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Research Paper

Analysis of Aquatic Insect Communities of Loktak lake and its Physico- Chemical Properties

Zoology

KEYWORDS : Aquatic insects; Loktak Lake; diversity; water quality.

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ABSTRACT

The present study was conducted to assess the five different sites of Loktak Lake insect communities through the determination of aquatic insect diversity, abundance, composition and water quality parameters. Water samples and insects were collected from the five different sites of the Loktak Lake of Manipur during March 2013 to February 2014. Correlation between insects species richness with hydrological attributes showed good relationship and water temperature, free carbon dioxide, dissolved oxygen and P^{H} were found the most important variables in shaping the insects assemblage. Altogether, a total of 3278 individuals and 58 insects species belonging to 44 genera, 20 families and 6 orders were recorded to the order Ephemeroptera, Odonata, Hemiptera, Coleoptera, Diptera, and Trichoptera, and order Hemiptera were the most abundance. The chemical properties and distinct taxa found in the water suggest that the water body is not polluted.

Introduction

Aquatic insects are group of arthropods that live or spend part of life cycle in water bodies (Pennak 1978). These organisms are an important component of aquatic (and sometime terrestrial) food webs because they break down and process organic matters and provide food for invertebrates and vertebrates (Bouchard 2004). Most importantly aquatic insects are very good indicators of water qualities since they have various environmental disturbances tolerant levels (Arimoro and Ikomi 2008). Aquatic insects are among the most directly affected and vulnerable organisms with respect to surface water pollution and constitute an important component of biodiversity in lotic systems (Verneaux et al. 2003). Some are very vulnerable and sensitive to pollution while others can live and proliferate in disturbed and extremely polluted waters (Merit and Cummins 1996). Anthropogenic activities of human encourage discharge of untreated animal waste, such as releases from sewage and septic tanks, run- off from agricultural lands, laundering into streams and rivers. Most water bodies have been subjected to increasing pollution loads consequently, affecting greatly their quality and health status and causes the changes in the physico – chemical properties of water e.g., temperature, dissolved oxygen, alkalinity, phosphates, nitrates and metal concentrations. Variations in these water properties greatly influence the distribution patterns of aquatic insects in the water, since some of them are highly sensitive to pollution while others are somewhat tolerant or completely tolerant or completely tolerant to pollution and environmental disturbances (Bauernfind and Moog 2000). The use of aquatic insects for assessing water quality provides information to environmental managers and decisions makers to take accurate and justifiable actions in regards to state and quality of water bodies (Amiro and Ikomi, 2008). However, the aquatic insect fauna of Manipur and India is poorly documented. Limited numbers of studies have been carried out on the ecological aspects of aquatic entomofauna. Aquatic insects are used as indicator of pollution (Krishnamoorthi and Sarkar 1979; Gupta and Paliwal 2007; Agarwal et al. 2008). Aquatic insects community fluctuation can give quickly changed due to physical and chemical environment (Singh 1997). These insects are commonly used as tools for making an integrated assessment of water quality. The diversity assessment and preparation of the aquatic insects' inventories are considered as essential task due to the importance of wetland in the conservation planning and endeavors. In view of the importance role played by the aquatic insects in the ecosystem, the present investigation was carried out to study the structure and composition of aquatic insects in the fresh water Loktak Lake in an attempt to evaluate their possible relevance as indicators of clean water conditions.

2. Materials and Methods

2.1 Study area

The present study was conducted at 5 sites of Loktak Lake viz., Tongbram (N24˚57. 691' E 93°38 250'), Takmupat (N24˚29 221' E 93°48 580'), Longum (N24˚20.812' E 93°11.310'), Ngaram (N24˚31.529' E 93°48 930'), and Ngaikhong during March 2013 to February 2014.The Loktak Lake is the largest freshwater lake and swamp in the North East India. Its lies in between 24° 25' N to 24° 40' N latitude and 93° 45' E to 93° 55' E longitude in the Southern part of the Imphal Valley of Manipur (Fig. 1). The geo-coordinates profile of the five different sites of Loktak Lake are provided in (Table 1).

2.2 Water sampling

The water samples were collected monthly at each site. The water parameters were determined according to APHA (1985) methods.

2.3 Aquatic insects sampling.

Aquatic insects sampling was done from the different microhabitats for one hour at each site to standardize sampling effort per site. The collected specimens were sorted and preserved in 70% alcohol and brought back to the laboratory and identified with the help of standard identification manuals and published literatures (Andersen et al. 2004; Bal et al. 1994 a, b; Bouchard, 2004; Epler, 2010; Westfall et al 1996).

2.4 Data Analysis

Data collected from the study were tested for normality. Data which failed normality were not used for further analysis. Species diversity (Shannon- Weiner index), component of dominance (Simpson dominance index) and Berger-Parker dominance were determined for each site. Comparison in species composition between different sites was estimated using single linkage cluster based on Bray-Curtis similarity. Species recorded in this study were ranked on the basis of relative abundance of individual species. Data of species richness counts of one year from the five sites were pooled to get rarefaction curves for comparison of estimated species richness between the sites. Bio-

diversity Pro version 2 was used to determine diversity indices, cluster analysis, rarefaction curves, species richness estimates and also used for rank abundance diagram. Pearson Correlation coefficient (r) was used to determine the interdependence of the parameters where physic-chemical parameters were correlated with themselves and abundance of insect species.

Results and discussion

3.1 Physico- chemical parameters of water

The physico –chemical parameters of the water of five different sites of the Loktak Lake is presented in (Table 2). The spatial trend in the pattern of each physico-chemical and heavy metal characteristics was similar along the stream, temperature, and P^H was varying considerably from site to site. It has been observed that the lowest temperature (26.5°C) was detected in at site 1(Tongbram) and highest temperature (30.6°C) was found in site III & V (Longum and Ngaikhong). The difference in water temperature may depend on the climate and the environment nearby the lake as well as sampling time, wind, water mixing and amount of sun light. A specific range of water temperature is required for aquatic insects to live in water because of different respiratory rate and metabolism.

For P^H and alkalinity, P^H values of water sample from each sampling site were not so different. Interestingly same value of P^H was found in site I & site II whereas in site II, IV & V. P^H is an important environment factor which affects the life process of animals inhabiting the water. The average of P^H value during study period is 6.5 to 7. The increase rate of decomposition of organic matters, influx of carbon dioxide, source of high water temperature and mixing of domestic sewage caused low P^H value, (Dubey et al. 2006). P^H value was normal at upper stretch and slightly alkaline in (site II, IV and V).

For alkalinity the values varied from 58 to 61 mg/l. The highest alkalinity value was found at site III (Longum) while the lowest value (58 mg/l) was found at site I (Tongbram). Alkalinity indicates that water was contaminated with ions, carbonate, bicarbonate and hydroxide. Two main sources of carbonate and bicarbonate are rain and soil including phosphate, borate and silicate. The alkalinity depends on the geology of the water shed area and presence of lime stone which is the source of natural alkalinity.

For dissolved oxygen (DO) contents of water are ranged from 6.5mg/l to 7 mg/l with almost all sites except site IV (Ngaram) having 7.00 mg/l. For free carbon-dioxide was due to high surface area influx of carbonic acid through rain water and also the decomposition of organic matter in the lake. Chloride ranges from 0.05 to 0.07 ppm during the observation period which may be due to large amount of sewage discharge in the lake.

For phosphate highest concentration (0.08mg/l) was found in site II (Takmupat) and site III (Longum) and lowest concentration (0.03 mg/l) was found in site V (Ngaikhong). Phosphate might be contaminated by the fertilizer used in nearby agricultural fields and detergent that are widely used.

Nitrate (NO_3) is below the level of 90 mg/l so it seems to have no effect on aquatic insects. Pearson's correlation coefficient (r) shows the relationship between the physic0- chemical parameters recorded in five different sites of Loktak Lake. The analysis shows that pH and temperature correlated positively, r= 0.358. Dissolve oxygen (DO) had direct correlation with temperature, alkalinity, total hardness, silicate and had inverse correlation with pH, co_2 chloride, nitrate, and phosphate (Table 3).

Insect fauna

A total of 3278 individuals representing 58 species belonging to 44 genera, 20 families and 6 orders were recorded. Maximum of 769 individual and 58 species of aquatic insects were recorded in Longum (site III) followed by Tongbram (site I) with 733 individual and 57 species, Takmupat (site II) with 686 individual and 58 species, Ngaikhong (site V) with 663 individual and 58 species and minimum of 427 individual and 57 species were recorded in Ngaram (site IV). Eleven species are reported for the first time from the state, out of eleven species, three species belongs to Hemiptera, seven species belongs to Coleoptera and one from Trichoptera (Table 4).

3.3 Species Diversity and Abundance Pattern

The present studies reveal that the order Hemiptera is the dominant order with respect to species diversity (48.5 % species), followed by Coleoptera (36.2%), Odonata (10.7%), Diptera (3.2 %), Ephemeroptera (2.2%), and Trichoptera (0.4%). Family wise member of the Dytiscidae (order Coleoptera) was the most species rich (10 species) and individualized (543 insects) followed by Hydrophilidae (8 species and 454 individuals), Nepidae (5 species and 228 individuals), Notonectidae, Gerridae and Libellulidae (4 species each and 135-196 individuals), Corixidae, Belostomatidae, Noteridae (3 species each and 144-401 individuals). Rests of the 11 families were recorded by 1 species each representing 9-189 individuals (Table 5).

The sample size of the five different sites were compared and Shannon H with log base 10 indicated that the site III (H_s =1.691) showed maximum diversity and least dominance (D_s =0.022) followed by the site I (H_s=1.65 and D_S=0.025), site II (H_s=1.63 and $D_{s=}$0.029), site V (H_s=1.659 $D_{s=}$0.025) and site IV (H_s=1.63 $D_{s=}$ 0.028) species diversity in vegetation site III and site I were higher than vegetation poor site II, site IV and site V. Hills diversity index indicated that site II, site III and site V was richest (58 species) followed by IV (57 species)and site I (with 57 species each) (Table 6).

3.4 Comparison of species turnover among different Sites

To examine the difference in species composition between the different sites (habitat) Bray Curtis cluster analysis (single link) was calculated based on the similarity richness and abundance of water beetle taxa and showed that the population structure similarity was very close similar between the site I and site III which form a single cluster and site II and site V formed another cluster (Fig. 2). Site IV stood apart as an out group of the cluster consisting of site IV and site V. The overall species composition and population structure at site I and site III were more similar compared to site II and site V whereas site II was completely different from these two groups.

3.5 Habitat preference species distribution

Species distribution of water beetle fauna at different sites was assessed. Almost all the species showed random and aggregated distribution (Table 7).

The present study revealed that the physical habitat variables play key role in the distribution of aquatic insects in Loktak Lake. We observed that among habitat attributes, water temperature, dissolved oxygen, pH are key assemblages and found the most important variables in shaping insect distribution. The variation in the habitat attributes like water temperature, pH, dissolved oxygen, across the different sites attributed to differences in land use pattern, which was responsible for variation of species diversity and distribution. Temperature values recorded during the sampling period ranged from 26 to 30˚C. This values falls within the optimal range for tropical fresh waters. This was also collaborated by (Ayodele and Anjani 1999), but that tropical freshwaters had temperature values ranging from 21 to 32˚C. The variation in temperature observed was a result of low solar heat radiation across the sites. Inundation by run - off water into the stream also causes a reduction in temperature. This temperature reading indicates a great impact on the abundance and distribution of aquatic insects as more species were collected at relatively high temperature than when there was a drop in tem-

perature. Pearson's correlation coefficient (r) analysis between insect abundance and water temperature showed that most of the species correlated inversely with water temperature (Table 8). Possibly some insect species are temperature dependent, this favors their rate of feeding and metabolism. Some other likes *Baetis spp. Mesovelia douglasis, Mesovellia vittigera, Neohydrocoptus subvittulus, Limnogonus nitidus, Aquarius spp. Gerris spp.* etc. had positive correlation with temperature. These groups of insects increase with decreasing temperature because they prefer cooler waters for their feeding rate, metabolism and reproduction (Pennak 1978).

Pearson correlation coefficient analysis showed a negative relationship of the insects and dissolved oxygen; most of species showed statistical significance at $p< 0.05$ value except few species.

Free CO2 and nutrients (nitrate and phosphate) correlated positively with insect species. It is likely that input of nutrients in the lakes enhanced secondary production. Site I recorded higher values in nutrient (nitrate) indicating significant input of organic discharged in the area. A similar study has recorded a trend in Woji Creek in the Niger Delta where organic wastes are discharged constantly into the stream (Zabby and Hart 2006; Amiro et al. 2007) also recorded similar result in Ethiope River in Niger Delta. Nutrient is also an important factor in the distribution and abundance of *Chironomus* sp. (Ali et al. 2003) reporting a positive correlation in his study carried out in Malaysia.

The multiple comparison tests showed that Odonatans were greatest in site II where macrophytes dominated. Odonata nymphs are usually associated with macrophytes (Carchini et al. 2004, 2000; Ravera 2001; Ruggiero et al 2003 and Amiro etal. 2007 b) and Dipteran abundance are attributed to considerable load of organic particles from untreated sewage and livestock effluents. Less sensitive species like Ephemeropteran, Trichopteran only occur sporadically and limited in most cases by high concentration of organic pollutants.

From five different sites of Loktak Lake P^H values of water show the average of P^H value during study period is 6.5 to 7. The P^H value obtained from this study ranged from slightly acidic to neutral. Most species such as water boatmen, *Chironomus* sp. and damselflies are only slightly affected by acidification hence their abundance in site II and III. While other like mayflies are acid sensitive and they are mostly found in clean water that are alkaline in nature.

Alkalinity values recorded during the study period varied from 58 to 61 mg/l. Pearson correlation relationship between alkalinity and other physico –chemical parameters showed direct relationship. In addition the correlations with insect showed direct relationship with pollution tolerant species like *Chironomus* sp. and *Culex* sp.

The physico –chemical parameters variation from the study greatly influence the aquatic insect species composition, distribution and abundance in Loktak Lake. In recent studies, water hyacinth affects the water temperature, P^H, bicarbonate, and alkalinity of water. The present study indicates that the water was contaminated with ions, bicarbonate, carbonate and hydroxide. The sources of carbonate and bicarbonate are mainly due to rain and soils. An aquatic insect's population was recorded, Hemiptera is the dominant order with respect to species diversity (48.5 % species), followed by Coleoptera (36.2%), Odonata (10.7%), Diptera (3.2 %), Ephemeroptera (2.2%), and Trichoptera (0.4%). The presence of Dipteran species were mostly represented by larvae of different mosquitoes and Chironomid flies which was inversely proportional to dissolve oxygen of the lake and presence of these aquatic insects indicates that the presence of more organic decay which has resulted in good growth of macro-hydrophytes in the lake. Takmupat was with high rate of Odonata species, Hemiptera, etc. This observation indicates that some Odonata species were found in fresh water habitats of rich oxygen.

Conclusion

In conclusion, water quality plays an important role in the distribution, abundance and diversity of aquatic insects. The high abundance and distribution of pollution tolerant orders of aquatic insects in site II indicates the relative pollution of the Lake. With special reference to Margalef's water quality index, values greater than 3 indicates clean conditions values less than one (1) indicates heavy pollution of a stream, while values between 1-3 indicates moderately polluted conditions (Lenat et al., 1980). Margalef index for site I is 19.89, site II is 20.09, site III is 19.75, site IV is 21.66 and site V is 20.20 thereby collaborating the evidence of the relative polluted nature of the lake and this showed that the various activities around the reservoir has not been polluted.

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Table 1: Coordinates (UTM) and altitudes (Alt.) of 5 collection sites of Loktak Lake of Manipur

Site No.	Locations Habitat types		UTM	Alt
SITE I	Tongbram	Lentic	N 23°57.691' E 93°38.250'	835
SITE II	Takmupat	Lentic	N 24°29.221' E 93°48.580'	804
SITE III	Longum	Lentic	N 24°20.812' E 93°11.310'	845
SITE IV	Ngaram	Lentic	N 24°31.529' E 93°48.930'	854
SITE V	Ngaikhong	wetland	N 24°28.005' E 92°42.554'	858

Table 2: Physico-chemical parameters of water in five different sites of Loktak lake.

Parameters	Collection sites				
	Site (TONGBRAM)	Site II (TAKMUPAT)	Site III (LONGUM)	Site IV (NGARAM)	Site V (NGAIKHONG)
Water temp (°C)	26.5	28.5	30.6	30	30.6
Depth (cm)	43.0	22.5	32.2	35.5	21.0
Transparency (cm)	65.5	72.0	72.0	71.0	70.0
P^H	7	6.5	7	6.5	6.5
Dissolved Oxygen (mgl^{-1})	6.5	6.5	6.5	7.0	6.5
Total alkalinity (mgl^{-1})	58	59	61	60	59
Free CO_2 ppm	20	16	17	15	16
Chloride ppm	0.05	0.06	0.07	0.05	0.06
Total hardness (mgl^{-1})	136	136	145	178	120
Nitrate ppm	0.25	0.16	0.15	0.16	0.14
Phosphate (mgl^{-1})	0.05	0.08	0.08	0.04	0.03
Silicate ppm	1.50	1.80	2.10	2.40	2.20

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Table 3: Pearson's Correlation values between the physico –Chemical parameters at five different sites of Loktak Lake.

	Water temp.	PH	Dissolved Oxygen	Total alkalinity	Free Co_2	Chloride	Total Hardness	Nitrate	Phosphate	Silicate
Water temp.										
pH	0.358	1								
Dissolved Oxygen	0.242	-0.408	1.							
Total alkalinity	0.776	0.080	0.2942	1.						
Free Co2	-0.766	0.806	-0.5231	-0.5244						
Chloride	0.568	0.218	-0.5345	0.629	1.					
Total Hardness	-0.148	-0.105	0.9083	0.4682	-0.1864	1.	1.			
Nitrate	-0.921	0.575	-0.1511	-0.662	-0.3681	-0.3607	-0.0497*	1.		
Phosphate	-0.100	0.356	-0.3885	0.3619	0.8843	-0.5924	-0.0202*	-0.0636	1.	
Silicate	0.898	-0.516	0.6325	0.6822	0.0903	0.5971	0.476	-0.7966	-0.3379	1.

*Indicates Significant relationship.

Table 4: Distribution profile of aquatic insect fauna at Loktak Lake of Manipur.

Order	Family	Species	Individual
Ephemeroptera	Baetidae	1	73
Odonata	Libellulidae	4	196
	Coenagrionidae	1	80
Hemiptera	Belostomatidae	3	318
	Nepidae	5	228
	Pleadae	1	189
	Hydrometridae	1	74
	Corixidae	3	401
	Notonectidae	4	135
	Gerridae	4	153
Coleoptera	Dytiscidae	10	543
	Hydrophilidae	8	454
	Chrysomelidae	1	10
	Noteridae	3	144
	Haliplidae	1	26
	Curculionidae	1	9
Diptera	Chironomidae	1	34
	Culicidae	1	65
	Tipulidae	1	26
Trichoptera	Phryganeidae	1	13
	Total	58	3278

Table 5: List of species and relative abundance of aquatic insects recorded in five different sites of Loktak Lake of Manipur.

Species	Tongbram (Site I)	Takmupat (Site II)	Longum (Site III)	Ngaram (Site IV)	Ngaikhong (Site V)	Total	RA%
Baetis spp.	25	4	15	16	13	73	2.22
Rhyothemis decoratus	10	10	10	10	12	52	1.58
Rhodothemis rufa	6	12	8	5	5	36	1.09
Pantala flavescens	10	9	8	7	7	41	1.25
Ischnura spp.	13	27	14	16	10	80	2.44
Tramea spp.	16	16	21	8	6	67	2.04
Diplonychus rusticus	38	50	35	25	28	176	6.36
Diplonychus molestus	28	36	22	18	28	132	4.02
Lethocerus indicus	2	3	2	1	2	10	0.30
Laccotrephes griseus	8	9	12	8	3	30	0.91
Laccotrephes ruber	20	18	20	3	10	71	2.16
Ranatra varipes	10	12	12	3	11	48	1.46
Ranatra sordidula	5	6	7	3	5	26	0.79
Ranatra gracilis	15	8	10	8	12	53	1.57
Anisops batilliforns	12	10	12	8	8	50	1.52
Anisops sardea	4	5	3	2	5	19	0.52
Enithare ciliata	8	9	9	3	4	33	1.00
Enithare mandalayensis	8	8	8	4	5	33	1.00
Micronecta scutellaris	45	50	38	36	42	211	6.43
Micronecta haliploides	35	42	32	25	28	162	4.94
Sigara distorta	7	7	7	2	5	28	0.85
Limnogonus hyalipennis	10	9	12	8	10	49	1.49
Limnogonus nitidus	9	6	8	4	5	32	0.97
Aquarius spp.	8	8	6	5	7	34	1.03
Gerris spp.	10	13	12	5	8	38	1.15
Mesovelia douglasi	9	8	6	4	5	32	0.97
Mesovelia vittigera	12	12	12	3	16	55	1.67
Paraplea liturata	20	17	23	13	15	88	2.68

Species	Tongbram (Site I)	Takmupat (Site II)	Longum (Site III)	Ngaram (Site IV)	Ngaikhong (Site V)	Total	RA%
Paraplea indistinguida	23	15	21	10	32	101	3.08
Hydrometra greeni	18	21	20	8	7	74	2.47
Hydrochus spp.	14	23	25	3	15	80	2.44
Hydrovatus acuminatus	15	12	17	6	26	76	2.31
Hydrovatus bonvouloiri	15	10	15	7	13	60	1.83
Hydrophilus indicus	5	8	5	3	18	39	1.18
Tropisternus spp.	15	7	12	8	21	63	1.92
Rhantus spp.	4	4	5	3	5	21	0.64
Cybister tripunctatus	3	3	5	2	3	16	0.48
Cybister sugillatus	4	4	5	2	5	20	0.61
Leiodytes nicobaricus	15	8	15	6	16	60	1.83
Hydrocanthus guignoti	23	12	21	10	20	86	2.62
Canthydrus nitidus	4	4	4	6	10	28	0.85
Laccophilus chinensis	20	14	18	9	19	80	2.44
Laccophilus parvulus	15	12	18	9	11	65	1.98
Laccophilus ineficience	13	10	12	8	5	48	1.46
Enochrus spp.	16	3	16	6	17	58	1.76
Amphiops spp.	12	8	16	8	13	57	1.73
Neohydrocoptus subvittulus	5	9	8	3	5	30	0.09
Regimbartia attenuata	20	14	10	8	16	68	2.07
Helochares crenatus	10	5	13	6	8	42	1.28
Halipid spp.	5	3	10	5	3	26	0.79
Cercyon spp.	8	12	14	5	8	47	1.43
Donacia spp.	2	1	5	1	1	10	0.30
Notiodes spp.	0	1	3	3	2	9	0.27
Hydrogyphus flammulatus	31	16	23	12	15	97	2.95
Chironomus spp.	2	2	12	3	15	34	1.03
Culex spp.	10	10	25	10	10	65	1.98
Tipula spp.	2	10	6	4	4	26	0.79
Phryganeid spp.	1	1	6	0	5	13	0.39
Total	733	686	769	427	663	3278	

Table 6: Diversity indices for different sites at Loktak Lake of Manipur.

Index	Tongbram (Site I)	Takmupat (Site II)	Longum (Site III)	Ngaram (Site IV)	Ngaikhong (site V)
Shannon H' Log Base 10	1.652	1.632	1.691	1.637	1.659
Simpson Diversity (D)	0.025	0.029	0.022	0.028	0.025
Hill's Number	57	58	58	57	58
Berger-Parker Dominance(d)	0.061	0.073	0.049	0.084	0.063
Berger-Parker Dominance(1/d)	16.28	13.72	20.23	11.86	15.78
Margaleff index	19.89	20.09	19.75	21.66	20.20

Table 7: Distribution profile of aquatic insect fauna at Loktak Lake of Manipur.

Species	Variance	Mean	Chi-sq	d.f.	Probability	Aggregation
Baetis spp.	7942.7002	51.8	613.3359	4	0	Aggregated
Rhyothemis decoratus	0.8	10.4	0.3077	4	0.986188	Regular
Rhodothemis rufa	8.7	7.2	4.8333	4	0.3043422	Random
Pantala flavescens	1.7	8.2	0.8293	4	0.9326642	Random
Ischnura spp.	42.5	16	10.625	4	0.0308283	Random
Tramea spp.	38.8	13.4	11.5821	4	0.0206684	Aggregated
Diplonychus rusticus	95.7	35.2	10.875	4	0.0277791	Random
Diplonychus molestus	46.8	26.4	7.0909	4	0.1297058	Random
Lethocerus indicus	0.5	2	1	4	0.9089377	Random
Laccotrephes griseus	10.5	8	5.25	4	0.2616577	Random
Laccotrephes ruber	56.2	14.2	15.831	4	0.0034252	Aggregated
Ranatra varipes	14.3	9.6	5.9583	4	0.2009018	Random
Ranatra sordidula	2.2	5.2	1.6923	4	0.7944442	Random
Ranatra gracilis	8.8	10.6	3.3208	4	0.5077745	Random
Anisops batilliforns	4	10	1.6	4	0.8108233	Random
Anisops sardea	1.7	3.8	1.7895	4	0.7770038	Random
Enithare ciliata	8.3	6.6	5.0303	4	0.2834842	Random
Enithare mandalayensis	3.8	6.6	2.303	4	0.6834664	Random
Micronecta scutellaris	31.2	42.2	2.9573	4	0.5677307	Random
Micronecta haliploides	43.3	32.4	5.3457	4	0.2526121	Random
Sigara distorta	4.8	5.6	3.4286	4	0.5092573	Random
Limnogonus hyalipennis	2.2	9.8	0.898	4	0.923416	Random
Limnogonus nitidus	4.3	6.4	2.6875	4	0.6144832	Random
Aquarius spp.	1.7	6.8	1	4	0.9089377	Random
Gerris spp.	10.3	9.6	4.2917	4	0.36828	Random
Mesovelia douglasi	4.3	6.4	2.6875	4	0.6144832	Random

Mesovelia vittigera	23	11	8.3636	4	0.0780593	Random
Paraplea liturata	15.8	17.6	3.5909	4	0.5342014	Random
Paraplea indistinguida	69.7	20.2	13.802	4	0.0081056	Aggregated
Hydrometra greeni	45.7	14.8	12.3514	4	0.0149597	Aggregated
Hydrochus spp.	76	16	19	4	0.0008894	Aggregated
Hydrovatus acuminatus	53.7	15.2	14.1316	4	0.007049	Aggregated
Hydrovatus bonvouloiri	12	12	4	4	0.4068319	Random
Hydrophilus indicus	35.7	7.8	18.3077	4	0.001194	Aggregated
Tropisternus spp.	32.3	12.6	10.254	4	0.0359658	Random
Rhantus spp.	0.7	4.2	0.6667	4	0.95275	Random
Cybister tripunctatus	1.2	3.2	1.5	4	0.8282991	Random
Cybister sugillatus	1.5	4	1.5	4	0.8282991	Random
Leiodytes nicobaricus	21.5	12	7.1667	4	0.1258967	Random
Hydrocanthus guignoti	33.7	17.2	7.8372	4	0.0964672	Random
Canthydrus nitidus	6.8	5.6	4.8571	4	0.3017547	Random
Laccophilus chinensis	20.5	16	5.125	4	0.2738933	Random
Laccophilus parvulus	12.5	13	3.8462	4	0.5716579	Random
Laccophilus ineficience	10.3	9.6	4.2917	4	0.36828	Random
Enochrus spp.	43.3	11.6	14.931	4	0.005021	Aggregated
Amphiops spp.	11.8	11.4	4.1404	4	0.3879162	Random
Neohydrocoptus subvittulus	6	6	4	4	0.4068319	Random
Regimbartia attenuata	22.8	13.6	6.7059	4	0.1507757	Random
Helochares crenatus	10.3	8.4	4.9048	4	0.2966347	Random
Halipid spp.	8.2	5.2	6.3077	4	0.1758461	Random
Cercyon spp.	12.8	9.4	5.4468	4	0.2433466	Random
Donacia spp.	3	2	6	4	0.1977535	Random
Notiodes spp.	1.7	1.8	3.7778	4	0.5618389	Random
Hydrogyphus flammulatus	58.3	19.4	12.0206	4	0.0171932	Aggregated
Chironomus spp.	38.7	6.8	22.7647	4	0.00018	Aggregated
Culex spp.	45	13	13.8462	4	0.0079554	Aggregated
Tipula spp.	9.2	5.2	7.0769	4	0.1304207	Random
Phryganeid spp.	7.3	2.6	11.2308	4	0.0239438	Aggregated

Table 8: Pearson correlation coefficient values (r) between the means of the physico-chemical parameters of water and aquatic insects encountered during the sampling period at Loktak lake.

Name of Species	Water Temp.	P^H	Dissolved Oxygen	Total Alkalinity	Free CO_2	Chloride	Total Hardness	Nitrate	Phosphate	Silicate
Baetis spp.	-0.41	0.49	0.10	-0.24	0.70	-0.5	0.14	0.72	-0.42	-0.26
Rhyothemis decoratus	0.43	-0.80	-0.25	-0.19	-0.23	0.13	-0.59	-0.40	-0.63	0.31
Rhodothemis rufa	-0.18	-0.06	0	0.04	0.07	-0.42	-0.19	-0.13	0.8	-0.38
Pantala flavescens	-0.91	0.56	-0.51	-0.57	0.81	-0.18	-0.29	0.81	0.44	-0.97
Ischnura spp.	-0.23	-0.35	0	-0.03	-0.27	0.04	0.13	-0.11	0.64	-0.22
Tramea spp.	-0.29	0.74	-0.48	0.25	0.48	0.49	-0.07	0.27	0.88	-0.53
Diplonychus rusticus	-0.53	0.12	-0.58	-0.30	0.28	0.21	-0.37	0.22	0.75	-0.71
Diplonychus molestus	-0.45	-0.18	-0.68	-0.60	0.19	0.10	-0.70	0.12	0.33	-0.64
Lethocerus indicus	-0.30	0	-0.79	-0.31	0.18	0.42	-0.68	0	0.61	-0.6
Laccotrephes griseus	-0.09	0.56	0	0.54	0.16	0.36	0.41	0.10	0.83	0.17
Laccotrephes ruber	-0.47	0.70	-0.83	-0.15	0.69	0.44	-0.54	0.41	0.70	-0.79
Ranatra varipes	-0.10	0.33	-0.97	-0.12	0.36	0.67	-0.85	-0.02	0.52	-0.52
Ranatra sordidula	-0.044	0.49	-0.82	0.23	0.28	0.84	-0.57	-0.12	0.76	-0.38
Ranatra gracilis	-0.52	0.58	-0.49	-0.60	0.85	-0.24	-0.53	0.71	-0.35	-0.59
Anisops batilliforns	-0.49	0.91	-0.55	0	0.77	0.29	-0.19	0.56	0.65	-0.70
Anisops sardea	-0.24	-0.21	-0.77	-0.60	0.17	0.18	-0.90	0	0.05*	-0.48
Enithare ciliata	-0.42	-0.60	-0.69	-0.01	0.52	0.47	-0.35	0.30	0.87	-0.71
Enithare mandalayensis	-0.52	0.65	-0.74	-0.13	0.64	0.39	-0.42	0.41	0.79	-0.79
Micronecta scutellaris	-0.61	-0.11	-0.62	-0.68	0.30	-0.04	-0.61	0.30	0.33	-0.74
Micronecta haliploides	-0.57	0.15	-0.62	-0.35	0.34	0.19	-0.43	0.27	0.72	0.76
Sigara distorta	-0.42	0.58	-0.91	-0.22	0.62	0.49	-0.68	0.31	0.65	-0.77

Limnogonus hyalipennis	0.18	0.73	-0.67	0.35	0.42	0.76	-0.46	-0.03	0.41	-0.19
Limnogonus nitidus	-0.57	0.92	-0.64	-0.19	0.90	0.20	-0.35	0.66	0.46	-0.78
Aquarius spp.	-0.69	0.14	-0.77	-0.77	0.57	-0.04	-0.76	0.48	0.21	-0.86
Gerris spp.	-0.26	0.39	-0.80	-0.01	0.34	0.61	-0.52	0.07	0.85	-0.61
Mesovelia douglasi	-0.86	0.48	-0.64	-0.61	0.77	-0.08	-0.045	0.72	0.46	-0.98
Mesovelia vittigera	-0.04	0.19	-0.93	0.32	0.35	0.49	-0.98	-0.02	0.09	-0.41
Paraplea liturata	-0.20	0.89	-0.64	0.20	0.64	0.57	-0.30	0.30	0.66	-0.51
Paraplea indistinguida	-0.09	0.19	-0.68	00.29	0.34	0.29	-0.384	0.05*	-0.34	-0.16
Hydrometra greeni	-0.46	0.56	-0.56	0.01	0.47	0.38	-0.19	0.32	0.90	-0.69
Hydrochus spp.	0.02	0.36	-0.83	0.17	0.20	0.82	-0.59	-0.16	0.78	-0.39
Hydrovatus acuminatus	0.25	0.09	-0.70	0.16	0.18	0.45	-0.86	-0.19	-0.24	-0.05*
Hydrovatus bonvouloiri	-0.20	0.79	-0.80	-0.12	0.75	0.43	-0.66	0.35	0.18	-0.53
Hydrophilus indicus	0.71	-0.33	-0.25	0.19	-0.40	0.47	-0.50	-0.66	-0.39	0.51
Tropisternus spp.	0.11	0.14	-0.45	-0.31	0.31	0.08	-0.68	0.05*	-0.58	-0.03
Rhantus spp.	0.33	0.32	-0.80	0.16	0.18	0.78	0.77	-0.28	0.18	-0.08
Cybister tripunctatus	0.25	0.66	-0.61	0.52	0.26	0.87	-0.32	-0.16	0.63	-0.12
Cybister sugillatus	0.13	0.37	-0.91	0	0.31	0.73	-0.86	-0.13	0.26	-0.28
Leiodytes nicobaricus	-0.01	0.59	-0.72	-0.14	0.58	0.38	-0.72	0.19	-0.11	-0.30
Hydrocanthus guignoti	-0.20	0.75	-0.69	-0.20	0.76	0.26	-0.62	0.41	-0.04	-0.46
Canthydrus nitidus	0.52	-0.56	0.08	-0.10	-0.41	-0.04	-0.30	-0.46	-0.78	0.54
Laccophilus chinensis	-0.25	0.60	-0.86	-0.33	0.71	0.33	-0.83	0.34	0.02	-0.56
Laccophilus parvulus	-0.14	0.90	-0.63	0.24	0.62	0.59	-0.29	0.27	0.61	-0.46
Laccophilus ineficience	-0.61	0.82	-0.27	-0.01	0.71	0.05*	0.10	0.65	0.64	-0.68
Enochrus spp.	0.07	0.61	-0.47	-0.04	0.54	0.25	-0.49	0.20	0.29	-0.12
Amphiops spp.	0.27	0.69	0.55	0.33	0.39	0.64	-0.42	-0.03	0.12	0.04
Neohydrocoptus subvittulus	-0.02	0.18	-0.68	0.179	0.05*	0.73	-0.43	0.20	0.88	-0.37
Regimbartia attenuata	-0.70	0.26	-0.65	-0.88	0.75	-0.27	-0.74	0.66	-0.20	-0.79
Helochares crenatus	0.09	0.88	-0.41	0.355	0.54	0.50	-0.19	0.18	0.23	-0.15
Halipid spp.	0.27	0.73	-0.03	0.73	0.19	0.54	0.28	0.04	0.47	0.12
Cercyon spp.	0.12	0.40	-0.68	0.38	0.12	0.86	-0.39	-0.22	0.87	-0.27
Donacia spp.	0.22	0.7	-0.33	0.63	0.30	0.69	0.01	-0.03	0.56	-0.04
Notiodes spp.	0.91	-0.21	0.51	0.90	-0.71	0.41	0.51	-0.76	-0.03	0.92
Hydrogyphus flammulatus	-0.67	0.90	-0.54	-0.33	0.97	-0.23	-0.31	0.80	0.23	0.92
Chironomus spp.	-0.73	0.02	-0.34	-0.40	0.21	-0.66	-0.45	0.58	-0.19	-0.45
Culex spp.	0.43	0.61	-0.25	0.78	0.05*	0.80	0.05*	-0.27	0.58	0.15
Tipula spp.	0.17	-0.36	-0.22	0.26	-0.46	0.51	-0.09	-0.50	0.73	0.60
Phryganeid spp.	0.60	0.30	-0.53*	0.47	-0.01	0.84	-0.50	-0.47	0.123	0.23

Correlation is significant at the 0.05 level and indicated by *

Table 8: Pearson correlation coefficient values (r) between the means of the physico-chemical parameters of water and aquatic insects encountered during the sampling period at Loktak lake.

Name of Species	Water Temp.	P^H	Dissolved Oxygen	Total Alkalinity	Free CO_2	Chloride	Total Hardness	Nitrate	Phosphate	Silicate
Baetis spp.	-0.41	0.49	0.10	-0.24	0.70	-0.5	0.14	0.72	-0.42	-0.26
Rhyothemis decoratus	0.43	-0.80	-0.25	-0.19	-0.23	0.13	-0.59	-0.40	-0.63	0.31
Rhodothemis rufa	-0.18	-0.06	0	0.04	0.07	-0.42	-0.19	-0.13	0.8	-0.38
Pantala flavescens	-0.91	0.56	-0.51	-0.57	0.81	-0.18	-0.29	0.81	0.44	-0.97

Name of Species	Water Temp.	P^{H}	Dissolved Oxygen	Total Alkalinity	Free CO_2	Chloride	Total Hardness	Nitrate	Phosphate	Silicate
Ischnura spp.	-0.23	-0.35	0	-0.03	-0.27	0.04	0.13	-0.11	0.64	-0.22
Tramea spp.	-0.29	0.74	-0.48	0.25	0.48	0.49	-0.07	0.27	0.88	-0.53
Diplonychus rusticus	-0.53	0.12	-0.58	-0.30	0.28	0.21	-0.37	0.22	0.75	-0.71
Diplonychus molestus	-0.45	-0.18	-0.68	-0.60	0.19	0.10	-0.70	0.12	0.33	-0.64
Lethocerus indicus	-0.30	0	-0.79	-0.31	0.18	0.42	-0.68	0	0.61	-0.6
Laccotrephes griseus	-0.09	0.56	0	0.54	0.16	0.36	0.41	0.10	0.83	0.17
Laccotrephes ruber	-0.47	0.70	-0.83	-0.15	0.69	0.44	-0.54	0.41	0.70	-0.79
Ranatra varipes	-0.10	0.33	-0.97	-0.12	0.36	0.67	-0.85	-0.02	0.52	-0.52
Ranatra sordidula	-0.044	0.49	-0.82	0.23	0.28	0.84	-0.57	-0.12	0.76	-0.38
Ranatra gracilis	-0.52	0.58	-0.49	-0.60	0.85	-0.24	-0.53	0.71	-0.35	-0.59
Anisops batilliforns	-0.49	0.91	-0.55	0	0.77	0.29	-0.19	0.56	0.65	-0.70
Anisops sardea	-0.24	-0.21	-0.77	-0.60	0.17	0.18	-0.90	0	0.05*	-0.48
Enithare ciliata	-0.42	-0.60	-0.69	-0.01	0.52	0.47	-0.35	0.30	0.87	-0.71
Enithare mandalayensis	-0.52	0.65	-0.74	-0.13	0.64	0.39	-0.42	0.41	0.79	-0.79
Micronecta scutellaris	-0.61	-0.11	-0.62	-0.68	0.30	-0.04	-0.61	0.30	0.33	-0.74
Micronecta haliploides	-0.57	0.15	-0.62	-0.35	0.34	0.19	-0.43	0.27	0.72	0.76
Sigara distorta	-0.42	0.58	-0.91	-0.22	0.62	0.49	-0.68	0.31	0.65	-0.77
Limnogonous hyalipennis	0.18	0.73	-0.67	0.35	0.42	0.76	-0.46	-0.03	0.41	-0.19
Limnogonus nitidus	-0.57	0.92	-0.64	-0.19	0.90	0.20	-0.35	0.66	0.46	-0.78
Aquarius spp.	-0.69	0.14	-0.77	-0.77	0.57	-0.04	-0.76	0.48	0.21	-0.86
Gerris spp.	-0.26	0.39	-0.80	-0.01	0.34	0.61	-0.52	0.07	0.85	-0.61
Mesovelia douglasi	-0.86	0.48	-0.64	-0.61	0.77	-0.08	-0.045	0.72	0.46	-0.98
Mesovelia vittigera	-0.04	0.19	-0.93	0.32	0.35	0.49	-0.98	-0.02	0.09	-0.41
Paraplea liturata	-0.20	0.89	-0.64	0.20	0.64	0.57	-0.30	0.30	0.66	-0.51
Paraplea indistinguida	-0.09	0.19	-0.68	00.29	0.34	0.29	-0.384	0.05*	-0.34	-0.16
Hydrometra greeni	-0.46	0.56	-0.56	0.01	0.47	0.38	-0.19	0.32	0.90	-0.69
Hydrochus spp.	0.02	0.36	-0.83	0.17	0.20	0.82	-0.59	-0.16	0.78	-0.39
Hydrovatus acuminatus	0.25	0.09	-0.70	0.16	0.18	0.45	-0.86	-0.19	-0.24	-0.05*
Hydrovatus bonvouloiri	-0.20	0.79	-0.80	-0.12	0.75	0.43	-0.66	0.35	0.18	-0.53
Hydrophilus indicus	0.71	-0.33	-0.25	0.19	-0.40	0.47	-0.50	-0.66	-0.39	0.51
Tropisternus spp.	0.11	0.14	-0.45	-0.31	0.31	0.08	-0.68	0.05*	-0.58	-0.03
Rhantus spp.	0.33	0.32	-0.80	0.16	0.18	0.78	0.77	-0.28	0.18	-0.08
Cybister tripunctatus	0.25	0.66	-0.61	0.52	0.26	0.87	-0.32	-0.16	0.63	-0.12
Cybister sugillatus	0.13	0.37	-0.91	0	0.31	0.73	-0.86	-0.13	0.26	-0.28
Leiodytes nicobaricus	-0.01	0.59	-0.72	-0.14	0.58	0.38	-0.72	0.19	-0.11	-0.30
Hydrocanthus guignoti	-0.20	0.75	-0.69	-0.20	0.76	0.26	-0.62	0.41	-0.04	-0.46
Canthydrus nitidus	0.52	-0.56	0.08	-0.10	-0.41	-0.04	-0.30	-0.46	-0.78	0.54
Laccophilus chinensis	-0.25	0.60	-0.86	-0.33	0.71	0.33	-0.83	0.34	0.02	-0.56
Laccophilus parvulus	-0.14	0.90	-0.63	0.24	0.62	0.59	-0.29	0.27	0.61	-0.46
Laccophilus ineficience	-0.61	0.82	-0.27	-0.01	0.71	0.05*	0.10	0.65	0.64	-0.68
Enochrus spp.	0.07	0.61	-0.47	-0.04	0.54	0.25	-0.49	0.20	0.29	-0.12
Amphiops spp.	0.27	0.69	0.55	0.33	0.39	0.64	-0.42	-0.03	0.12	0.04
Neohydrocoptus subvittulus	-0.02	0.18	-0.68	0.179	0.05*	0.73	-0.43	0.20	0.88	-0.37
Regimbartia attenuata	-0.70	0.26	-0.65	-0.88	0.75	-0.27	-0.74	0.66	-0.20	-0.79
Helochares crenatus	0.09	0.88	-0.41	0.355	0.54	0.50	-0.19	0.18	0.23	-0.15
Halipid spp.	0.27	0.73	-0.03	0.73	0.19	0.54	0.28	0.04	0.47	0.12

Name of Species	Water Temp.	PH	Dissolved Oxygen	Total Alkalinity	Free CO_2	Chloride	Total Hardness	Nitrate	Phosphate	Silicate
Cercyon spp.	0.12	0.40	-0.68	0.38	0.12	0.86	-0.39	-0.22	0.87	-0.27
Donacia spp.	0.22	0.7	-0.33	0.63	0.30	0.69	0.01	-0.03	0.56	-0.04
Notiodes spp.	0.91	-0.21	0.51	0.90	-0.71	0.41	0.51	-0.76	-0.03	0.92
Hydrogyphus flammulatus	-0.67	0.90	-0.54	-0.33	0.97	-0.23	-0.31	0.80	0.23	0.92
Chironomus spp.	-0.73	0.02	-0.34	-0.40	0.21	-0.66	-0.45	0.58	-0.19	-0.45
Culex spp.	0.43	0.61	-0.25	0.78	0.05*	0.80	0.05*	-0.27	0.58	0.15
Tipula spp.	0.17	-0.36	-0.22	0.26	-0.46	0.51	-0.09	-0.50	0.73	0.60
Phryganeid spp.	0.60	0.30	-0.53*	0.47	-0.01	0.84	-0.50	-0.47	0.123	0.23

Correlation is significant at the 0.05 level and indicated by *

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