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Research Article

Spatial Variations in Aquatic Insect Community Structure in the Winam Gulf of Lake Victoria, Kenya

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Background. Aquatic insect community structure is dynamic due to threats by anthropogenic activities coupled with changing climatic conditions. The insect's survival is dependent on the substrate, water quality, and environmental effects. The changes in water quality influence their distribution and abundance and are reflected in spatial and temporal trends. This study sought to document the effects of spatial variation on aquatic insects in Winam Gulf of Lake Victoria, Kenya. *Materials and Methods*. Systematic random design was used in sampling, and water quality parameters were assessed. Insects were sampled by profundal lake procedure, pooled, sorted, and identified based on the morphological approach and diversity indices analyzed. The relationship between insects and water quality was established. *Results*. Statistical homogeneity in water quality parameters was documented with the exception of nitrates, nitrites, soluble reactive phosphorus, ammonium, and silicates, which displayed significant variation at $p < 0.05$. A total of 383 individual insects representing 19 species, 19 genera, 16 families, and six orders were obtained from Winam Gulf. *Hemiptera*, *Ephemeroptera*, and *Diptera* were the most predominant orders, respectively. *Chironomus* spp. and *Ablebesmyia* spp. were representatives of the *Chironomidae* family. Species distribution and water quality were determined using cluster analysis (CA) and conical correspondence analysis (CCA). *Conclusion*. The findings of this study demonstrated that spatial variations were associated with change in water quality and had a corresponding influence on insect community structure.

1. Background

Freshwater ecosystems are a powerhouse of biodiversity, currently threatened by environmental perturbations associated with human-induced activities [1–7]. The disturbances in freshwater ecosystems alter natural biogeophysical processes through increased eutrophication, acidification, and input of toxic pollutants [8–11]. Lake Victoria ecosystem is no exception [12–19]. The changes in catchment land use and riparian vegetation, coupled with downstream sedimentation, nutrient loading, and siltation of both organic and inorganic materials have negatively affected water quality variables and the lake's biodiversity [20–23]. The cumulative effect of anthropogenic activities influences ecosystem productivity, population dynamics, species composition, and the genetic diversity of the aquatic flora and fauna [24–29]. In addition, hydrogenic activities have led to massive biodiversity dysfunction and alteration of community structure and functions [30–36].

Previous studies have shown a pollution-linked decline in population dynamics of both vertebrates and invertebrates including insects utilized as food and feeds by riparian communities [23, 37–44]. The dynamics negatively affect the ecological integrity of large water bodies such as Lake Victoria [45–47]. Most previous studies on documentation of spatial assemblages have concentrated on macroinvertebrates with little attention to insects [48–53]. Data on the spatial and temporal analysis of pollution indicator species such as insects remain obscured, particularly in the use of larval stages of insects rather. However, analysis of the submerged larval stages of insect growth may offer useful information for the sustainable management of such water bodies [54, 55]. Insect larval stages of growth are diverse, ultrasensitive, and rich providing a perfect biomonitoring tool [56–61]. This study investigated the spatial distribution of aquatic larval insect assemblages in relation to pollution levels in offshore and inshore ecosystems of Lake Victoria, second-largest freshwater lake in the world.

2. Materials and Methods

2.1. Study Area. Aquatic insect samples were obtained from Winam Gulf of Lake Victoria (Figure 1). The gulf is a semienclosed bay, with an area of 1400 km^2 on the Kenyan side of the lake [62], which connects to the main lake trough Rusinga channel and extends as a shallow indented bay with a depth of 2–4 m eastwards to Kisumu [63]. The shoreline is approximately 500 km long with flat sandy or muddy areas, the latter being predominant in sheltered bays. The climate is tropical and is marked by four seasons annually: short rains, long rains, short dry, and the long dry seasons. The annual temperature range is 18.6–25°C and average annual rainfall is 886–2609 mm [64]. Four inshore and two offshore sampling stations were identified based on reported pollution gradient as outlined in Table 1 [65]. Out of the four, inshore points included Kisumu Bay, Kendu Bay, and Homa Bay, which had a surrounding with suburban human settlement with more anthropogenic activities and point pollution from sewage treatment plants and one fishing landing station (Dunga Beach). Two offshore sampling stations identified as Maboko Island were located at the heart of Kisumu Bay and Ndere Island within the Ndere National Park with relatively less polluted water. The Kenya Fisheries Service Kisumu Center provided a motor boat on hire that helped reach the inshore sites.

2.2. Experimental Design. A systematic random design was used in the sampling. Approximately 50 m belt along the lake shores was estimated and a first point was randomly located at the center. A transect was developed across and three points were identified for random sampling of water and sediments in triplicates. The samples were pooled to obtain composite homogeneous sample for physical and chemical analysis. Insect samples were collected from three sampling points on the transects and pooled together to form a representative sample for the stations. The *in situ* parameters (water temperature in degrees Celsius, pH, electrical conductivity in μs·cm^{-1}, dissolved oxygen in mg/l, ORP, total hardness in mg/l, total alkalinity in mg/l, salinity, and total dissolved solids in mg/l) were measured and recorded at each sampling point.

2.3. Sampling. In situ variables measured included temperature, pH, electrical conductivity, dissolved oxygen (DO), and turbidity using water quality multiparameter instrument, the YSI Pro DSS (digital sampling system). Secchi depth was measured using a standard Secchi disk of 20 cm diameter, with quadrants painted in black and white. Turbidity was measured using a 2100Q Hach Turbidometer while pH was measured using model 8685 AZ IP65 pH meter. Depth, temperature, conductivity, and phytoplankton biomass (chlorophyll a) were measured using a submersible conductivity-temperature-depth profiling system (CTD, Sea-bird Electronics®), programmed to take measurements at 5 seconds intervals. Total suspended solids and total dissolved solids were determined using gravimetric method [66]. Total alkalinity was measured based on titration of water sample to designated pH using dilute sulphuric acid (0.1 N or H_2SO_4) equivalent to 5 mg of $CaCO_3$ and 1 ml of 0.02 N H_2SO_4 equivalent to 1.00 $MgCaCO_3$ and then measured by phenolphthalein by titration to pH 8.3 using a digital titrator. Total hardness was determined by titrating the standard solution of ethylene diamine tetra acetic acid (EDTA) in the form of disodium salt of EDTA which is a complexing agent titration as outlined in [67].

Water samples for nutrient analyses were collected using 2.2-liter vertical water bottle and a Van-dorm sampler into 2.5 L amber bottles, which were prewashed with distilled water and dried. Each sample was treated with 1 g mercuric chloride and mixed for 5 minutes to kill microorganisms that could lead to degradation. The sterilized samples were kept in an icebox containing ice blocks and later stored in a refrigerator at 4°C prior to extraction.

A profundal lake sampling procedure was employed for insect samples as outlined in the standard SFS 5076, 1989 [68]. A boat was used to reach a 50 m distance inshore for littoral zone sampling. At the anchoring site, Ekman grab-Birge dredge sampler was used to make random triplicate grabs of submerged insect larvae placed into the plastic bucket through a bucket sieve with a mesh and pooled to obtain a composite sample. The contents emptied for sorting aided by washing the bottle to flash the remaining content using alcohol, were placed in paper slips and labeled (location, date, time, collector, sampling method, habitat, habitat description, weather and photographs of every site taken, and sample number), were filled with 80% alcohol as in ISO-EN 5667-3, 1994 [69], and were closed and packed in readiness for transportation in cooler boxes at 20°C. Sampling was carried out in the morning hours between 7 am and 11.30 am.

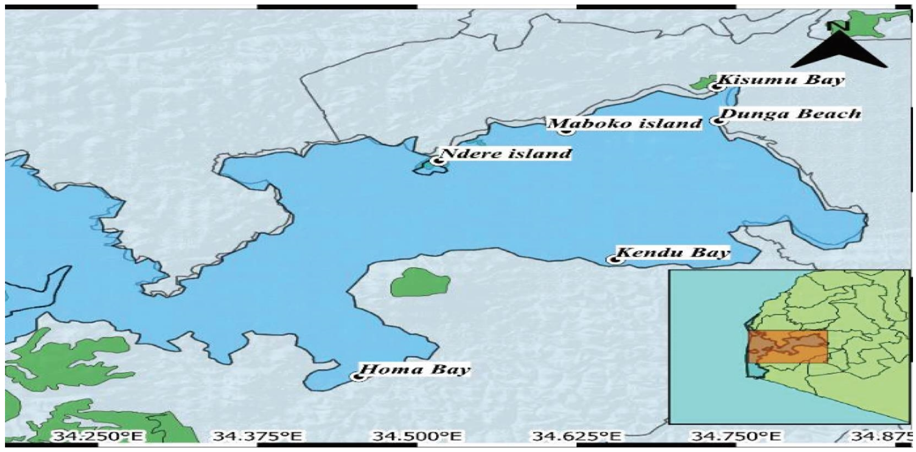


Figure 1: Map of Winam Gulf in western Kenya showing the exact sampling stations of aquatic edible insects. The sampling stations included inshore stations (Kisumu, fish landing beaches, Homa Bay, and Kendu Bay) and offshore stations (Maboko Island and Ndere Island).

2.4. Sample Processing. Nutrient analysis was performed as outlined in [70, 71]. Samples were pretreated and analysis was performed using the spectrophotometric techniques. Each analysis was performed in triplicate, and the average value was recorded. Ammonia (NH_4-N) content was analyzed using the London phenol method/phenate method involving oxidation with sodium hypochlorite and phenol solution while nitrates (NO_3-N) and nitrites (NO_2-N) were analyzed using the cadmium-reduction method [72]. Total nitrogen (TN) and total phosphorous (TP) were determined on unfiltered water samples. Digestion of TN with potassium per sulfate and autoclaving process was carried out to convert organic nitrogen to nitrate nitrogen while TP was oxidized using hot 5% potassium per sulfate in distilled water, autoclaved, and then further cooled at room temperature to liberate organic phosphorus as inorganic phosphate. Soluble reactive phosphorous (PO_4-P) was analyzed using the ascorbic acid method. Silicates were analyzed using the heteropoli blue technique according to [73].

Insect community composition analysis was performed using three insect's samples from each station which were pooled and emptied into a bucket, and the content was sieved into white enamel trays through kitchen sieves. Separation of the aquatic invertebrates was performed using the forceps. Sorting was performed to obtain rough morphtypes as per the orders. Further sorting involved morphological identification, which was performed by observation of external features using magnifying lenses (×10) and (×15) and a Nikon SM Z660 Zoom stereo binocular microscope (with a zoom range of ×0.8–5 with eye piece lens of ×10 and working at a distance of 115 mm with a zoom ratio of 6.3 : 1). The larvae body parts observed included the head, head capsule, thorax, abdomen, and legs for identification into orders, genus, and species level.

The sorted insects were transferred into the vials (screw capped vials containing 70% ethanol) with inner seals or neoprene/rubber stoppered to avoid evaporation of alcohol. A well labeled vial (including specimen identity, date of collection, and name of collector and site of collection) containing insects were stored in cool and dark cabinets. Identification guides were used for taxonomic work as outlined in [74–82]. The para-taxonomic analysis was undertaken as outlined in [82], followed by taxonomic work using the primary identification guides [83–86]. The non-biting midge-*Chironomidae*, a bioindicator and a representative sample isolated across all stations, was used for heavy metal analysis, nutritional status analysis, and molecular analysis. Preliminary laboratory work was performed within 15 days in preparation for comprehensive analysis.

2.5. Data Analysis. Descriptive statistics were employed to evaluate data on physical and chemical parameters, across stations. ANOVA at 95% confidence level was used to establish variations among stations followed by Tukey's post hoc test to find any existing significant variations. Cluster analysis was then undertaken to establish similarities and differences among the physical and chemical parameters.

The composition of aquatic insects was independently analyzed based on morphological approach and expressed as a percentage. The species richness and relative abundance of the insect taxa were evaluated using PAST statistical tool version 4.03. Simpson's index (D), Simpson diversity index ($1 - D$), and Shannon–Weiner diversity indices (H) were calculated, following [87–90]; Pielou's evenness index (J) and Shannon equitability index (E) were determined using PAST statistical tool version 4.03. One-way analysis of variance (ANOVA) of the insect community was performed. The existing relationships amongst the insect communities were determined using Pearson's correlation coefficient (r) and cluster analysis (CA). Conical correspondence analysis (CCA) was used to elucidate the relationships between insect's abundance and the water quality parameters [91].

3. Results

Freshwater hosts approximately 10% of the world's biodiversity [92–95] with 64% of the animal biodiversity being aquatic insects [96]. Currently, the aquatic insects comprise of more than 88,500 species from approximately 13 orders

Table 1: The GPS, substrate type, and anthropogenic and ecological activities of sampling stations.

Sampling stations	Inshore or offshore	Geo-reference point	Elevation (m)	Surrounding site characteristics
Maboko Island	Offshore	00°09′34.14″S, 034°37′0.18″E	1134	Human settlements, hotels, fish landing, and slightly disturbed
Kisumu bay	Inshore	00°05′41.16″S, 034°44′5.16″E	1134	Treated sewage discharge and sublittoral vegetation
Fish landing beach	Inshore	00°08′42.2″S, 034°44′11″E	1134	Human settlements, Phytoplankton blooms, and fish landing
Ndere Island	Offshore	00°12′14″S, 034°31′01″E	1134	Government protected park and largely undisturbed
Kendu bay	Inshore	00°20′58.26″S, 034°39′19.26″E	1139	Littoral and sublittoral vegetation and floating vegetation
Homa bay	Inshore	00°31′18″S, 034°27′15″E	1133	Human settlements, treated effluent disposal, and fish landing

[97–99]. The major taxa include *Coleoptera*, *Diptera*, *Ephemeroptera*, *Hemiptera*, *Lepidoptera*, *Megaloptera*, *Neuroptera*, *Odonata*, *Plecotera*, and *Trichoptera* [100]. Four of the major species which include *Ephemeroptera*, mayflies; *Plecoptera*, stoneflies; *Tricoptera*, caddisflies; and *Odonata*, dragonfies are sensitive to pollution and habitat degradation, while other orders such as *Diptera* are pollution tolerant [101, 102]. The knowledge to understand the patterns is vital as the insects serve as indicator species [95, 96, 103–105]. Their distribution patterns and community structure as a whole are dependent on the environmental factors. Therefore, alterations are expected due to the changing climatic conditions attributed to global warming from the rising populations projected to 9.8 B in 2050 [106]. In addition, divergences and convergences are likely to occur attributed to evolution, hence the need to address the biodiversity crisis [92–94] by mitigation and conservation of inland waters. Assessment of the distribution patterns offer guidance of the strategies to be used. The knowledge to understand the biodiversity patterns in the second largest lake in the world is obscured. However, the lake is a hub of insects that provide an alternative protein-rich source as live feed and food; the *Chironomus* spp. is pollution tolerant and couples as a bioindicator. The current research sought to document the effects of spatial variation on the aquatic insects in Winam Gulf of Lake Victoria.

3.1. Physicochemical Characteristics. The physical and chemical water quality parameters from the six sampling stations were analyzed and expressed as mean ± SE as shown in Table 2. The significantly ($p < 0.05$) lowest ambient water temperature was experienced at fish landing beaches (26.00 ± 0.59°C), while the highest was at Ndere Island (27.73 ± 0.75°C). The water samples recorded a weakly alkaline pH ranging from 6.34 ± 0.13 (Maboko Island) to 8.17 ± 0.11 (Homa Bay station). Kendu Bay station posted the highest electrical conductivity (EC) of $201.97 \pm 59.88\,\mu S{\cdot}cm^{-1}$, while the fish landing beaches had the least value of $128.50 \pm 3.45\,\mu S{\cdot}cm^{-1}$. Dissolved oxygen (DO) levels varied significantly ($p \leq 0.05$) between stations with the highest being experienced at $8.62 \pm 0.97\,mg{\cdot}L^{-1}$ (Maboko Island) followed by 6.65 ± 1.09 (Ndere Island) while the lowest was recorded at Kendu Bay with $5.72 \pm 0.06\,mg{\cdot}L^{-1}$. The oxygen reduction potential (ORP) recorded was within a range of 211.43 ± 12.36 mV at Homa Bay station and 242.25 ± 8.031 mV at fish landing beaches. Total alkalinity (TA) posted was in the range of $45.50 \pm 4.43\,mg{\cdot}L^{-1}$ for the fish landing beaches, $167.05 \pm 1.8\,mg{\cdot}L^{-1}$ for Kisumu Bay, and $126.0 \pm 0.00\,mg{\cdot}L^{-1}$ for Ndere Island. Kisumu station recorded the highest levels in TA and TH. The total dissolved solids (TDS) ranged from $83.92 \pm 2.90\,mg{\cdot}L^{-1}$ at the fish landing beaches to $112.02 \pm 2.63\,mg{\cdot}L^{-1}$ at Kisumu Bay.

Nutrient concentrations of water samples are outlined in Table 3. Significantly ($p \leq 0.05$) higher concentrations of NO_3 ($32.21 \pm 2.39\,\mu g{\cdot}L^{-1}$) and NO_2 ($11.13 \pm 0.65\,\mu g{\cdot}L^{-1}$) were observed in water samples from Kendu Bay while SRP ($102.00 \pm 16.10\,\mu g{\cdot}L^{-1}$), NH_4 ($126.23 \pm 29.34\,\mu g{\cdot}L^{-1}$), and SiO_2 ($26.08 \pm 0.55\,mg{\cdot}L^{-1}$) were significantly higher ($p \leq 0.05$) in water samples from Kisumu, Homa Bay, and Maboko Island, respectively. Silicates posted highly significant variations (<0.001) amongst the sampling stations. However, no significant ($p > 0.05$) variations were observed in the concentrations of TN ($\mu g{\cdot}L^{-1}$), TP ($\mu g{\cdot}L^{-1}$), and chlorophyll in the water samples.

A cluster analysis of physicochemical data of water samples from six sampling stations within the gulf revealed three main clades shown in Figure 2. Kendu Bay and Homa Bay separated into their own clade with a similarity index distance of about 300. The remaining four sites separated at a distance of about 600 similarity index, with Kisumu Bay fragmenting into its own clade, followed by Ndere Island, which dissociated at about 300 similarity index. In terms of physicochemical parameters of the water samples, the fish landing beaches and Maboko Island were the most closely associated sites, separating at 100 similarity index.

3.2. Composition, Distribution, and Relative Abundance of Aquatic Insect Community. A total of 383 individual aquatic insect samples representing nineteen [19] species, nineteen [19] genera, sixteen [16] families, and six [6] orders were obtained from the study area (Table 4). Out of these 19 species, 74 were obtained from Fish Landing Beaches. Furthermore, 164, 31 and 22 individual aquatic insects were obtained from urban environs. These environs included Kisumu bay, Kendu Bay, and Homa Bay, respectively. Maboko and Ndere Islands which were offshore stations produced 44 and 48 individual aquatic insects, respectively. All the 19 insect species were present in inshore stations in Winam Gulf. In offshore stations, six species: *Agrion virgo*, *Sericostomatidae* sp, *Polycentropus* sp, *Pentagenia viltigera*, *Ablebesmyia* sp, and *Ambryosus mermon* were present in Ndere Island while all the observed species were present in Maboko Island, except *Agrion virgo*, *Psepheaus* sp, *Brauchycentridae* sp, *Sericostomatidae* sp, *Caenis moesta*, *Pentagenia viltigera*, *Gillis altilis*, and *Microvelia borealis*.

The overall insect composition, abundance, and distribution from Winam Gulf of Lake Victoria are summarized in Table 4. 383 individual aquatic insects are distributed as outlined in Table 4 and Figure 3. The order *Hemiptera* (234 individual insects; 61.1% total abundance) and *Diptera* (68 individual insects; 17.5% total abundance) had the highest species richness followed by *Ephemeroptera* (37 individual insects; 9.66% total abundance), *Coleoptera* (28 individual insects; 7.31% total abundance), *Odonata* (10 individual insects; 2.61% total abundance), and *Trichoptera* (6 individual insects; 1.57% total abundance), respectively.

The percentage (%) composition of aquatic insect species in Winam gulf revealed that Kisumu Bay (164, 42.82%) had the highest number of aquatic insects followed by fish landing beaches (74, 19.32%), Ndere Island (48, 12.54%), Maboko Island (44, 11.49%), Kendu Bay (31, 8.09%), and Homa Bay (22, 5.74%) as shown in Table 4. Although Kisumu Bay had the highest abundance, the dominant species were only seven taxa, representing 164

Table 2: Spatial variation in physical and chemical parameters of water samples from six study sites within Winam Gulf, Lake Victoria.

Sampling stations	Air temp (°C)	Water temp (°C)	pH	E.C. (μ Scm^{-1})	D.O (mg·L^{-1})	ORP	Hard (mg·L^{-1})	Alk (mg·L^{-1})	Salinity (mg·L^{-1})	TDS (mg·L^{-1})
Maboko Island	23.47 ± 0.20	23.47 ± 0.20	6.34 ± 1.81	175.1 ± 2.3	8.62 ± 0.97	242.25 ± 8.03	268.00 ± 16.00	57.20 ± 16.89	0.08 ± 0.00	108.55 ± 0.65
Kisumu	23.70 ± 0.35	27.9 ± 0.62	7.46 ± 0.31	183.97 ± 8.48	6.75 ± 1.17	218.88 ± 6.16	379.50 ± 40.84	167.05 ± 18.75	0.08 ± 0.01	117.43 ± 3.00
Fish LB	24.07 ± 1.53	26.07 ± 0.41	7.74 ± 0.08	126.97 ± 1.15	7.02 ± 0.80	246.35 ± 13.44	155.00 ± 15.10	45.50 ± 4.43	0.06 ± 0.00	83.92 ± 2.90
Ndere Island	22.13 ± 0.38	25.73 ± 0.43	7.90 ± 0.16	169.43 ± 1.70	6.65 ± 1.09	227.10 ± 0.00	126.00 ± 0.00	60.00 ± 0.00	0.08 ± 0.00	108.25 ± 0.00
Kendu Bay	27.77 ± 3.40	26.13 ± 2.33	7.58 ± 0.03	201.97 ± 34.57	5.72 ± 0.06	236.90 ± 7.62	181.33 ± 55.58	58.67 ± 1.15	0.08 ± 0.00	107.25 ± 1.72
Homa Bay	25.23 ± 1.13	27.27 ± 0.81	8.17 ± 0.06	155.90 ± 34.57	7.13 ± 0.26	211.43 ± 12.36	220.67 ± 52.62	54.67 ± 4.62	0.08 ± 0.00	112.02 ± 2.63
F. statistics	0.486589	0.770872	1.21521	1.21521	0.056408	0.323605	0.230431	N1.466525	0.072464	NS0.017812
p value	0.624093	0.490891	0.324247	0.324247	0.945353	0.728463	0.796951	0.261986	0.930423	0.982366
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note. E.C: electrical conductivity; D.O: dissolved oxygen; ORP: oxygen reduction potential; Alk: alkalinity; TDS: total dissolved solids. Level of significance at <0.05 is depicted by letters as follows: S: significant; HS: highly significant; NS: not significant.

TABLE 3: Spatial variation in nutrient concentrations of water samples from six study sites within Winam Gulf, lake Victoria.

Sampling stations	NO_3 ($\mu g{\cdot}L^{-1}$)	NO_2 ($\mu g{\cdot}L^{-1}$)	TN ($\mu g{\cdot}L^{-1}$)	SRP ($\mu g{\cdot}L^{-1}$)	TP ($\mu g{\cdot}L^{-1}$)	NH_4 ($\mu g{\cdot}L^{-1}$)	SiO_2 ($mg{\cdot}L^{-1}$)	CHLO ($mg{\cdot}m^{-3}$)
Maboko Island	13.45 ± 0.09d	8.96 ± 0.18b	39.16 ± 4.61	56.29 ± 6.23c	97.81 ± 7.39	28.28 ± 4.89d	26.08 ± 0.55a	244.47 ± 20.58
Kisumu	24.00 ± 8.15b	9.95 ± 2.12ab	122.75 ± 43.46	102.00 ± 16.10a	436.86 ± 204.11	84.18 ± 36.58b	25.87 ± 0.42a	237.24 ± 57.62
Fish LB	5.54 ± 1.62e	1.67 ± 1.13c	29.95 ± 2.84	22.95 ± 6.67 d	43.52 ± 6.67	17.51 ± 5.80f	3.60 ± 1.43 d	353.52 ± 141.70
Ndere Island	22.66 ± 0.71b	10.77 ± 1.18a	50.56 ± 19.01	74.38 ± 8.26b	180.67 ± 82.46	60.33 ± 4.38c	24.18 ± 0.44ab	492.44 ± 91.16
Kendu Bay	32.21 ± 2.39a	11.13 ± 0.65a	46.96 ± 0.86	58.67 ± 4.54c	110.67 ± 16.67	31.62 ± 9.11e	20.44 ± 0.49c	1021.8 ± 739.15
Homa Bay	19.41 ± 5.43bc	9.78 ± 1.74ab	67.67 ± 28.60	98.19 ± 15.61a	256.38 ± 104.54	126.23 ± 29.34a	19.86 ± 0.19c	4294.05 ± 3289.88
F. statistics	4.741	7.040	2.1639943	7.74777326	2.0406757	4.3574634	144.52418	1.32720.4
p value	0.0127132	0.0027409	0.1268606	0.0018277	0.1445171	0.0170981	<0.001	0.3170887
Significance	S	HS	NS	HS	NS	S	HS	NS

Note. NO3: nitrates; NO2: nitrites; TN: total nitrogen; SRP: soluble reactive phosphorous; T.P.: total phosphorous; NH4: ammonium ions, $SiO2^{-}$; CHLO: chlorophyll. Level of significance at <0.05 is depicted by letters as follows: S: significant; HS: highly significant; NS: not significant.

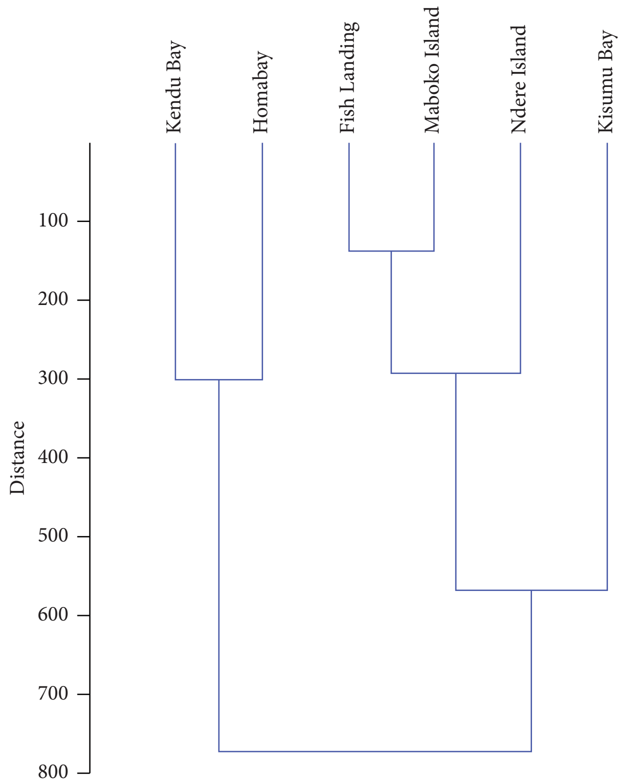


FIGURE 2: Cluster dendrogram showing the relationship between physical-chemical parameters of water samples from six sampling stations in Winam Gulf.

individual insect counts while the adaptive and tolerant species flourished. This was unlike the fish landing beaches with an abundance of only 19.32%, representing seventeen [17] taxa.

The most diverse station was fish landing beaches with seventeen [17] species followed by Maboko Island station with eight [8] in Figures 4(c) and 5(c), Table 4, Figures 4(b) and 5(b), and Table 4, respectively. The common species in the two stations included *Corixini* sp., *Ablebesmyia* sp., *Baetis calorina*, *Polycentropus* sp., and *Hydrophyllus* sp. (Table 4). Relatively, a fewer number of insect species were retrieved from Kendu Bay [3]. Only three species (*Habrophlebia* sp, *Chironomus* sp, and *Ambryosus mermon*) were recorded in Kendu Bay while a total of five species (*Baetis calorina*, *Chironomus* sp, *Ablebesmyia* sp, *Corixini* sp, and *Ambryosus mermon*) were observed in Homa Bay. *Chironomus* sp and *Ambryosus mermon* were the most common species in Kendu Bay and Homa Bay sampling sites (Figures 4(e), 4(f), 5(e), and 5(f) and Table 4).

Taxonomic families observed in Winam Gulf included members of *Corixidae* (38.12%) which had the highest species density, followed by *Naidae* (20.365%), *Chironomidae* (17.75%), *Psephenidae* (5.7%), *Polymitarcyidae* (4.17%), *Agriidae* (2.61%), *Baetidae* (2.34%) and *Naucoridae* (1.04%), *Caenidae* and *Leptophlebiidae* (1.56%), *Pleidae* (1.044%), *Sericostomatidae* and *Validae* (0.522%), and *Brauchycentridae* (0.261%) (Figures 6(a) and 6(b)). Orders *Hemiptera*, *Ephemeroptera,* and *Diptera* were the most predominant and were found across all the six stations. *Coleoptera* was observed at Maboko Island, Kisumu Bay, and the fish landing beaches. *Trichoptera* was only found in Maboko Island, Kisumu Bay, and the fish landing beaches while *Odonata* was observed in the fish landing beaches and Ndere Island. At a total of 68 *Chironomidae* were detected having the most predominant genera within the order *Diptera* represented across all stations. Spatial variations were observed in the species between *Chironomus* sp and *Ablebesmya* sp as shown in Table 4. The highest relative abundance in species recorded was at Kisumu Bay [107] in the order *Hemiptera*, genera *Corixidae,* and *Corixini* sp. (Figures 6(a) and 4(d); Table 4).

Diversity indices calculated from the sampled insect species are shown in Table 5. The maximum diversity index observed was $H = 2.09$, having the least dominance of $D = 0.1655$, while minimum diversity index was $H = 0.8851$ with the highest dominance of $D = 0.5456$. Regarding the sampling sites, the fish landing beaches had the most diverse insect species, with the least dominance while Kisumu and Kendu bays had the least diverse collections. Analysis of the species diversity index denoted that Shannon H indices recorded the highest value of 2.109 at the fish landing beaches followed by 1.364 at Maboko Island, 1.246 at Ndere Island, 1.245 at Homa Bay, 0.9436 at Kisumu Bay, and 0.8851 at Kendu Bay.

Species evenness ($e^{H/S}$) defined as **t**he numerical closeness amongst the aquatic insect species within the community was established using Pielou's evenness index (J) (Table 5). The evenness values were in the range of 0.367 (Kisumu Bay) and 0.8078 (Kendu Bay). Kendu Bay station had the highest species evenness (0.80566), followed by the fish landing beaches (0.77151), Kisumu Bay (0.74670), Ndere Island (0.68413), and Maboko Island (0.62099), and the lowest was observed in Homa Bay (0.64463).

Shannon equitability index (J) defined as a measure of the evenness of species in a community was determined to show similarity in abundance of the insect species (Table 5). The recorded results showed that Kendu Bay had the highest equitability index (J) with 0.8057 > fish landing beaches (0.7787) > 0.7734 (Homa Bay) > Ndere Island (0.6956) > Maboko Island (0.621) > Kisumu Bay (0.4849) with the lowest index in a descending order. The results showed a similar trend to species evenness with the exception of Kisumu with the lowest equitability index and Homa Bay stations with the lowest species evenness.

Alpha diversity (α-diversity) indices defined as the mean diversity of different sampling stations within Winam Gulf were calculated to define the structure of aquatic insects' ecological community in Winam Gulf and diversity profiles developed. Alpha diversity based on sampling stations delineated fish landing beaches as with the highest diversity while Kendu Bay had the least probably due to variations in environmental parameters. Consequently, α-diversity based on species richness described *A. merman* as the highest followed by *Chironomus* sp. and then *Ablebesmyia* sp, while *Psepheaus* sp was the least diverse. On the other hand, Chao 1 was defined as an estimator based on abundance and

Table 4: Composition and distribution of aquatic insects in Winam Gulf, lake Victoria.

Order	Family	Genus	Genus coding	Insect taxa: Maboko Island	Kisumu bay	Fish LB	Ndere Island	Kendu bay	Homa bay	No. of individual insect counts	% compositio n
Hemiptera	Veliidae	*Microvelia borealis*	Mbor	—	—	1	—	—	—	1	0.261
	Nepidae	Ramastra represented	Ram	—	—	1	—	—	—	1	0.261
		Nepa apculata uheri	Nap	—	—	1	4	—	1	6	1.567
	Naucoridae	*Ambryosus mermon*	Amor	27	3	12	9	19	2	72	18.8
		Gillis altilis	Galt	—	—	4	—	—	—	4	1.04
	Corixidae	*Corixini* sp	Cor	5	118	20	—	—	3	146	38.12
	Pleidae	*Paraplea brunni*	Pbru	1	3	—	—	—	—	4	1.04
Diptera	Chironomidae	*Ablebesmyia* sp	Able	1	17	2	23	0	1	44	11.488
		Chironomus sp	Chiro	1	1	1	0	9	12	24	6.266
Ephemeroptera	Leptophlebiidae	*Habrophlebia* sp	Hab	2	1	—	—	3	—	6	1.567
	Polymitarcyidae	*Pentagenia viltigera*	Pvil	—	—	15	1	—	—	16	4.177
	Baetidae	*Baetis calorina*	Bcal	1	—	5	—	—	3	9	2.35
	Caenidae	*Caenis moesta*	Cmoe	—	—	6	—	—	—	6	1.567
Tricoptera	Phryganeidae	*Polycentropus* sp	Poly	1	—	1	1	—	—	3	0.783
	Sericostomatidae	*Sericostomatidae* sp	Seri	—	—	1	1	—	—	2	0.522
	Brauchycentridae	*Brauchycentridae* sp	Brau	—	—	1	—	—	—	1	0.261
Coleoptera	Psephenidae	*Psepheaus* sp	Psep	—	21	1	—	—	—	22	5.744
	Hydrophilidae	*Hydrophyllus* sp	Hydr	5	—	1	—	—	—	6	1.567
Odonata	Agriidae	*Agrion virgo*	Avir	—	—	1	9	—	—	10	2.61
Number of individual insect counts				44	164	74	48	31	22	383	100.0
Composition				11.49	42.82	19.32	12.54	8.09	5.74	—	

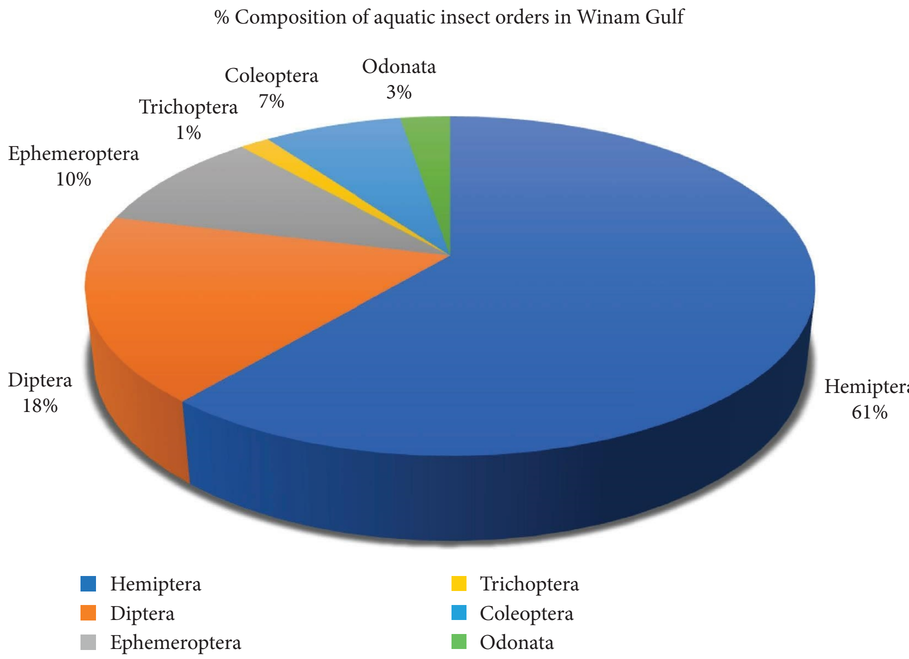


Figure 3: A pie chart showing the percentage (%) composition of aquatic insect orders in Winam Gulf, Lake Victoria.

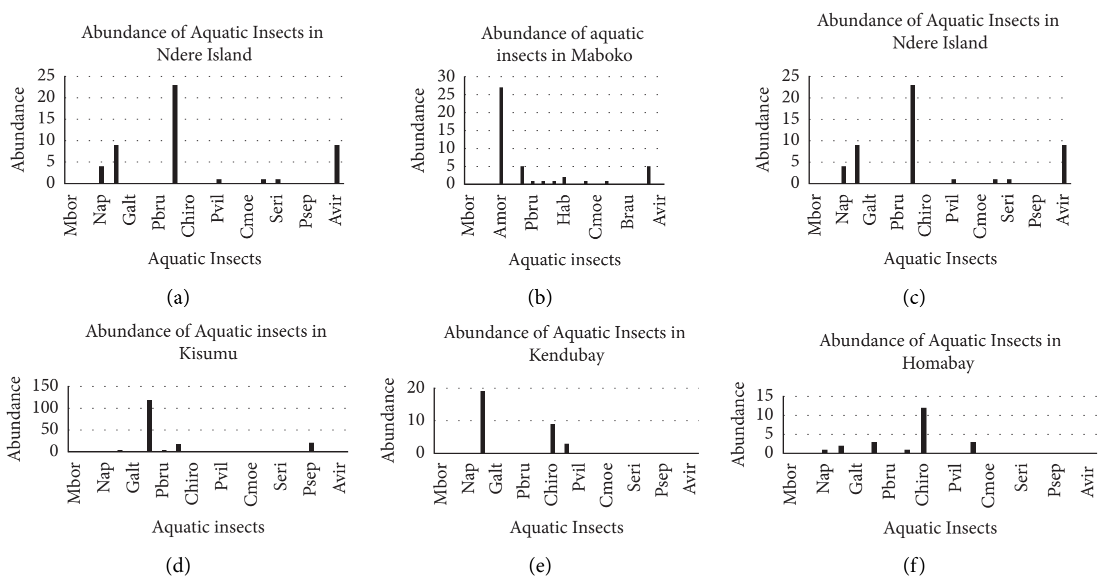


Figure 4: (a–f) Stack charts with frequencies on y axis and species of insects on x axis showing the abundance of aquatic insects per sampling station. The stations are abbreviated as follows: nder: Ndere Island; Mab: Maboko Island; fish: fish landing beaches; Hom: Homa Bay; Ken: Kendu Bay; kis: Kisumu bay. The aquatic insects are abbreviated as (A) Mbor: *Microvelia borealis*; (B) Galt: *Gillis altilis*; (C) Amor: *A. merman*; (D) Cor: *Corixi* sp.; (E) Pbru: *Paraplea brunni*; (F) Able: *Ablebesmyia* sp; (G) Chiro: *Chironomus*.; (H) Hab: *Habrophlebia* sp; (I) Pvil: *Pentagenia viltigera*; (J) Bcal: etis carolina; (K) Cmoe: *C. moesta*; (L) Poly: *Polycentropus* sp; (M) Seri: *Sericostomatidae* sp; (N) Brau *Brauchycentridae* sp; (O) Psep: *Psepheaus* sp, (P) Hydro: *Hydrophyllus* sp; (Q) Avir: *Agrion virgo*. The diversity indices were calculated using P.A.S.T version 4.03 statistical tool.

required data that referred to the abundance of individual species belonging to a certain class and was based on species richness.

One-way ANOVA at 0.05 revealed statistically insignificant differences in the community structure of aquatic insects between the sampling stations, whereas a homogeneity test was significant ($p = 0.0003$).

3.3. Existing Relationships in the Aquatic Insect Community Structure. Further analysis was performed by using Pearson's correlation coefficient (r) to establish any associations as outlined in Figure 7 and Table 6. The results revealed a strong positive correlation, $r \geq 90$, between *Corixi* sp and *Microvelia borealis*, *Gillis altilis*, *Paraplea brunni*, *Psepheaus* sp, *Habrophlebia* sp., *Pentagenia viltigera*, *C. moesta*, and

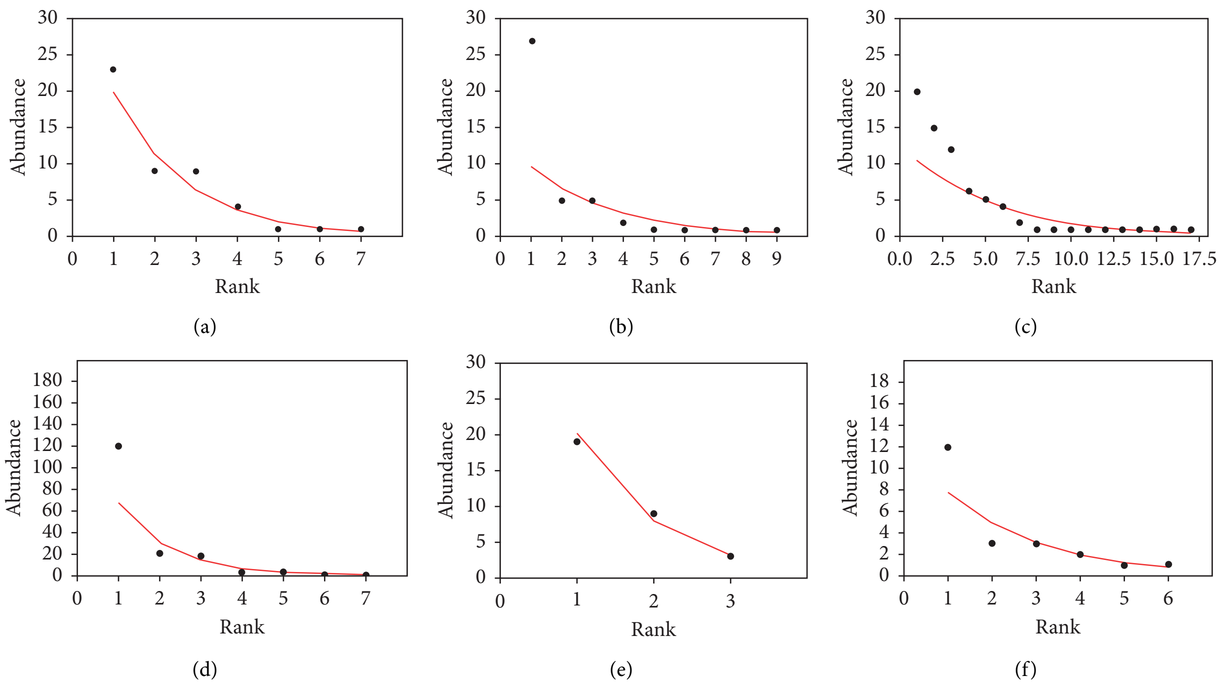


Figure 5: (a–f) Abundance distribution model with the rank on x axis against abundance on the y axis of aquatic insects per sampling station. The stations are abbreviated as follows: nder: Ndere Island; mab: Maboko Island; fish: fish landing beaches; hom: Homa Bay; ken: Kendu Bay; kis: Kisumu bay. The aquatic insects are abbreviated as (A) Mbor: *Microvelia borealis*; (B) Galt: *Gillis altilis*; (C) Amor: *A. merman*; (D) Cor: *Corixi* sp.; (E) Pbru: *Paraplea brunni*; (F) Able: *Ablebesmyia* sp.; (G) Chiro: *Chironomus* sp.; (H) Hab: *Habrophlebia* sp.; (I) Pvil: *Pentagenia viltigera*; (J) Bcal: *etis carolina*; (K).Cmoe: *C. moesta*; (L) Poly: *Polycentropus* sp.; (M) Seri: *Sericostomatidae* sp.; (N) Brau: *Brauchycentridae* sp.; (O) Psep: *Psepheaus sp*; (P) Hydro: *Hydrophyllus* sp; (Q) Avir: *Agrion virgo*. The diversity indices were calculated using P.A.S.T version 4.03 statistical tool.

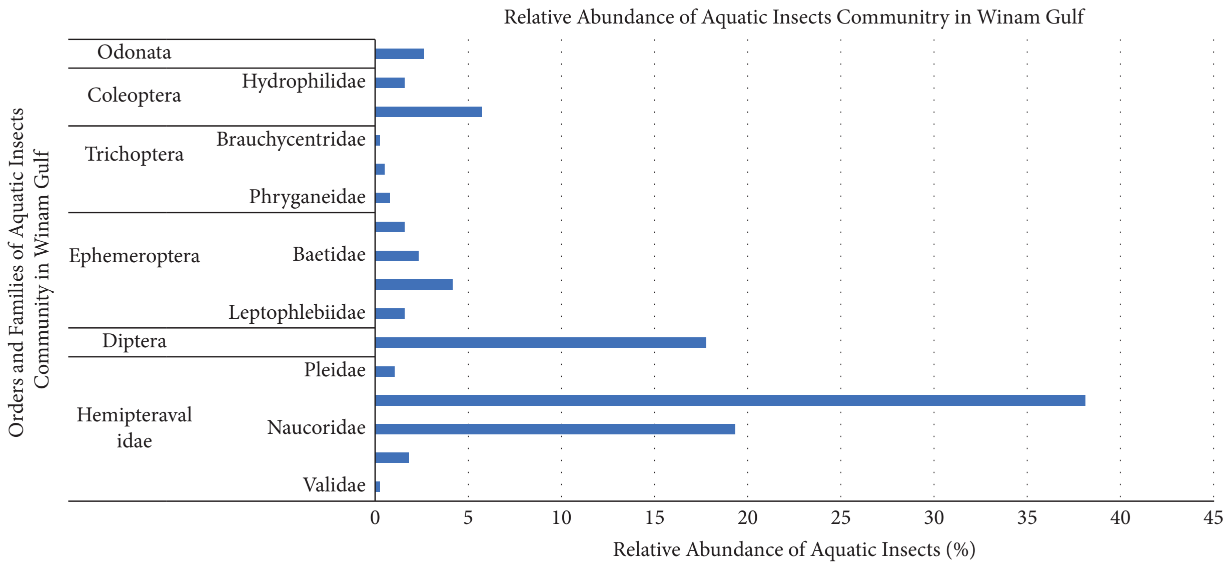
Brauchycentridae sp. Consequently, *Pentagenia viltigera* displayed same characteristics with *A. merman*, *Hydrophyllus* sp, and *Agrion virgo* while *Psepheaus* sp. also positively influenced *Paraplea brunni* and *Habrophlebia* sp. at $r \geq 90$. *Baetis calorina* also impacted on *Hydrophyllus* sp. positively.

However, *Ablebesmyias* sp. was observed to significantly impact negatively on *Chironomus* sp, $r = -0.56$, and *Baetis calorina*, $r = -0.50$, while *Chironomus* sp influenced *Polycentropus* sp, $r = -0.70$, and *Sericostomatidae* sp, $r = -0.53$. *Habrophlebia* sp. and similarly influenced *Baetis calorina*, $r = -0.53$, and *Sericostomatidae* sp, $r = -0.61$ (Figure 7 and Table 6).

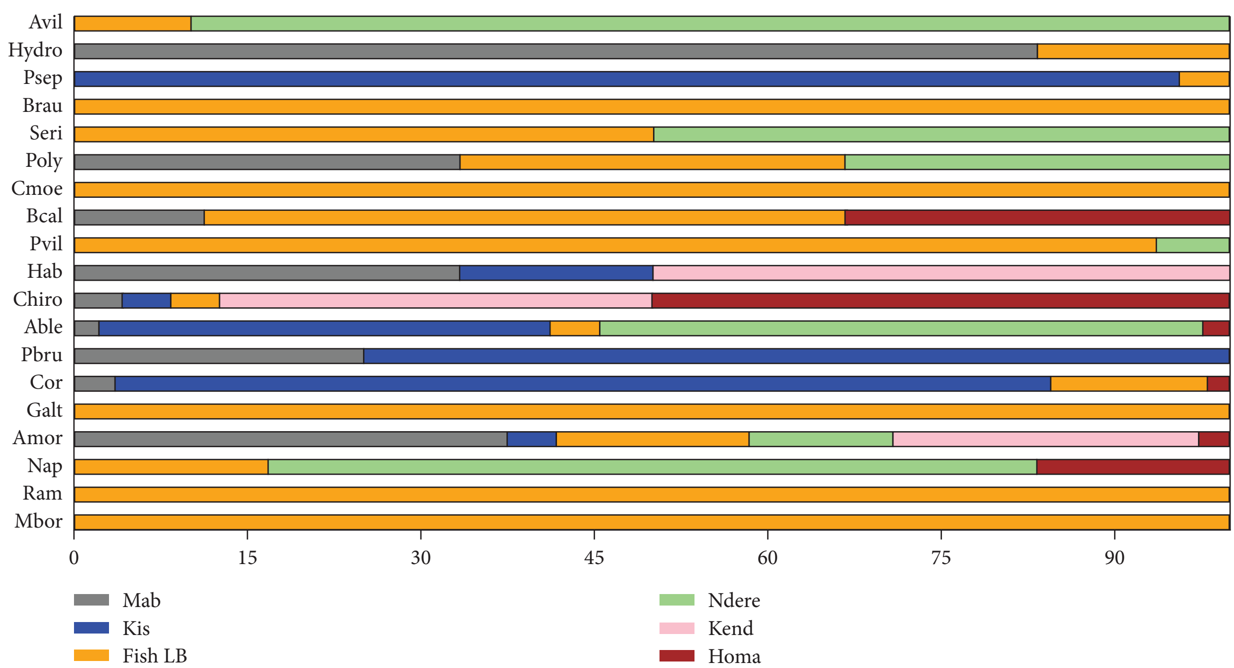
Determination of existing associations in the aquatic insect fauna was developed using hierarchical clustering algorithm paired group (UPGMA) with similarity index of Euclidean at Cophen. Correlation of 0.9974 is shown in Figure 8(a). The observations made indicate that all species were closely related and had similar characteristics with the exception of *Corixi* sp which differed from other species by a greater distance of >75. *Polycentropus* sp, *Sericostomatidae* sp, *Brauchycentridae* sp, and *Microvelia borealis* appear to have had similar origin while *Baetis calorina, Gillis altilis*, and *C. moesta* shared some characters. Further observations showed that *Paraplea brunni*, *Habrophlebia* sp, and *Hydrophyllus* sp were closely related with a separating distance of <5. *Corixi* sp, *A. merman*, *Ablebesmyia* sp, and *Psepheaus* sp had a separation distance of $0 \geq 30$ while *Chironomus* sp and *Ablebesmyia* species had a separation distance of <15

Principal correspondence analysis was employed to evaluate the existing association between the sampling stations and the insect community. The results pointed out clusters including Kisumu Bay, Ndere Island, Homa Bay and Kendu Bay, and Maboko Island based on pollution gradient. Distribution of the insect species was associated with the environmental parameters in each sampling station. For instance, Kisumu Bay, which was the most heavily polluted site, had more insects belonging to the *Corixi* sp, *Psepheaus* sp, and *Paraplea brunni* while Ndere Island, the offshore station located furthest in the gulf, had insects belonging to the species *Sericostomatidae* sp, *Polycentropus* sp, *Pentagenia viltigera*, *Agrion virgo*, *C. moesta*,and *Microvelia borealis*. Homa Bay and Kendu Bay are located within close proximity and share similar environmental conditions that favored the existence of Chironomus sp. Maboko Island, though an offshore station, had insect species which were closely associated with those obtained from Homa Bay and Kendu Bay including Baetis calorina, Habrophlebia sp, and Hydrophyllus sp.

Conical correspondence analysis (CCA) was used to separate the highly polluted site, Kisumu Bay, from the moderately polluted sites, Homa Bay and Kendu Bay, and the less polluted sites, Maboko Island and the fish landing beaches (Figure 9). The previously predicted site also known



(a)



(b)

FIGURE 6: (a) A bar graph of orders and families showing the relative abundance of aquatic insect species expressed as a percentage in Winam Gulf, Lake Victoria. (b) Stacked bar charts showing comparisons in % composition of individual species amongst the sampling stations. A: *Microvelia borealis*; B: Gillis altilis, *A. merman*, Corixi sped, Paraplea brunni, and *Ablebesmyia* sp; G: *Chironomus* sp.; H: *Habrophlebia* sp; I: *Pentagenia viltigera*; J: Baetis Carolina's *C. moesta*; L: *Polycentropus* sp and M: *Sericostomatidae* sp; N: *Brauchycentridae* sp; O: *Psepheaus* sp; P: *Hydrophyllus* sp; Q: *Agrion virgo*.

as the reference point, Ndere Island, was completely separated from the other sites. The trend was as depicted by the cluster analysis. CCA image in Figure 8 shows a close association between water quality parameters and insect community structure. Ndere Island in the 1st quarter showed a closer association between NO_2 and ORP and *Sericostomatidae* sp, *Nepa apculata uheri*, *Polycentropus* sp, *Agrion virgo*, and *Pentagenia viltigera*. Homa Bay, Kendu Bay, and Maboko located in the 2nd quarter were marked with the influence of electrical conductivity, E.C.; dissolved oxygen, D.O.; nitrates, NO_3; and chlorophyll which were closely associated with *Hydrophyllus* sp, *Habrophlebia* sp, *Chironomus* sp, *Baetis calorina*, and *A. merman*. The 3rd quarter, where the highly polluted sampling station, Kisumu Bay, was located, was distinctly influenced by nutrients which include TP, TN, SRP, and other physicochemical parameters (total alkalinity, total hardness, total dissolved solids, and water temperature).

Table 5: Diversity indices and other indices for aquatic insects in Winam Gulf, Lake Victoria.

		Maboka Island	Kisumu	Fish LB	Ndere Island	Kendu Bay	Homa Bay
TAXA_	Symbols	9	7	17	7	3	6
Individuals sp. count		44	164	74	48	31	22
Dominance	D	0.407	0.5456	0.157	0.3802	0.4693	0.3471
Shannon	H	1.364	0.9436	2.195	1.429	0.8851	1.373
Evenness	$e^{H/s}$	0.4348	0.367	0.5281	0.5965	0.8078	0.6979
Equitability	J	0.621	0.4849	0.7745	0.7345	0.8057	0.7663
Fisher	Alpha	3.424	1.485	6.909	2.255	0.82	2.718
Chao-1		14	8	39.5	10	3	6.5

Note. The diversity indices and other indices were calculated using the P.A.S.T version 4.03 statistical.

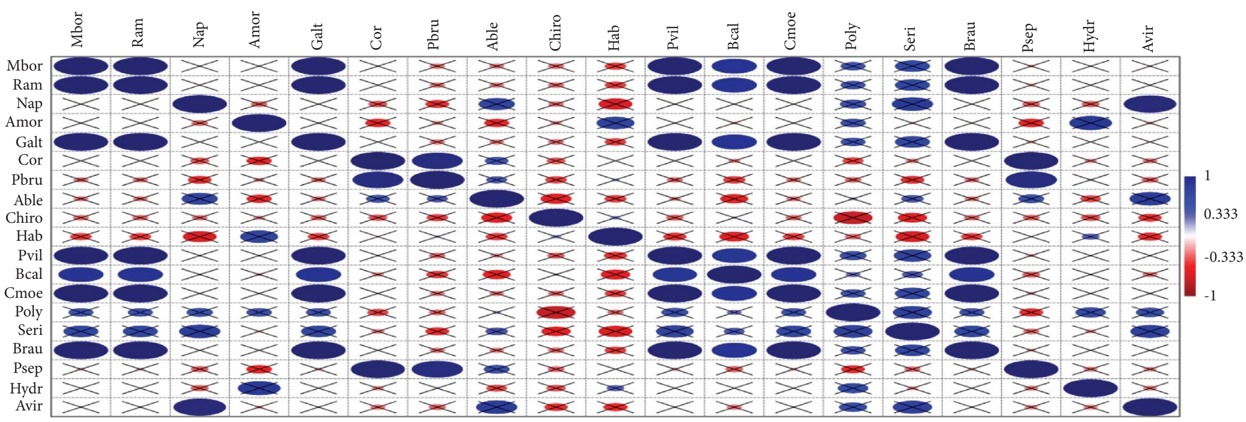


Figure 7: Pearson's correlation coefficients between individual insect species within Winam Gulf. A: *Microvelia borealis*; B: *Gillis altilis*, *A. merman, Corixi sped, Paraplea brunni, Ablebesmyia* sp, G: *Chironomus* sp., and H: *Habrophlebia* sp; I: *Pentagenia viltigera*; J: *Baetis Carolina's C. moesta*; L: *Polycentropus* sp; M: *Sericostomatidae* sp; N: *Brauchycentridae* sp; O: *Psepheaus* sp; P: *Hydrophyllus* sp; Q: *Agrion virgo*. *Note*. Level of significance: the cross (X) shows insignificant correlation at $r < 0.05$ while significant correlation has no cross.

Table 6: Pearson's correlation coefficients between individual insect species within Winam Gulf.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
A		0.00	1.00	**0.93**	0.61	0.62	0.58	0.45	0.00	0.04	0.00	0.37	0.18	0.00	0.77	1.00	**0.86**
B	1.00		1.00	**0.93**	0.61	0.62	0.58	0.45	0.00	0.04	0.00	0.37	0.18	0.00	0.77	1.00	**0.86**
C	0.00	0.00		0.37	0.70	0.37	0.70	0.13	**0.98**	0.78	1.00	0.36	**0.82**	1.00	0.36	0.07	0.77
D	-0.05	-0.05	-0.45		0.01	0.40	0.51	**0.91**	**0.90**	0.68	**0.93**	0.46	0.65	**0.93**	0.00	0.68	0.61
E	-0.27	-0.27	-0.21	**0.93**		0.47	0.45	**0.81**	0.58	0.43	0.61	0.56	0.40	0.61	0.01	**0.88**	0.56
F	-0.26	-0.26	-0.45	0.42	0.37		0.25	0.44	0.69	0.31	0.62	0.78	0.43	0.62	0.35	0.47	0.09
G	-0.29	-0.29	-0.21	-0.34	-0.39	<u>-0.56</u>		0.73	0.54	**0.83**	0.58	0.11	0.28	0.58	0.56	0.50	0.41
H	-0.39	-0.39	0.69	-0.06	0.13	-0.39	0.18		0.41	0.28	0.45	0.58	0.20	0.45	**0.97**	0.54	0.39
I	1.00	1.00	-0.01	-0.06	-0.29	-0.21	0.31	-0.42		0.05	0.00	0.33	0.14	0.00	0.75	**0.98**	**0.96**
J	**0.83**	**0.83**	-0.15	-0.22	-0.40	-0.50	0.11	-0.53	**0.81**		0.04	0.61	0.47	0.04	0.54	**0.93**	0.61
K	1.00	1.00	0.00	-0.05	-0.27	-0.26	0.29	-0.39	1.00	**0.83**		0.37	0.18	0.00	**0.77**	1.00	**0.86**
L	0.45	0.45	0.45	-0.38	-0.30	0.15	<u>-0.71</u>	-0.29	0.48	0.26	0.45		0.12	0.37	0.40	0.26	0.31
M	0.63	0.63	-0.12	-0.24	-0.43	0.40	<u>-0.53</u>	<u>-0.61</u>	0.68	0.37	0.63	0.71		0.18	0.58	0.71	0.11
N	1.00	1.00	0.00	-0.05	-0.27	-0.26	-0.29	-0.39	1.00	**0.83**	1.00	0.45	0.63		0.77	1.00	**0.86**
O	-0.15	-0.15	-0.46	**0.99**	**0.94**	0.46	-0.30	-0.02	-0.17	-0.32	-0.15	-0.43	-0.29	-0.15		0.64	0.66
P	0.00	0.00	0.78	-0.22	0.08	-0.37	-0.35	0.32	-0.02	0.05	0.00	0.55	-0.19	0.00	-0.25		0.63
Q	-0.09	-0.09	-0.16	-0.27	-0.30	0.75	-0.42	-0.44	-0.02	-0.27	-0.09	0.51	0.71	-0.09	-0.23	-0.25	

Note. Pearson's correlation coefficients between individual insect species within Winam Gulf. A: *Microvelia borealis*; B: *Gillis altilis*, *A. merman*, Corixi sped, Paraplea brunni, and *Ablebesmyia* sp; G: *Chironomus* sp.; H: *Habrophlebia* sp; I: *Pentagenia viltigera*; J: Baetis Carolina's *C. moesta*; L: *Polycentropus* sp; M: *Sericostomatidae* sp; N: *Brauchycentridae* sp; O-: *Psepheaus* sp; P: *Hydrophyllus* sp; Q: *Agrion virgo*. *Note*. Level of significance, the cross (X) shows insignificant correlation at $r < 0.05$ while significant correlation has no cross. The bold values show the high level of significance.

The parameters were influential to the flourishment of five species: Psepheaus sp, Corixidae sp, Paraplea brunni, and Microvelia borealis and Agrion virgo. However, *Ablebesmyia* sp in the 4th quarter in close vicinity with silicates, SiO_2, and the pH was off and dissociated with any sampling station. Fish landing beaches was also not clearly associated with other water quality parameters except for salinity which was closely related to *Brauchycentridae* sp and *C. moesta* (Figure 8).

4. Discussion

Aquatic insects are a key in the water ecosystems, are the largest, and play a vital role in energy flow in the systems.

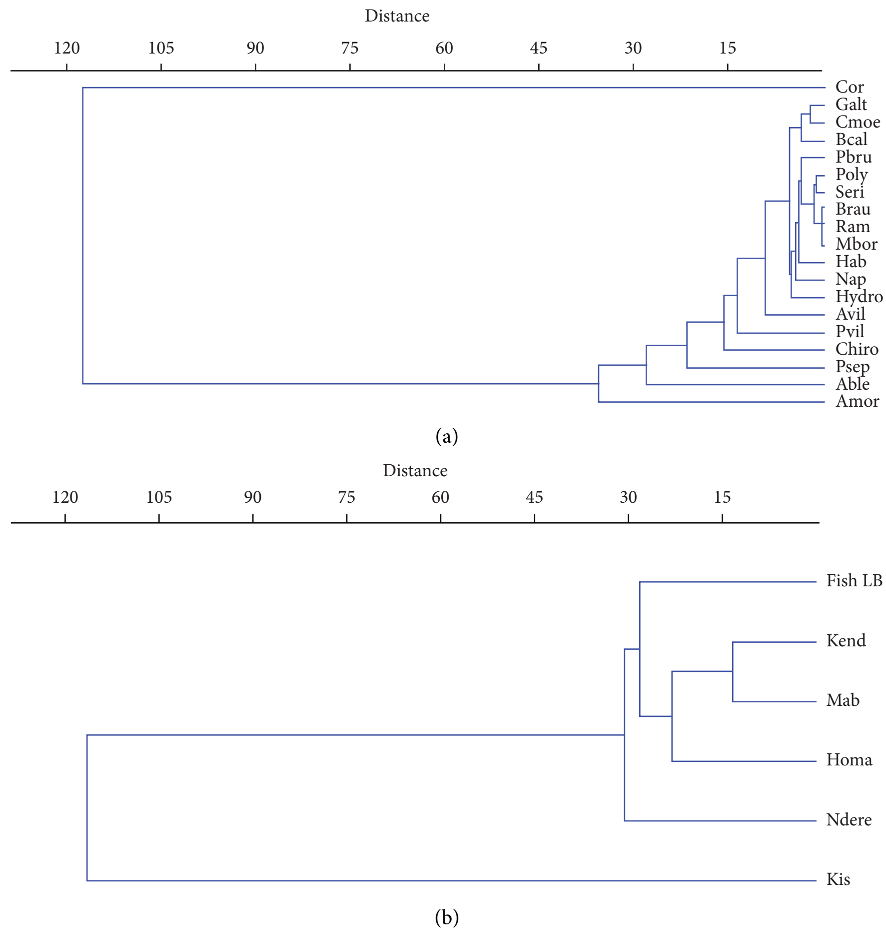


Figure 8: (a) Hierarchical clustering of species of aquatic insects in Winam Gulf. (A) Mbor: *Microvelia borealis*; (B) Galt: *Gillis altilis*; (C) Amor: *A. merman*; (D) Cor: *Corixi* sp.; (E) Pbru: *Paraplea brunni*; (F) Able: *Ablebesmyia* sp; (G) Chiro: *Chironomus* sp.; (H) Hab: *Habrophlebia* sp; (I) Pvil: *Pentagenia viltigera*; (J) Bcal: *etis carolina*; (K) Cmoe *C. moesta*; (L) Poly: *Polycentropus* sp; (M) Seri: *Sericostomatidae* sp; (N) Brau: *Brauchycentridae* sp; (O) Psep: *Psepheaus* sp; (P) Hydro: *Hydrophyllus* sp; (Q) Avir: *Agrion virgo*. The diversity indices were calculated using P.A.S.T version 4.03 statistical tool. (b) Hierarchical clustering was performed on individual species based on sampling stations in Winam Gulf, Lake Victoria. The stations are abbreviated as follows: nder-Ndere Island; mab-Maboko Island; fish-Fish Landing Beaches; hom-homabay; ken-Kendubay; kis-Kisumu Bay.

The insects are a part of the food chains and food webs in the systems, particularly for the predators [108]. Their survival is entirely dependent on the physical-chemical parameters, biological parameters, and human-induced factors in the ecosystem. The environmental factors coupled with the climatic factors affect their composition, distribution, and abundance, hence the community structure. In addition, their composition may also be dependent on morphometry configuration, vegetation type, water velocity, and properties of the aquatic insects [109–113]. Besides, previous research indicated that growth and survival were also threatened by the pollution within the environs, e.g., by chemical hazards (heavy metals, pesticides, persistent organic matter, and even antibiotics). Pollutants associated with ecological imbalances could result in the extinction of some species especially intolerant species. Pollutants could also inhibit the reproduction cycle. However, some species strive even better in polluted environments due to their level of tolerance to harsh conditions. The segregated properties allow the use of such insects as bioindicators of the dynamic ecosystem. The present research was assertive and in agreement with the previous works which confirm that insects are good in bioassay assessment of the pollution [107, 114–118]. Hence, early warnings on the changing environment attributed to pollution are provided. Although the pollutants have previously been documented in freshwater ecosystems such as Winam Gulf, a lot of emphasis has been on compositions and abundance without the reflection of the causative agents. The risks have been implied; however, the effect of chemical hazards such as heavy metals on the nutritive components and phylogenetic components received little attention. The present research attempted to elucidate and document the effects in Winam Gulf, Lake Victoria, Kenya.

Aquatic insects' community structure survival is influenced by a number of factors: the substrate, water quality, and environmental effects [107, 119]. Similar findings were observed in the present research from the conical correspondence analysis where a close association between physical-chemical parameters and nutrients and specific insect communities was marked as outlined in CCA image in

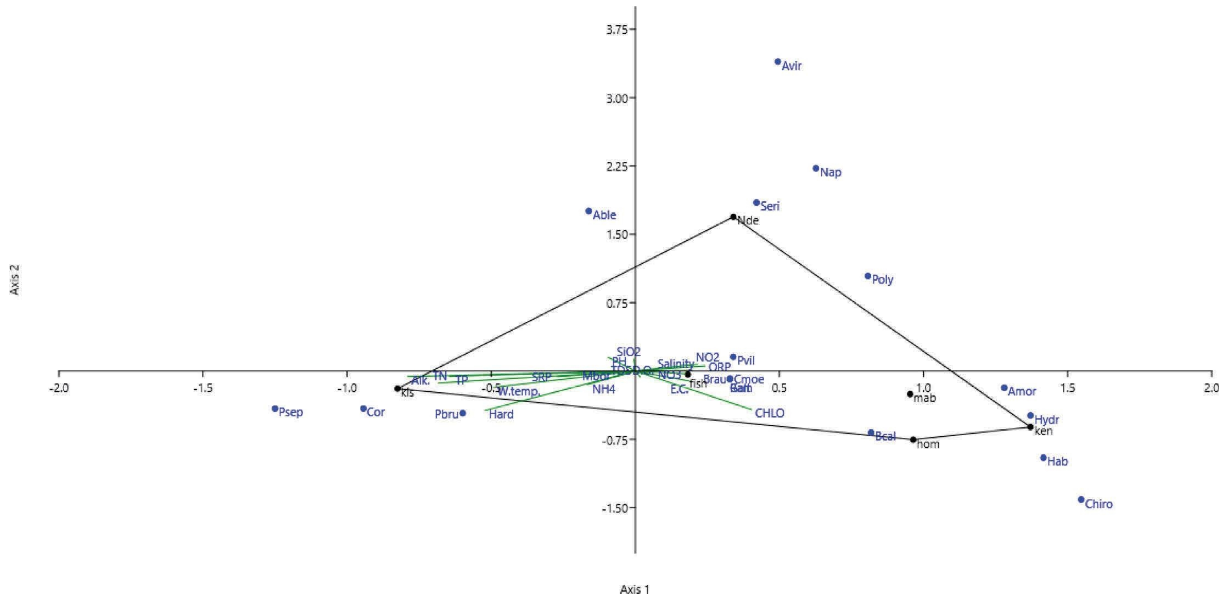


Figure 9: Conical correspondence analysis (CCA) of physicochemical parameters and nutrients in relation to aquatic insect community sampled in Winam Gulf, Lake Victoria. *Note*. Aquatic insect taxa in the ordination of space of the 1st and 2nd taxa codes correspond. The insect taxa are in blue and the black dots are the sampling stations. Mbor: *Microvelia borealis*; Galt: *Gillis altilis*; Amor: *A. merman*; Cor: *Corixi* sp.; Pbru: *Paraplea brunni*; Able: *Ablebesmyia* sp; Chiro: *Chironomus* sp.; Hab: *Habrophlebia* sp; Pvil: *Pentagenia viltigera*; Bcal: *Baetis carolina*; Cmoe: *C. moesta*; Poly: *Polycentropus* sp; Seri: *Sericostomatidae* sp; Brau: *Brauchycentridae* sp; Psep: *Psepheaus* sp; Hydro: *Hydrophyllus* sp; Avir: *Agrion virgo*. Sampling stations were denoted as follows: Mab: Maboko Island; Kis: Kisumu Bay; nder: Ndere Island; fish: fish landing bay; ken: kendu Bay; hom: Homa Bay. The diversity indices were calculated using the P.A.S.T version 4.03 statistical tool.

Figure 9. Furthermore, the study clearly showed that only tolerant species were confined to highly polluted zones such as Kisumu Bay, Homa Bay, and Kendu Bay as *Psepheaus* sp., *Corixi* sp., and *Chironomus* sp., respectively. In addition, the study also revealed that intolerant species were confined to presumably cleaner sites, Ndere Island, which include *Sericostomatidae* sp., *Agrion virgo*, and *Polycentropus* sp. The study results also affirmed that variations in insect communities occur due changes in locality which is influenced by different environmental factors, natural or man-made, hence the dynamics in insect community structures.

Furthermore, the present study (Figures 4(c) and 5(c) and Table 4) also revealed that *Hemiptera*, *Ephemeroptera*, *Diptera*, *Trichoptera*, *Coleoptera*, and *Odonata* were represented in the gulf particularly in the fish landing beaches. However, isolated cases such as *Diptera*, *Ephemeroptera*, and *Hemipteran* were exceptionally dominant in specific locations in Kisumu Bay (Figure 4(d) and Table 4), fish landing beaches (Figure 4(c) and Table 4), and Kisumu Bay (Figure 4(d) and Table 4), respectively. For instance, *Ephemeroptera* was confined in presumably cleaner sites which included the fish landing beaches (Figure 4(c) and Table 4), Maboko Island (Figure 4(b) and Table 4), and Ndere Island (Figure 4(a) and Table 4). However, *Diptera*, the *Chironomidae* family, was observed to be tolerant species found in all sampled stations, except Ndere Island (Figure 4(a) and Table 4) though dominantly in Kisumu Bay, the most polluted system located at the heart of the city. Other than that, C*orixini* spp., family *Corixidae,* and order *Hemiptera* were also dominant in Kisumu Bay. The other orders such as *Coleoptera* and *Odonata* were only found in the fish landing beaches (Figure 4(c) and Table 4) probably due to their intolerant nature to the shifting environmental characteristics, hence termed as predictors of good water quality [120, 121]. The dominance of the few species which strived well as displayed in Kisumu Bay was attributed to high adaptability and tolerance to the shifting environmental parameters. The high numbers of species at fish landing beaches were attributed to the relative cleanliness of the sampled station. The absence of the order Plecoptera and the low % in *Trichoptera* and *Ephemeroptera* could be attributed to the pollution of the environment. The orders *Plecoptera*, *Tricoptera*, and *Ephemeroptera* are made up of sensitive and vulnerable species which rapidly respond to changes in the environment [121, 122]. The orders are also referred to as indicators of biological integrity in aquatic ecosystem.

The *Corixini* spp., family *Corixidae*, order *Hemiptera*, was designated the most dominant species with the highest percentage at 38.1% (146/383) (Figures 6(a) and 6(b) and Table 4, column 12) in the ecological community of the aquatic insects in the Winam gulf. The inclination occurred due to adaptability and tolerance of the species.

5. Conclusion

The result obtained from the present study revealed insignificant variations in physical and chemical parameters and some nutrients (TN, TP, and chlorophyll) indicating homogeneity in the gulf. However, variation in nutrient loads was highly significant in NO_2, SRP, and SiO_2. Cluster analysis in the sampling stations delineated Kisumu, a highly polluted station, Homa Bay, and Kendu Bay as moderately polluted stations while the Maboko and Ndere Island as offshore stations relatively cleaner. Analysis of insect community structure from the six sampling stations revealed that Kisumu Bay had the highest number of individual aquatic insects followed by fish landing beaches, Ndere Island, Maboko Island, Kendu Bay, and Homa Bay at a decreasing order. The present research revealed that *Hemiptera*, *Diptera*, and *Ephemeroptera* were the most predominant orders represented across all the six stations. At a total of sixty-seven [67], *Chironomidae* was the most predominant genera, the order *Diptera,* represented across all stations. The highest Shannon diversity was recorded at fish landing beaches while the least at Kendu Bay. The highest Shannon equitability (E) value was recorded at Kendu Bay and the least at Kisumu Bay.

The relationship between species distribution and localities was depicted by cluster analysis (CA) and conical correspondence analysis (CCA) which delineated the gulf into four categories based on water quality parameters: Kisumu Bay, cluster 1; Kendu Bay and Homa Bay, cluster 2; fish landing beaches and Maboko Island, cluster 3; and Ndere Island, cluster 4. This was a reflection of the differences in the status of the water quality depicting the inshore stations: Kisumu Bay, highly polluted, Kendu Bay and Homa Bay, moderately polluted, fish landing beaches, a cleaner station among the inshore stations, and Ndere Island and Maboko Island, the offshore stations. In conclusion, the study findings affirmed that different locations have varying water quality parameters which influence the insect community structure resulting to dynamic populations, hence the need to urgently put in efforts and enforce measures to mitigate against deteriorations of the aquatic ecosystems. Furthermore, indebt studies on spatial and temporal trends should be undertaken for biomonitoring and to ascertain the general effects on other macroinvertebrates.

Data Availability

The data presented in the current study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Misiko Florence Monicah carried out the experiments and laboratory analysis. Benson Onyango and Taurai Bere provided guided research, data analysis, and advice on implementation. Andika provided advice on research and contributed to analysis of the information, while Okoth provided guidance on data curation and analysis. All authors discussed the results and contributed to the final manuscript and revisions and consent to its publication.

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