differ in feeding ecology, the former being a benthic opportunistic omnivore and the latter principally a grazer on algae and detritus, so that any difference in accumulation between them bears on the pathway by which metals are acquired.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Kpata area of the Lower River Niger, Lokoja, Kogi State, Nigeria, at approximately 7°48' N and 6°46' E. Lokoja lies at the confluence of the River Niger and the River Benue. Three sampling zones, designated A, B and C, were established along the reach (Figure 1).

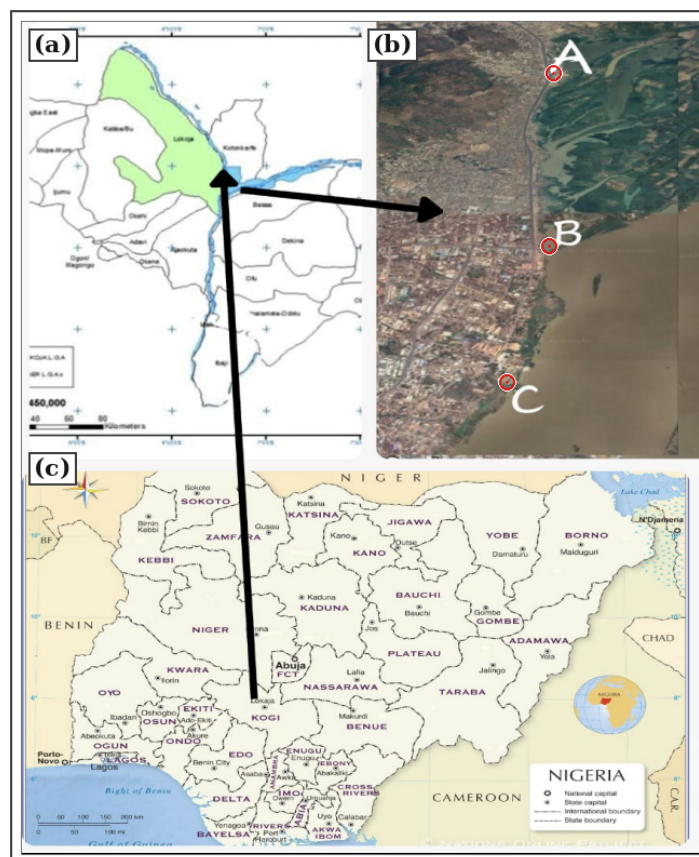


Figure 1: Map of the study area showing Lokoja and environs within Kogi State and a view of the Kpata reach of the Lower River Niger with the sampling zones A, B and C.

2.2 Fish Sampling

Sampling was conducted across two hydrological periods: January to March 2025, representing the dry season, and June to August 2025, representing the wet season. Forty specimens of each species were collected in each season, giving 160 specimens in total.

2.3 Tissue Preparation and Laboratory Analysis

Specimens were dissected and the liver excised. Liver samples were washed with deionised water to remove surface contamination, oven dried to constant weight, digested and analysed for cadmium, lead, chromium, zinc, mercury, copper and arsenic. Concentrations are reported in milligrams per kilogram wet weight.

2.4 Bioaccumulation Factor

The bioaccumulation factor was calculated as the ratio of metal concentration in fish liver to that in the ambient matrix, following Lau et al. (1998):

$$BCF_{\text{water}} = C_{\text{fish}} (\text{mg kg}^{-1}) / C_{\text{water}} (\text{mg L}^{-1}) \quad (1)$$

$$BCF_{\text{sediment}} = C_{\text{fish}} (\text{mg kg}^{-1}) / C_{\text{sediment}} (\text{mg kg}^{-1}) \quad (2)$$

A value greater than unity indicates net accumulation above the concentration of the surrounding matrix (USEPA, 2000).

2.5 Human Health Risk Assessment

The estimated daily intake represents the daily mass of metal ingested per kilogram of body weight through fish consumption and was calculated following USEPA (2011):

$$EDI = (MC \times FIR) / BW \quad (3)$$

where *MC* is the metal concentration in fish, *FIR* the fish ingestion rate and *BW* the body weight. The target hazard quotient is a dimensionless non carcinogenic risk estimator

$$THQ = (EF \times ED \times FIR \times C \times 10^{-3}) / (RfD \times BW \times AT_n) \quad (4)$$

in which *EF* is the exposure frequency, *ED* the exposure duration, *RfD* the oral reference dose and *AT_n* the averaging time. The hazard index sums the quotients across metals,

$$HI = \sum_i THQ_i \quad (5)$$

and the margin of exposure compares the reference dose with the estimated intake (Watanabe et al., 2003),

$$MOE = RfD / EDI = 1 / THQ \quad (6)$$

A hazard index below unity indicates that cumulative non carcinogenic risk lies within an acceptable range, and a margin of exposure greater than unity indicates that intake lies below the reference dose. The identity in equation (6) follows directly from the definitions of the two indices and is used here as an internal consistency check on the computed values.

2.6 Statistical Analysis

Data are expressed as mean ± standard deviation. Independent samples *t* tests were used to assess differences between the two species and between the two seasons. Significance was assessed at α = 0.05.

3. Results

3.1 Heavy Metal Concentrations in Fish Liver

Seven heavy metals were detected in the liver tissue of both species in both sampling periods (Table 1). In the dry season, chromium recorded the highest mean concentration in both species, at 1.110 ± 0.08 mg per kg in *C. gariepinus* and 1.090 ± 0.03 mg per kg in *O. niloticus*, followed by zinc and copper. Mercury was the least abundant metal throughout, at or below 0.0008 mg per kg.

Table 1: Mean heavy metal concentrations in liver tissue of *Clarias gariepinus* and *Oreochromis niloticus* from the Kpata area of the Lower River Niger across two hydrological seasons

Period	Species	Cd	Pb	Cr	Zn	Hg	Cu	As
January to March	<i>C. gariepinus</i>	0.066±0.01 ^a	0.069±0.01 ^a	1.110±0.08 ^a	5.07±0.13 ^a	0.0003 ^a	3.47±0.12 ^a	0.021±0.01 ^a
	<i>O. niloticus</i>	0.058±0.03 ^b	0.056±0.01 ^b	1.090±0.03 ^a	4.84±0.19 ^b	0.0003 ^a	3.42±0.11 ^a	0.007±0.01 ^b
	Grand mean	0.062	0.063	1.100	4.955	0.0003	3.445	0.014
June to August	<i>C. gariepinus</i>	0.068±0.01 ^a	0.069±0.01 ^a	1.163±0.11 ^a	5.10±0.17 ^a	0.0008 ^a	3.69±0.09 ^a	0.015±0.00 ^a
	<i>O. niloticus</i>	0.059±0.02 ^b	0.058±0.03 ^b	1.127±0.01 ^b	4.85±0.23 ^b	0.0003 ^a	3.61±0.18 ^a	0.012±0.00 ^b
	Grand mean	0.064	0.064	1.145	4.975	0.001	3.650	0.014
Comparison value adopted	–	0.005	0.010	0.003	3.000	0.001	0.020	0.010

Note. Concentrations in mg kg^{-1} wet weight, expressed as mean $\pm$ standard deviation. Within a column and season, values carrying different superscript letters differ significantly between species at $p < 0.05$. The comparison values in the final row are those adopted by the authors and are not the FAO and WHO maximum levels for fish tissue; several correspond in magnitude to drinking water guideline values. Exceedance statements based on this row should be read with that in mind and are revisited in Section 4.4.

Metal concentrations in *C. gariepinus* were significantly higher than those in *O. niloticus* for most metals in both seasons. With the exception of mercury, concentrations were higher in the wet season than in the dry season, which is consistent with greater catchment runoff and resuspension of sediment bound metals during periods of high flow.

3.2 Species Specific Bioaccumulation

Bioaccumulation factors calculated relative to ambient water and sediment were below unity for every metal in both species (Table 2). Liver concentrations therefore did not exceed those of the surrounding matrices, and on this measure the fish are not concentrating metals above environmental levels. Chromium recorded the highest factor in both species and against both matrices, and mercury and lead the lowest. The accumulation order relative to water was chromium, zinc, cadmium, copper, arsenic, lead and mercury.

Table 2: Bioaccumulation factors for heavy metals in *Clarias gariepinus* and *Oreochromis niloticus* relative to ambient water and sediment concentrations, averaged across seasons

Metal	<i>C. gariepinus</i> (mg kg^{-1})	<i>O. niloticus</i> (mg kg^{-1})	BCF water, <i>C.g.</i>	BCF water, <i>O.n.</i>	BCF sediment, <i>C.g.</i>	BCF sediment, <i>O.n.</i>
Cd	0.067	0.059	4.18×10^{-1}	3.62×10^{-1}	7.31×10^{-2}	6.35×10^{-2}
Pb	0.069	0.057	3.00×10^{-2}	2.50×10^{-2}	1.06×10^{-2}	8.77×10^{-3}
Cr	1.137	1.109	8.47×10^{-1}	8.19×10^{-1}	8.71×10^{-1}	8.49×10^{-1}
Zn	5.085	4.845	4.94×10^{-1}	4.70×10^{-1}	3.99×10^{-1}	3.80×10^{-1}
Hg	0.0006	0.0003	1.29×10^{-2}	4.80×10^{-3}	1.53×10^{-2}	7.69×10^{-3}
Cu	3.580	3.515	3.36×10^{-1}	3.29×10^{-1}	3.38×10^{-1}	3.32×10^{-1}
As	0.018	0.010	2.42×10^{-1}	1.94×10^{-1}	3.19×10^{-1}	1.85×10^{-1}

Note. Every value is below unity, indicating that liver concentrations did not exceed the concentrations of the matrices from which the metals derive.

3.3 Human Health Risk Assessment

Estimated daily intakes were low for both species (Tables 3 and 4). For *C. gariepinus* the intake ranged from 7.14×10^{-7} mg per kg per day for mercury to 3.61×10^{-3} mg per kg per day for zinc. Target hazard quotients were below unity for every metal in both species, and the hazard index reached 0.443 for *C. gariepinus* and 0.430 for *O. niloticus*. Margins of exposure exceeded unity for every metal, the narrowest being that for chromium at 3.69 in *C. gariepinus*.

Table 3: Estimated daily intake, target hazard quotient, margin of exposure and hazard index for heavy metals in *Clarias gariepinus* from the Kpata area

Metal	Fish concentration (mg kg^{-1})	EDI ($\text{mg kg}^{-1} \text{ day}^{-1}$)	THQ	MOE	Interpretation
Cd	6.60×10^{-2}	4.71×10^{-5}	4.71×10^{-2}	21.2	No immediate risk
Pb	7.10×10^{-2}	5.07×10^{-5}	1.01×10^{-2}	99.0	No immediate risk
Cr	1.14×10^0	8.14×10^{-4}	2.71×10^{-1}	3.69	Warrants monitoring
Zn	5.05×10^0	3.61×10^{-3}	1.20×10^{-2}	83.3	No immediate risk
Hg	1.00×10^{-3}	7.14×10^{-7}	2.38×10^{-3}	420	No immediate risk
Cu	3.64×10^0	2.60×10^{-3}	6.50×10^{-2}	15.4	No immediate risk
As	1.50×10^{-2}	1.07×10^{-5}	3.57×10^{-2}	28.0	No immediate risk
HI (ΣTHQ)	–	–	0.443	–	No cumulative risk

Note. Body weight 70 kg; reference doses from USEPA (2011). The intake values correspond to a fish ingestion rate of 50 g per day. Margins of exposure are computed as the reciprocal of the target hazard quotient, in accordance with equation (6); see Section 4.4.

Table 4: Estimated daily intake, target hazard quotient, margin of exposure and hazard index for heavy metals in *Oreochromis niloticus* from the Kpata area

Metal	Fish concentration (mg kg^{-1})	EDI ($\text{mg kg}^{-1} \text{ day}^{-1}$)	THQ	MOE	Interpretation
Cd	6.15×10^{-2}	4.39×10^{-5}	4.39×10^{-2}	22.8	No immediate risk
Pb	5.70×10^{-2}	4.07×10^{-5}	1.02×10^{-2}	98.0	No immediate risk
Cr	1.12×10^0	8.00×10^{-4}	2.67×10^{-1}	3.75	Warrants monitoring
Zn	4.96×10^0	3.54×10^{-3}	1.18×10^{-2}	84.8	No immediate risk
Hg	1.00×10^{-3}	7.14×10^{-7}	2.38×10^{-3}	420	No immediate risk
Cu	3.23×10^0	2.31×10^{-3}	5.80×10^{-2}	17.2	No immediate risk

Metal	Fish concentration (mg kg ⁻¹)	EDI (mg kg ⁻¹ day ⁻¹)	THQ	MOE	Interpretation
As	1.55×10^{-2}	1.11×10^{-5}	3.71×10^{-2}	27.0	No immediate risk
HI (Σ THQ)	–	–	0.430	–	No cumulative risk

Note. Parameters as in Table 3.

Table 5: Summary comparison of mean heavy metal concentrations, exceedance status against the comparison values adopted, bioaccumulation rank and species specific target hazard quotients

Metal	C.g. (mg kg ⁻¹)	O.n. (mg kg ⁻¹)	Comparison value (mg kg ⁻¹)	Exceeds adopted value	BCF rank	THQ C.g.	THQ O.n.
Cd	0.067	0.059	0.005	Yes, both	3rd	4.71×10^{-2}	4.39×10^{-2}
Pb	0.069	0.057	0.010	Yes, both	6th	1.01×10^{-2}	1.02×10^{-2}
Cr	1.137	1.109	0.003	Yes, both	1st	2.71×10^{-1}	2.67×10^{-1}
Zn	5.085	4.845	3.000	Yes, both	2nd	1.20×10^{-2}	1.18×10^{-2}
Hg	0.0006	0.0003	0.001	No	7th	2.38×10^{-3}	2.38×10^{-3}
Cu	3.580	3.515	0.020	Yes, both	4th	6.50×10^{-2}	5.80×10^{-2}
As	0.018	0.010	0.010	Yes, C.g. only	5th	3.57×10^{-2}	3.71×10^{-2}

Note. Bioaccumulation rank is based on the water phase factor, with 1st denoting the highest. Exceedance is assessed against the comparison values adopted by the authors, which are discussed in Section 4.4.

4. Discussion

4.1 Species Differences and the Feeding Pathway

Metal concentrations were consistently higher in *C. gariepinus* than in *O. niloticus*, and the difference was statistically significant for most metals in both seasons. This corresponds to the difference in trophic niche between the two species. *C. gariepinus* is an opportunistic benthic omnivore that feeds actively on the river bed, where metals associated with fine sediment and organic particulate matter are concentrated, whereas *O. niloticus* grazes principally on algae and suspended detritus in the water column.

The pattern is most pronounced for arsenic and cadmium, both of which show strong affinity for organic particulate matter and tend to concentrate in sediment organic fractions accessible to benthic feeders (Alloway, 2013). The practical implication is that exposure through fish consumption is not uniform across the catch: a household eating predominantly catfish is more exposed than one eating predominantly tilapia from the same reach, and dietary advice framed in terms of fish generally would obscure that difference.

4.2 Seasonal Pattern

With the single exception of mercury, concentrations were higher in the wet season. This is consistent with greater catchment runoff during high flow, which mobilises metals from terrestrial sources, and with the resuspension of sediment bound metals under increased discharge. That mercury does not follow the pattern is unsurprising given its distinct biogeochemistry, in which atmospheric deposition and methylation in anoxic sediment are the controlling processes rather than particulate transport (Adebayo, Aborisade and Oladipo, 2016).

4.3 Bioaccumulation Factors Below Unity

A result that deserves particular emphasis, because it qualifies the framing of the study, is that every bioaccumulation factor was below unity, against both water and sediment and for both species. Strictly interpreted, this means that liver concentrations did not exceed those of the surrounding matrices, and therefore that net bioaccumulation in the technical sense was not demonstrated.

Two observations follow. First, the ranking of factors remains informative even where all lie below unity, since it indicates the relative efficiency with which each metal is transferred from environment to tissue, and chromium ranks highest on that measure in both species. Second, the finding that environmental concentrations exceed tissue concentrations directs attention to the matrices themselves. If water and sediment at this reach carry metal burdens greater than those found in fish liver, the contamination of the reach is itself the primary concern, and the fishery is better read as an indicator of that contamination than as its principal consequence.

4.4 Interpreting the Comparison Values and the Risk Indices

Three features of the quantitative framework require comment, because each affects how the results should be read and each is a matter the authors may wish to revisit.

The first concerns the comparison values in the final row of Table 1. Several of these, notably 0.010 mg per kg for lead, 0.010 for arsenic and 0.001 for mercury, correspond in magnitude to drinking water guideline values expressed in mg per litre rather

than to the maximum levels for fish tissue issued by the Codex Alimentarius Commission and commonly cited as FAO and WHO limits, which are substantially higher. Comparing tissue concentrations in mg per kg against water guidelines in mg per litre is not a like for like comparison, and the number of metals recorded as exceeding permissible levels is sensitive to which set is used. The exceedance column in Table 5 is therefore presented against the values the authors adopted and labelled accordingly, rather than as an unqualified statement of regulatory breach.

The second concerns the margin of exposure. Since the margin is defined as the reference dose divided by the estimated daily intake, and the hazard quotient as the intake divided by the same reference dose, the two are exact reciprocals. The values reported in Tables 3 and 4 have been computed on that identity, which is why the narrowest margin, that for chromium at 3.69, is the reciprocal of its hazard quotient of 0.271. Margins of this size are comfortably above unity but are not large, and chromium is on this measure the metal closest to the threshold of concern.

The third concerns the consumption assumption. The intake values correspond to an ingestion rate of 50 g per day at a body weight of 70 kg. Nigerian per capita fish consumption averages considerably less than this, in the region of 8 to 9 g per day, so the estimates reported here are conservative for an average consumer. They are not conservative for a fishing household on this reach, where consumption may exceed 50 g per day. Because the indices scale linearly with intake, the hazard index of 0.443 would fall to approximately 0.07 at the national average and would reach unity at an intake of roughly 113 g per day. That last figure is the practically useful one: it identifies the consumption level at which cumulative risk would become a concern, and it is not far above the rate modelled.

4.5 Chromium as the Risk Determining Metal

Chromium accounted for 61.2 percent of the hazard index in *C. gariepinus* and 62.1 percent in *O. niloticus*, ranked first on bioaccumulation factor in both species, and carries the narrowest margin of exposure. On every measure applied in this study it is the metal that determines risk, and it is the only one for which the interpretation column in Tables 3 and 4 records a need for monitoring. Any monitoring programme established for this reach should accordingly prioritise chromium rather than distributing effort evenly across the seven metals.

It should be noted that the assessment does not speciate chromium. Trivalent chromium is an essential micronutrient of low toxicity whereas hexavalent chromium is a recognised carcinogen, and the reference dose applied differs by orders of magnitude between them. Speciation is therefore the single most valuable analytical addition that could be made to this work.

4.6 Limitations

Several limitations qualify these findings. Risk indices are derived from liver concentrations whereas the tissue ordinarily consumed is muscle, and liver typically carries higher metal burdens than muscle, so the estimates are likely to overstate dietary exposure for consumers who do not eat the organ. Sampling covered a single year across two seasons, so interannual variation is unobserved. Water and sediment concentrations underlying the bioaccumulation factors are reported as averages without dispersion, which prevents the factors from being given confidence limits. Chromium was not speciated, as noted above. Finally, the comparison values adopted for permissible limits require verification against the applicable tissue standard before any regulatory inference is drawn.

5. Conclusion and Recommendations

This study assessed heavy metal bioaccumulation and human health risk in *Clarias gariepinus* and *Oreochromis niloticus* from the Kpata area of the Lower River Niger. All seven metals examined were detected in liver tissue of both species in both seasons, with chromium highest throughout. Concentrations were significantly higher in *C. gariepinus* than in *O. niloticus* and, except for mercury, higher in the wet season than the dry. Bioaccumulation factors were below unity for every metal and matrix combination, and target hazard quotients were below unity for every metal, giving hazard indices of 0.443 and 0.430 for the two species respectively.

The study concludes that consumption of fish from this reach does not presently indicate a cumulative non carcinogenic risk at the intake rate modelled, but that the margin is not large and that chromium determines what margin there is. The following recommendations follow.

1. **Establish quarterly fish tissue monitoring for both species**, reporting muscle as well as liver concentrations so that dietary exposure is estimated from the tissue actually consumed.
2. **Speciate chromium in subsequent sampling**. Because the trivalent and hexavalent forms differ greatly in toxicity, and chromium determines the hazard index, speciation would materially change the confidence attaching to the risk estimate.
3. **Verify the permissible limits applied**. Exceedance should be assessed against the Codex maximum levels for fish tissue before any regulatory conclusion is drawn.
4. **Characterise water and sediment concentrations with replication**. Since every bioaccumulation factor fell below unity, the contamination of the matrices themselves is the finding that most warrants follow up.

5. **Target advice at high consumption households.** The hazard index reaches unity at an intake of approximately 113 g per day, which is attainable in fishing households on this reach, so advisory effort should be directed there rather than at the general population.

Conflict of Interest

The authors have no conflict of interest to disclose regarding this work.

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Authors Contributions

Udechukwu Peace Onyinye: conceptualisation, field sampling, laboratory analysis, data analysis and drafting of the manuscript. **Adang Kombe Lucas:** supervision, methodology, validation, review and editing. **Peace Onas Somdare:** interpretation of results, review and editing.

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