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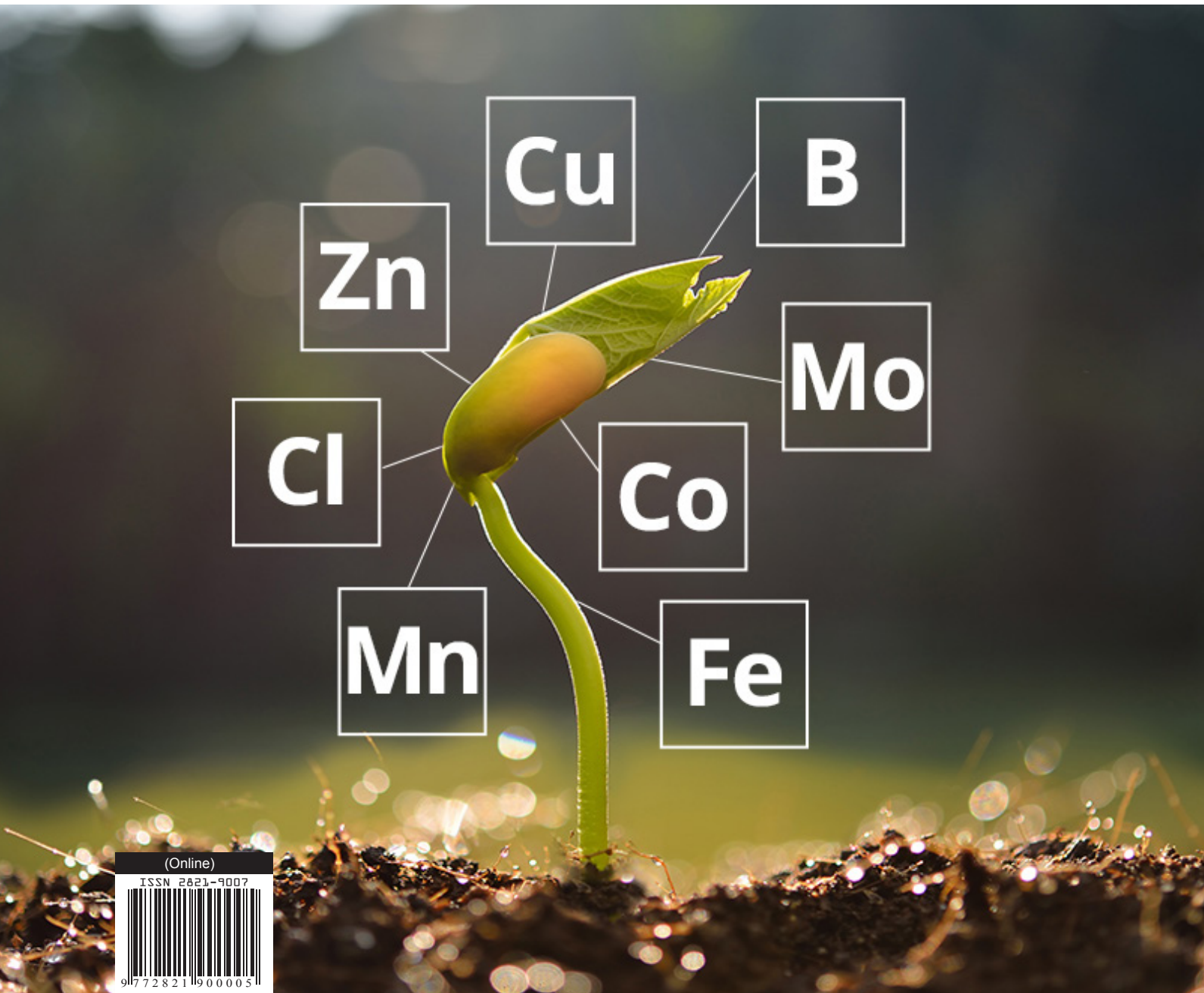

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The Role of Micronutrients in the Prevention and Management of Neurodevelopmental Disorders: A Systematic Review

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ABSTRACT

The prevalence of various neurodevelopmental disorders (NDs) in children continue to progress along a world that is increasingly advancing in research, technology and record keeping. The usual long-term nature of these disorders causes many caregivers to use complementary and alternative medicine (CAM) to help improve the lives of affected children or to prevent the condition from occurring. Micronutrients are among the commonly used CAM in many instances. The objective was to review the role that micronutrients play in the prevention and management of NDs. A search for eligible studies published overtime up to January 2023 was conducted on PUBMED, semantic scholar, TandFonline, and World Health Organisation's International Clinical Trials Registry. The search yielded 2,362 studies, however, 145 reports were included in the review. Serum levels of micronutrients were found to be significantly lower in children with Autism Spectrum Disorder (ASD) and Attention Deficit Hyperactivity Disorder (ADHD) compared to Typically Developing (TD) children. Also, micronutrient usage was associated with perceived improvement in ASD and ADHD symptoms with maternal prenatal intakes and levels of micronutrients lowering the odds of ASD in offspring. Appropriate use of micronutrients in the management of NDs may decrease the severity of these conditions. Additionally, improving maternal serum levels of micronutrients before and during pregnancy may potentially reduce the risk of ASD.

Keywords: Micronutrients, nutrition, neurodevelopmental disorders, autism, Attention Deficit Hyperactivity Disorder, children

Introduction

Neurodevelopmental disorders (NDs) are a group of conditions with onset in the developmental period of a child characterized by developmental deficits that produce impairments of personal, social, academic, or occupational function (APA,2013). These deficits vary among affected people, ranging from very specific learning limitations or control of executive functions to global impairment of social skills or intelligence. The Diagnostic and Statistical Manual of Mental Disorders (DSM-5) describes NDs under six broad categories: Intellectual Disability, Communication Disorders, Autism Spectrum Disorder, Attention Deficit Hyperactivity Disorder, Specific Learning Disorder, and Neurodevelopment motor disorders. These NDs may co-present in individuals and their prevalence range from 9 to 18 percent (Arora et al., 2018; Bosch et al., 2021; Tatishvili et al., 2017).

Genetic disorders (Fragile X syndrome); medical conditions (cerebral palsy and epilepsy); environmental factors (nutrition, perinatal exposures to environmental toxicants(Banerjee et al., 2007; Rossignol et al., 2014), birth by caesarian section(Zhang et al., 2019), perinatal hypoxia, respiratory stress(Arora et al., 2018; Carlsson et al., 2021), diverse maternal inflammatory states during pregnancy(Han et al., 2021), transient income decline during childhood); and biological factors (advanced paternal age, low birth weight, and birth defects)

(Carlsson et al., 2021) have been associated with the risk of NDs .

Due to the stress involved in caring for children with NDs, caregivers continue to explore other measures in an attempt to manage this condition. Hence, Complementary and Alternative Medicine (CAM) is steadily gaining popularity among this population. Multivitamins, vitamin C, vitamin D and minerals are among the most used CAM products among children with neurologic conditions and NDs (Galicia-Connolly et al., 2014; Trudeau et al., 2019; Wilson et al., 2005). Undoubtedly, health workers' ability to provide information that is evidence-based to families that are considering CAM for prevention or treatment of NDs, will prove to be timely and resource saving.

No published systematic review on this topic in whole or in parts exist except a few that has focused on the role of single micronutrients in the treatment of a specific ND(Granero et al., 2021; Hoxha et al., 2021). Hence this review examines the role micronutrients play in the prevention and management of NDs.

METHODS

Eligibility Criteria

All forms of experimental and non-experimental studies about children that relate one or more ND to one or more micronutrients were included in this review. Studies published in English and had reported on children up to 18 years of age were eligible for inclusion. Studies on animal subjects and the effect of toxic metals were excluded.

Information Sources

Using PUBMED, Semantic scholar, Tandfonline, the WHO International Clinical Trials Registry Platform (ICTRP), and Cochrane CENTRAL, a search was made for published and gray materials concerning the subject being reviewed.

Search Strategy

As required for a good search strategy, a review protocol was developed (Aromataris & Riitano, 2014). The primary outcomes for the search were: the effectiveness of micronutrients in treating NDs, the biological levels of micronutrients in children with NDs and the risk associated with levels and usage of micronutrients in relation to NDs. Using various sentences that included MeSH terms like; micronutrients, minerals, vitamins, diet, treatment, prevention, management, neurodevelopmental disorders and children, the search for published materials was made. A Boolean search was also made on the ICTRP for gray material. Filters were applied to include only articles with full free texts that were published up to 15th January 2023 and exclude commentaries, books and documents.

Study Selection Process

The principal author scanned through all abstracts of studies obtained from all aforementioned search engines. When there was uncertainty about an abstract, the full version was sought for. Also, full versions of studies that did not have abstracts were sought for and scanned for relevance. The co-authors double-checked to ensure that all articles qualified for inclusion in accordance to the PRISMA study selection guidelines(Matthew J Page et al., 2020).

Data Collection Process

Relevant information from the different studies were identified and tabulated by the principal author and co-authors double-checked the entries. Similar research designs were entered in succession and where available, *P*-values, confidence intervals and standard deviations were added to the extraction table.

Data Items

Outcomes included in the data collection were the type of study, population studied, type of NDs studied, kind of micronutrient studied, and results of relevance to the review.

RESULTS

Study selection using the PRISMA flow diagram

Using the PRISMA flow diagram, the study selection process has been explained below in Fig.1.

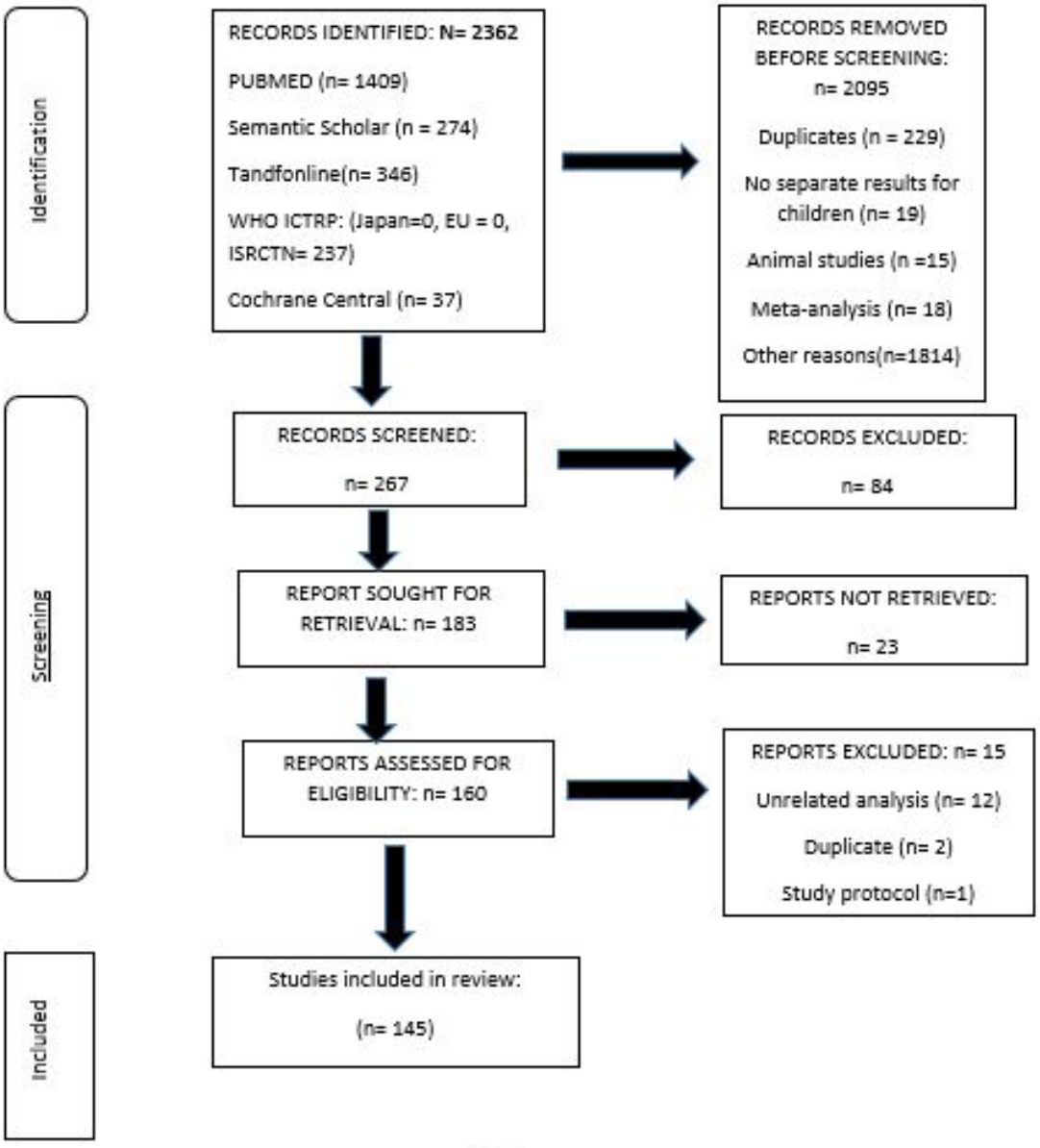

FIG.1

Study Characteristics

Table 1: The Use of Micronutrients in the Management of ND Symptoms.

Study Type and Area	Age (years)	Number of Subjects	Micronutrient Studied	Outcome	Reference
Studies on Autism Spectrum Disorders (ASD)					
[1]CR, UK	4	1 boy	Vitamin D and calcium	Supplementation with Ca and Vitamin D resulted in hypercalcaemia and hypervitaminosis D.	(Boyd & Moodambail, 2016)
CR, China	2	1 girl	Vitamin D	Six months supplementation with vitamin D3 didn't improve autism rating.	(Feng et al., 2020)
CR, India	5	1boy	B6, B9, B12	[2]CARS score decreased to 32 after treatment with the B vitamins.	(Gowda & Srinivasan, 2022)
[3]CS survey, USA	<17	1286(966 children)	Vitamin and mineral supplements	The uses of any B12, Calcium, Magnesium, Zinc, Vitamin D, or a multivitamin specifically formulated for ASD were significantly related to perceived positive improvement in ASD symptoms[p≤0.01].	(Adams et al., 2021)
CS Survey, USA	9.9±4.1	157 primary caregivers	Multivitamin, B12 and Zn	On a scale of 1-5, the average parental rating of the effectiveness of multivitamin was 3.65, methyl B12 injection was 4.01 and Zn was 3.96.	(Hopf et al., 2016)
Retrospective open-label [4]CaS,USA	4-11	19	Fe	The majority of children with ASD, [5]RLS and serum ferritin <30 µg/L had improvement on the [6]CGI scale and significantly better serum iron parameters after a single IV [7]FCM infusion.	(DelRosso et al., 2022)

1 Case Report
2 Childhood Autism Rating Scale
3 Cross Sectional
4 Case Series
5 Restless Leg Symptoms
6 Clinical Global Impression
7 Ferric Carboxymaltose

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Study Type and Area	Age (years)	Number of Subjects	Micronutrient Studied	Outcome	Reference
[8]RDBPCT, USA	5-16	53(26cases)	Combined Vitamins (8) and minerals (14)	For the [9]PGI-R Average Change, the supplement group had a significantly greater improvement than the placebo group (p= 0.003).	(Adams et al., 2011)
[10]OLT, China	1-3	102 cases (30 routine treatment + 37[11]ESDM + 35 ESDM & Vit D3)	Vitamin D	ESDM + Vit D3 group, showed the highest (but statistically insignificant across groups) improvement (p< 0.01) on the [12]CARS and [13]ABC scores.	(Feng et al., 2019)
Two-arm RDBPCT, USA.	3-14	48(23 cases)	[14]Vitamin B_9	Verbal communication improvement, was significantly greater in treatment group compared to placebo group (Cohen's *d*=0.70).	(Frye et al., 2018)
[15]RCT, Russia	3-14	99(74 cases)	I	Iodine-Bromine baths decreased stress system indicators significantly (p<0.01) in cases with hyperactivity.	(Golubova & Nuvoli, 2022)
[16]RDBPCT, USA	3-7	57	Vitamin B_{12}	After 8 weeks, the [17]CGI-I score was statistically significantly better in the methyl B12 group than in the placebo group (p= 0.005).	(Hendren et al., 2016)
[18]OLT, USA	2-7	82(40 cases)	Vitamins B_{12} (Methyl cobalamin) and B9	There were significant increases in the transmethylation metabolites and glutathione concentrations (*P*< 0.001) after 3 months treatment.	(James et al., 2009)

8 Randomised Double-Blind Placebo-Controlled Trial
9 Parental Global Impression- Revised
10 Open-Label Trial
11 Early Start Denver Model
12 Childhood Autism Rating Scale
13 Autism Behaviour Checklist
14 Folinic Acid
15 Randomised Controlled Trial
16 Randomised Double-Blind Placebo-Controlled Trial
17 Clinical Global Impressions
18 Open-Label Trial

Study Type and Area	Age (years)	Number of Subjects	Micronutrient Studied	Outcome	Reference
Intervention study, Poland	3-16	236 cases	Vitamin B and Magnesium	Supplementation with vitamins B and magnesium greatly impacted tryptophan (an amino acid involved in sleep disorder in ASD) levels ($p< 0.05$).	(Kałużna-Czaplińska et al., 2017)
Single-blind non-randomized intervention pilot study, China	1-6	64	Vitamin A	The scores of ABC, CARS and [19]SRS scales showed no significant differences ($P >0.05$) in all subjects after 6 months of intervention.	(Liu et al., 2017)
RDBPCT, New Zealand	2-8	67 (Intervention group=51)	Vitamin D	With all children included, Vitamin D had no effect on behavioural outcomes. When only children with elevated IL-1β at baseline were included, Vitamin D produced a greater improvement in SRS-awareness ($P= 0.01$).	(Mazahery et al., 2020)
An intervention study, France	1-10	66 (33 cases)	Magnesium and vitamin B_6	The Mg-B6 regimen led to improvement in ASD symptoms in 23/33 children ($p < 0.0001$).	Mousain-Bosc et al., 2006)
An intervention study, Germany	2-12	25 cases	[20]Vitamin B_9	[21]CSF [22]5MTHF was low in 23 patients. Oral B9 supplementation led to partial or complete clinical recovery.	(Ramaekers et al., 2007)
[23]OLT, China	3-6	66 (22 matched controls)	Vitamin B_9	800μg folic acid daily for 3 months improved autism symptoms($p<0.05$).	(Sun et al., 2016)
Studies on Attention Deficit Hyperactivity Disorder (ADHD)					

19 Social Responsiveness Scale
20 Folinic Acid
21 Cerebrospinal Fluid
22 5-methyltetrahydrofolate
23 Open-Label Trial

Study Type and Area	Age (years)	Number of Subjects	Micronutrient Studied	Outcome	Reference
[24]RDBPCT, USA	6-14	52(24 placebo-matched controls)	Zinc	Zinc did not improve ADHD symptoms except in parent-rated inattention(d=-0.31).	(Arnold et al., 2011)
Open label, (reversal design), New Zealand	8-12	18 cases	Combined minerals and multivitamins	Clinically and statistically significant change in ADHD symptoms between the intervention and withdrawal phases (d=1.2–2.2).	(Gordon et al., 2015)
RDBPCT, Iran	6-12	66(intervention arm=33)	Magnesium and Vitamin D	The intervention group had significant reduction in several ADHD scores ($p \leq 0.007$) compared to placebo group.	(Hemamy et al., 2021)
[25]RDBPCT, USA	6-12	135(81cases)	All vitamins & known essential minerals	No significant between-group differences were found on the parent-rated [26]CASI-5 composite score (p = .70); On individual CASI-5 subscales, a DMDD trend favoured micronutrients (−0.42) over placebo (−0.22) in symptom reduction (p = .09).	(Johnstone et al., 2022)
RDBPCT, Iran	6-12	86(42cases)	Vitamin D	No significant reduction in 8-isoprostan as an oxidative stress marker in both the treatment and placebo groups (P < 0.05)	(Mohammadzadeh Honarvar et al., 2022)
[27]RCT, Thailand	[28]N/A	52(26cases)	Fe	Total parents' Vanderbilt ADHD symptom scores showed a significant improvement between the groups (p = 0.037) after treatment with methylphenidate and iron.	(Pongpitakdamrong et al., 2022)
RCT, Iran	6-15	120	Vitamin D	Significantly lower ADHD mean scores in the group treated with neurofeedback combined with Vit.D.	(Rahmani et al., 2022)

24 Randomised Double-Blind Placebo-Controlled Trial
25 Randomised Double-Blind Placebo-Controlled Trial
26 Child and Adolescent Symptom Inventory-5
27 Randomised Controlled Trial
28 Not Available

Study Type and Area	Age (years)	Number of Subjects	Micronutrient Studied	Outcome	Reference
RDBPCT, New Zealand	7-12	93(Treatment arm=47).	Minerals and multivitamins	Significant between-group differences favouring micronutrient treatment on the [29]CGI-Improvement (ES=0.46).	(Rucklidge et al., 2018)
RDBPCT, Iran	6-12	86(42cases)	Vitamin D	Three months supplementation with Vit.D did not have significant effect on inflammatory cytokines (IL-6 and TNF-α).	(Samadi et al., 2022)
RCT, New Zealand	7-12	17(Treatment arm=10)	Minerals and vitamins	A significant difference in the change of observed [30]OTU between the treatment and placebo groups ($p=0.05$).	(Stevens et al., 2019)
Database analysis, Canada	7-8	120 children with bipolar disorder (24% ADHD)	36-ingredient micronutrient formula (EMPowerplus)	A 40% decline in ADHD symptoms observed (ES= 0.62).	(Rucklidge et al., 2010)
Studies on Intellectual Disability					
[31]CaS, Saudi Arabia	4&5	2 siblings	Vitamin B9	Daily dosing of folinic acid caused seizures to stop and improved neurological functioning in both cases.	(Al-Baradie & Chaudhary, 2014)
[32]RDBPCT, USA	5-8	2 sets of identical twins	Vitamin B9	No statistically significant changes in the developmental testing scores between groups after 1-year treatment with folic acid.	(Han et al., 2019)
Exploratory study (double blind experiment), UK	5-15	16(group1=5, group2=11)	8 minerals and 11 vitamins	During phase1 and phase 2, the supplement group significantly increased their average IQ by 5.0-9.6($p < 0.05$) and at least 10.2($P < 0.001$) respectively, but the placebo group showed negligible change.	(Harrell et al., 1981)

29 Clinical Global Impression

30 Operational Taxonomic Units

31 Case Series

32 Randomised Double-Blind Placebo-Controlled Trial

Study Type and Area	Age (years)	Number of Subjects	Micronutrient Studied	Outcome	Reference
RDBPCT, USA.	2- 5	60(31treatment)	Choline	The treatment effect on [33]EI items recalled was significant in the younger participants (≤4.0yrs). An inverse relation between choline dose and memory improvement (p= 0.041) was observed.	(Wozniak et al., 2015)
Studies on Specific Learning Disorders					
CaS, UK.	7-11	3 cases	Vitamin B_6	Intellectual performance overtime did not increase, and it did not differ among all cases.	(Rankin et al., 2007)
Placebo-controlled double-blind study, Canada	7-14	20(10treatment)	Vitamins B_1, B_3, B_5 and C	No significant between group differences were found in the test scores after 6 months	(Kershner et al., 1977)
Studies on Neurodevelopment Motor Disorders					
[34]CS-c, UK	5-7	76(42 Tourette syndrome cases +34 controls)	Vitamins and mineral supplements	Multivitamin users (n=6) didn't report any notable changes, but magnesium users (n=3) reported improved vocal tics	(Smith & Ludlow, 2021).
[35]OLT, Italy	4-17	34(17cases)	Vit.B6	Combined L-Theanine and vitamin B6 was significantly more effective than psychoeducation in reducing tics($p \leq 0.05$).	(Rizzo et al., 2022)

33 Elicited Imitation

34 Cross – Sectional Comparative

35 Open-Label Trial

Table 2: Micronutrients levels and the Prevention of NDs.

Studies on the Levels of Micronutrients in ASD					
[36]CR, Australia	12	1 boy	Vitamin A, B_9 and Iron	Low vitamin A, haemoglobin and folate levels observed.	(Chiu & Watson, 2015)
CR, Sweden	7	1 boy	Vitamin A	Xerophthalmia with retinol <0.2µmol/l	(Enekvint et al., 2021)
CR, Canada	6	1 boy	Vitamin C, D, and Iron	Low serum ascorbic acid, Fe , and 5-(OH)D observed	(Erdle et al., 2017)
CR, UK	4	1 case	Vitamins A and D	Hypercarotenaemia and low Vitamin D level observed.	(Keown et al., 2014)
CR, Canada	10	1 boy	Vitamins C, A, D and Zinc	Abnormally low ascorbic acid level(<5µmol/l) and low levels of Vitamin A, D, and zinc observed.	(Kinlin et al., 2018)
CR, Italy	3	1 girl	Vitamin C, D and B_9	Low Vitamin C (below limit of quantification), vitamin D and folate levels.	(Liuzzo Scorpo et al., 2021)
CR, Italy	4	1 boy	Vitamin C	Low serum vitamin C and haemoglobin observed.	(Saavedra et al., 2018)
[37]CaS, USA	5-17	6	Vitamin A	All subjects had a barely detectable Vitamin A level (<10 mcg/dL)	(Godfrey et al., 2022)
[38]CS-c, Saudi Arabia	3-12	82(30 matched controls)	Vitamin E	Cases had lower vitamin E concentrations that correlated with the severity of the social and cognitive impairment measures.	(Alabdali et al., 2014)

36 Case Report

37 Case Series

38 Cross-Sectional Comparative

[39]CS-c, Canada	<18	34(27 cases)	Copper and Zinc	Cases had lower prenatal($p<0.001$) and postnatal ($p<0.05$) Cu, and lower Copper-to-Zinc ratio compared to controls. Language and communication scores were positively related to prenatal Cu exposure and Cu/Zn ratio ($p<0.05$).	(Frye et al., 2020)
CS-c, USA	8-14	37(18 cases)	Vitamin D, Ca	Serum levels for Ca and vitamin D did not differ between groups.	(Neumeyer et al., 2013)
[40]CS, Pakistan	5-11	61 cases	Vitamin D	85% had below normal 25(OH)D levels.	(Cheema et al., 2016)
Retrospective chart review, Canada	1-10	96 cases	Iron	Lower ferritin values correlated with higher communication scores ($p=0.005$)	(Dosman et al., 2006)
CS, USA	2-11	222 cases	Iron	Only 8% had Serum Ferritin (SF) <12μg/L and 1% had Iron deficiency.	(Reynolds et al., 2012)
Multicentre survey, China	2-7	2600(1321 cases)	Vitamin D	Serum 25(OH)D levels were significantly lower in cases than in healthy controls and were associated with the presence or absence of ASD.	(Qi et al., 2022)
CS, Japan	≤15	1967 cases	Zn, Mg, Ca, Fe, Cr, Mn, Cu, Co	Scalp hair analysis showed Zn, Mg and Ca deficiencies in 29.7%,17.6% and 5.8% cases respectively. Incidence rate less than 2% was recorded for the other minerals.	(Yasuda et al., 2013)

39 Cross-Sectional Comparative

40 Cross-Sectional

CS-c, China	N/A	589(269cases)	Vit.D	Cases had significantly lower levels of serum vitamin D and a significantly higher rate of vitamin D deficiency (< 20 ng/ml) compared to healthy controls (67.7% vs 34.1%).	(Zhang et al., 2022)
CS-c, China	2-6	180(120cases)	Vitamins A, B, C	Vitamins B, A and C faecal concentrations were reduced ($p<0.05$). B6 negatively correlated with partial subscales. Vitamin A positively correlated with neurodevelopment scores.	(J. Zhu et al., 2022)
CS-c, Omani	3-4	80(40 matched controls)	Vitamin B9 and B12	Significantly lower serum folate and B12 levels observed in cases compared to controls ($p<0.05$).	(Ali et al., 2011)
CS-c, Iran	5-12	62(31 cases)	Vitamin D	Average serum 25(OH)D level in the cases was significantly lower ($P>0.001$) than the control group	(Arastoo et al., 2018)
CS-c, Czech Republic	4-7	85(40 matched controls)	Vitamin D	No significant difference in vitamin D level was observed between groups.	(Bičíková et al., 2019)
CS-c, India	6-14	20(10 cases)	Zinc	Lower but insignificant mean concentration of salivary zinc in cases compared to controls.	(Deshpande et al., 2019)
CS-c, China		226(117 cases)	Vitamin D	Serum level of 25(OH)D was significantly lower in cases than in healthy controls ($P<0.01$).	(Du et al., 2015)
Exploratory study, Italy	3-8	80(40 matched controls)	Vitamin C and B6	Significantly higher vitamin C levels ($p<0.001$) and lower levels of active form of vitamin B6 ($P<0.05$) in cases.	(Gevi et al., 2020)
CS-c, Japan	3-9	97(58 matched controls)	Vitamin E	Higher but insignificant α-tocopherol levels in ASD cases ($p= 0.967$) than control.	(Hirayama et al., 2020)
CS-c, USA	2-7	102(68 cases).	Iron	No significant differences in mean serum ferritin levels between groups.	(Lane et al., 2015)

CS-c, USA	4-8	89(49 cases)	Vitamin D	No significant group differences of 25(OH)D levels were observed (p =0.4).	(Molloy et al., 2010)
[41]CS-c, Saudi Arabia	5-12	80(30 matched controls)	Vitamin D	Cases had significantly lower serum levels of 25(OH)D, (P< 0.001), which had significant negative correlations with [42]CARS (P< 0.001)	(Mostafa & Al-Ayadhi, 2012)
CS-c, Saudi Arabia	3-10	200(100cases)	Vitamin D	Significantly lowered [43]OR for Autism was observed for children consuming a Vitamin-D rich diet (OR=0.23, 95% CI=0.11-0.46)	(Oommen et al., 2018)
CS-c, Italy	<18	90(54 cases)	Vitamin D	Mean level of 25(OH)D was significantly lower in cases (p= 0.014) and it had an association with ASD (p= 0.006)	(Petruzzelli et al., 2020)
CS-c, Jamaica	2-8	218(109 matched controls)	Manganese	No significant association was found between Blood Manganese Concentration and ASD, (P =0.29).	(Rahbar et al., 2014)
Retrospective and CS-c, Turkey	3-18	Phase I: n=1521 Phase II: n=200 (100 cases)	Vitamin D Calcium and phosphorus	Mean vitamin D level was significantly lower in cases than in controls (P=0.037), Ca was not significantly different between groups, but P was significantly higher among the cases (p=0.015).	(Şengenç et al., 2020)

41 Cross-Sectional Comparative

42 Childhood Autism Rating Scale

43 Odds Ratio

CS-c, Russia	1-9	90(60 cases)	12 minerals	Hair Ca and Se levels were significantly lower in cases (p=0.002 and p=0.004 respectively). No significant difference in serum Ca between groups. Hair Zn level was insignificantly lower among cases. Serum V and Mg were significantly higher among cases.	(Tinkov et al., 2019)
Multicenter CS-c, China.	2-7	2058(1038 matched controls)	Zinc, magnesium and copper	Serum Mg, Cu, and Zn levels in cases were significantly lower than in controls (P< 0.05). Mg and Zn levels inversely correlated with the total and communication ability scores.	(Zhang et al., 2021)
CCS, China	N/A	183(92cases)	Ca, K, Mg, Na, Mn, Se, Co, Mo, Cu, Zn, Fe	Ca, K, and Mg were significantly higher in the cases than in the controls. Zn and Cu were significantly lower in cases	(Ma et al., 2022)
[44]CCS, Malaysia	3-6	155(81 cases)	Ca, Mg, Zn and Fe +	Urinary Mg, Zn, Fe, and Ca were significantly lower (p<0.05) in both groups. The odds of ASD reduced significantly by 5.0% and 23.0% with an increment of every 1.0µg/dL urinary Zn and Fe, respectively.	(Abd Wahil et al., 2022)

44 Case-control Study

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CCS, Qatar	<8	616(308 cases)	Vitamin D and Iron + Mg, K, Ca and P	Significantly lower serum iron levels in cases than in controls (p =0.003). Significantly higher Vitamin D deficiency among cases (p= 0.004). Significantly higher levels of the other minerals in controls compared to cases (p< 0.001).	(Bener et al., 2017)
CoS, Poland.	6-10	287	Selenium	The presence of ASD was associated with lower serum and toenail selenium (p< 0.001).	(Błażewicz et al., 2020)
CoS, UK	<1	6644 pregnant women + 7013 children	Iodine	No association between I:Creatinine or Urinary Iodine Concentration and ASD risk in children aged 8–12 years (p= 0·3).	(Cromie et al., 2020)
CoS, China	3	1550(310cases)	Vitamin D	The median 25(OH)D3 level was significantly lower in children with ASD compared to controls (p< 0.0001). Neonatal vitamin D status was significantly associated with ASD risk and intellectual disability	(Wu et al., 2018)
Studies on Maternal micronutrient intake/serum levels and prevention of ASD					
CCS, Sweden	4-17	200(100 cases)	Vitamin B9 and D	Positive association between higher maternal serum folate concentrations and increased ASD occurrence (OR per 1 SD increase: 1.70, 95% CI 1.22–2.37). No association between maternal Vitamin D3 level and offspring autism occurrence.	(Egorova et al., 2020)

CCS, USA	2-5	606(346 cases)	Vitamin B9	High [45]FA intake (>800μg) in the first pregnancy month was associated with decreased ASD despite exposure to air pollutants, during the first trimester (*P*-interaction = 0.04).	(Goodrich et al., 2018)
Population – based [46]CCS, USA	2-5	566(288 cases)	Prenatal vitamins	Prenatal vitamins use 3 months before pregnancy through to the first month was associated with lower risk for autism (unweighted OR = 0.62 [95% CI = 0.42–0.93])	(Schmidt et al., 2011)
CCS, USA	2-5	724 cases and controls	Vitamin D	No association between a 25nmol/L increase in maternal 25(OH)D and ASD was observed (OR=0.97, CI: 0.87, 1.08).	(Schmidt, Niu, et al., 2019)
CCS, USA	2-5	806(466 cases)	Vitamin B9	ASD was increased in association with < 800μg of FA and any indoor pesticide exposure compared to low FA [OR= 1.2 (95% CI: 0.7, 2.2)] or indoor pesticides [OR = 1.7 (95% CI: 1.1, 2.8)] alone.	(Schmidt et al., 2017)
CCS, USA	2-5	866(520 cases)	Iron	The highest category of maternal iron intake (≥86 mg/day) during the index period was associated with significantly reduced risk of ASD in the child (OR= 0.49, 95% CI: 0.29, 0.82).	(Schmidt et al., 2014)
CCS, USA	2-5	837(429 cases)	Vitamin B9	A mean daily FA intake of ≥600μg during pregnancy month1 was associated with reduced ASD risk (aOR: 0.62; 95% CI: 0.42, 0.92).	(Schmidt et al., 2012)

45 Folic Acid

46 Case-Control Study

Nested CCS, Finland	N/A	3116(1558 controls)	Vitamin D	The increased risk of ASD was associated with deficient (aOR 1.44, 95% CI 1.15–1.81) and insufficient maternal 25(OH)D levels (aOR 1.26, 95% CI 1.04–1.52,) compared with sufficient levels.	(Sourander, Upadhyaya, et al., 2021)
Nested CCS, USA	2-5	516(296 cases)	Vitamin B9	Children with pesticide exposure and low maternal FA intake were at least twice as likely to have ASD than those with no exposure and high maternal FA intake.	(Barrett, 2017)
CCS, Sweden	<1	Maternal sample = (449 cases + 574 controls) Neonatal sample = (1399 cases + 1607 controls)	Vitamin D	In adjusted models, compared with neonates with 25(OH)D ≥50nmol/L, those with 25(OH)D <25nmol/L had 1.33 times higher odds of ASD. Children with both maternal 25OHD and neonatal 25OHD below the median had 1.75 times the odds of ASD compared with children with maternal and neonatal 25OHD both below the median.	(B. K. Lee et al., 2021)
Population-based, prospective [47]CoS, Norway	<1	109,000	Vitamin B9	In children whose mothers took folic acid, 0.10% had ASD, compared with 0.21% in those unexposed to folic acid. [aOR =0.61,95% CI:0.41–0.90).	(Berry, 2013)
Observational prospective CoS, Sweden	4-15	273,107 mother-child pairs	Multivitamin, Vitamin B9 and iron	Maternal multivitamin use with or without additional iron or folic acid, or both was associated with lower odds of offspring ASD with intellectual disability (OR 0.69, 95%CI: 0.57-0.84).	(DeVilbiss et al., 2017)

47 Cohort Study

CoS, Israel	<1	45,300 mother-child pairs	Multivitamin and Vitamin B9	Maternal exposures to folic acid and/or multivitamin supplements before or after pregnancy were both significantly associated with a lower likelihood of offspring ASD compared with no exposures before or after pregnancy. Before:(RR, 0.39; 95% CI: 0.30-0.50); After:(RR, 0.27; 95% CI: 0.22-0.33)	(Levine et al., 2018)
Prospective CoS, Canada	3-4	610 mother – child pairs	Vitamin B9	Folic Acid supplementation during pregnancy consistently and significantly attenuated the positive associations between gestational urinary phthalate concentrations and greater risk of overall social impairment.	(Oulhote et al., 2020)
Prospective CoS, USA	<1	1257 mother – child pairs	Vitamin B9, B12 and multivitamins	There was a "U" shaped relationship between maternal multivitamin supplementation frequency and ASD risk. Very high levels of maternal plasma folate and B12 at birth had 2.5 times increased risk of ASD compared to folate levels in the middle 80th percentile[95%CI;1.3-4.6(Folate); 1.4-4.5(B12)].	(Raghavan et al., 2018)
Prospective CoS, Norway	3-7	85176 (61042 mothers exposed)	Vitamin B9	Of the children whose mothers took folic acid from 6 weeks before to 6 weeks after conception, 0.10% had autistic disorder, compared with (0.21%) of the children whose mothers did not (aOR 0.61, 95% CI 0.41 to 0.90).	(Schmidt, 2013)

[48]CoS, UK	N/A	5015 mother-baby pairs	Vitamin D	No significant association between maternal serum 25-hydroxyvitamin D during pregnancy and any offspring autism-associated outcome was found (aOR=0.98, 95% CI=0.90–1.06)	(Madley-Dowd et al., 2022)
Nationwide prospective CoS, Japan	3	96,931mother-child pairs	B9	No association between prenatal folic acid supplementation and ASD in offspring(aOR, 1.189; 95%CI, 0.819-1.727).	(Nishigori et al., 2022)
Prospective CoS, USA	2-5	241 younger siblings of ASD children + mothers	Prenatal vitamins	Prenatal vitamins during the first month of pregnancy is associated with lesser offspring ASD diagnosis (aRR= 0.50; 95% CI, 0.30-0.81) but not a non-[49]TD 36-month outcome (aRR, 1.14; 95% CI, 0.75-1.75) compared with no prenatal vitamins exposed mothers.	(Schmidt, Iosif, et al., 2019)
[50]OLT, USA	3	19 pairs	Vitamin D	5% siblings born to mothers given vitamin D developed autism in contrast to the known recurrence rate of approximately 20%.	(Stubbs et al., 2016)
Studies on Levels of Micronutrients in ADHD					
[51]CS, USA	5-10	48	Zinc and Magnesium	Normal serum Mg levels were observed. Serum Zn correlated at r = -0.45 (p= 0.004) with parent-teacher-rated inattention.	(Arnold et al., 2005)

48 Cohort Study
49 Typically Developing
50 Open-Label Trial
51 Cross-Sectional

CS, Turkey	6-15	89	Iodine	Significant association was found between urinary iodine levels and hyperactivity section of [52]CTRS ($p < 0.05$).	(Kanık Yüksek et al., 2016)
Multi-centre CS, Turkey	5-12	100 cases	Iron and Vitamin B12	[53]CPRS total scores were not significantly associated with the Hb and ferritin or vitamin B12 levels ($p > 0.05$).	(Unal et al., 2019)
Secondary data analysis from a multiphase, [54]RDBPCT, USA.	6-14	52	Iron	87% of the sample had a low ferritin concentration at baseline. Serum ferritin concentration inversely correlated with ADHD scores ($p < 0.05$).	(Calarge et al., 2016)
[55]CS-c, Egypt		100(75cases)	Zinc and iron	Serum ferritin level in cases was significantly lower compared to the control. Serum Zn was significantly higher in the ADHD compared to the control group.	(Abd El Naby & Naguib, 2018)
CS-c, Egypt	6-12	103(41 cases)	Iron	There were no significant differences in ADHD symptoms or ADHD index subscale scores between children with serum ferritin levels <30ng/mL and those ≥30ng/mL ($p > 0.05$).	(Abou-Khadra et al., 2013)
CS-c, USA	8-18	49(22 cases)	Iron	No significant differences ($p > 0.05$) in brain iron measures between control subjects and ADHD patients.	(Adisetiyo et al., 2014)

52 Corner's Teacher Rating Scale
53 Conner's Parents Rating Scale
54 Randomised Double-Blind Placebo-Controlled Trial
55 Cross-Sectional Comparative

CS-c, USA	8-18	59(30cases)	Iron	Youth with ADHD may have less prominent age-related brain iron increases than that seen in typical development, which long-term use of psychostimulant medications may compensate.	(Adisetiyo et al., 2019)
CS-c, China	6-14	102 (51 cases)	Fe	Several brain regions were iron deficient. The left anterior cingulum showed positive correlation with the symptom severity ($r = 0.326$, $p < 0.05$).	(Chen et al., 2022)
CS-c, Turkey	6-7	70(40 cases)	Vitamin B9	No statistical difference ($p=0.055$) in blood folic acid levels between groups.	(Gokcen et al., 2011)
CS-c, USA	5-18	108(82 cases)	Iron	No significant differences in ferritin levels for those with and without ADHD.	(Gottfried et al., 2013)
CS-c, USA	7-12	34(17 cases)	Vitamin D	No significant differences between children with and without ADHD for vitamin D.	(Holton et al., 2019)
[56]CS-c, Egypt	5-15	83(58 cases)	Zn, Fe, Mg and Cu	Serum zinc, ferritin and magnesium levels were significantly lower in cases than controls ($p<0.05$) Copper levels were not significantly different.	(Mahmoud et al., 2011)
CS-c, Brazil	6-15	62(41cases)	Iron	No significant correlation between dimensional measures of ADHD symptoms and ferritin levels was found.	(Menegassi et al., 2010)

56 Cross-Sectional Comparative

CS-c, Turkey	11-14	118 cases	Zinc and Iron	[57]CPRS Total score was significantly related with serum zinc level. CPRS Hyperactivity score was associated both with zinc and ferritin levels.	(Oner et al., 2010)
CS-c in China	5-16	102(53cases)	Fe	The brain total iron content of children with ADHD was lower than that of healthy children ($p < .05$)	(Tang et al., 2022)
CS-c, China	6-14	592(296 cases)	Zn, P, Se, Ca, Vitamin B2	A nutrient pattern rich in zinc, phosphorus, selenium, calcium, and riboflavin was inversely associated with ADHD (p=0.014). Blood zinc was negatively related to ADHD (p=0.003).	(Zhou et al., 2016)
[58]CCS, Turkey	6-15	60(30 matched controls)	Vitamins B6, B9 and B12	Pyridoxine, folate, and vitamin B12 were significantly lower in the cases compared to the control group (p<0.05) No correlation between age, intelligence level and pyridoxine, folate and vitamin B12 levels except positive correlation between intelligence level and vitamin B12 (p<0.05).	(Altun et al., 2018)
CCS, Sweden	5-17	404(202 matched controls)	Vitamin D	No significant differences in cord blood vitamin D concentration were found between cases and controls (p=0.43). No linear association between ADHD and vitamin D levels (OR: 0.99, 95% CI:0.97–1.02).	(Gustafsson et al., 2015)

57 Conners's Parent Rating Scale

58 Case-Control Study

CCS, Sweden	5-17	332(166 cases)	Selenium and manganese	No associations between cord manganese or selenium concentration and ADHD were observed. Children with selenium concentrations above the 90th percentile had 2.5 times higher odds (95% CI:1.3–5.1) of having ADHD.	(Ode et al., 2015)
Nationwide [59]CoS, Denmark		643,401	Manganese	Exposure to Mn >100μg/L of water at any one time during the first 5yrs of life was associated with a 51% and 20% increased risk of ADHD in females and males respectively.	(Schullehner et al., 2020)
Prospective study, Spain	6-14	60 cases	Iron	About 63% had iron deficiency.	(Soto-Insuga et al., 2013)
RDBPCT, Netherlands	8-18	63(33placebo)	Fe, Zn	No significant correlations between baseline ferritin and zinc serum levels and the baseline ADHD scores(p>0.05)	(Rosenau et al., 2022)
Studies on Maternal micronutrient intake/serum levels and prevention of ADHD					
Nested CCS, Finland	2-14	2052(1026 matched controls)	Vitamin B12	Lower maternal Vitamin B12 levels was not associated with offspring ADHD (aOR 0.97, 95% CI 0.79–1.18).	(Sourander, Silwal, et al., 2021)

59 Cohort Study

Prospective Population-based CoS, Norway	6-13	53,360 mother-child pairs	Iodine	No association between iodine intake from food and risk of child ADHD diagnosis (p= 0.89). No beneficial effects of maternal use of iodine supplements on child ADHD diagnosis or symptom score was found. Iodine supplement use in gestational weeks 0-12 was associated with a ~29% increased risk of ADHD diagnosis (95% CI: 0–67%, p= 0.053)	(Abel et al., 2017)
CoS, USA	6-9	680 mother-child pairs	Vitamin D	No associations between maternal 25(OH)D at 10–18 weeks of gestation and offspring ADHD observed. Associations between maternal vitamin D sufficiency and offspring ADHD observed in the third trimester [OR: 0.47, 95% CI: 0.26–0.84].	(Chu et al., 2022)
CoS, Spain	7	946 mother-child pairs	Fe	Hb levels in the first and third trimester of pregnancy were not related to ADHD risk in children.	(Díaz-López et al., 2022)
Based on Danish National Birth Cohort	7	1026 (642 ADHD)	Vitamin B9 and multivitamin	No association between early folic acid supplementation and ADHD medication prescription. Early multivitamin use in pregnancy was associated with about 21% reduced risk for ADHD medication prescriptions (aHR: 0.79, 95% CI:0.62–0.98)	(Virk et al., 2018)

Studies on Micronutrient levels in ID					
Case series, Egypt	5-17	6 cases	Manganese and Zinc	Mn and Zn levels in blood were either low or very low-normal in all cases due to defective Mn and Zn transport.	(Boycott et al., 2015)
Case report, USA	9	1girl	Iron and vitamins	Pica eating and iron deficiency and anaemia were resolved with iron and multivitamin supplementation.	(Pace & Toyer, 2000)
[60]CS, Poland	Not given	82 cases	Mg, Ca, Cu. Zn and Fe	Fe concentrations in hair was found to be generally lower. Mg, Ca, Cu and Zn levels varied for the different subgroups.	(Józefczuk et al., 2017)
CS, Canada.	3-9	77	Vitamin A	22% had serum carotenoid level above 300µg/ml.	(Patel et al., 1973)
Retrospective review, Korea	7-15	143 cases	Vitamin D	$25(OH)D_3$ levels were lower in cases than in patients with normal intelligence quotient levels (p=0.03)	(Baek et al., 2014)
Studies on Micronutrient levels and/or their association with SLD					
CS-c, Jordan	3-7	70(35cases)	Mg, Fe, K, Zn	All minerals in hair were similar between groups except Zn that was significantly lower in cases ($p<0.05$)	(Rashaid et al., 2022)
CS-c, China	[61]MA=9.7±1.3	469(239cases)	Mn	The highest quartile of urinary manganese was found to have a 3.87-fold (95 % CI = 1.39-10.74) elevated dyslexia risk compared with the lowest quartile among the rs27072 mutation carriers.	(K. Zhu et al., 2022)

60 CS- Cross-Sectional

61 Mean Age

[62]CS-c, China	8-11	456(228 cases)	Selenium and other metals	The multivariable-adjusted ORs of dyslexic children were 0.32 (95%CI: 0.13–0.83) for selenium, and 3.31 (95%CI: 1.09–10.05) for argentum. No significant associations were observed for other metals.	(Xue et al., 2020)
National Health Survey, USA	4-11	1,076	Se	Serum Se concentration was lower among children with LD than those without LD (P=0.08). Each 10 ng/mL increment in serum Se concentrations was associated with 31% (OR 0.69, 95% CI 0.51-0.93) lower odds of LD	(Liu et al., 2022)
Nested [63]CCS, Finland.	7-12	3214(1607 matched controls)	Vitamin D	No significant associations between maternal vitamin D and offspring [64]SLD (aOR 0.98, 95% CI 0.82–1.18).	(Arrhenius et al., 2021)
Studies on Micronutrient levels and/or their association with NMD					
CS-c in 9 European countries & Israel	3-16	451(327 cases + 124controls)	Vitamin D	A 10 ng/ml increase in 25(OH) D was associated with higher odds of having [65]CTD (OR 2.08, 95% CI 1.27–3.42,). There was no association between 25(OH)D and tic severity.	(Bond et al., 2022)
CS-c, China	3-14	368(179 cases)	Vitamin D	Serum 25(OH)D level was significantly associated with presence or absence of tic disorder (aOR = 0.89; 95 % CI 0.863–0.921) and was also significantly associated with tic severity (p=0.02).	(Li et al., 2018)

62 CS-c –C ross-Sectional Comparative

63 Case-Control Study

64 Specific Learning Disorders

65 Chronic Tic Disorders

CS-c, China	3-14	276(132 cases)	Vitamin D	Serum 25(OH)D levels were significantly lower in the tic disorder cases than in the control group (P<0.01).	(Li et al., 2017)
[66]CS-c, China	6-12	4062cases + controls	Cu, Mg, Mn, Zn, and Fe	There were no significant differences in blood copper, manganese and magnesium levels between children with tic disorders and controls (P>0.05). Cases had a significantly decreased blood zinc and iron levels compared to controls (P<0.05).	(Liu et al., 2013)
Studies on Micronutrient levels and/or their associations in mixed NDs					
CS-c, Italy	Up to 18	167(93 ASD +74 Other NDs)	Fe	Lower Ferritin in ASD group. Ferritin > 24 ng/mL and [67]MCV showed a significant association with only ASD (p <0.05)	(De Giacomo et al., 2022)
CS-c, Turkey	3-18	79(36 ADHD + 18 ASD + 25 controls)	Iron, Vitamins B12 and D	The cases showed significantly lower levels (p<0.01) of Iron, vitamin B12 and vitamin D.	(Garipardic et al., 2017)
(Prospective) Multiphase study, USA	5-7	114 cases of NDs	Iron	21% of the sample had serum ferritin level <20μg/L. Ferritin was inversely associated with the severity of disruptive behaviour and positively associated with prosocial behaviour.	(Calarge et al., 2016)
Study based on the EMA population-based [68]CCS, USA	4-9	1189 (563 ASD + 190 ID + 436 controls)	Vitamin D	Lower 25(OH)D was not associated with higher risk of ASD or ID	(Windham et al., 2019)

66 Cross-Sectional Comparative

67 Mean Corpuscular Volume

68 Case-Control Study

Prospective CoS, USA	N/A	1550 mother-infant dyads	Se	Maternal RBC Se levels were positively associated with child risk of ASD [aOR of 1.49 (95% CI: 1.09, 2.02)] and ADHD. [aOR: 1.29; (95% CI: 1.04, 1.56)] per IQR increase in Se.	(A. S. E. Lee et al., 2021)
3 population –based birth cohorts, (Netherlands, Spain and UK)	Not given	5546 mother-child pairs (ASD and ADHD)	Iodine	Lower Urinary Iodine/Creatinine ratio (<150µg/l) was not associated with ADHD (OR: 1.2; 95% CI: 0.7, 2.2) or with a high autistic-trait score (OR: 0.8; 95% CI: 0.6, 1.1).	(Levie et al., 2020)

Discussion

Autism Spectrum Disorder (ASD) was the most reported category (53.8%) of Neurodevelopmental Disorders (NDs) while Neurodevelopmental Motor Disorders (NMDs) and Specific Learning Disorders (SLDs) were the least reported categories (4..1 % each). More than a third of the extracted documents originated from Europe (41%), followed by the Asia (29%), North America (26%), and Africa (4%). Using the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) classification, studies on all categories of Neurodevelopmental Disorders (NDs) were identified except those on Communication Disorders (CDs). Study outcomes were grouped under two main themes: the use of micronutrients in the management of NDs and micronutrient levels and the prevention of NDs.

The use of Micronutrients in the Management of NDs

In one case report an alternative therapist gave micronutrients to a child with ASD, which led to very elevated levels of calcium and vitamin D (Boyd & Moodambail, 2016). The single micronutrient that was reported most for ASD (9 times) was the B vitamin. All studies on vitamin B, reported significant effectiveness in improving ASD core symptoms. Nevertheless, vitamin D, the second most reported (2 times) single micronutrient was found to cause no significant improvement in ASD core symptoms. In two cross-sectional studies (Adams et al., 2021; Hopf et al., 2016) and a randomised controlled trial (Adams et al., 2011), the use of vitamins and minerals was linked to an improvement in the core symptoms of ASD.

The eleven studies for ADHD, reported on three single micronutrients (Vitamin D, Zn and Fe) and combined minerals and vitamins. Four studies and a database analysis found that combining micronutrients was linked to significant improvement of ADHD symptoms (Calarge et al., 2010; Gordon et al., 2015; Hemamy et al., 2021; Rucklidge et al., 2010; Stevens et al., 2019). Only one trial (Johnstone et al., 2022) did not find such association. In one study, it was found that taking ADHD medicine with Fe made it work better for controlling symptoms. (Pongpitakdamrong et al., 2022). In two trials, (Mohammadzadeh Honarvar et al., 2022; Samadi et al., 2022), vitamin D supplementation did not affect the oxidative stress marker, 8-isoprostan or the inflammatory citokines, IL-6 and TNF-α. Yet in two studies, vitamin D in combination with neurofeedback therapy (Rahmani et al., 2022) and vitamin D in combination with magnesium (Hemamy et al., 2021) caused a significant reduction in ADHD scores. Zinc did not have any effect on ADHD symptoms according to the only study on zinc.

Two of the studies in Intellectual Disability (ID) used vitamin B9. One study, which used folinic acid, found that neurological functions got better (Al-Baradie & Chaudhary, 2014) while the other, which used folic acid found that developmental testing scores did not change (Han et al., 2019). For the remaining two studies, one found combined minerals and vitamins to cause significant improvement in IQ (Harrell et al., 1981), and the other, using choline, reported significant treatment effect on Elicited Imitation items recalled (Wozniak et al., 2015) .

Furthermore, in the two studies (1 case series and 1 placebo - controlled double-blind study) on Specific Learning Disorders (SLDs), vitamins B and C did not cause any significant improvement in intellectual performance over time (Kershner et al., 1977; Rankin et al., 2007).

Multivitamin users under Neurodevelopmental Motor Disorders (NMDs) reported no notable improvements in symptoms but magnesium users reported improved vocal tics (Smith & Ludlow, 2021). Nevertheless, sample size was small, and diagnosis and change in symptoms was based on self-reports, which is subjective. Also, vitamin B6 was reported by a different study to be significantly more effective than psychoeducation in reducing tics when combined with L-Theanine (Rizzo et al., 2022).

Micronutrients levels and the prevention of NDs:

In relation to ASD, Serum levels of 56 separate micronutrients were reported by 23 different studies,

seven case reports and one retrospective case series. In addition, reports on 29 micronutrients from hair, saliva, urine and stool were identified from six studies. Mostly, micronutrient levels were reported as being low among this group and in many instances, the lower levels were statistically significant. Vitamins D and B, and Fe were the most studied micronutrients. In eight out of ten, serum vitamin D level was found to be significantly lower among children with ASD and correlated with ASD scores on four separate occasions (Mostafa & Al-Ayadhi, 2012; Petruzzelli et al., 2020; Qi et al., 2022; Wu et al., 2018). Maternal serum levels and intake of micronutrients (predominantly vitamin B9, prenatal vitamins/multivitamins and vitamin D) were primarily reported to be associated with lower risk of ASD in offspring . Yet, one study found no association between prenatal vitamin B9 use and risk of ASD in 3-year- old offspring (Nishigori et al., 2022).

Vitamin B9 stands out as the single vitamin that was associated with lower odds/risk of ASD even in the presence of environmental pollutants. Dosages ≥ 800 µg seem to be more advantageous in preventing ASD (Goodrich et al., 2018; Schmidt et al., 2017; Schmidt et al., 2012). However, higher levels of maternal serum folate (≥60.3 nmol/L) and B12 (≥536.8 pmol/L) at birth was reported by one study to be associated with higher odds of ASD in offspring (Raghavan et al., 2018). Another study found a weak association between higher total folate levels in early pregnancy and a higher risk of ASD in the child (Egorova et al., 2020). Prenatal vitamins/multivitamins with or without folic acid, were reported to be associated with lower odds of ASD. This association seems stronger when prenatal vitamins are started three months before pregnancy and latest by the first month of pregnancy (Schmidt et al., 2011; Schmidt, Iosif, et al., 2019).

Serum/cord levels of 40 separate micronutrients were analyzed and reported for ADHD. Fe, vitamin B, and Zn were the most reported micronutrients in descending order. Fe serum levels (mostly measured with ferritin levels) were reported as being lower in four studies (Abd El Naby & Naguib, 2018; Calarge et al., 2016; Mahmoud et al., 2011; Soto-Insuga et al., 2013) with three out of the four showing an association between Fe level and severity of ADHD. However, one study (Gottfried et al., 2013) found no difference in Fe levels between ADHD and non ADHD controls. All four studies reporting on brain iron content, suggested lower levels (Adisetiyo et al., 2019; Adisetiyo et al., 2014; Chen et al., 2022; Tang et al., 2022).Vitamin B, Zn, and I had modest repeated associations (two times each) with ADHD risk and/or symptoms.

Five studies reported on five different micronutrients (Mn, Zn, Fe, Vitamins A and D) in Intellectual Disorders (IDs). All the studies reported low serum/hair levels of micronutrients. Except for one retrospective study that used a moderate sample size, the rest utilized very small sample sizes.

Selenium was reported twice in the five studies included in the SLD group and in both cases it was found to be associated with a learning disorder (Liu et al., 2022; Xue et al., 2020). Interestingly, Xue et al. further reported that children with higher levels of urine argentum and lower level of urine selenium had a significantly higher risk of dyslexia than those with low levels of both argentum and selenium. However, this study did not consider potential confounders like renal function and BMI of the children. Another study found no correlation between offspring SLD and maternal vitamin D level in early pregnancy (Arrhenius et al., 2021).

Among the four studies on NMD, three reported on vitamin D and all reports found serum vitamin D to be significantly associated with presence or absence of tic disorder(Bond et al., 2022; Li et al., 2018; Li et al., 2017). The other reported that serum Cu, Mg, and Mn were not different for children with NMD. However, it reported lower Zn and Fe levels among NMD than typically developing children (Liu et al., 2013).

Altogether, six studies focused on a mixture of NDs. In three studies, Fe was reported to be lower in children with NDs and on an occasion, associated with disruptive behaviour (Calarge et al., 2016; De Giacomo et al., 2022; Garipardic et al., 2017). Also, maternal prenatal Se level

was associated with risk of ASD and ADHD (A. S. E. Lee et al., 2021) and urinary Iodine/creatinine ratio was not associated with ASD or ADHD (Levie et al., 2020). Then, according to one study, lower levels of vitamin D in newborns are not associated with ASD or ID (Windham et al., 2019).

These findings indicate that information on micronutrients intake and levels is essential in managing the core symptoms of various NDs. Also, maternal micronutrient intakes could be a leveraging point to help reduce the risk of ASD. Therefore, policies to improve micronutrient intake in children with NDs and in women of reproductive age could be formulated or strengthened to help improve the management of NDs and reduce their occurrence.

This study has identified the need for more research in the nutritional risk factors for ADHD, ID, NMD, SLD and CD. Future research will help to better understand the nutritional management and/ or of prevention these conditions.

A noteworthy limitation is the fact that studies included in this work were of different study designs, and may thus affect the generalisation of the findings. Nonetheless, there were many controlled studies included in this study that will likely enhance the observation of real effects. Also, the methodological diversity including differences in diagnosis and outcome measurements and statistical diversity in the various studies might affect interpretation of the findings. This limitation was mitigated by thoroughly reading complete studies to interpret results correctly. Furthermore, different studies used different biological samples - blood, hair, urine, brain, and nails, to assess levels of micronutrients, which could affect the interpretation of data obtained. However, this limitation was overcome by including the sample type in the analysis.

Conclusion

Overall, there were more studies on micronutrients in relation to ASD and ADHD compared to ID, SLD, and NMD, with most of the studies coming from Europe. In the management of ASD, vitamin B was the most reported micronutrient and it was found to cause significant improvement in ASD core symptoms. Serum levels of micronutrients especially for vitamin D were significantly lower in ASD and often correlated with ASD scores. Sufficient maternal serum levels and intake of vitamin B9, prenatal vitamins/multivitamins, and vitamin D are associated with lower risk of ASD in offspring. Furthermore, combined micronutrients are more effective in managing ADHD symptoms and Fe levels are lower among children with ADHD. However, the evidence was insufficient to conclude on the potential of micronutrients in reducing the risk of ADHD, ID, SLD or NMD.

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Food Habits of Family Cichlidae in the Riverine Area of South Western Nigeria

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ABSTRACT

Studies of gut content analysis of fish are essential for understanding the food habits and trophic levels of fish and how they interact with their environment. One hundred and fifteen (115) individuals of cichlids which comprise of 6 species namely: *Hemichromis fasciatus, Hemichromis bimaculatus, Oreochromis niloticus* , *Oreochromis aureus, Sarotherodon galilaeus and Tylochromis sudanensis* were studied between December 2020 and May 2021. The frequency of occurrence (FO), number method (Cn) and volumetric method (Cv) of food items analysis and viscera-somatic index (VSI) were used in this study. The food items in the stomach of *H. fasciatus, H. bimaculatus, O. niloticus, O.* aureus and *T. galilaeus* showed that these fishes found in this study were euryphagous thus, they feed on a wide range of food items. *T sudanensis* was the only species found to be stenophagous thus, feeding on a limited variety of food items. *T. sudanensis* had the least numbers recorded of the fishes caught. This is related to its observed food habit in this study, therefore its abundance is related to food availability. The viscero-somatic index of all 115 individuals varied between average of 3.79 and 5.09 which indicates all species examined have higher weight of flesh than weight of viscera. The result from this study proved that cichlids in Nigeria are of good culture potential except *T. sudanensis.*

Keywords: Fish: Ecology; Gut content; Viscera-somatic index; Euryphagous; Stenophagous

Introduction

Fishes are sources of food for human beings and other animals,. They are rich in protein and vitamins. Statistics have shown that fish accounts for more than forty percent of the protein diet of two-thirds of the global population (FAO, 2018). Fish is a resource mostly exploited by man and is linked to the trophic chain in its entire environment where they are commonly found (Craig et al., 2004) Fish populations need resources to survive and one of the most fundamental questions in ecology is what resources a particular species requires to exist (Litvaitis, 2000). Therefore, it is necessary to identify the resources used by fishes and document the availability of those resources. In fish ecology, documentation of gut content is critical in efforts to preserve endangered species and manage exploited populations (Manly et al., 2002).

Knowledge of natural diet in a fish species is generally essential in order to know the nutritional habits of fish and to understand its trophic, material and energy dynamics and to model outcomes for their ecosystems (Cutwa and Turingana 2000, Jordan et al., 2006, Navia et al., 2010). Stomach content analysis is a very important part of the food habit study, feeding ecology and, in general terms, a necessary step in research focused on fish ecology. Data on feeding ecology can be used to construct food webs and predict possible changes in food chains and material and energy transfer between and within ecosystems (Nakano and Murakami 2001; Baxter et al. 2004, 2005, Rezende et al., 2008). Fish stomach contents can therefore be used to identify differences in fish feeding strategies, fish health, habitat related food availability, as well as to gather information regarding the trophic relationships in aquatic communities. The knowledge of diet composition and feeding habits is, therefore, an important introduction to the natural history of any species (Ahlbeck et al., 2012; Litvaitis 2000).

Stomach content analysis is used to understand many aspects of the ecology of fishes at the individual, population, community and ecosystem levels. Gut content analysis also gives information on seasonal and life history changes of fish because the types and magnitude of food available as well as the season it occurs plays an important role in the evolutionary history of fishes (Akinwumi, 2003).

Viscero-somatic index is used to evaluate the dress out percentage of a fish after processing which is an indicator of fish quality. It helps to determine how much food fish is left for fish to consume after the visceral mass has been removed. Viscera means the visceral organs in the fish like the intestine. Viscero-somatic index is basically used to investigate how much materials is deposited in the viscera rather than in the muscle (the edible part of the fish) that is the ratio of the viscera mass to the body mass of the fish. The structure, length and conformation of the intestines are closely related to the diet of the fish (Miller and Harley, 2002). Therefore, understanding this relationship is important to predict the diet of fishes, how fishes feed and the mechanism of feeding (Malami et al., 2007). As a group, cichlids exhibit a similar diversity of body shapes, ranging from strongly laterally compressed species (such as *Altolamprologus, Pterophyllum,* and *Symphysodon*) to species that are cylindrical and highly elongated (such as *Julidochromis, Teleogramma, Teleocichla, Crenicichla*, and *Gobiocichla*). Generally, however, cichlids tend to be of medium size, ovate in shape, and slightly laterally compressed, and generally similar to the North American sunfishes in morphology, behaviour, and ecology (Helfam et al., 1997). Cichlids are efficient and often highly specialized feeders that capture and process a very wide variety of food items. This is assumed to be one reason why they are so diverse. Various species have morphological adaptations for specific food sources (*Kullander 2019*) but most cichlids consume a wider variety of foods based on availability. Therefore, this study was conducted in order to determine the gut content and viscerosomatic index of family *Cichlidae* in Nigeria to harness its culture potential.

Materials and Methods

Study Area

The study area is in the riverine area, River Igbokoda of western Nigeria in West Africa. It has coordinates of North (Latitude 6 °21′12″) and East (Longitude 4°47′58″) with land elevation of 40 meters above sea level and with a population of 71,027. Ondo State coastal waters are parallel to South-western coastline of Nigeria and are characterized by extensive lagoons and river delta systems. The area is subject to tidal fluctuations with salt water incursion, two to ten months of the year. The study area is separated from the open ocean by a strip of sandy land which varies in width from about 2-16 kilometres. The area is highly low lying and highly susceptible to tidal fluctuations. The rivers and creeks overflow their banks during the rainy season, thus isolating most farming communities and settlements. There are three subzones which are freshwater (< 30 ppt), brackish water (30 ppt – 33 ppt), saltwater (> 33 ppt) bordering the coastal swamps and creeks. There are two hydrological cycles in the area i.e the wet and dry seasons. The wet seasons spans May to October while the dry season spans November to April. The area is highly susceptible to climate change. The rivers and creeks overflow their banks during the rainy season, thus isolating most farming communities and settlements. The river serves as means of transportation to other states like Lagos, Ogun and Delta States among others.

It is longest territorial water in Nigeria and has fishing terminal. Babatunde (2010) reported that 80% of the population of the study area engage in fishing and that the area records the bulk production in Ondo state. Each of the male fishermen is also likely to be married to two or more wives who are also engage in different stages of fish processing so that all of them can combine their businesses along the stages of fishing. Their level of education is lower than the national average, especially for women.

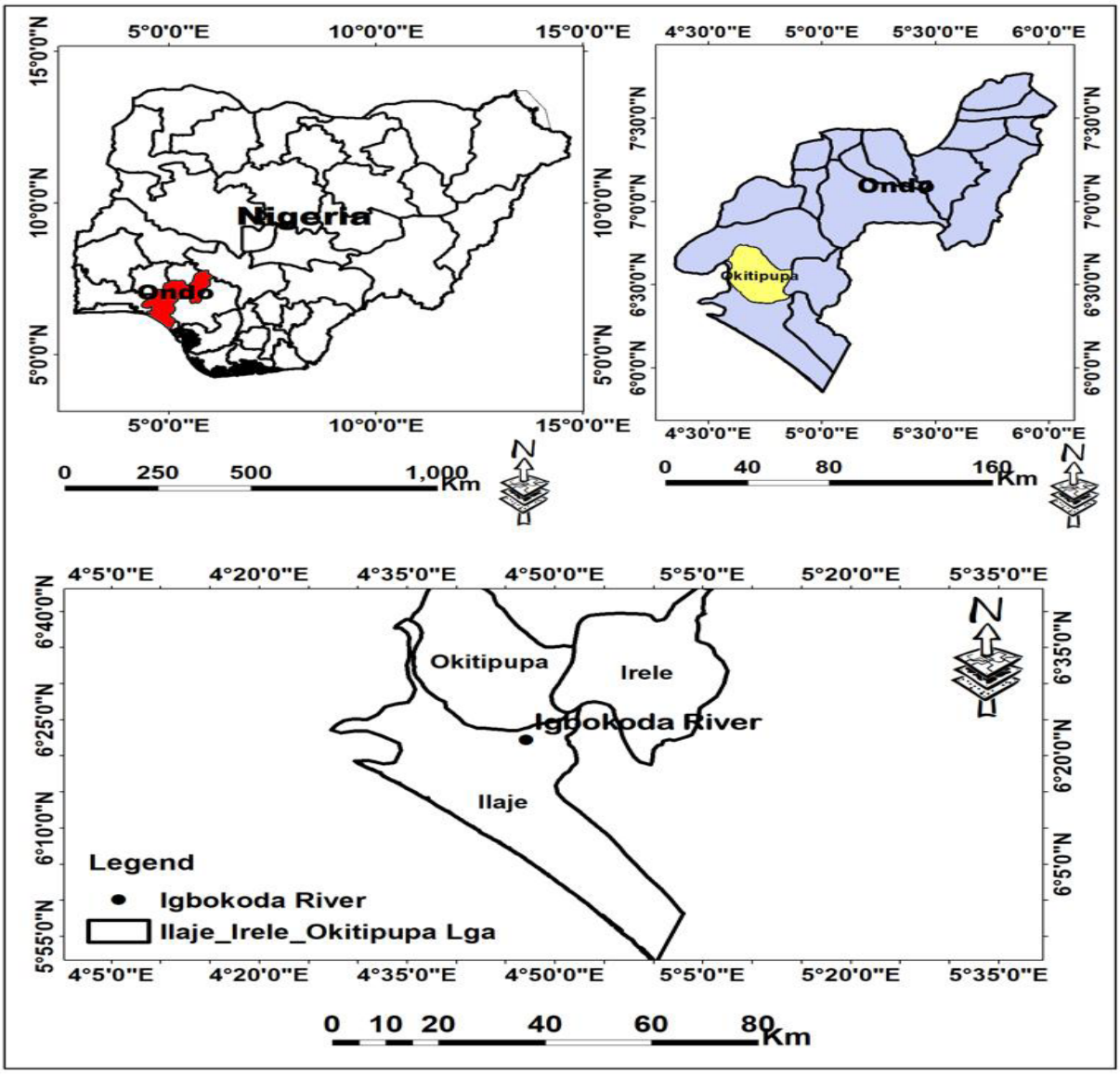

Figure 1: Map of Nigeria showing Ondo state with the study area, Igbokoda River highlighted.

Fish Collection and Identification

A total of one hundred and fifteen (115) samples of cichlids were collected from Igbokoda river in Ilaje with the assistance of fishermen using non-return valve trap from the period of December 2020 to May 2021. The fishes were transported in containers with openings to The Federal University of Technology, Akure obakekere limnology laboratory for analysis. The fish samples were sorted into species level based on the taxonomic keys provided on FishBase website, and Adesulu and Sydenham (2007). Assistance of the head Laboratory Technologist, and experienced fisher folks who provided the local names of the fish species.

Sample Preparation and Examination

The fishes collected were dissected to remove guts and expose the condition of the stomach. The stomach contents were placed in sealed nylon bags with distilled water and refrigerated prior to examination. Stomach samples were mixed with distilled water in a petri-dish for proper separation and easy identification of food materials under a microscope. Each prepared sample was placed on the glass slides, the food items were viewed under light microscope at a magnification of x10 to x20 and captured using photomicrograph at 5, food items were sorted and identified with the aid of taxonomic keys provided by Math/Science Nucleus (2004)

Analysis of Stomach Content

The various items in the fish stomach was analysed using Frequency of Occurrence (FO), Composition by number (C_n) and Index of Relative Importance (IRI).

Number method - The number of individual of each food type in stomach is counted and expressed as a percentage of the total number of food items in the sample studied, or as a percentage of the gut contents of each specimen examined, from which the total percentage composition is estimated.

Frequency of Occurrence, $Oi = \frac{Ni}{N}$ ----Where, Ni is number of fish containing prey i and N is the number of fish with food in their stomach.

Volumetric method - In this method the contents of each sample is considered as unity, the various items being expressed in terms of percentage by volume as estimated by inspection.

In point (volumetric) method, percentage volumes within each subsample are calculated as:

$$\alpha = \frac{number\ of\ points\ allocated\ to\ component\ a}{total\ point\ allocated\ to\ subsample} \text{ X } 100$$

Where α is the percentage volume of the prey (food item) component α

Index of fullness- This is measured as the ratio of food weight to body weight as an index of fullness, which is very widely employed. (The ratio of corresponding volume can also be used.)

$$\text{Fullness index} = \frac{weight\ of\ the\ stomach\ contents\ x\ 100}{weight\ of\ fish}$$

Index of Relative Importance: This index is an integration of measurement of number, volume and frequency of occurrence to assist in evaluating the relationship of the various food items found in the stomach.

Index of relative importance, IRIi = (%Ni + % Vi) %Oi, Where, Ni, Vi and Oi represent numerical, volumetric and frequency of occurence of prey i respectively.

$$\text{Viscero somatic index- VSI} = \frac{weight\ of\ fish\ visceral}{weight\ of\ fish}\ X\ 100$$

Ethics approval and consent to participate –A waiver was approved by The Federal Ministry of Agriculture, Ondo State Nigeria. The fishes used for the experiment were processed and sold off as finished products with the approval of the Centre for Research and Development (CERAD) at The Federal University of Technology, Akure. Nigeria.

Results

A total number of one hundred and fifteen (115) specimens were examined comprising of thirty (30) individuals of *Hemichromis fasciatus*, twenty (20) individuals of *Hemichromis bimaculatus,* twenty-five (25) individuals of *Oreochromis niloticus,* fifteen (15) individuals of *Oreochromis aureus*, twenty (20) individuals of *Sarotherodon galilaeus* and five (5) individuals of *Thylochromis sudanensis.*

Table 1: Summary of stomach contents analysis of *hemichromis fasciatus* in river Ogbokoda, south western Nigeria.

Food Items	Occurrence ($\%O_i$)	Number ($\%N_i$)	Volumetric ($\%V_i$)	Index of relative importance ($\%N_i+\%V_i)\%O_i$	IRI % (rank)
BACCILLARIOPHYTA					
Naviula spp	48	11.11	17.5	1373.28	20.02 (2)
Thalassisira spp	4	0.92	0.60	6.08	0.09 (17)
Licmophora spp	20	4.62	2.75	183.4	2.67 (7)
Nitzchia spp	32	7.4	1.00	268.8	3.92 (6)
Psuedonitzchia spp	4	0.92	0.25	4.68	0.68 (13)
Guirnadia spp	4	0.92	1.20	8.48	0.12 (16)
Plaurosigma spp	16	3.70	3.50	115.2	1.67 (9)
Cheatoceros spp	16	3.70	8.66	512.67	7.47 (5)
Cyclotella spp	8	1.85	4.95	54.4	0.79 (12)
Striatella spp	34	5.55	4.60	868.02	12.65 (3)
CRUSTACEAN					
Zoea	16	3.70	10.30	609.76	8.88 (4)
DINOFLAGELLATES					
Ceratium spp	16	3.70	3.80	120	1.74 (8)
Dinopyhsis spp	4	0.92	0.5	1.84	0.030 (15)
TENTACULATA					
Ctenophora spp	12	2.77	5.2	95.64	1.39 (10)
COSCINODISCOPHYCEAE					
Coscinodiscus spp	8	1.85	6.50	66.8	0.97 (11)
INSECT					
Insect part	4	0.92	12.5	46	0.67 (14)
FISH					
Fish egg	36	8.33	8.60	609.48	8.88 (4)
OTHERS					
Cysts	76	17.59	7.60	1914.44	27.91 (1)

Table 2: Summary of stomach contents analysis of *hemichromis bimaculatus* in river Igbokoda, Ondo state

Food Items	Vi	Ni	Oi	IR1	IRI% (rank)
BACCILLARIOPHYTA					
Naviula spp	45	15.51	29.36	2019.15	53.86 (1)
Thalassisira spp	5	1.72	0.70	12.1	0.32 (12)
Licmophora spp	10	3.44	4.36	78	2.08 (9)
Nitzchia spp	20	6.89	2.45	186.8	4.98 (5)
Psuedonitzchia spp	5	1.72	0.31	10.15	0.27 (14)
Striatella spp	10	3.44	6.17	96.1	2.56 (8)
CRUSTACEAN					
Zoea	5	1.72	2.39	20.55	0.55 (11)
Dinopyhsis spp	5	1.72	0.50	11.1	0.29 (13)
CHLOROPHYCEAE					
Pediastrum spp	5	1.72	6.05	38.85	1.04 (10)
COSCINODISCOPHYCEAE					
Coscinodiscus spp	10	3.44	8.91	123.5	3.29 (7)
FISH					
Fish egg	20	6.89	13.00	397.8	10.61 (3)
PLANT					
Plant material	10	3.44	9.35	127.9	3.41 (6)
OTHERS					
Cysts	25	8.62	16.45	626.75	16.71 (2)

Table 3: Summary of stomach contents analysis of *oreochromis niloticus* in river Igbokoda, Ondo state

Food Items	**Oi**	**Ni**	**Vi**	**IRN**	**IRN% (rank)**
BACCILLARIOPHYTA					
Naviula spp	64	14.41	16.89	2003.2	35.63 (1)
Licmophora spp	12	2.70	5.80	102	1.81 (9)
Guirnadia spp	16	3.60	3.62	115.52	2.06 (7)
Plaurosigma spp	40	9.00	8.50	700	12.45 (3)
Cyclotella spp	8	1.80	1.62	27.36	0.48 (11)
CRUSTACEAN					
Zoea	4	0.90	3.85	19	0.34 (13)
DINOFLAGELLATES					
Ceratium spp	12	2.70	6.79	113.88	2.02 (8)
COSCINODISCOPHYCEAE					
Coscinodiscus spp	28	6.30	7.05	373.8	6.65 (5)
Skeletonema spp	8	1.80	1.25	24.4	0.43 (12)

MEDIOPHYCEAE					
Leptocylindricus spp	8	1.80	1.74	28.32	0.50 (10)
FISH					
Fish egg	12	2.70	8.40	133.2	2.40 (6)
PLANT					
Plant material	24	5.40	19.39	594.96	10.58 (4)
OTHERS					
Cysts	50	11.71	16.00	1385.5	24.65 (2)

Table 4: Summary of stomach contents analysis of *oreochromis aureus* in river Igbokoda, Ondo State

Food Items	Oi	Ni	Vi	IRN	IRN% (rank)
BACCILLARIOPHYTA					
Naviula spp	60	18.00	20.15	2289	49.35 (1)
Guirnadia spp	20	6.00	6.20	244	5.26 (5)
Plaurosigma spp	26.5	8.00	9.69	468.75	10.12 (3)
Cheatoceros spp	13.3	4.00	11.07	200.43	4.32 (6)
COSCINODISCOPHYCEAE					
Coscinodiscus spp	13.3	4.00	4.40	111.72	2.40 (7)
Skeletonema spp	6.5	2.00	6.00	52	1.12 (9)
FISH					
Fish egg	6.5	2.00	8.60	68.9	1.49 (8)
PLANT					
Plant material	13.3	4.00	15.55	260.01	5.60 (4)
OTHERS					
Cysts	33.3	10.00	18.34	943.72	20.35 (2)

BACCILLARIOPHYTA					
Naviula spp	35	5.64	31.17	1288.35	32.89 (2)
Licmophora spp	20	3.22	1.61	96.6	2.46 (8)
Nitzchia spp	10	1.61	0.50	21.1	0.54 (12)
Psuedonitzchia spp	20	3.22	1.95	103.4	2.64 (7)
Guirnadia spp	10	1.61	7.45	90.6	2.31 (9)
Plaurosigma spp	10	1.61	3.19	48	1.23 (11)
Cheatoceros spp	20	3.22	12.20	308.2	7.87 (3)
CRUSTACEAN					
Zoea	15	2.41	9.00	171.15	4.37 (6)
DINOFLAGELLATES					
Ceratium spp	15	2.41	1.55	59.4	1.52 (10)
COSCINODISCOPHYCEAE					
Coscinodiscus spp	25	4.03	4.40	210.75	5.38 (5)
ZYGNEMATOPHYCEAE					
Closterium spp	5	0.80	0.25	5.25	0.13 (13)
FISH					
Fish egg	20	3.22	8.00	224.4	5.73 (4)
OTHERS					
Cysts	50	8.06	17.73	1289.5	32.92 (1)

Table 5: Summary of stomach contents analysis of *tilapia galileus* in river Igbokoda, Ondo State

Food Items	Oi	Ni	Vi	IRI	IRN% (rank)
BACCILLARIOPHYTA					
Naviula spp	35	5.64	31.17	1288.35	32.89 (2)
Licmophora spp	20	3.22	1.61	96.6	2.46 (8)
Nitzchia spp	10	1.61	0.50	21.1	0.54 (12)
Psuedonitzchia spp	20	3.22	1.95	103.4	2.64 (7)
Guirnadia spp	10	1.61	7.45	90.6	2.31 (9)
Plaurosigma spp	10	1.61	3.19	48	1.23 (11)
Cheatoceros spp	20	3.22	12.20	308.2	7.87 (3)
CRUSTACEAN					
Zoea	15	2.41	9.00	171.15	4.37 (6)
DINOFLAGELLATES					
Ceratium spp	15	2.41	1.55	59.4	1.52 (10)
COSCINODISCOPHYCEAE					
Coscinodiscus spp	25	4.03	4.40	210.75	5.38 (5)
ZYGNEMATOPHYCEAE					
Closterium spp	5	0.80	0.25	5.25	0.13 (13)
FISH					
Fish egg	20	3.22	8.00	224.4	5.73 (4)
OTHERS					
Cysts	50	8.06	17.73	1289.5	32.92 (1)

Table 6: Summary of stomach contents analysis of *tylochromis sudanensis* in river Igbokoda, Ondo State

Food Items	Oi	Ni	Vi	IRN	IRN% (rank)
BACCILLARIOPHYTA					
Licmophora spp	40	12.5	19.28	1271.2	32.40 (2)
Nitzchia spp	40	12.5	7.35	794	20.24 (3)
Psuedonitzchia spp	20	6.25	15.37	432.4	11.02 (4)
Skeletonema spp	20	6.25	65.00	1425	36.32 (1)

Table 7: Summary Of Stomach Fullness During The Period Of Study.

Species	No	Empty	%	¼ full	%	half-full	%	¾full	%	Full	%
H.fasciatus	30	0	0	14	46.66	12	40.00	4	13.33	0	0
H.bimaculatus	20	0	0	4	20	9	45	5	25	2	10
O.niloticus	25	0	0	9	36	15	60	1	4	0	0
O.aureus	15	0	0	7	46.66	6	40	1	6.67	1	6.67
T.galileus	20	0	0	4	20	11	55	4	20	1	5
T.sudanensis	5	0	0	1	20	3	60	1	20	0	0
Total	115	0	0%	39	31.55%	58	50%	16	14.83%	4	3.61%

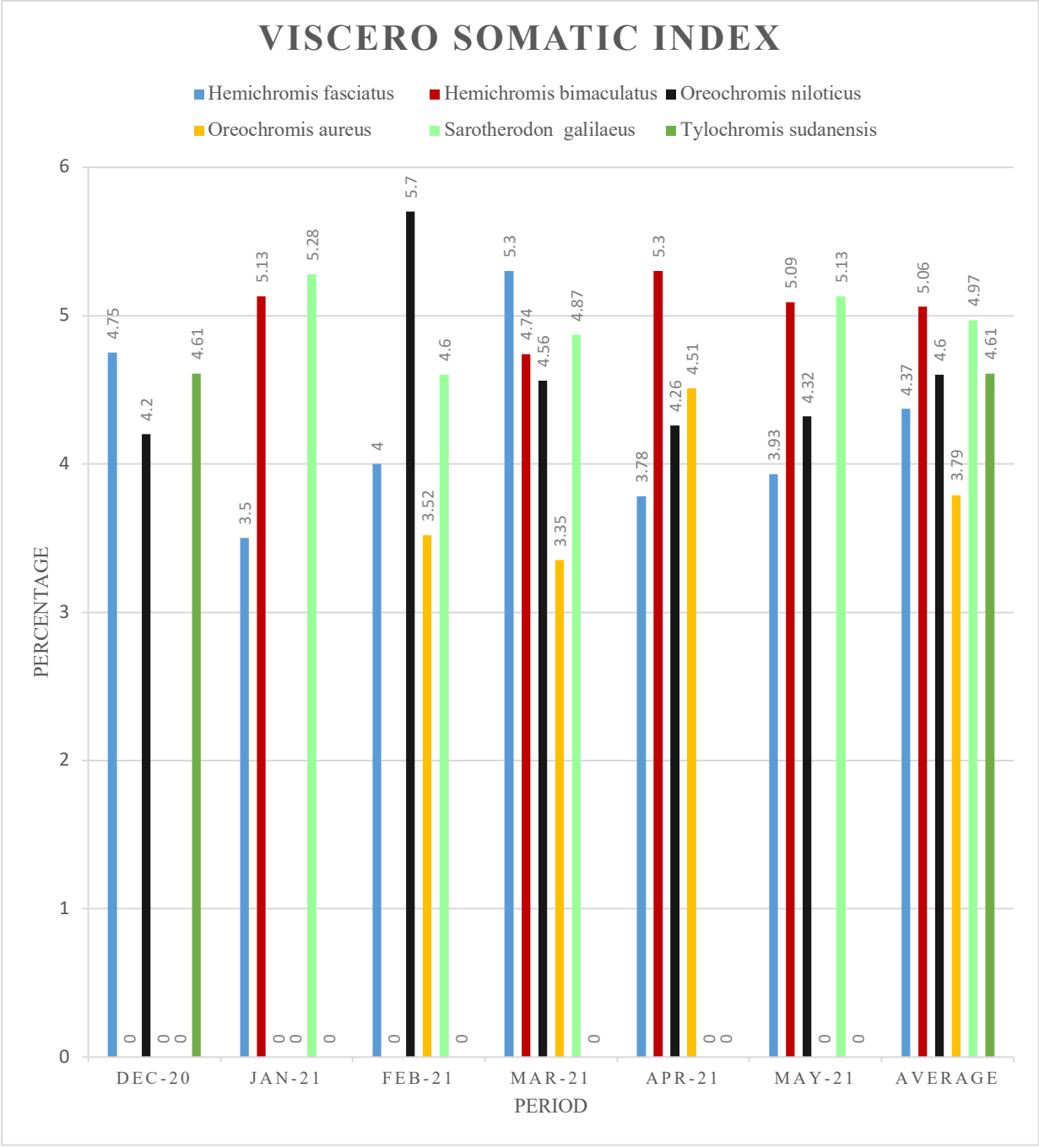

Figure 2: Viscero-somatic index of samples during the period of study

DISCUSSION

Gut Content Analysis

A summary of food items that constituted the diet of *Hemichromis fasciatus* is given in Table.1. *Navicular spp*, Zoea, *Thallasiosira spp*, insect parts, *Nitzchia spp, Pseudonitzchia spp, Guinardia spp, Cyclotella spp, Stritella spp, Ceratium spp, Dinopyhsis, Coscinodiscus spp, Ctenophora spp,* and *Cheatoceros spp,* cysts and fish eggs were present in the stomach samples collected. Indicating that the fish is omnivorous, this result is similar to results of studies by (Oribhabor *et al.,* 2019) who reported that *H. fasciatus* found in Qua Iboe River in Akwa Ibom State, Nigeria fed on benthic invertebrates and occasionally on species of fish, but this species was found to feed also on plant materials and also agrees with studies by (Oronsaye, 2009) who reported that *H.fasciatus* found in Ikpoba dam Benin city, Nigeria feeds on insects, fish, plankton and plant materials

A summary of the food items that constituted the diet of *Hemichromis bimaculatus* from River Igbokoda is given in Table.2. *Navicula spp*, plant material, *Nitzchia spp*, *Striatella spp*, *cysts*, *Coscinodiscus spp*, fish egg, *Licmophora spp Thalassiosira spp, Zoea, Psuedonitzchia spp, Dinophysis spp,* and *Pediastrum spp* were present in the stomach of samples collected. Indicating that the fish was omnivorous, this result is similar to results studied by Ayoade and Ikulala (2007) who reported *H.bimaculatus* from Eleiyele Lake in southwestern Nigeria fed mainly on algae, crustaceans, diatoms, plant materials and fish egg.

A summary of the food items that constituted the diet of *Oreochromis niloticus* is given in Table.3 *Navicular spp*, *Pluarosigma spp*, cysts *Conscinodiscus spp*, plant material, fish egg, *Leptocylindricus spp*, *Ceratium spp*, *Striatella spp*, *Skeletonema spp*, *Cyclotella spp* and *Guinardia spp* were present in the stomach of samples collected. Indicating that the fish is omnivorous but feeding mainly on Bacillariophyceae, this result corresponds to results of studies by (Mohsen 2003) who stated that Bacillariophyceae were dominant in the stomach of cichlids cultivated in a pond in Egypt. Also, Abidemi-Iromini (2019) reported that Bacillariophyceae constituted 38.22% of the food items thus the most prevailing food items in the stomach of *Oreochromis niloticus* found in the Lagos lagoon.

A summary of the food items that constituted the diet of *Oreochromis aureus* is given in table.4. *Navicula* spp, *Guinardia spp, Cheatocerus spp, Plaurosigma spp*, *Conscinodiscus spp*, *Skeletonema spp*, fish egg, plant material and cysts. Indicating that this fish species is omnivorous which is in corresponds with results of studies by Horsfall et al., (2004) who reported that *S.galilaeus* found in Sombriero River Cross River, Nigeria fed mainly on plant food substances such as phytoplankton, plant parts, leaf parts and some percentages of animal food include insect pupae, insect larva and protozoa.

A summary of the food items that constituted the diet of *Sarotherodon galilaeus* is given in table.5. N*aicula spp, Licmophora spp, Nitzchia spp, Psuedonitzchia spp, Guinardia spp, Plaurosigma spp, Cheatoceros spp*, zoea, *Conscinodiscus spp*, *Closterium spp, Ceratium spp* were present in the stomach of samples collected. This indicates that it is omnivorous. A summary of the food items that constituted the diets of *Tylocromis sudanensis* is given in Table 6, *Licmophora spp*, *Nitzchia spp, Psuedonitzchia spp* and *Skeletonema spp* were present in the stomach of samples collected. Indicating that this fish species is planktivorous feeding exclusively on planktons which is in contrast with (Konan 2011) who reported that *Tylochromis spp* found in Ebrie Lagoon, Ivory coast fed on benthic invertebrates, insects larvae, zooplankton, and terrestrial plants.

Stomach Fullness

The summary of the stomach fullness of samples during the period of study is shown in Table7. A total number of 115 samples were examined 0 (0%) had empty stomachs, 39 (31.55%) had ¼ full stomachs, 58 (50%) had half-full stomachs, 16 (14.83%) had ¾ full stomachs and 4 (3.61%) had full stomachs. 56% of *Hemichromis fasciatus* had ¼ full stomachs, 28% of sample had half full stomachs and 16% had ¾ full stomachs, with majority (56%) having ¼ full stomachs. This result agrees with results of studies by Oribhabor et al., (2019) with reported that *H. fasciatus* found Qua Iboe River in Akwa Ibom State, Nigeria had 100% of stomachs had a

food item inside. Table.7 shows the stomach fullness of *Hemichromis bimaculatus* during the period of study. 20% of the sample had ¼ full stomachs, 45% of sample had half-full stomachs, 25% had ¾ full stomachs and 10% having full stomachs, with majority(45%) having half-full stomachs, indicating that 100% of samples had food in their stomachs. This result agrees with Oribhabor *et al.,* (2019) who reported that *H. bimaculatus* found in Qua Iboe River in Akwa Ibom State, Nigeria had 100% of stomachs with food items inside them. Also, results of studies by Ayoade & Ikulala (2007) showed that 74.2% of *H.bimaculatus* from Eleiyele Lake in southwestern Nigeria examined had food in their stomachs. 36% of *Oreochromis niloticus* had ¼ full stomachs, 60% of sample had half full stomachs and 4% had ¾ full stomachs, with majority (60%) having half full stomachs indicating that 100% of samples had food in their stomachs. Similarly Oso *et al.,* (2017) also reported that *O.niloticus* found in Ero dam Ekiti, Nigeria had 90.5% stomachs containing food items.

20% of *Sarotherodon galilaeus* had ¼ full stomachs, 55% of sample had half full stomachs, 20% had ¾ full stomachs and 5% had full stomachs, with majority (55%) having half-full stomachs indicating that 100% of samples had food in their stomachs. This result is similar to results of studies Gbaguidi *et al.,* (2016) who reported that *S. galilaeus* found in a man-made lake in Benin Republic had 99.60% of stomach with food inside them. 20% of *Tylochromis sudanensis* had ¼ full stomachs, 60% of sample had half full stomachs and 20% had ¾ full stomachs, with majority (60%) having half-full stomachs.

Viscero-Somatic Index

Figure 2. shows the average percentage of viscera weight in average total fish weight for *Hemichromis fasciatus* during the period of study was 4.37 percent which indicates that the weight of fish before dressing out is higher than the weight of fish after dressing out. The average percentage of viscera weight in average total fish weight for *Hemichromis bimaculatus* and *Oreochromis niloticus* during the period of study indicates that the weight of fish before dressing out is higher than the weight of fish after dressing out. This result tallies with (Araujo *et al*., 2020) who reported the viscero somatic index of *Oreochromis niloticus* found in rivers in Brazil to vary between 2.70 and 8.36 indicating that the weight of fish flesh is higher than fish visceral. *Oreochromis aureus* had the lowest average values for VSI and this is an indication that *Hemichromis bimaculatus* which recorded the highest value has more fillet for consumption than *Oreochromis aureus* in relation to total body mass. *Sarotherodon galilaeus, Tylochromis sudanensis* also followed the same trend. The visceral somatic index of all samples collected varied between averages of 3.79 and 5.03 indicating that species have more weight in ratio of fish flesh to fish visceral. With respect to this study, the fishes studied are good fishes for consumption because of its rich fillet quality.

Conclusion

Based on the findings of this research, it has been established that *Hemichromis fasciatus* is found to be omnivorous, *Hemichromis bimaculatus* is herbivorous, *Oreochromis niloticus* is omnivorous, *Oreochromis aureus* is herbivorous, *Tilapia galileus* is omnivorous and *Tylochromis sudanensis* is herbivorous. There was no obvious seasonality in the abundance of food items consumed generally in all species examined, because the fishes fed mainly on the same food items during the period of study, although at varying quantities and intensities. *Tylochromis sudanensis* was the only species reported to be strictly planktivorous and stenophagous. *Tylochromis sudanensis* was the least occurring species amongst the fish species examined. It is therefore implied that the food habit of this species is relative to its abundance in the water body. The viscero-somatic indices for all the species indicated that every fish species examined has more flesh than viscera organs. The average percentage of viscera in average total body weight of *Hemichromis fasciatus, Hemichromis bimaculatus, Oreochromis niloticus, Oreochromis aureus, Sarotherodon galilaeus* and *Tylochromis sudanensis* indicates that the weight of fish before dressing out is higher than the weight of fish after dressing out. It also established that all the examined fish species are omnivores except *Tylochromis sudanensis* which is a planktivore. This implies that all the examined

species except *Tylochromis sudanensis* have good aquaculture potential in relation to feeding.

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An Impactful North-South Collaborative for Injury Prevention and Treatment in Ghana and Globally

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ABSTRACT

Injuries, such as from road traffic crashes and violence, cause a significant burden of death and disability in Ghana and globally. Universities have a key role to play in addressing the injury problem, both in training professionals and in undertaking research that will inform and stimulate action locally and globally. The main objective of this report is to highlight the importance of building institutional mentoring capacity to train next generation of injury prevention and trauma care researchers and leaders. Since 2005, the Kwame Nkrumah University of Science and Technology (KNUST) Fogarty-Quartey scholarship programme, a collaborative between KNUST and the University of Washington, has made significant contributions to injury prevention and trauma care in Ghana. The programme has provided scholarships to 37 long-term degree (e.g., MPH, PhD) scholars who are professionals from a variety of disciplines, most of whom have learned the basics of injury research and gone on to hold influential positions that involve road safety, prehospital care, emergency care, and trauma care in Ghanaian institutions. Research conducted by these scholars has led to real-world improvements in road safety and trauma care in Ghana. This research has led to 70 peer-reviewed publications, many of which have been extensively referenced and which have helped to inform the global evidence base on injury control. The collaborative has also led to beneficial academic exchanges and additional grant opportunities. This article summarizes the key elements for success of this programme, including its administrative structure, its methods for building mentorship capacity at Ghanaian institutions, and its support for the career development of scholars. The article also addresses the challenges that the programme has faced and the innovative solutions that have been implemented to overcome these challenges and to assure its long-term sustainability.

Key words: Injury, trauma, road safety, trauma care, violence prevention, research, collaboration

Introduction

Injuries, such as from road traffic crashes and violence, cause a significant burden of death and disability in Ghana and globally. There are many actions that can be taken to decrease this burden, both through injury prevention and through strengthening care for the injured.

Universities have an important role to play in addressing the injury problem, both in training professionals to fill key positions in government and other agencies, and in undertaking research that will inform and stimulate action locally and globally.

Since 2005, Kwame Nkrumah University of Science and Technology's (KNUST's) Fogarty-Quartey scholarship programme has made significant contributions to injury prevention and treatment in Ghana. The programme has provided scholarships for long-term degree (e.g., MPH, PhD) training to 37 professionals from a variety of disciplines, most of whom have gone on to hold influential positions that involve road safety, prehospital care, emergency care, and trauma care in Ghanaian institutions. Through their work in these positions, they contribute to efforts to decrease the burden of injury in Ghana. In addition, the research that they carried out while in the Fogarty-Quartey programme has been influential in informing and promoting more effective injury prevention and trauma care in Ghana. This research has also contributed significantly to the evidence base for injury control (prevention and treatment) globally. Finally, the programme has evolved over time with increased capacity for mentoring at KNUST.

In this article, we summarize the history and structure of the programme, along with the key outcomes of trained professionals and research undertaken. We also discuss challenges the programme has faced, solutions that we have found, and plans for future sustainability.

History and Current Structure of the Programme

The Fogarty-Quartey programme started in 2005, with funding garnered from the US National Institutes of Health's (NIH) Fogarty International Center, which funds international collaborations in medical research, typically partnerships between universities in the USA and other countries. The name of the programme was chosen to honor the memory of Prof. J.K.M. Quartey, a urologist from Korle Bu Teaching Hospital, who was renowned for his service and dedication to his patients, and who tragically died in a car crash that year. We hope that the same spirit of service and dedication will be taken up by our scholars.

The programme started as a partnership between KNUST and the University of Washington (UW), in Seattle, USA, an institution known for its trauma care and injury prevention research, especially through its Harborview Injury Prevention and Research Center (HIPRC). For the first 10 years, Charles Mock led the programme and UW was the main grant recipient, with a subcontract to KNUST for activities in Ghana. During this time, significant portions of the training occurred at UW. As the capacity for mentorship in injury research and for grants management increased at KNUST, Peter Donkor assumed the overall leadership of the programme and KNUST became the prime recipient of the grant, dealing directly with the NIH. The role of UW has gradually decreased, now providing supplemental mentorship on injury research, but with most of the training and mentorship occurring at KNUST.

The programme structure is summarized in Figure 1. The day-to-day activities of the programme are run by the Leadership Team, all except one of whom are at KNUST. They represent a spectrum of expertise, including trauma care, public health, and nursing. Many members of the team are in daily communication with each other. A Training Advisory Committee (TAC) provides advice, at annual meetings and as needed in between. The TAC consists of senior leadership from other universities and government agencies, especially agencies involved with road safety. They assist the Leadership Team in identifying high-quality applicants for scholarships and in providing advice on research projects that will help to inform injury control in Ghana.

The programme undertakes several activities, including workshops and distance learning, but the foundation is long-term degree training, especially at KNUST (Figure 1, Table 1). Several key components for success include careful selection of trainees (scholars). Criteria for inclusion in training include: 1) present involvement in injury-related work or research; 2) specific request to the program for training by relevant institution; and 3) need for faculty development. We especially look for people who have been active in some aspect of injury control already and who hold positions at universities or government agencies to which they will return after training. The TAC, with its knowledge of injury control

in Ghana, has been especially helpful in identifying suitable candidates.

During the programme, the main mentors for the scholars are their KNUST School of Public Health (SPH) degree supervisors. There is active co-supervision by project leadership, with input regarding what topics are timely in the injury scientific literature and that will result in publishable papers. The trainee's progress is monitored by the mentors (KNUST SPH faculty, UW mentors, and other programme leadership) through use of individual development plans. In person meetings with KNUST SPH supervisors occur weekly to monthly. Zoom and in person meetings with UW mentors occur three to four times per year, with more frequent communication by email. Meetings with mentors address satisfactory progress in the course work, as well as selecting, developing, and implementing a successful research project. KNUST SPH supervisors and programme leaders interview each scholar at the completion of their degrees to understand their experiences and identify possible areas for continuing improvement of the programme. Programme leaders and other mentors continue to be involved with the scholars after they receive their degrees, especially for converting the thesis into a publication and for long-term career advice.

Outcomes: Trained Professionals

The programme has provided scholarships to 37 long-term degree scholars (Table 2). These include MPH (or other master levels) degrees that are given to two categories: (a) pre-doctoral scholars, whose highest prior level of training was a bachelor's degree and who usually work for government agencies; and (b) post-doctoral level scholars, typically medical doctors. The latter obtain MPH degrees to obtain research expertise, in addition to their clinical expertise. In recent years, our programme has increasingly focused on PhD training, usually oriented towards university lecturers with existing Masters degrees. The PhD training allows them to work at a higher level, advance further in their careers, and undertake future research using their injury expertise.

A main goal of the programme is to increase the injury research capacity of Ghanaian institutions, especially through the roles the scholars undertake after completion of their training. Hence, it is notable that all 37 long-term scholars have returned to or remained in Ghana, with most working in in roles that utilize their injury skills and that contribute to lowering the burden of death and disability from injury in Ghana. Two notable examples:

- **Dr. Maxwell Osei-Ampofo,** spent two years as Head of the Directorate of Emergency Medicine at the Komfo Anokye Teaching Hospital (KATH) and now serves the Ministry of Health as the Deputy Director of the National Ambulance Service.
- **Prof. Emmanuel Nakua** is now Head of the Department of Epidemiology and Biostatistics and Vice Dean of the School of Public Health at KNUST.

A full listing of the scholars and their positions are in Table 2. KNUST and KATH have especially benefited. But many other scholars have taken up positions in and are contributing to the work of a wide variety of government agencies and other universities, including (among others): Building and Roads Research Institute (BRRI), National Ambulance Service, Police Hospital, Tamale Teaching Hospital, and University of Cape Coast.

Outcomes: Research Conducted

Research conducted by the scholars, especially for their theses, has helped to inform and strengthen the practice of injury control (both prevention and treatment) in Ghana and has contributed to the global evidence base. This research covers the spectrum of injury control, as shown in Figure 2, with several examples. Two examples of the strong research conducted by the programme scholars are summarized below:

- **Dr. James Damsere-Derry (BRRI)** measured speeds of 20,000 vehicles, documenting minimal compliance with posted speed limits in locations with high rates of pedestrian injury

(Damsere-Derry et al., 2007, 2008). This work was highly publicized in Ghana through press conferences and radio talk shows. This publicity helped to increase popular demand for traffic calming infrastructure (e.g. speed bumps) and governmental interest in implementing such measures (Figure 3). The result was an increase in use of such infrastructure on many of Ghana's roads, with consequent decreased rates of pedestrian death at these locations (Damsere-Derry et al., 2019, Gyaase et al., 2022). This work has also informed the global evidence base on pedestrian safety in LMICs. One of Damsere-Derry's publications (Damsere-Derry et al., 2010) has been cited by 153 other scientific publications (as identified through Google Scholar).

- **Dr. Dominic Yeboah (KATH)** used a trauma quality improvement (QI) technique (preventable death panel review) at KATH. This documented a high rate of preventable deaths and several inadequacies in care. This led to more regular QI activities and, on 10 year follow up, a decrease in definitely preventable deaths (25% of all trauma deaths in 2007 vs. 13% in 2017) and improvements in care, especially resuscitation for patients in shock. His first article has been cited by 52 other scientific publications, showing wide global interest in this topic (Yeboah et al., 2014; Konadu-Yeboah et al., 2020).

Most scholars have published their Masters theses or PhD dissertations, sometimes with multiple publications. Many scholars have continued the research they started as scholars (as with the examples of Dr. Damsere-Derry and Dr. Yeboah, above). As part of the programme, funds are made available to some of the scholars after they finish training, for promising research projects. Scholars are also encouraged and mentored to apply for additional funding from other agencies. For example, **Prof. Adam Gyedu (KNUST)** obtained his own funding as principal investigator from the US NIH for a study on trauma care at district and regional hospitals (Gyedu et al., 2022). **Dr. Tolgou Yempabe** (an orthopaedic surgeon at Tamale Teaching Hospital) undertook a study of practices of traditional bonesetters (TBS) in the Northern Region (Yempabe et al., 2020; 2021) for his MPH thesis. Through the trust he built with the TBSs, he was able to obtain funding from the AO Foundation for training of the TBSs to better recognize and refer difficult cases, such as open fractures.

Finally, some of the scholars have undertaken research on neglected topics with their research highlighting these problems, the benefits of which might take years to manifest. For example, a very sensitive injury issue is violence, especially violence against women. Scholar **Amy Budu Ainooson** interviewed women with disabilities about violence they had experienced, publishing on ways to increase health care access for them (Budu-Ainooson et al., 2020). Altogether, through their theses and through follow up activities, the Fogarty-Quartey programme has directly sponsored 70 peer-reviewed publications (listed in reference section). As with the above-noted studies, these 70 publications address the spectrum of injury control, including surveillance, injury prevention (e.g. road safety, violence prevention), prehospital care, initial emergency care, and surgical care (Figure 2).

Outcomes: Research Leadership

At the start of the programme Peter Donkor, Charles Mock, and Robert Quansah co-mentored all the scholars together with their academic supervisors. The current programme leadership includes early Fogarty-Quartey scholars who have matured into independent and successful academic and research leaders. They play key roles in mentoring new scholars and are also recipients of a number of competitive injury-related grants from the NIH and other funders. This is a major plank in the drive towards ensuring sustainability of the programme.

Innovative Solutions to Challenges Faced

Local Expertise

The programme has faced several challenges. At the onset, KNUST had limited experience for research mentoring on injury topics. KATH had considerable clinical expertise in traumatology, but limited experience in publishing its work. The partnership with UW brought in considerable injury research experience, from which early scholars benefited. However, training at UW was expensive. Hence, early on the programme developed a training model in which most scholars obtained their degrees at KNUST, with dual mentorship. KNUST faculty members were direct supervisors for the degrees and provided in-depth knowledge of local realities. UW mentors provided expertise on injury research, including specific techniques (e.g. adjusting for injury severity, setting up trauma registries, development of questionnaires for household surveys on injury). With time, the injury research expertise and the institutional capacity for mentoring in injury research has expanded at KNUST with UW mentors called in only as needed.

Injury research expertise and related capacity for mentoring in injury research at KNUST includes several former scholars, who have now risen to be professors and department heads and who now mentor many trainees on their own, without funding from the Fogarty-Quartey programme. As just one example, one such trainee obtained their own funding and undertook a notable, published study on the effectiveness of speed bumps in decreasing road traffic injuries (Gyaase et al., 2022). Each year, the KNUST School of Public Health has around 4 students undertaking injury research for their theses. The school also has integrated injury examples into several of its core courses and has created a new course specifically on injury control (FEAB 656: Injury Epi, Prev, and Control).

Career Development

A major goal of the programme is that scholars assume positions of responsibility in Ghanaian institutions and use their new skills to address the injury problem in Ghana. Some positions lend themselves naturally to this, such as jobs in road safety at the BRRI or jobs as surgeons or emergency physicians. Some jobs, such as lecturers in public health are less directly connected with injury. In all cases however, the undertaking of impactful research on injury is not automatic, especially for a field with relatively modest funding available. There would be a tendency for completed scholars to not actively use their new skills and to become frustrated and leave for other employment or even leave the country. The programme has attempted to address this issue through the possibility of additional "re-entry" funding after the completion of the degree (as noted above) and through continued mentoring. Members of the leadership team and other mentors continue their relationships with the completed scholars, often for years, assisting them with additional publications and with garnering their own funding. Table 2 shows the wide variety of important positions that our scholars have assumed, most of which are involved with some aspect of injury control.

Gender Equity

Recipients of scholarships who entered during the first phase of the programme (2005-2015) were predominantly male (only 4 out of 17 scholars were women). This inequity was partly due to the fact that some parts of the injury field (such as traumatology and emergency medicine) are still heavily male dominated. During the second phase of the programme (2016 to current), we have more actively recruited qualified women. In part, we have approached this through actively recruiting in fields such as nursing which have high percentages of women. To increase our involvement with nursing, and especially nursing research, we have relied on experienced researchers at the Department of Nursing at KNUST, in identifying potential scholars. We have also been flexible in our approach by allowing female scholars who start families or have other family responsibilities, to have as much time as needed to finish their theses. Thus far, no one has had to drop out of the programme because of

such family responsibilities. These approaches have been successful. Recipients of scholarships during the second phase of the programme have been more evenly matched by gender with 11 out of 20 being women. Future plans include to focus more attention on workshop attendees to assure gender equity in this set of activities also.

Extending the Network

The work in Ghana has been based at KNUST, but programme graduates have taken positions throughout Ghana. Nonetheless, in order to expand the influence of the programme to better address the huge injury problem, additional ways of working were needed. One of these was to actively work with other universities to identify promising candidates working there, who would return to that institution with their new injury expertise, as has been done with University of Cape Coast and University of Development Studies/Tamale Teaching Hospital. Another has been to be flexible and offer scholarships at other institutions. We have sponsored one prior student (Mphil in epidemiology) and a current student (PhD in bioengineering) at the University of Ghana.

The foundation of the programme is the long-term degrees. To reach a broader audience, we have conducted a wide variety of workshops, for 20 – 100 participants each, ranging from one day to one week, usually held two to three times per year. In total, these workshops have had thousands of attendees. Early in the programme, we organized week-long workshops on injury control as a scientific field. These were attended by a wide range of injury stakeholders including representatives of government agencies dealing with injury in some way (e.g. road safety, emergency care, disaster management). These helped to show participants the commonality of their work with others in different agencies and thus helped to build constituency for injury control in Ghana. Workshops have focused on specific issues as needed and have highlighted injury topics that have thus far received only minimal attention, such as violence prevention and drowning. Further examples of the workshops are in Table 3. Workshops have been evaluated by written surveys given before and after the workshops. Also, **every 5 years, we survey people who have attended the workshops during the past 5 year cycle to see what parts of the workshops were most beneficial for them.**

The workshops involve the network of current and former programme scholars, both as presenters and attendees, which assists with ongoing mentorship and career development. The workshops have also expanded the programme's reach to the sub-region, with workshops conducted most years at the annual West African College of Surgeons conferences.

Conclusions – Sustainability

Partnerships for capacity building in research mentoring in global health have had variable outcomes (Potash, 2019). The Fogarty-Quartey collaborative is a successful partnership which has been systematically developed over several years and sustainably transitioned from HIC to LMIC leadership. The programme has considerably expanded the capacity for injury research in Ghana. It has trained 37 long-term scholars, almost all of whom are working in some aspect of injury control in Ghanaian institutions. Research conducted by the scholars has been impactful to improve injury prevention (especially road safety) and trauma care in Ghana. This research has been published in leading journals and has contributed to the global evidence base for injury control. This has been accomplished by gradually increasing the capacity for injury mentorship at KNUST and decreasing reliance on foreign expertise. Our experience has shown that a successful North-South partnership must aim to 1) first build mentorship capacity of LMIC senior faculty and 2) train graduate students and junior faculty to become independent researchers and effective mentors for sustainability. Another major part of the model for success has been the continued mentorship for career development for completed scholars. This model is eminently applicable to other institutions and other partnerships. Next steps for the programme are to develop more standardized mentoring guidelines and materials, which will help assure sustainability and which

could be of use to other universities. Such materials have been shown to be important to the broader field of global health mentorship (Hansoti et al., 2019).

The funding garnered for this programme has been an important component for its success. However, no funding lasts forever. Hence, we have worked to keep long-term sustainability in mind. Currently, former scholars who have assumed positions at KNUST and other institutions are engaging in impactful injury work, most of which is no longer supported by our programme. The KNUST SPH now has a course specifically on injury control and routinely has multiple students studying injury topics for their theses. Our completed scholars at KNUST and other institutions have been successful at garnering funds for their own research. Thus, regardless of any specific funding, the Fogarty-Quartey Programme is poised to continue its important contributions to decreasing the tragic problem of injury.

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*Funded through a supplement on Alzheimer's Disease and Related Dementias

Table and Figure legends

Table 1. Key components for success of long-term, degree scholars

1. Careful selection of trainees to ensure a good fit and retention

2. Co-supervision of trainees by project leadership at all stages of student training

3. Monitoring of trainee progress through the use of Individual Development Plans

4. Financial support – tuition, stipend, computer, research support

5. Guidance through manuscript writing

6. Support with payment of article publishing charges (APCs)

7. Supplemental training through focused workshops

8. Pilot grants for graduates

9. Active oversight by Leadership Team and advice from a TAC (Training Advisory Committee) consisting of senior leadership from other universities and government agencies.

Table 2. Summary of long-term scholars (trainees) in the KNUST Fogarty-Quartey Injury Programme

	Scholar	Degree	Year Received	Topic of Thesis Research Project (and other research supported by the programme)	Initial Position before Joining Programme	Current Position
Pre-doctoral	Koranteng, Adofo*	MPH	2007	Injury Surveillance	Research Assistant, Department of Surgery, KNUST	Principal Research Officer, Department of Surgery, KNUST
	Kuutiero, Lillian	Long-term, non-degree training	2008	Laws on road safety	Participatory Development Associates (a local NGO)	Advocacy Officer, OXFAM, Ghana
	Yankson, Isaac *Note: also listed later for PhD, 2022*	MPH	2008	Press reporting of road traffic crashes in Ghana	Teacher, Senior secondary school, Kumasi	Senior Scientific Officer, BRRI
	Damsere-Derry, James*	MPH	2009	Pedestrian injury, speed control	Research Assistant, BRRI	Senior Research Officer, BRRI
	Asiedua, Jessie	MPH	2010	Childhood injury	Nursing Officer, Koforidua Hospital	Head, Nursing Training College, Nkawkaw
	Japiong, Kennedy	MPH	2014	Trauma care at the Ghana Police Hospital	Nursing Officer, Police Hospital, Accra	Officer-in-Charge of the Emergency Clinic of the National Police Headquarters
	Donkor, Isaac	MPH	2015	Distracted driving	Manager of Red Cross Services, Brong Ahafo Region	Eye Health Officer, Vision for a Nation Foundation, Accra
	Gyamfi, Adwoa*	MPH	2015	Electronic medical record use in Emergency Department of Komfo Anokye Teaching Hospital	Nursing Manager, Child Welfare Clinic, Agogo Presbyterian Hospital	Lecturer, Department of Nursing, KNUST
	Paitoo, Benjamin	MPH	2016	Occupational injuries Ghana Fire Service staff	Municipal Fire Officer, Ghana Fire Service, Obuasi	Lecturer, University of Energy and Natural Resources, Sunyani
	Agyemang, Eunice	MPH	2017	Workplace Violence	Nursing Officer, Department of Emergency Medicine, KATH	Health tutor, Koforidua Nursing Midwifery Training College

	Scholar	Degree	Year Received	Topic of Thesis Research Project (and other research supported by the programme)	Initial Position before Joining Programme	Current Position
Pre-doctoral	Boakye, Godfred	MPH	2017	Supply chain management in trauma care	Research Officer, Department of Surgery KNUST	Military officer, Ghana Armed Forces
	Budu Ainooson, Amy	MPH	2018	Dependency violence in women with disabilities	National Service Officer, Center for Disability Studies, KNUST	Behavior technician, Autism Compassion Africa, Cape Coast
	Appiah, Anthony Baffour	Mphil (UG)	2020	Association of head injury and helmet use among injured motorcyclists in northern Ghana	Research Assistant, Department of Surgery, University of Cape Coast	Research Assistant, Department of Surgery, University of Cape Coast
	Adjei, Benjamin Noble	MPH	2021	Factors affecting helmet use in northern Ghana	Research Assistant, School of Public Health UG	Head, Medical Records, Techiman Gov't Hospital
	Miilon, Sommik Duut	MPH	2021	Role of first responders in prehospital care	Ashanti Regional Administrative Manager, National Ambulance Service	Ashanti Regional Administrative Manager, National Ambulance Service
	Achempim, Emmanuel Asiedu	MPH	Pending	Epidemiological features and outcomes of occupants of auto tricycle crashes: a descriptive study of auto-tricycle related injuries in Kumasi	Administrator, Emergency Medicine Research and Innovation Office, Emergency Medicine Directorate, KATH	Mphil student
	Akorli, Ruth	Mphil	Pending	Impact of climate change on road traffic crashes	Teaching and Research Assistant, Department of Environmental Science, KNUST	Mphil student
	Appiah, Abigail	Mphil	Pending	Physical health consequences of traumatized elderly persons.	Nurse in charge, School Health Unit, North Suntreso Gov't Hospital	Mphil student
	Boateng, Patience Achiamaa	Mphil	Pending	Trauma-related amputations among children; experiences of children and caregivers post-amputation.	Senior Tutor, Nursing and midwifery training school, Fomena-Adansi	Mphil student
	Osei, Elizabeth	Mphil	Pending	Workplace violence against female health care	Tutor, Nursing and midwifery training college, Atibie	Mphil student
	Tetteh, Abigail Aban	Mphil	Pending	Traumatic Injuries in the Abattoir, A Case Study in Kumasi Abattoirs	Nursing Officer, Theatre Unit, Suntreso Government Hospital	Mphil student

	Scholar	Degree	Year Received	Topic of Thesis Research Project (and other research supported by the programme)	Initial Position before Joining Programme	Current Position
Post-doctoral	Ankomah, James	MPH	2010	Burn injury in Ghana	Medical officer, Dept of Surgery, KATH	Medical superintendent Goaso Municipal Hospital
	Gyedu, Adam	MPH	2012	Childhood injury (household surveys: peri-urban; rural) Trauma care capacity in Ghana; enumeration of all surgery performed in Ghana	Lecturer in Surgery, KNUST	Associate Professor in Surgery, KNUST
	Forson, Paa Kobina	MPH	2013	Effect of emergency medicine physicians at district hospitals	Resident in emergency medicine, KATH	Specialist-in-charge of Emergency Medicine, Offinso District Hospital
	Osei-Ampofo, Maxwell	MPH	2013	Injuries in pregnant women presenting to KATH	Resident in Emergency Medicine, KATH	Deputy Director, National Ambulance Service
	Yeboah, Dominic	MPH	2013	Preventable trauma death panel review at KATH	Medical Officer, Department of Surgery, KATH	Senior Lecturer and Consultant Surgeon: Orthopaedics and Traumatology, KATH
	Appiagyei, Helena Serwaa	MPH	2019	Occupational injuries to health workers in district hospitals	Medical Officer, Hope Exchange Medical Center, Kumasi	Senior Medical Officer, Hope Exchange Medical Center, Kumasi
	Boakye, Nathaniel Adu	MPH	2019	Violence against children	Medical Officer, Manhyia District Hospital, Kumasi	Medical Officer, Manhyia District Hospital, Kumasi
	Yempabe, Tolgou	MPH	2019	Utilization of traditional bonesetters in the Northern Region	Orthopedic Trauma surgeon, Tamale Teaching Hospital	Orthopedic Trauma surgeon, Tamale Teaching Hospital
	Larmie, Robert	Mphil	Pending	Impact of climate change on road traffic crashes; commercial drivers experience and perceptions	Senior Specialist, KATH	Mphil student

	Scholar	Degree	Year Received	Topic of Thesis Research Project (and other research supported by the programme)	Initial Position before Joining Programme	Current Position
PhDs	Nakua, Emmanuel	PhD	2018	Occupational injuries to goldminers	Lecturer, School of Public Health, KNUST	Professor and Head of Department, Biostatistics & Epidemiology, SPH, KNUST
	Okyere, Paul	PhD	2021	Seatbelt usage and promotion.	Lecturer, KNUST	Senior Lecturer, KNUST
	Yankson, Isaac Note: also listed earlier for MPH, 2008	PhD	2022	Occupational Injury Risks among Road Construction Employees	Scientific Officer, BRRI	Senior Scientific Officer, BRRI
	Karikari, Akua Kusiwaa	PhD	2023	Training for emergency nursing at district hospitals in Ghana	Deputy Director of Nursing Services, KATH	Deputy Director of Nursing Services, KATH
	Abebrese, Abena Kyerew	PhD	Pending	Violence among women; development and validation of a screening tool	Lecturer, Department of Nursing, KNUST	PhD student
	Amissah, John	PhD	Pending	Assess the emergency preparedness of the health system in road traffic trauma care in Ghana	Research officer, School of Public Health, KNUST	PhD student
	Bart-Plange, Akofa	PhD (UG)	Pending	Assessing the Responsiveness of EMS and Availability of Radiology Equipment in Healthcare Facilities for Injury Management in Ghana	Biomedical engineer and equipment consultant, The Gigaton Group	PhD student
	Boateng-Osei, Estella	PhD	Pending	Improving trauma care and safety among petty traders (hawkers) in the Ashanti region due to the rise in traffic accidents and injuries	Lecturer, Department of Nursing, KNUST	PhD student

BRRI: Building and Roads Research Institute; KNUST: Kwame Nkrumah University of Science and Technology; UG: University of Ghana;

*Obtained PhDs on own, after completing Fogarty-Quartey Programme.

Table 3. Selected workshops conducted by the Fogarty-Quartey Programme

	Title	Year	Partners	Location
Injury Control Courses in Ghana	Multi-sectoral Course on Injury Control	2006 (May), 2006 (Nov)		Kumasi
	Press Reporting on Road Safety	2007		Accra
	Injury Control for Parliamentarians	2009	Parliament	Accra
	Injury Surveillance	2011		Kumasi
	Injury Research	2012		Kumasi
	Injury Research for Northern Ghana	2016	UDS	Tamale
	Injury Research for the Coastal Area	2017	UCC	Cape Coast
	Strengthening Injury Prevention and Trauma Care	2017	CUCG	Fiapre
	Research for Trauma and Emergency Care in Northern Ghana	2017	UDS	Tamale
	Preventing Violence in Ghana	2018	WACS, Ghana Chapter	Kumasi
	Addressing National Surgical Disease Burden through Effective Planning	2019	WACS, Ghana Chapter	Accra
	Strengthening the Base of First Responders	2019		Kumasi
	Drowning Prevention	2020	UCC	Cape Coast
Research Courses for Residents	Research for KNUST Residents	2010, 2014, 2015		Kumasi
	Responsible Conduct of Research	2018		Kumasi
	Research Training for Residents	2018		Kumasi
	Research Supervision for Surgical Trainers	2018	WACS, Ghana Chapter	Accra
	Research Training for Residents	2019	WACS, Ghana Chapter	Accra
	Research: Ethics and Methodology	2022		Kumasi
	Biostatistics and Data Science	2022-2023		Kumasi

West Africa-wide Courses	Trauma System Planning	2012	WACS	Monrovia
	Trauma System Planning & Research Symposium	2013, 2014	WACS	Lome, Kumasi
	Trauma System Planning	2015, 2016	WACS	Abidjan, Yaounde
	Trauma Care Research	2017	WACS	Ougadougou
	National Surgical, Obstetric, and Anesthesia Plans	2019	WACS	Dakar
	Traditional Bone Setters: Train and link vs. Discourage and diminish	2020	WACS	Abuja
	How to Turn Your Dissertation into a Publication	2022	WACS	Monrovia

CUCG: Catholic University College of Ghana. UCC: University of Cape Coast. UDS: University of Development Studies. WACS: West African College of Surgeons.

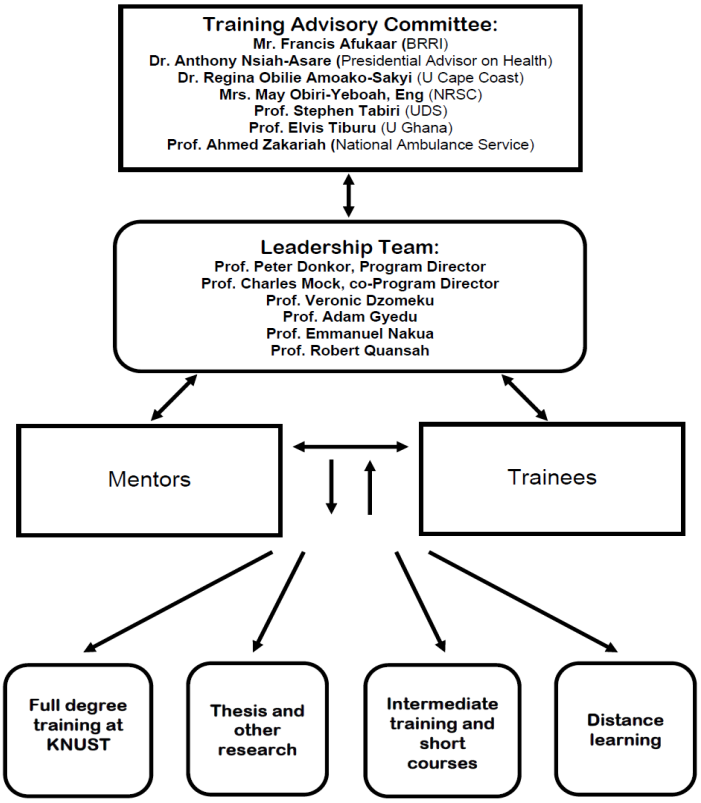

Figure 1: Administrative Structure of KNUST's Fogarty-Quartey Programme

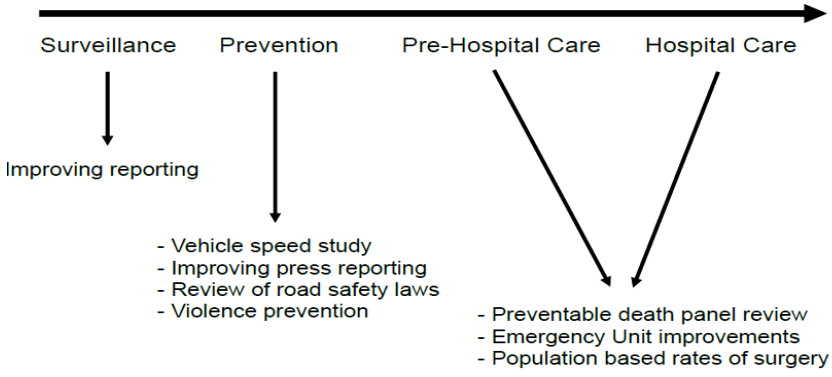

Figure 2: Spectrum of Injury Control: Examples of Research Activities**.**

Figure 3: Photograph of a campaign sign along Tamale-Kintampo road in 2016, showing people's demand for safety. Such demand has increased over time through the speed control advocacy undertaken as a result of James Damsere-Derry's studies on pedestrian safety.

The significance of carbonates in gold mineralization process of the Ashanti Gold Belt: Evidence from the country rocks of Ashanti and Prestea gold mines, Ghana

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Abstract

Mineralogical and textural changes which occurred in the country rocks (Sedimentary and volcanic rocks) following their deposition in the early Proterozoic resulted in the development of new minerals, disappearance of pre-existing minerals or recrystallization of the pre-existing minerals which led to the formation of siderite and ankerite among others. Electron microprobe analysis was carried out on carbonates in country rocks from Ashanti and Prestea mines of the Ashanti gold belt of the Birimian in southern Ghana. Results showed that the carbonates formed at about 350°C in the country rocks are probably related to hydrothermal activity which caused the alteration of these rocks. The alteration processes involved in the transformation were sulphidation, sericitization, rutile formation, silicification, carbonation, carbonitization and chloritization and some of these processes were related to major gold mineralization in the country rocks. The high content of Fe and Mg carbonates suggest the abundance and critical role of these minerals in the gold formation as this could be a factor in the abundance of Fe related minerals that contain gold in the country rocks.

Keywords: Alteration, siderite, ankerite, gold mineralization, Birimian, Ashanti, Prestea, Ghana

Introduction

Most of Ghana's economically viable mineral deposits including gold, bauxite, and manganese are hosted in the Paleoproterozoic Birimian sedimentary and volcanic rocks. The gold deposits and occurrences are largely associated with parallel northeasterly volcanic belts; namely the Kibi-Winneba, Ashanti, Sefwi, Bui, and Bole-Nangodi belts as well as the north-trending Lawra belt. The volcanic belts consist of low-grade metamorphosed basalts of originally predominantly tholeiitic composition (Abouchami et al. 1990) separated by basins consisting of isoclinally folded metasedimentary rocks composed of dacitic volcaniclastic rocks, wackes and volcanogenic argillites, which are derived from the belts (Leube et al.,1986, Abouchami et al., 1990, Lompo et al., 2009).

In the Birimian terrane, wall-rock alteration of the country rocks often took the form of pyritization, arsenopyritization, sericitization, chloritization, silicification and carbonitization and the processes or mechanisms responsible for these alterations and possible gold mineralization include hydrothermal activity, metamorphism and post-metamorphic deformation (Manu et al, 2013). The hydrothermal phase produced Fe- and Mg-rich chlorite, sulphide, sericite, siderite and ankerite, epidote and quartz during or after the prevalent metamorphism in the rocks (Manu et al, 2013). The Fe-rich carbonates form hydrothermal halos of variable sizes from few centimeters up to several tens of meters wide in wall rocks of gold deposits and occur in veinlets and disseminated throughout the ores (Mumin and Fleet, 1995).

The siderite and ankerite are carbonate mineralization which is usually associated with many mesothermal gold deposits of all ages worldwide, Phanerozoic (Sandiford and Keays, 1986; Panteleyev, 1990), Proterozoic (Leube et al., 1990; Leonardos et al., 1991; Mumin, 1994) and Archean (Colvine et al., 1988; Robert, 1991). In some places the carbonate minerals are primary constituents of the host and country rocks, or, more commonly, part of the secondary metamorphic mineral assemblage (Mumin and Fleet, 19995). Several research works have shown that compositional variations of individual carbonate phases are independent of changes in host rock, and vary little with pressure (Harker and Turtle, 1955; Goldsmith and Newton, 1969; Powell et al., 1984). The coexistence of some carbonate mineral pairs such ankerite-siderite and calcite-dolomite indicate cation variations may be sensitive to a wide range of temperatures (i.e. 350 to 400°C), making them potentially useful as geothermometers (Harker and Turtle, 1955; Hutcheon and Moore, 1973; Nesbitt and Essene, 1982; Essene, 1983; Powell et al., 1984; Anovitz and Essene, 1987).

Carbonate minerals of siderite and ankerites commonly occur in all country rock as well as in mineralized rocks both in the altered and unaltered varieties. The siderites and ankerites commonly occur in a wide range of composition and this property make them potential indicator minerals for change in physical and chemical parameters during the evolution of the hydrothermal system. Previous research in lode gold deposits have concentrated on their fluid inclusion or stable isotope systematics and Mumin and Fleet, 1995 reported on the compositional variation and zoning of these carbonates and reconstructed the thermal and chemical evolution of the Bogosu-Prestea hydrothermal system. In this study, we present data on microprobe analysis of siderite and ankerite to get a closer understanding of the processes associated with gold mineralization in the Birimian.

Geological setting

Regional Geology

The Birimian of Ghana is made up of metasedimentary and metavolcanic rock units (Figure 1). The Birimian metasedimentary units consist of phyllites, hornblende-actinolite schists, carbonate-chlorite schists and greywackes, and weakly metamorphosed tuffs, feldspathic sandstones and metamorphosed chemical sediments whilst the Birimian metavolcanic rocks contain most of metamorphosed rhyolitic and basaltic and andesitic lavas, minor amounts of metamorphosed rhyolitic and dacitic lavas and tuffs, Mn-rich and Si-rich chemical sediments also occur (Opare-Addo et al., 1993; Feybesse et al., 2006; Ibrahim et al., 2020; Sakyi et al., 2020; Sapah et al., 2021). Diabases and porphyries intrude the metavolcanic rocks (Eisenlohr, 1989; Nyame et al., 2020).

According to Ntiamoah-Agyakwa (1979), the Birimian rock unit about 10-15 km thick, generally dips to the southeast and is isoclinally folded. Two main types of granitoid intruded the Birimian. The Cape Coast type which is voluminous in mass, rich in aluminum (peraluminous) and intrudes the Birimian assemblage and the Dixcove granitoid type; smaller in mass and relatively Na-rich, may be contemporaneous with volcanism of the Birimian metavolcanics (Eisenlohr, 1989).

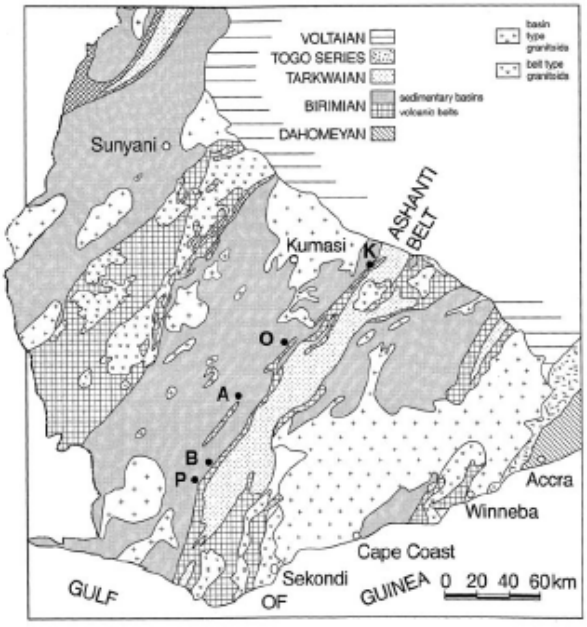

Figure 1: General geology of southern Ghana (after Leube and Hirdes, 1986, modified according to W. Hirdes and G. Loh, 1995). Locations of gold mines: K, Konongo;

O, Ashanti mine at Obuasi; A, Ayanfuri; B, Bogosu, and P, Prestea.

Local Geology

The Ashanti and Prestea mines are in a similar geological environment, the Ashanti belt. The Ashanti Belt generally assumes a synformal structure (Eisenlohr and Hirdes, 1992) and parts of the Birimian greenstones (metavolcanics/metavolcaniclastics) are overlain by a small unit of Tarkwaian metasedimentary rocks (Loh and Hirdes, 1996) which are intruded by mafic/ultramafic rocks (Dampare et al. 2008). The Birimian volcanic/volcaniclastic rocks and the mafic/ultramafic rocks were intruded by the Dixcove type granitoid (Opare-Addo et al., 1993; Feybesse et al., 2006).

According to Manu (1993), the metasedimentary rocks at both Ashanti and Prestea mines are mainly phyllites, metagreywacke and siliceous rocks. The phyllites megascopically, have a planar to crumple foliation. The evenly foliations with somewhat 'dull' lustre are pronounced in the grey-green to light green pure phyllite, ankerite phyllites and metagreywacke whereas the graphite phyllites, which is black in colour has a silky lustre (Manu, 1993). The phyllitic rocks, particularly the graphite ankerite phyllites occasionally contain millimeter big pyrites. The siliceous rock is black, hard and compact with foliation (Manu, 1993). The metavolcanic rocks are mainly metarhyolite. They are mainly grey-green, fine- to medium-grained, and massive and sometimes contain various sulphides including centimeter long arsenopyrite needles. The quartz reefs are grey, milky-white or glassy in colour.

Method

Fresh samples were taken from the Obuasi and Prestea mines and prepared into sections for microprobe analysis, using Cameca microbeam (Type Camebax MB) at the Geologische Institute, University of Hannover, Germany operated at a 15 KV accelerating voltage with 18 nA beam current.

Results and Discussion

Metamorphism of the country rocks

Mineralogical and textural changes occurred in the sedimentary and volcanic rocks following their deposition in the early Proterozoic. These changes were attained by the development of new minerals, the disappearance or recrystallization of the pre-existing minerals. Researchers have recognized contact and regional metamorphism in the Birimian. Local contact metamorphism (of the hornblende-hornfels facies) on the Birimian metavolcanic rocks caused predominantly by a tonalitic magma intrusion has been observed by Leube and Hirdes (1988) and is characterized by actinolite, epidote and albite minerals. Leube and Hirdes (1986) suggested that though the regional metamorphism grade varies between sub-greenschist (pumpellyite-prehnite) facies and amphibolite (almandine-amphibolite) facies, the bulk of the Birimian rocks is confined to the chlorite zone of the greenschist facies. Post-metamorphic shear zones have been recognized in the dormant and existing mines and can be interpreted as ductile to brittle deformation styles. Microscopically, the shear or deformation zones are characterized by elongate mineral grains or aggregate or deformed grains in the country rocks or differences in deformation intensity in the later formed quartz veins.

Hydrothermal alteration

Carbonates are widespread alteration minerals reported in the mines in Ghana and their formation is attributed to hydrothermal event. They are formed in S_2 and probably in pre-S_2 (i.e. S_1) deformation planes (Figure 2). This means that the formation conditions of the carbonates can be conveniently related to the hydrothermal event, which occurred after S_1. Cooper (1934) and Afenya (1976) termed the carbonates at Prestea mine as ankerites and additional carbonate as siderite was found by Adjimah (1988). Similar carbonates reported at the Ashanti mine are ankerites and ferroan dolomite by Gyapong (1980) and siderite and ferroan dolomite by Hirdes and Leube (1989). Since the compound $CaFe(CO_3)_2$ does not exist (Reeder, 1983), phases with this molecule have been referred to by various writers as ankerites and ferroan dolomite because there are no strict rules. Using the

popular preference and suggestion by Reeder (1983) that the term ankerites be used for more Fe-rich phases and ferro and dolomite for less Fe-rich phases, the presented series here (i. e. the $Ca(Fe,Mg)CO_3$ (see Table 1) are Fe-rich phases. Hence they are termed ankerites. Tables 1 and 2 show that the analysed carbonates are ankerites and siderite respectively, with slight enrichment in magnesium. The siderites tend to be more enriched in Mg than the ankerites. The reported carbonates at Prestea and Obuasi contrast slightly with those given here (Tables 1 and 2), due to the bulk analytical technique (namely X-ray diffraction and wet chemical methods) for the reported carbonates, which disregards textural and compositional differences compared to the electron microprobe analyses for those in Tables 1 and 3. The presence of the slightly enriched magnesium content in the siderites and ankerites is explained by the generally accepted complete substitution of Mg for Fe which exists in these minerals (Deer et al., 1963). The total carbonate composition (in mole %) was plotted in a triangular diagram in Figure 4. The siderites and ankerites show only little range in composition among themselves and no trend in composition towards one another (Figure 4). This suggests distinct generations for the carbonates. There are carbonates with "zoning" beside the homogeneous ones (e.g. 18/OB/310/6 in Obuasi and 23/307/10 in Prestea). Microprobe analyses of one such "zoned" mineral (e.g. Mg-siderite in 18/OB/310/6 of Table 3) showed no chemical variations in MgO, FeO, CaO or MnO content between the core and the margin. The "zoned" appearance is probably due to the incorporation of carbonaceous materials in the core of the mineral during the early stages of their formation (Figure 3). This explanation is also supported by the fact that the "zoning" is more clearly seen microscopically when the carbonaceous material in the rock is high (compare 23/301/6 and 23/307/3). In Table 1, the maximum $FeCO_3$ content of the magnesian ankerite is less than 25 moles %. This corresponds to the experimental work by researchers such as Rosenberg (1967): Bickle and Powell, 1977; Powell et al. 1984, who found that ankerites with $FeCO_3$ < 25 mole % ($MgCO_3$- and $CaCO_3$- contents not given) are formed at about 350°C. Three samples (18/OB/310/6, 33/OB/138/10 and 23/301/6) have co-existing siderite and ankerites (Tables 1 and 2). The $FeCO_3$ mole content in the siderites suggest that the carbonates were formed at about 350°C. Since carbonates were also formed in S_1 and S_2 planes, the formation temperature at about 350°C for the carbonates is deduced to represent the temperature of the hydrothermal alteration event.

Figure 2: Photomicrograph of phyllite showing crenulation cleavage. Sample 38/OB/155/6

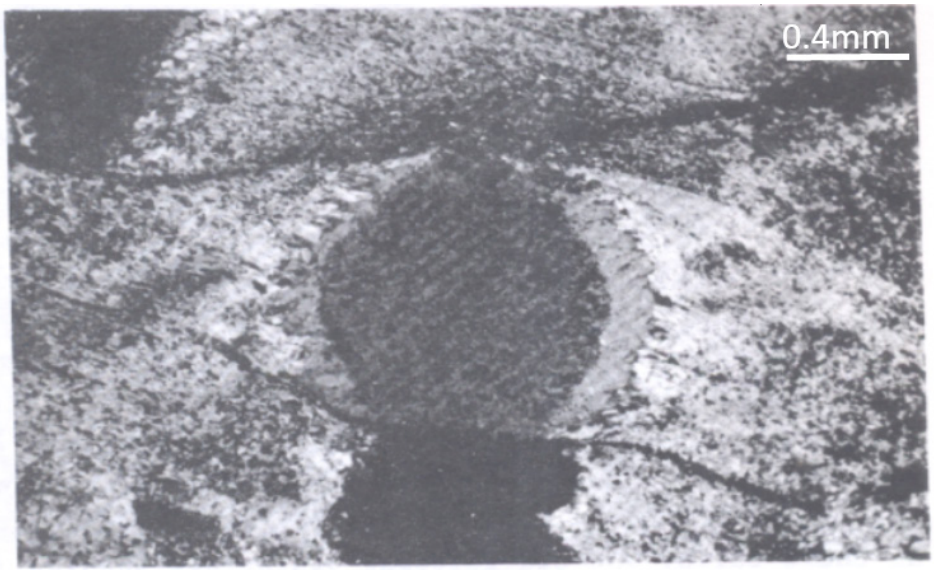

Figure 3: Porphyroblastic ankerite mottled at its core by opaques. Also at its margin are quartz and sericite intergrowth. Sample 23/308/4

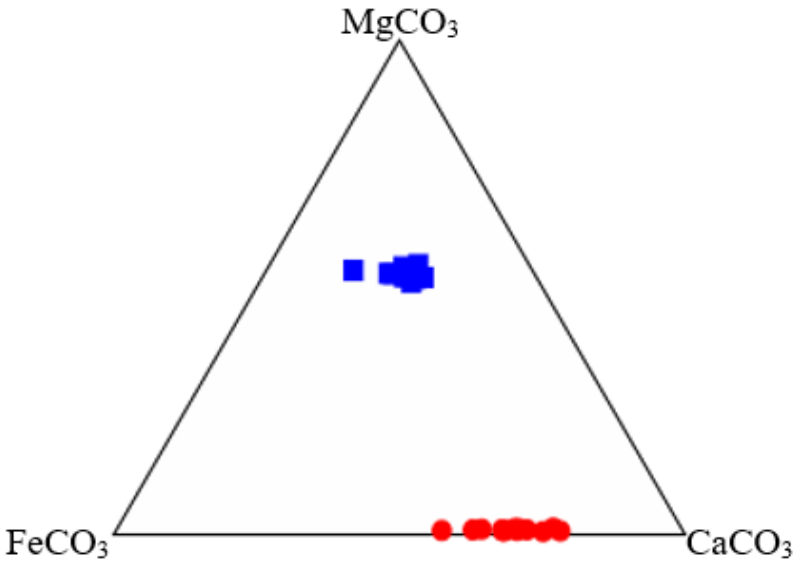

Figure 4: Analyses of carbonates from the country rocks in the system MgCO3-FeCO3-CaCO3. ● Siderite and Ankerite ■

Table 1: Microprobe analyses of ankerites in country rocks from Ashanti and Prestea mines.

	33/ OB/10			**18/OB/310/1**			**18/ OB/310/14**			**23/301/6**	
FeO	14.56	17.12	14.82	16.85	15.58	16.13	16.61	18.16	16.44	9.95	13.78
MnO	0.29	0.31	2.3	0.66	0.59	0.06	0.62	0.67	0.46	0.58	0.46
MgO	11.73	10.57	10.19	9.79	10.61	10.51	9.07	9.28	10.36	14.76	11.78
CaO	29.62	28.65	29.53	28.28	28.4	29.08	30.47	29.18	29.21	29.74	28.966
SiO_2	0.02	0	0.12	0.04	1.52	0	0.06	0	0.09	0.95	0.3
Al_2O_3	0.01	0	0	0.05	0.02	0.04	0	0.02	0.02	0.01	0.1
*CO_2	43.71	43.27	43.03	44.29	43.2	43.59	43.17	42.65	43.36	43.94	44.49
Sum	99.94	99.93	99.99	99.96	99.91	99.41	99.99	99.96	99.94	99.94	99.87
Wt%											
$FeCO_3$	23.48	27.62	23.9	27.18	25.13	26.02	26.8	29.29	26.52	16.06	22.22
$MnCO_3$	0.47	0.51	3.73	1.07	0.95	0.09	1	1.09	0.75	0.94	0.75
$MgCO_3$	24.52	22.11	21.31	20.47	22.18	21.98	18.96	19.4	21.67	30.87	24.64
$CaCO_3$	52.88	51.13	52.71	50.48	50.69	51.91	54.39	52.09	52.14	53.08	51.69
Mole%											
$FeCO_3$	19.56	23.25	20.02	23.45	21.59	22.16	22.74	24.74	22.38	13.12	18.85
$MnCO_3$	0.43	0.48	3.52	1.04	0.92	0.09	0.96	1.04	0.7	0.87	0.72
$MgCO_3$	28.9	2.33	25.25	24.98	26.96	26.48	22.76	23.18	25.87	35.32	29.57
$CaCO_3$	51.11	49.94	51.22	50.52	50.53	51.28	53.54	51.04	51.05	50.32	50.86
Cations											
Fe^{2+}	0.4	0.47	0.41	0.47	0.44	0.45	0.46	0.5	0.45	0.27	0.38
Mn^{2+}	0.01	0.01	0.06	0.02	0.02	0	0.02	0.02	0.01	0.02	0.01
Mg^{2+}	0.57	0.52	0.5	0.49	0.53	0.52	0.45	0.45	0.51	0.7	0.58
Ca^{2+}	1.03	1.01	1.04	1.02	1.02	1.03	1.08	1.03	1.03	1.02	1.03
Total	2.01	2.01	2.01	2	2.01	2	2.01	2	2	2.01	2

Total Fe as FeO

Table 2: Microprobe analyses of siderites in country rocks from Ashanti and Prestea mines.

	23/308/3			33/OB/138/12					23/301/6	33/OB/10	23/307/10	18/OB/310/1	
FeO	43	38.56	41.8	38.59	42.36	45.08	43.8	43.74	35.61	41.75	46.68	39.53	47.13
MnO	0.37	0.68	0.44	0.57	0.35	0.68	0.68	0.4	0.22	0.39	0.66	0.25	0.95
MgO	13.06	16.58	14.55	16.811	14.65	12.76	13.56	13.77	19.73	14.62	11.45	16.27	10.29
CaO	0.46	0.35	0.28	0.39	0.24	0.39	0.31	0.48	0.27	0.34	0.15	0.45	0.57
SiO_2	0.54	0.03	1.15	0.78	1.12	0.76	0.12	0.04	0.1	0.69	0.09	0.3	0.04
Al_2O_3	0.4	0	0.28	0.41	0	0.05	0.02	0	0.01	0.65	0.03	0.14	0
$*CO_2$	42.04	43.73	41.47	42.07	41.23	40.24	41.31	41.57	44	41.33	40.94	42.99	40.96
sum	99.87	99.93	99.97	99.62	99.95	99.96	99.79	100	99.92	99.77	99.99	99.93	99.95
wt%													
$FeCO_3$	69.36	62.19	67.42	62.24	68.33	72.71	70.64	70.55	57.43	67.34	75.29	63.77	76.02
$MnCO_3$	0.6	0.68	0.72	0.93	0.57	1.1	1.1	0.65	0.35	0.63	1.06	0.41	1.55
$MgCO_3$	27.31	16.58	30.42	35.5	30.63	26.69	28.35	28.8	41.25	30.57	23.94	34.03	21.52
$CaCO_3$	0.82	0.35	0.5	0.69	0.43	0.69	0.56	0.85	0.48	0.61	0.27	0.79	1.02
Mole%													
$FeCO_3$	63.27	54.93	60.69	54.68	60.69	54.68	64.63	62.72	62.43	60.13	68.03	56.29	69.49
$MnCO_3$	0.6	1.1	0.72	0.92	0.72	0.92	1.1	1.1	0.65	0.63	1.08	0.41	1.59
$MgCO_3$	35.24	43.33	38.08	43.7	38.08	43.7	33.56	35.61	36.05	38.61	30.61	42.5	27.83
$CaCO_3$	0.9	0.64	0.51	0.7	0.51	0.7	0.71	0.58	0.87	0.63	0.28	0.8	1.08
Cations													
Fe^{2+}	1.3	1.11	1.22	1.11	1.23	1.31	1.27	1.26	1	1.22	1.37	1.14	1.4
Mn^{2+}	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.03
Mg^{2+}	0.69	0.85	0.76	0.86	0.76	0.66	0.7	0.71	1	0.76	0.6	0.84	0.55
Ca^{2+}	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02

Total Fe as FeO

Table 3: Microprobe analyses of "zoned" siderite in country rock sample 18/OB/310/6

	Core		**Margin**	
FeO	47.29	46.57	45.96	45.96
MnO	0.76	0.78	0.29	0.15
MgO	11.32	11.5	11.96	12.13
CaO	0.33	0.47	0.61	0.52
SiO_2	0.02	0.02	0.27	0.13
Al_2O_3	0	0	0.04	0
$*CO_2$	40.23	40.64	40.76	40.98
Sum	99.95	99.96	99.89	99.87
Wt%				
$FeCO_3$	76.28	75.11	74.14	74.14
$MnCO_3$	1.24	1.27	0.46	0.24
$MgCO_3$	23.67	24.04	25.02	25.36
$CaCO_3$	0.58	0.83	1.09	0.93
Mole %				
$FeCO_3$	68.2	67.35	66.6	71.24
$MnCO_3$	1.25	1.28	0.47	0.27
$MgCO_3$	29.95	30.5	31.14	27.46
$CaCO_3$	0.61	0.87	1.14	1.04
Cations				
Fe^{2+}	1.38	1.36	1.35	1.34
Mn^{2+}	0.02	0.02	0.01	0
Mg^{2+}	0.59	0.6	0.62	0.63
Ca^{2+}	0.01	0.02	0.02	0.02
Sum	2	2	2	1.99

Total Fe as FeO

Gold mineralization

Petrographic investigation by Manu et al. (2013) suggests that the metasedimentary and metavolcanic rocks in the Birimian gold belt are transformed mainly by metamorphism and to a lesser extent by hydrothermal activity. The alteration processes involved are silicification, sulphidation, rutile-formation, sericitization, carbonation, and different stages of chloritization and some of these processes are related to the main gold mineralization in the country rocks. Several works elsewhere (e.g. Kiefer, 2004) have shown the importance of carbonate formation in gold mineralization. For example, high CO^2 content in hydrothermal fluid has been shown to aid in the formation of ferroan dolomite associated with gold mineralisation (e.g. for Golden Mile deposit; Philips & Brown, 1987 and Blue Dot Mine; Adomako-Ansah et al., 2013). From this study, the abundance of carbonate minerals (ankerites and siderites) in the Birimian formed at about 350°C gives further indication of high CO^2 content in the hydrothermal fluid that deposited the gold and this suggestion is further buttressed by fluid inclusion studies at Ashanti, Prestea and Mpesatia gold mines in Ghana that have indicated the abundance of high CO^2 content in the gold mineralization fluids (e.g. Manu, 1993; Leube and Hirdes, 1990). Zoned siderite (Table 3) showed enrichment in Fe and this composition indicates Fe substitution among other minerals and that gold mineralization and the carbonate alteration might not have been in a stable phase with the ore-bearing fluid.

Implications of carbonates for gold exploration

Major gold deposits found in the Ashanti belt of the Birimian of southwestern Ghana have been found to be associated with arsenopyrite, chalcopyrite and pyrite (Dzigbodi-Adjimah, 1993) and these minerals have been used as pathfinders which have led to exploration success in the Birimian of southwestern Ghana. Since from this study, the sulphides together with the carbonates (siderites and ankerites) were produced by the same hydrothermal activity which brought about the gold mineralization, the carbonates could be a useful guide and could be employed in existing mines and for future exploration work in the Ashanti belt and the Birimian of Ghana in general.

Conclusion

From the study, carbonates in the country rocks of Ashanti and Prestea mines in the Ashanti gold belt of the Birimian of Southern Ghana can be related to hydrothermal activity. The hydrothermal activity altered the country rocks and introduced the carbonates, and this carbonitization process is related to the main gold mineralization in the country rocks. Other alterations caused by the hydrothermal activity which led to the gold mineralization include sulphidation, carbonation and chloritization. It can therefore be said that the carbonates and gold were deposited under similar conditions as those of the hydrothermal activity.

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Conflict of interest

The authors declare that they have no competing interests.

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Manuscripts reporting studies involving human participants, human data, human tissue or animals, must:

- include a statement on ethics approval (even where the need for approval was waived) and consent (in the case of human subjects)
- include the name of the ethics committee that approved the study and the committee's reference number if appropriate.

Sections heading

Sections should not be numbered. The subsections may be given a brief heading, with each heading appearing on a separate line.

Presentation

Font, Times New Roman, 12: double spacing, maximum of 15 pages (including references Figures and Tables). All "et als" must be italicized.

Referencing

The APA (American Psychological Association) referencing style must be used. For detailed information, please see the publication manual of the American Psychological Association, 6th edition, http://www.apastyle/org/ and http://blog.apastyle.org/ or the Taylor and Francis summary given here (http://www.tandf.co.uk/journals/authors/style/reference/tf_APA.pdf). References should be listed alphabetically and should not be numbered. See examples below

Book

Calfee, R. C., & Valencia, R. R. (1991). *APA guide to preparing manuscripts for journal publication.* Washington, DC: American Psychological Association.

Journal article

Kernis, M. H., Cornell, D. P., Sun, C. R., Berry, A., Harlow, T., & Bach, J. S. (1993). There's more to self-esteem than whether it is high or low: The importance of stability of self-esteem. *Journal of Personality and Social Psychology, 65,* 1190-1204.

Electronic source

Eco, U. (2015). How to write a thesis [PDF file]. (Farina C. M. & Farina F., Trans.) Retrieved from https://www.researchgate.net/...How_to_write_a_thesis/.../Umberto+Eco-How+to+Write+... (Original work published 1977).

Preparing figures

When preparing figures, please follow the formatting instructions below:

- Figures should be embedded in the main manuscript file (maximum five figures)
- All figures should be referred to in the text
- Each figure should be closely cropped to minimize the amount of white space surrounding the illustration
- Multi-panel figures (those with parts a, b, c, d etc.) should be labelled appropriately
- Figures should be numbered in the order they are first mentioned in the text, and uploaded in this order
- Figures should be in the correct orientation
- Figure titles (max. 15 words) and legends (max. 150 words) should be provided in the main manuscript
- Figure key should be incorporated into the graphic and not into the legend of the figure
- Individual figures should not exceed 10 MB. If a suitable format is chosen this file is adequate for extremely high quality figures.
- Please note that it is the responsibility of the author(s) to obtain permission from the copyright holder to reproduce figures (or tables) that have previously been published elsewhere. In order for all figures to be open access, authors must have permission from the rights holder if they wish to include images that have been published elsewhere in non-open access journals. Permission should be indicated in the figure legend, the original source included in the references list.

Figure file types

We accept the following file formats for figures:

- TIFF (suitable for images)
- JPEG (suitable for photographic images, less suitable for graphical images)
- PNG (suitable for images)
- BMP (suitable for images)
- CDX (ChemDraw- suitable for molecular structure)

Figure size and resolution

Figures are resized during publication detailed below:

Figures on the web:

- Width of 600 pixels (standard), 1200 pixels (high resolution)

Figures in the final PDF version:

- Width of 85 mm for half page width figure
- Width of 170 mm for full page width figure
- Maximum height of 225 mm for figure and legend.
- Image resolution of approximately 300 dpi (dots per inch) at the final size

Figures should be designed such that all information, including text, is legible at these dimensions. All lines should be wider than 0.25 pt when constrained to standard figure widths. All fonts must be embedded.

Preparing Tables

When preparing tables, please follow the formatting instructions below:

- Tables should be numbered and cited in the text in sequence using Arabic numerals (i.e. Table 1, Table 2 etc.)
- Table titles (max. 15 words) should be included above the table and legends (max. 150 words) should be included underneath the table
- Tables should not be embedded as figures or spreadsheet files, but should be formatted using 'Table object' function in your word processing program
- Tables should be included in the main manuscript file.
- Colour and shading may not be used in the tables. Parts of the table can be highlighted using superscript, numbering, lettering, symbols or bold text, the meaning of which should be explained in a table legend
- Commas should not be used to indicate numerical values

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