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Spatial Variation of Benthic Odonate (Odonata: Insecta) Community Structure in the Urban River Killiyar in Southern Kerala, India

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Abstract

The spatial variation of benthic odonate community assemblage in various zones (upper, middle, and lower zones) of the urban river Killiyar was assessed using the tools of geographic information system (GIS) and investigated their interaction with select water quality parameters. Benthic odonate larvae collected during this study belong to predators–engulfers of the functional feeding groups. A total of 147 individuals of 12 genera across nine families of benthic odonate taxa were recorded in this study. Out of the total taxa observed, Gomphidae comprised 34% individuals, followed by Libellulidae (33%). The former taxa were the dominant family in all the zones except the lower zone. The spatial analysis demonstrated high diversity and richness in the stations of the middle zone while moderate diversity in the rest of the stations. The population density observed was high at station Idappazhanjhi (K10). The distribution of taxa was relatively higher in the middle zone than that of other zones. The taxa Libellulidae was observed in most stations and directly associated with water temperature, pH, and dissolved oxygen. The major drivers that govern benthic odonate community assemblages in Killiyar were pH and dissolved oxygen. Investigating the community assemblage using GIS tools is novel and provides a better understanding of the ecology of odonate larval communities and their association with water quality. The outcome of this study supports the formulation of management strategies to protect the odonate diversity and conservation of their habitats, the riverine ecosystems in the urban landscapes in particular.

Keywords: Diversity metrics, Spatial variation, Functional feeding groups, GIS–tools, Riverine Ecosystems, Urban landscapes

1. Introduction

Benthic odonate community (BOC) comprises nymphs of the suborder Anisoptera (Dragonfly) and Zygoptera (Damselflies) of the class Insecta, Order Odonata. They are the vital components of the aquatic biotic community. They either live attached to the macrophytes or bottom substrates and play a significant role in the food web's predator and prey population. They serve as biological indicators since these communities are sensitive to changes in the environment (Watson *et al*., 1982; Clark and Samways, 1996; Samways and Steytler, 1996; Foote and Rice Hornung, 2005; Stewart and Samways, 2008; Al–Shami *et al*., 2014; Buss *et al.*, 2015; Gebrehiwot *et al.*, 2017). They also function as biological controlling agents, and the effectiveness of larvae and adults of Odonata, *Bradinopyga germinata* (Anisoptera: Libellulidae) against the dengue vectors was identified by Venkatesh and Tyagi (2013, 2015).

Nevertheless, very few studied the ecology of benthic odonate larval communities; most of them were focused primarily on the adult odonates and macroinvertebrate taxa altogether. The odonate larval communities belong to a particular group of insect fauna that is subjected to a high risk of extinction due to habitat loss and climate change (Hadfield, 1993; Thomas *et al*., 2004). Odonates, along with Molluscs and Decapods, make up 77% of total listed freshwater invertebrates that dominate the Red List of International Union for Conservation of Nature (IUCN), as discussed by Strayer (2006) and Collier *et al*. (2016). IUCN estimated that "approximately 12000 species of freshwater invertebrates are imperilled or have been extinguished by human activities" (Strayer, 2006). Globally about 10% of the odonates are threatened, and most of the species in the tropical habitats remain poorly studied (Clausnitzer *et al*., 2009). In this context, managing odonate diversity and protecting their habitats is an utmost priority to maintain a productive ecosystem. The spatial analysis of BOCs and water quality (WQ) of riverine habitats are scarce in limnological research and relevant in assessing the status of stream ecology. Such information forms the baseline data for the capacity building for the protection of aquatic biodiversity. Therefore, the present paper discusses the spatial variation of BOC distribution using GIS–tools and their dependence on select WQ parameters in the Killiyar according to the river continuum. This approach would be beneficial for the better understanding, management and protection of the odonate diversity and conservation of their habitats, the riverine ecosystems in the urban landscapes in particular.

2. Materials and Methods

2.1. Study Area

Killiyar, a tributary of Karamana river, originates from Karinchathanmoola near Panavoor of Nedumangadu Taluk in Thiruvananthapuram District, South Kerala, India located between the latitudes 8°40'30" N, 8°27'0"N and longitudes 76°57'E, 77°2'0"E (Fig.1). Killiyar flows about 33 km through the various habitats of Nedumangadu Taluk, Nedumangadu Municipality and the Corporation of Thiruvananthapuram and finally opens to the Karamana River at Kalladimukham near Thiruvallom. A recent

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census report estimated about 1.68 million people living in the Corporation of Thiruvananthapuram (Census of India, 2011). In the upstream, people directly depend on this river for their basic needs. However, the river has been in a degraded state and has triggered public outrage over the deterioration of WQ. It is assumed that inputs from the various point and non–point sources have affected WQ and biodiversity. Dinesh *et al*. (2017) discussed the changes in riparian land use, the release of untreated wastes, dumping of garbage and encroachments. In the present investigation, the river's entire course was divided into three zones (upper, middle and lower), and each contains four stations considering the urbanisation pressure and anthropogenic disturbances. Sampling stations in each zone are located approximately three km apart were selected for physical, chemical and odonate sampling. A detailed description of the sampling stations is given in Table 1.

2.2 Data Collection and Analysis

The channel width and water depth of the river at each station were estimated following methods outlined by Phiri (2000). Water temperature was measured with a centigrade thermometer. Total dissolved solids (TDS), pH, and electrical conductivity (EC) of water were tested in situ using Eutech portable tester. Dissolved oxygen (DO) of water was estimated using modified Winkler's Iodometric method as described by Rice *et al*. (2012). The hardness of water was estimated titrimetrically following the method

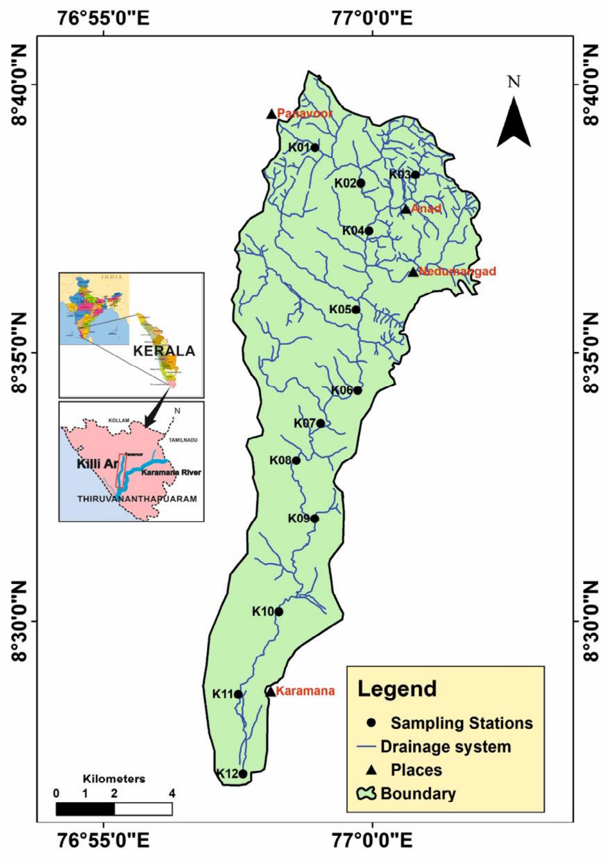

Fig. 1. Location map of the Killiyar showing the sampling locations visualised by GIS computer software, ArcGIS, Version 10.2.1 using topographic maps of 1:25000 scale.

described by Trivedy and Goel (1984). Benthic odonate specimens were collected using a D–frame net (Dimensions of the frame are 0.3 m width and 0.3 m height (Barbour *et al*., 1999) with a mesh size of 100 µm. The samples were collected during the summer month of 2016 (April). In all stations, a 50 m stretch of the river was sampled for 40 minutes for odonate specimens. Samples collected were transferred to a glass jar containing a little water and transported to the laboratory. All samples were sorted out by a thorough search on the same day using a white enamel pan and later preserved in 70% ethanol as described by Barbour *et al*. (1999). Samples were later counted and identified up to the family level using standard keys, including Morse *et al*. (1994), McCafferty and Provonsha (1998), and Yule and Yong (2004), under a stereomicroscope (Headz–HD600D).

The habitat characterisation and functional feeding groups were identified following Morse *et al*. (1994). This study computed various diversity metrics viz., population density which is expressed as individuals/m^2 (ind./m^2), Shannon–Weiner index (Shannon and Wiener, 1949), Simpson index (Simpson, 1949), Margalef index (Margalef, 1958) and Evenness index (Pielou, 1966) as described by Magurran (1988) using computer program Paleontological Statistics (PAST) Version 3.19 (Hammer *et al*., 2001) in order to assess the variation in BOC assemblage across different stations and zones.

The study analysed the BOC structure and WQ using GIS–tools using inverse distance weighted method (IDW) using ArcGIS Desktop version 10.2.1 (Esri Inc. 2011). The geographic coordinates of the sampling stations were recorded with a portable GPS (GARMIN ETR eTrex Venture). Non–electronic data (topographic maps) were digitised to GIS format and projected to the same coordinate system (GCS WGS 1984) prior to spatial analysis. The multiple geospatial databases linked with attribute data (diversity metrics and WQ) were projected and presented in both vector and raster format for spatial interpolation (Chen *et al*., 2009).

2.3 Statistical Analysis

Seven physicochemical parameters of water and five diversity metrics pertained to BOCs were analysed in this study. To enhance normality and quality of variances, square root transformed taxon assemblage and WQ data were used for statistical analysis as recommended by Rocha *et al*. (2012). The coefficient of correlations was computed to test the association between individual taxa and physical and chemical variables. One–way analysis of variance (ANOVA) was performed to test the variation in water parameters and diversity metrics between different zones (Larned *et al*., 2006; Fu *et al*., 2015). Hierarchical cluster analysis using Ward's method with Euclidean similarity index was performed to show the spatial similarity of stations with pooled odonate diversity metrics and environmental variables as described by Mangadze *et al*. (2016) using PAST (Version 3.19) following the methods outlined by Marcucci and Sharma (1997), Reghunath *et al*. (2002), and Barakat *et al*. (2016). All statistical analyses were done using the statistical package SPSS Version 16.0 (SPSS Inc. 2007).

Table 1. Description of sampling stations in the urban river Killiyar, Southern Kerala, India

Station Code	Name of the station	Latitude & Longitude	Type of Land Use	Type of biotope
Upper Zone				
K01	Theerthankara	N08p 38’47.8" E77p 59' 02.2"	Mixed plantation	Cobble, Coarse gravel.
K02	Unnupaalam	N08p 38’29.9" E76p 59’43.9"	Rubber plantation	Fine gravel, coarse sand, Very coarse sand.
K03	Anadu	N08p 38’21.0" E77p 00’45.3"	Mixed plantation	Very coarse sand, Clay.
K04	Pazhakutti	N08p 37’25.0" E76p 59’51.7"	Mixed plantation	Boulders, Rocky.
Middle Zone				
K05	Nedumangadu	N08p 35’58.7" E76p 59’41.8"	Urban settlements	Coarse gravel.
K06	Azhikkodu	N08p 34’30.9" E76p 59’44.7"	Mixed plantation and human settlements	Rocky, Fine gravel.
K07	Enikkara	N08p 34’07.0" E76p 59’06.8"	Mixed plantation and human settlements	Rocky
K08	Vazhayila	N08p 34’55.1" E76p 59’97.7"	Mixed plantation	Rocky, Coarse gravel.
Lower Zone				
K09	Melathummal	N08p 31’57.0" E76p 58’56.1"	Mixed plantation	Coarse gravel, Clay.
K10	Idappazhanjhi	N08p 30’15.7" E76p 58’12.9"	Urban settlements	Clay.
K11	Killippalam	N08p 2853.1" E76p 57’30.7"	Urban settlements	Rocky, Clay.
K12	Kalladimukham	N08p 27’18.2" E76p 57’32.0"	Urban settlements	Very coarse sand, Clay.

3. Results and Discussion

In Killiyar, the BOC was composed of 147 individuals of 12 genera belonging to nine families. Taxa recorded belonged to the families of Cordulidae, Coenagrionidae, Calopterygidae, Euphaeidae, Gomphidae, Macromiidae, Platycnemidae, Libellulidae and Protoneuridae. Out of the total taxa, 34 % belongs to Gomphidae and Libellulidae (Fig. 2). The dominant families observed are Gomphidae, Libellulidae, and Coenagrionidae. This was in accordance with the observation of Sharma and Joshi (2007), who found a higher abundance of these families in the Dholbaha Dam in Punjab Shivalik, India. See Fig. 3 for the result of spatial analysis of diversity and richness and Fig. 7 for the photographs of benthic odonates recorded from Killiyar during this study.

The population density ranged from 4 ind./m^2 to 28 ind. / m^2, and maximum density was found at station Idappazhanjhi (K10) and minimum at Enikkara (K07). Spatial analysis revealed that odonate larvae were *abundant* in the majority of the stations; however, it showed a *higher abundance* at stations like Anadu (K03), Azhikkodu (K06), Melathummal (K09), and Idappazhanjhi (K10) (See Fig. 3A). Compared to that of other zones, the population density was high in the lower zone (61 ind./ m^2), where the riparian land use was mostly urban residential area with sparse vegetation. However, in station Killippalam (K11), located amidst an urban area where several direct effluent discharges from the Corporation of Thiruvananthapuram open to this river, odonate communities were not observed. One–way

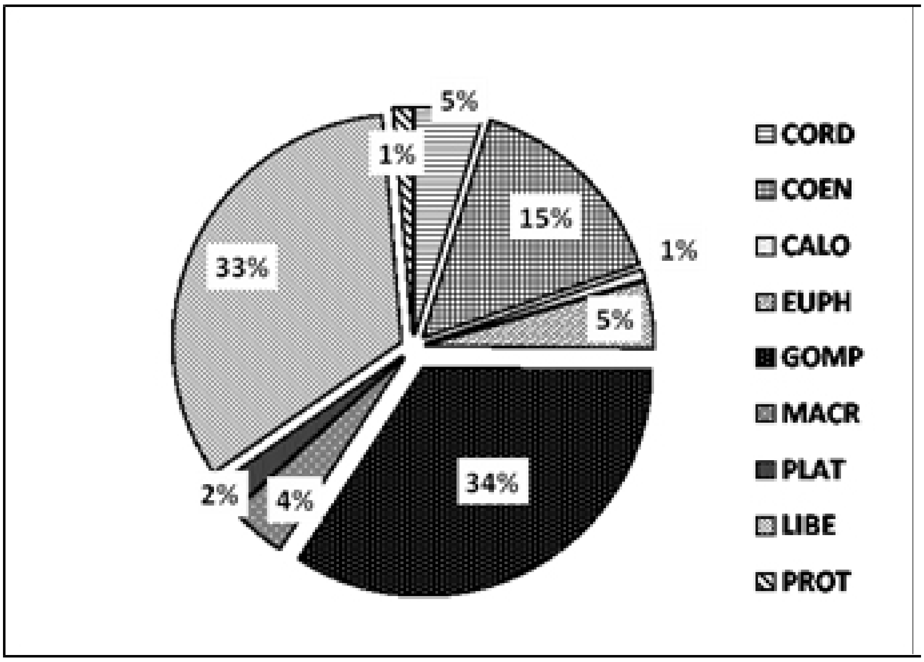

Fig. 2. Percentage composition of benthic odonate communities recorded from the urban river Killiyar, Southern Kerala, India. CORD: Cordulidae, COEN: Coenagrionidae, CALO: Calopterygidae, EUPH: Euphaeidae, GOMP: Gomphidae, MACR: Macromiidae, PLAT: Platycnemidae, LIBE: Libellulidae, PROT: Protoneuridae.

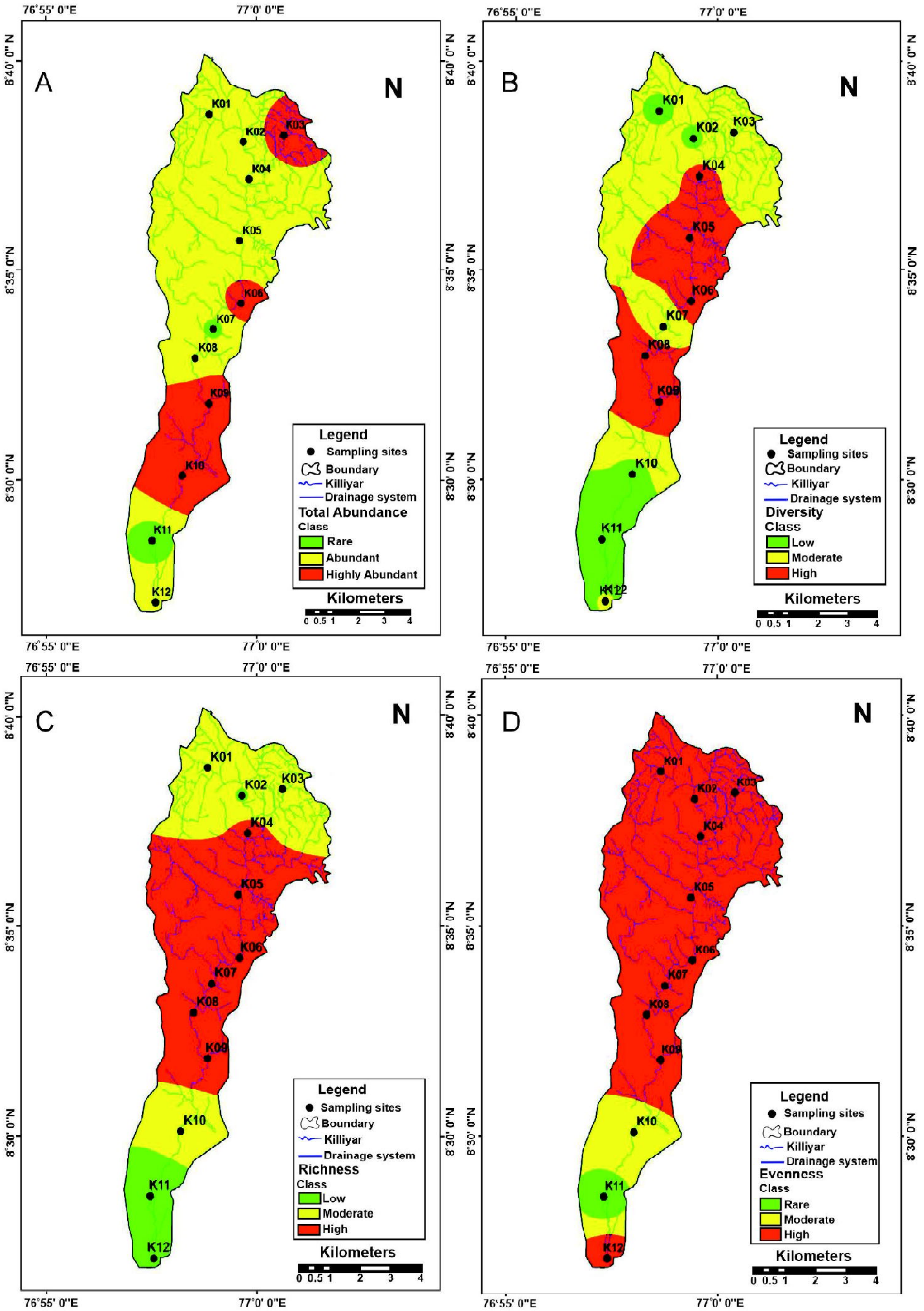

Fig. 3. The map shows spatial variation of benthic odonate community assemblage in the urban river Killiyar, Southern Kerala, India; **(A)** Total abundance: Below 4: Rare; between 4 and 15: Abundant; above 16: highly abundant **(B)** Shannon–Weiner diversity: below 0.6: Low; between 0.61 and 0.98: Moderate; above 0.99: High) **(C)** Richness: below 0.49: low; between 0.5 and 0.90: Moderate; above 0.91: High) **(D)** Evenness.

ANOVA indicated that there was no significant difference in population density (f=0.039; P=0.962) between zones. The habit characteristics assessment revealed that 40% of the BOC belonged to sprawlers; in turn, the burrowers and climbers constituted about 35% and 25%, respectively. During this study, all the specimens collected were belonging to predators–engulfers of functional feeding groups. The percentage dominance studied showed that Gomphidae was dominant in both upper and lower zones whilst Libellulidae dominated the middle zone. Both these taxa were observed in most stations, indicating that they can survive in the available environmental conditions as a consequence, exhibit zero biotope specificity. This was in agreement with Shelton and Edward (1983), who indicated that common species have more individuals than uncommon species and had the potential to thrive in existing environmental conditions. See Table 2 for the distribution of odonate nymphs in the various stations of Killiyar. Odonate nymphs found in the upper zone belonged to Coenagrionidae, Euphaeidae, Gomphidae, Libellulidae, and Protoneuridae. The middle zone was composed of individuals of families viz, Coenagrionidae,

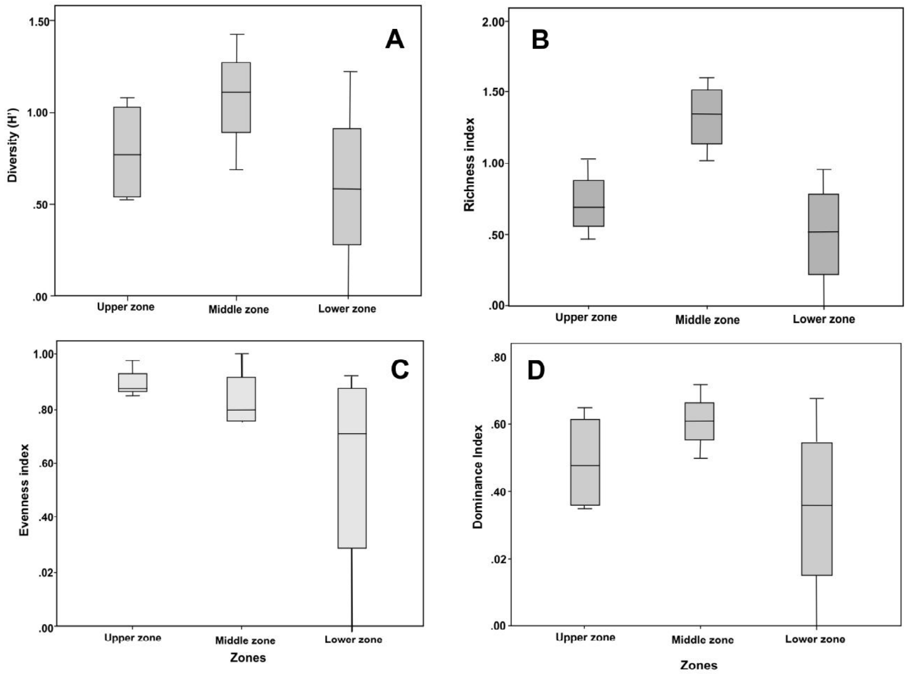

Fig. 4. The box plot shows the variation of **A**) Shannon–Weiner diversity index, **B**) Richness **C**) evenness index, and **D**) dominance between the various zones in the urban river Killiyar, Southern Kerala, India.

Calopterygidae, Gomphidae, Platycnemidae and Libellulidae. Families found in the lower zone were Cordulidae, Coenagrionidae, Gomphidae, Macromiidae and Libellulidae.

The diversity index ranged from 0.53 to 1.42, and maximum diversity was recorded at station Vazhayila (K08) and minimum at Unnupaalam (K02). The richness was high at stations Vazhayila (K08) and Enikkara (K07), located in the middle zone. This could be due to the minimal urban agglomeration and anthropogenic disturbances existing in this zone. Extremely low richness was recorded at stations Kalladimukham (K12) and Unnupaalam (K02). Spatial analysis showed that high diversity and richness were found in the middle zone of the river (Fig. 3B & 3C). Moreover, the diversity and richness were less at upper and lower zones where odonate larvae were either rare or absent. There was no statistically significant variation in diversity (f=1.26; P=0.329) and richness (f=1.29; P=0.262) between the selected zones (Fig. 4 A & B).

The evenness index ranged from 0.58 to 1.00, maximum at station Enikkara (K07), and minimum at Idappazhanjhi (K10). Extremely low evenness was found in the lower zone at station Idappazhanjhi (K10), which established variation in the evenness (Fig. 3D). The dominance index ranged from 0.3 to 0.72, and the highest dominance was found at station Vazhayila (K08) and lowest at station Idappazhanjhi (K10). The station Vazhayila (K08) supports a considerable number of odonate larval communities compared to that of other stations. However, there was no statistically significant variation in both evenness (f=1.03; P=0.395) and dominance (f=1.51; P=0.271) exist between different zones (Fig. 4C & 4D).

3.1. Spatial variation of water quality

See Table 3 to summarise physicochemical parameters with mean and standard deviations of water parameters recorded during this study. Although pH was high in the stations of the upper zone, it was in the acceptable range in most stations (Fig. 5A). This could be due to washing and bathing in the upstream stations that can affect the

Table 2. Distribution of benthic odonate community recorded in the various stations from the urban river Killiyar, Southern Kerala, India.

Family	Stations											
	K 01	K 02	K 03	K 04	K 05	K 06	K 07	K 08	K 09	K 10	K 11	K 12
CORD	–	–	–	–	–	–	–	–	+	–	–	–
COEN	–	–	+	+	+	+	–	+	–	+	–	–
CALO	–	–	–	–	–	+	–	–	–	–	–	–
EUPH	–	–	+	–	–	–	–	–	–	–	–	–
GOMP	+	+	+	+	+	+	+	+	+	+	–	+
MACR	–	–	–	–	–	–	–	–	+	–	–	–
PLAT	–	–	–	–	+	–	–	+	–	–	–	–
LIBE	–	+	–	+	+	+	+	+	+	+	–	+
PROT	+	–	–	–	–	–	–	+	–	–	–	–

CORD: Cordulidae, COEN: Coenagrionidae, CALO: Calopterygidae, EUPH: Euphaeidae, GOMP: Gomphidae, MACR: Macromiidae, PLAT: Platycnemidae, LIBE: Libellulidae, PROT: Protoneuridae

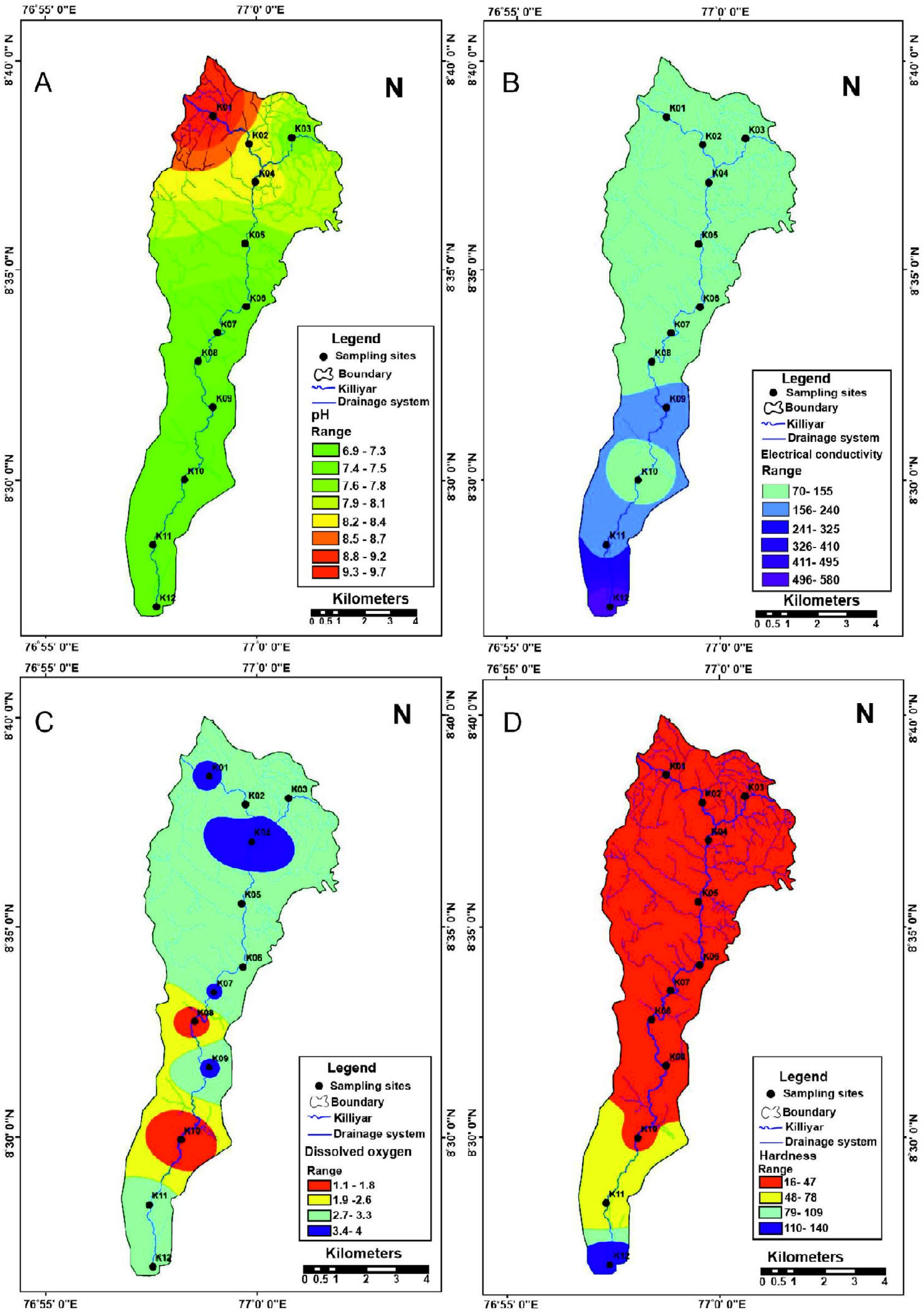

Fig. 5. Mapping of spatial variation of water quality parameters observed in the urban river Killiyar, Southern Kerala, India by using GIS computer software, ArcGIS, Version. 10.2.1. (A) pH, (B) Electrical conductivity, (C) Dissolved oxygen and (D) Hardness.

water environment and faunal abundance, as reported by Ojija and Laizer (2016). Conductivity, a strong predictor of aquatic insect abundance, was higher in the stations of the lower zone (Fig. 5B), and showed an inverse association with most of the BOCs (See Table 4). The DO ranged from 1.1 mg/l to 4 mg/l, which was poor and below the permissible level (4 mg/l) in the majority of the stations (Fig. 5C). Poor DO in the downstream stations could be attributable to the inflow of household wastewater and urban run-off and indicates organic enrichment. Hardness was low in most of the stations (Fig. 5D) and showed an inverse association with all the odonate families. Similar results were reported from the Etowah River basin in Northern Georgia (Walters *et al*., 2009). In contrast to other stations, pH, DO, and hardness were substantially different at station Kalladimukham (K12). This could be due to the saline intrusion due to the tidal impact, which is comparable to the observations of Lakshmi and Madhu (2014), Chattopadhyay and Harilal (2017), and Harikumar (2017).

The BOCs showed a significant association with environmental parameters. Libellulidae was found in the majority of the stations (Table 2) where the water temperature was in the range of 27 °C to 29.5 °C, and

Table 3. Physicochemical parameters with mean and standard deviations of water samples recorded from various zones of the urban river Killiyar, Southern Kerala, India

Station	WT (ºC)	pH	EC (µS/cm)	DO (mg/L⁻¹)	Hard (mg/L–1)	Dep (cm)	CW (m)
Upper Zone							
K01	25.2	9.7	70	3.3	16	18	7.55
K02	28	8.3	80	3.1	24	15	7.75
K03	28	7.6	140	2.9	32	20	3.4
K04	28	8.2	100	4	30	27	14.6
Mean+SD	27.3±1.4	8.45±.8	97.5±30.9	3.32±0.5	25.5±7.2	20±5.1	8.32±4.6
Middle Zone							
K05	27	7.6	150	2.6	34	50	12
K06	28	7.4	140	3	44	75	31
K07	28	7.4	140	3.4	44	120	18
K08	28	7.4	140	3.4	42	70	13
Mean+SD	27.27±.5	7.45±.1	142.5±5	3.1±.4	41±4.7	78.75±29.5	18.5±8.7
Lower Zone							
K09	29.5	7.1	170	2.9	42	160	15
K10	29	7.2	120	2.6	46	63	34
K11	28	6.9	220	1.2	50	90	15
K12	28	6.9	580	1.1	140	220	16
Mean+SD	28.62±.75	7.025±.15	272.5±21	1.95±.9	69.5±47.1	133.25±70.8	20±9.3

(WT: Water Temperature, EC: Electrical conductivity, DO: Dissolved oxygen, Har: Hardness, Dep: Depth, CW: Channel Width, SD: Standard deviation).

they were showing a direct association with water temperature, pH and DO (Table 4). The abundance of Libellulidae was high at station Idappazhanjhi (K10) where the DO was at 2.6 mg/L. A strong direct association of the former taxa with DO and corresponding high abundance indicated their tolerance to hypoxic aquatic environments. The families like Coenagrionidae, Calopterygidae and Protoneuridae showed a strong direct association with the stream width. Platycnemidae and Cordulidae were in direct association with water depth. The former taxa were found only at Nedumangadu (K05) and Vazhayila (K08); these stations belonged to the middle zone and the latter at Melathummal (K09), which in turn belonged to the lower zone where the depth was relatively higher than the others. Table 4 shows the coefficient of correlation between environmental parameters and population density. The pH showed a significant direct relationship with DO. The electrical conductivity showed a strong significant association with the hardness and water depth. Similarly, the hardness showed a direct association with the water depth. The study revealed that

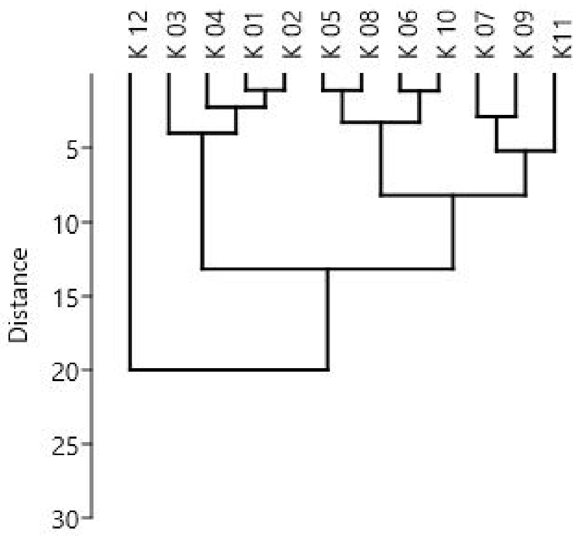

Fig. 6. Dendrogram of cluster analysis. The results indicated that the cluster groups were formed based on the relative similarity of different sampling stations with respect to the Odonate larval assemblage and water quality (The distance axis shown indicates that the lesser the distance, the greater the similarity between stations).

Table 4. Pearson's coefficient of correlation between environmental parameters and population density from the urban river Killiyar, Southern Kerala, India

Environmental parameters	pH	EC	DO	Hard	Dep	CW	PD
WT	0.52	–0.21	0.5	–0.24	–.25	–0.28	–0.24
pH	1	0.21	0.9**	0.26	0.11	0.05	–0.01
EC		1	0.02	0.9**	0.73*	0.13	–0.12
DO			1	0.1	0	0.09	0.11
Hard				1	0.81**	0.2	–0.00
Dep					1	0.26	0.03
CW						1	0.43

**. Correlation is significant at the 0.01 level (2–tailed).
*. Correlation is significant at the 0.05 level (2–tailed).
WT: Water temperature, EC: Electrical conductivity, DO: Dissolved oxygen, Hard: Hardness, Dep: Depth, CW: Channel width, PD: Population density.

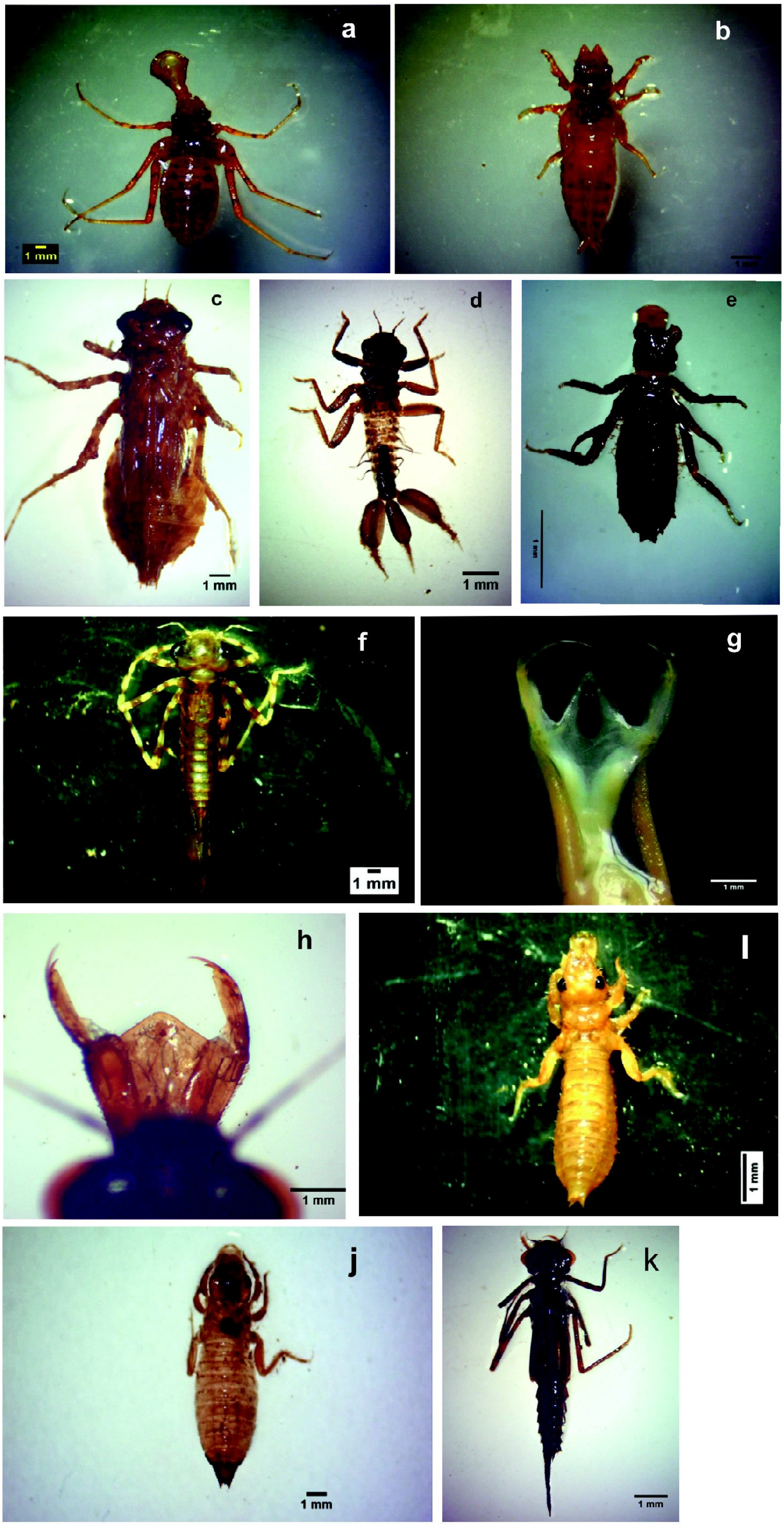

Fig. 7. Benthic Odonates recorded from the urban river Killiyar, Southern Kerala, India. **a**) *Crocothemis sp*. (Libellulidae), **b**) *Megalogomphus sp*. (Gomphidae), **c**) Libellulidae (Odonata), **d**) *Anisopleura sp*. (Euphaeidae), **e**) *Sinogomphus sp*. (Gomphidae), **f**) *Argiocnemis sp*. (Coenagrionidae), **g**) Prementum of *Mnais*. *sp*. (Calopterygidae), **h**) Prementum of *Prodasineura sp*. (Protoneuridae), **i**) *Megalogomohus sp*. (Gomphidae), **j**) *Stylogomphus sp*. (Gomphidae), **k**) *Prodasineura sp*. (Protoneuridae)

the majority of the environmental parameters showed an inverse association with population density, indicating the adverse impact of WQ on the odonate communities (Table 4).

3.2. Cluster Analysis

In cluster analysis, the stations studied form three distinct clusters in the dendrogram based on the odonate assemblage and environmental parameters (Fig. 6). All the stations in the upper zone formed the first cluster, indicating that they are comparable with respect to the BOC assemblage pattern and water parameters. The second cluster contains three middle zones (K05, K06, and K08) and a lower zone (K10) stations, indicating the comparable population abundance and diversity, in particular, in these stations. The cross clustering of the downstream station Idappazhanjhi (K10) to the second cluster indicated the range extension of urban and anthropogenic impacts towards the upstream. The third cluster is formed by clustering two lower zone and middle zone stations. However, station K12 in the lower zone did not form a cluster with any other stations, indicating that the variation of environmental factors and BOC diversity metrics from the rest of the stations.

4. Conclusion

The GIS–tools based spatial analysis and mapping of BOC assemblage and interactions with WQ were effective in understanding the distribution and dependence of the BOCs. In Killiyar, the BOCs were abundant in the lower zone. However, richness and evenness were found high in the middle zone. In this study, the DO was below the permissible level and, hence, inadequate for the sustenance of BOC assemblage. Though alkaline in the upstream stations, the pH was at the permissible level during this study. In the majority of stations, the dominant families were Gomphidae and Libellulidae, indicating that their distribution was irrespective of the biotope characteristics and are capable of surviving in adverse environmental conditions. This taxon could be capable of adapting to adverse environmental conditions like low pH and low oxygen. Sharma and Rawat (2009) reported morphological and behavioural adaptations advantage the odonate taxa to overcome the ecosystem challenges. The majority of the environmental variables studied showed an inverse association, indicating that physicochemical parameters adversely affected the population density. In Killiyar, the benthic odonate fauna, particularly the Libellulidae, showed sensitivity to the water temperature, DO, and pH. Thus, in general, the BOC depends directly on the physical and chemical environment, and their community structure varied according to the river continuum.

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