Available online at: www.mbai.org.in doi:10.6024/jmbai.2024.66.1.2436-04

Seasonal variability in physicochemical parameters and fish larval abundance along the coastal waters of Dakshina Kannada, southwest coast of India

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Received: 04 May 2023 Revised: 12 Jan 2024
Accepted: 20 Feb 2024 Published: 01 May 2024

Original Article

Abstract

The study attempted to record the seasonal variability in the physicochemical parameters that influence the fish larval abundance in six stations from the Netravathi-Gurupura and the Mulki-Pavanje estuaries along the coast of Dakshina Kannada for a period of 36 months (2014-2016). Pronounced variations in the primary production, chlorophyll a, and physicochemical parameters such as water temperature, pH, salinity, dissolved oxygen, and nutrients were observed in the estuarine and coastal waters. Between stations, the one-way ANOVA revealed highly significant variations ($p<0.001$) in pH, salinity, Chlorophyll a, Nitrate-N, Ammonia- N, and Silicate-Si concentrations and significant differences in dissolved oxygen and chlorophyll c ($p< 0.05$) concentrations. Multivariate comparisons (Tukey HSD) revealed variations in the physicochemical parameters within the stations. Nearshore stations and estuarine waters were distinct concerning physicochemical parameters. Environmental factors influencing fish larval abundance in the nearshore waters include rainfall ($r = 0.487$, $p< 0.01$), river discharge ($r = 0.444$, $p< 0.01$), dissolved oxygen ($r = 0.395$, $p< 0.05$), and silicate-Si concentration ($r = 0.423$, $p<0.05$). Similarly, the tidal height ($r= 0.536$, $p<0.01$) also played an additional key role in influencing and determining the seasonal abundance of fish larvae in the estuarine waters. The water quality index (WQI) in estuaries and nearshore waters is indicated as Good to Poor state as per USEPA (2012) rating. Improving the quality of near-shore coastal waters can increase the survival of fish larvae, protect fish breeding sites, and ultimately contribute to enhanced fisheries productivity.

Keywords: *Fish larvae, nearshore waters, tropical estuarine waters, physicochemical parameters, hydrography*

Introduction

A coastal ecosystem shows varying degrees of freshwater, estuarine, and marine zones (Rabalais *et al.,* 2002). Freshwater zones generally refer to the river bodies which are dependent on river water flow while an estuarine zone is highly dynamic as they are continuously subjected to alteration owing to marine, freshwater, and other environmental perturbations. Estuaries host unique biodiversity, delivering a range of ecosystem services but are also among the most degraded ecosystems on Earth (Chilton *et al.,* 2021). Coastal waters of Dakshina Kannada exhibit a similar type of three-tier tropical hydrographic system as it comprises the nearshore waters off the Arabian Sea, estuarine waters of Nethravathi-Gurupura Estuary and Mulki-Pavanje Estuary, the freshwater components from Netravathi, Gurupura rivers and the Mulki (Shambavi), Pavanje (Nandini) rivers (Ratheesh *et al.,* 2020). Dakshina Kannada also called Mangalore coast is a major upwelling region along the southwest coast of India. Hence the marine ecosystem of this coast is highly influenced by coastal upwelling through nutrient cycling, overall productivity and carbon export (Vidal *et al.,* 2017). Adding to this, this coast is also influenced by rainfall, the quantum of freshwater inflow, tidal incursion and other biological activities as well as anthropogenic activities. The estuaries are dominated by fringe mangroves in addition to those planted by the Karnataka Forest Department in 2011.

Dakshina Kannada District is well populated with an average population of 21.65 lakh (Government of India, Census 2011 -2022) people who are dependent on these coastal waters for food, water as well as livelihood. The district comprises industries from small-scale, micro-enterprises to large mega-scale industries. Small-scale enterprises mainly include food industries, paper/wood, leather-based, chemical-based, rubber, and metal-based engineering units. Large-scale industries include iron ore, fertilizers, chemical industries, cement factories, refineries and port-based activities. the nearshore areas also have many fish meal and oil plants which come under the medium scale industries. The fishing sector is also a major industry and the majority of the population is dependent on this for their livelihood.

The annual rainfall of Dakshina Kannada is 3000 mm which contributes to runoff in the rivers Netravathi, Gurupura, Mulki (Shambavi) and Pavanje (Nandini) especially during monsoon causing flooding and coastal erosion. Salinity ingression during the dry season in coastal aquifers is also recorded (Bindu *et al.,* 2016). Major issues such as water quality deterioration, frequent algal blooms decrease in river water flow and deforestation of mangroves along the coastal waters have been observed which has eventually led to the loss of breeding grounds of many aquatic fauna including fish over the last few decades and has been of great concern (Murugan and Usha, 2018).

The present study focussed on the hydrodynamics of physico-chemical parameters and the other key factors such as rainfall, river runoff and anthropogenic activities influencing the water quality and health of the coastal waters of Dakshina Kannada from 2014 to 2016. The study also emphasises the physiochemical parameters influencing the fish larval abundance in these coastal waters.

Material and methods

Study area

Two near-shore stations, St 1 and St 2 (7 m depth) and 4 estuarine stations, 3 from the Nethravathi- Gurupura (St 3, St 4 and St 5) and one from Mulki-Pavanje (St 6), off Mangaluru in Dakshina Kannada District were selected for the present study as they have been identified as good nurseries and breeding grounds (Murugan and Usha, 2018) (Fig. 1).

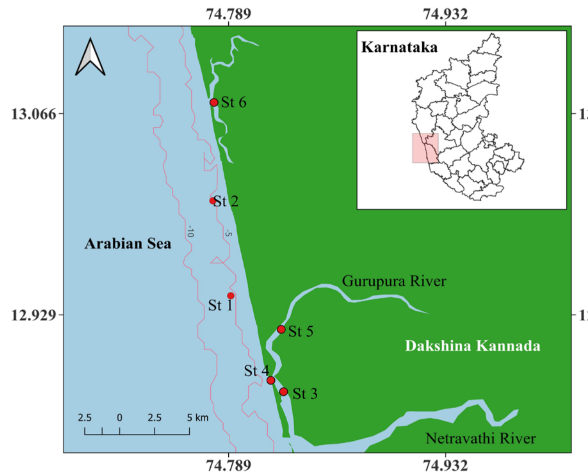

Fig. 1. Map showing the sampling locations in the nearshore waters off Dakshina Kannada

Sample collection and data analysis

Monthly surface water samples were collected during the early mornings. Surface water temperature was measured using a centigrade mercury thermometer (-10 ºC to 110 ˚C; OMSONS) and the salinity was measured potentiometrically using a multi-parameter instrument (WTW 320i, Xylem Analytics LLC, Germany). Dissolved oxygen was estimated following Winkler's method (Strickland and Parsons, 1968). Chlorophyll *a* was estimated by spectrophotometric method (UV-VIS Lambda 365, Perkin Elmer,) and dissolved inorganic nutrients (ammonia-N, nitrite-N, nitrate-N, phosphate-P, and silicate-Si) were determined using standard analytical methods (American Public Health Association-APHA, 1981). The water quality index (WQI) was also evaluated, as per the selected environmental indicators of the United States Environmental Protection Agency (2012). The analysed water quality results were compared with the corresponding baseline range concentrations (Table 1) from the National Coastal Assessment Report (United States Environmental Protection Agency (USEPA), 2012). Monthly average rainfall data and river water discharge data for Dakshina Kannada were obtained from the National Water Information System in collaboration with CWC, for the period 2014-2016. Sea surface current data were obtained from NASA's website (http://www.oceanmotion.org/html/resources/oscar.htm). The surface current was obtained from Ocean Surface Current Analyses Real-time (OSCAR) the global surface current database. Fish larvae were sorted out from zooplankton samples collected from the selected stations and were identified up to the family level by referring to literature and fish larvae identification guides (Smith and Richardson, 1977; Leis *et al.*, 2000). In the present

Table 1. Range of selected environmental indicators for water quality indexing

WQI	DIN mg l^{-1}	DIP mg l^{-1}	DO mg l^{-1}	Chl a µg l^{-1}
Good	<0.1	<0.01	>5	<5
Fair	0.1-0.5	0.01-0.05	2–5	5-20
Poor	>0.5	>0.05	<2	>20

study, total fish larval abundance was taken to correlate with the physicochemical parameters.

Statistical analysis

To test the differences in physicochemical parameters between stations each parameter was tested using a one-way ANOVA, and a post-hoc Fisher Least Significant Difference (LSD) analysis was performed to identify significantly different mean values. The influences of environmental factors on fish larval abundance were analysed using Spearman correlation analysis (2-tailed) carried out using SPSS statistical software (SPSS 23).

Results and discussion

The one-way ANOVA showed significant variations for the physiochemical parameters such as AT, phosphate -P concentrations, dissolved oxygen and chlorophyll c ($p< 0.05$) and highly significant variations in pH, salinity, chlorophyll a, nitrate-N, ammonia-N and silicate-Si concentrations. This was followed by multivariate comparisons (Tukey HSD) to know the variation in the physicochemical parameters within the stations and the results clearly showed the marine and estuarine stations distinctly concerning the physicochemical parameters. The nearshore stations varied from all the estuarine stations for pH, salinity, and nutrient concentrations such as nitrate- N, silicate- Si, ammonia- N and chlorophyll a concentration ($p<0.05$). St 5 and St 6 also showed a distinct variation concerning pH, salinity, nitrate, silicate, ammonia and chlorophyll a concentration ($p<0.05$). This is because St 5 being the upstream station is highly influenced by freshwater and anthropogenic activities like sand mining and effluent water discharge while St 5 is part of Mulki Pavanje Estuary.

Nearshore waters

The SST along the nearshore waters was observed to be ranging from 24.75-34 ±1.74°C, minimum during the post-monsoon season of 2016 while maximum observed during the premonsoon season of 2015 which could be due to 2015-16 being a strong El Nino year. Salinity ranged from 22.85 to 35.55 ±2.35 ppt, minimum observed during the monsoon season of 2015, while the maximum was during the premonsoon season of 2016. Salinity and SST were positively correlated ($R= 0.398, p<0.05$). Lower salinity is due to the influx of fresh water and dilution of estuarine waters during monsoon season which causes a decrease in salinity, whereas the low rainfall, increased solar radiation causing a high rate of evaporation, and the dominance of neritic water leads to increased salinity in premonsoon and postmonsoon seasons (Karolina *et al.,* 2009; Sruthi and Rajashekhar, 2014). The pH ranged between 7.05 - 8.45 ±0.361 (Ramana and Reddy, 2004; Sushanth *et al.,* 2011; Sushanth and Rajashekhar, 2014). Dissolved oxygen and chlorophyll a ranged between 5.24-8.83 ±0.81 mg/l and 0.19- 26.56 ±9.73 mg/m^3 respectively. Maximum dissolved oxygen was observed during the premonsoon season of 2016 while minimum during the post-monsoon season of 2016. The highest chlorophyll a (26.56 mg/m3) was observed during the premonsoon season of 2014 which indicates a eutrophic condition (Fig. 2).

Nutrients such as phosphate-P, silicate-Si, nitrite-N, nitrate-N and ammonia-N ranged between, 0.011 - 1.258 ± 0.24 mg/l, 0.021 - 1.82 mg/l ± 0.39, 0.0004 - 0.103 ±0.01 mg/l, 0.002 - 0.17 ±0.03 mg/l and 0.354 ±0.06 mg/l respectively. Maximum nitrate-N, nitrite-N, silicate-Si and ammonia- N concentrations observed during the monsoon season may be due to freshwater influx attributed to monsoonal rainfall into the system (Santhanam and Perumal, 2003). Nitrate- N ($r = 0.411, p<0.05$), nitrite-N ($r = 0.766, p<0.01$) and silicate- Si concentration ($r = 0.778; p<0.01$) were observed to be positively correlated with rainfall. Maximum phosphate-p concentration was observed during the post-monsoon. Phosphate-P concentration was highly significantly correlated with river discharge ($r= 0.513, p<0.01$). Minimum concentrations of phosphate - P and nitrate- N concentrations were observed during the premonsoon seasons of 2015 and 2016 respectively. It represents an oligotrophic condition as a bloom of *Ornithocercus* sp. was already reported during the study period (Lavanya *et al.,* 2022). A similar trend in seasonal variation of physico-chemical parameters was observed by Andrade *et al.* (2011) Ramana and Reddy (2004) (Table 2 a).

Estuarine waters

The physicochemical parameters of the Nethravathi-Gurupura estuarine waters revealed the surface water temperature ranged between 25.4-33.5±°C, maximum during the premonsoon season of 2015 while minimum during the post-monsoon season of 2016. Salinity ranged from 0 to 31.13±4.34 ppt, maximum during the premonsoon (2016) season and minimum during the monsoon season (2014). pH ranged between 6.49-8.20±0.47 throughout the period. Chlorophyll a concentration ranged from 2.37-25.7±5.2 mg/m^3, maximum was observed during the premonsoon season (2015) while minimum during the post-monsoon season (2015).

Chlorophyll a was significantly correlated with estuarine water temperature ($r = 0.410, p<0.05$) and salinity ($r = 0.516; p<0.01$) and significantly negatively correlated with tide height ($r = -0.495; p<0.05$) (Eugene and Gary, 1967; Blauw *et al.,* 2012). Estuarine water during the premonsoon months is observed

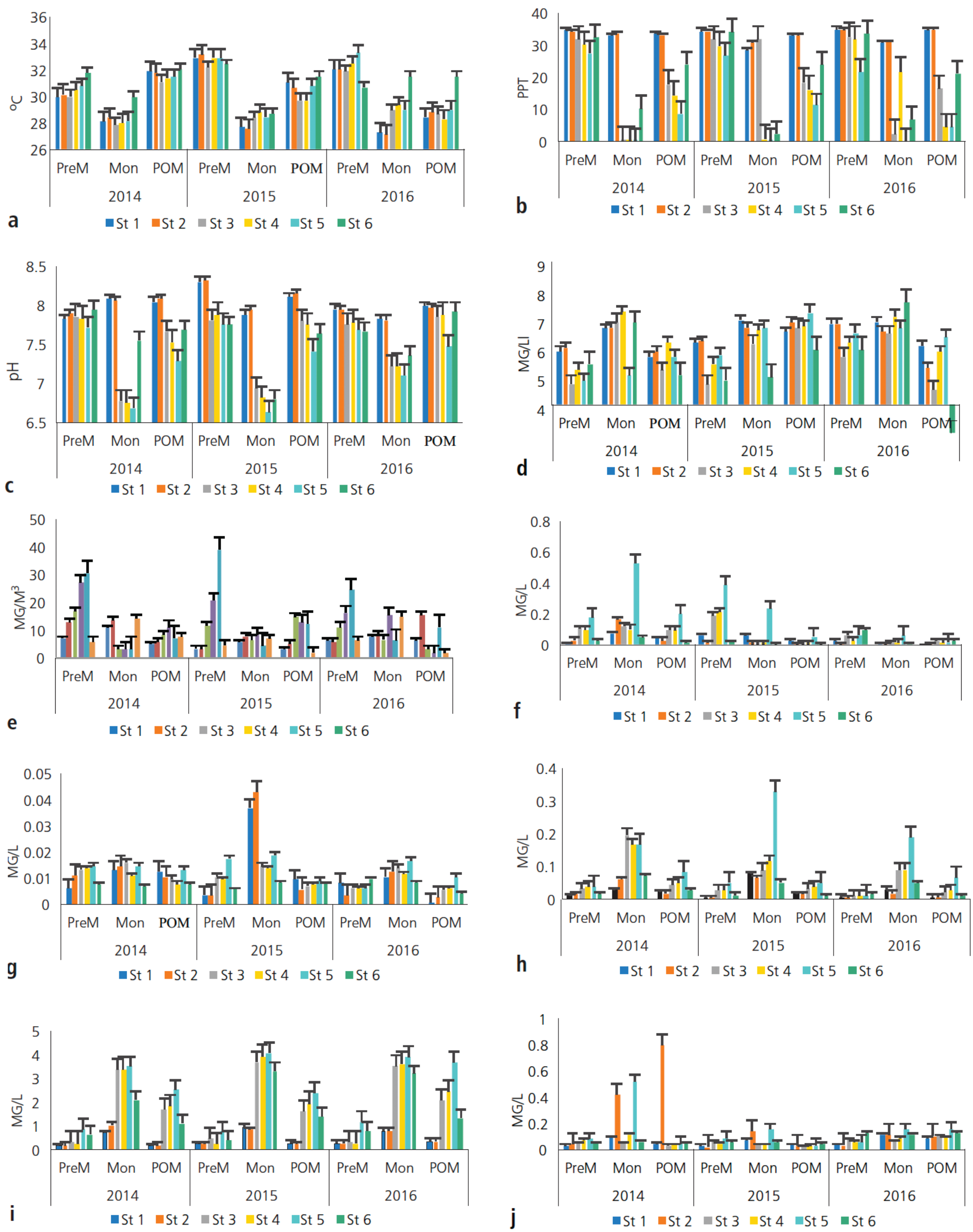

Fig. 2. Seasonal variations in the physicochemical parameters (maximum and minimum range) of nearshore and estuarine waters off Dakshina Kannada for the period 2014-2016. a) Sea Surface Temperature °C, b) Salinity ppt, c) pH, d) Dissolved Oxygen mg/l, e) Chlorophyll a mg/m^3, f)Ammonia - N mg/l, g) Nitrite - N mg/l, h) Nitrate - N mg/l, i) Silicate - Si mg/l, j) Phosphate - P mg/l

Table 2a. Correlation within physio chemical parameters and fishlarval abundance along the nearshore waters of Dakshina Kannada

		SST	pH	SALINITY	DO	PHOSPHATE	NITRATE	NITRITE	AMMONIA	SILICATE	CHLA	CHLB	CHLC	FISHLARVAE	meancurrent	rainfall	riverunoff
SST	Correlation Coefficient	1.000	.505**	.398*	-.080	-.467**	-.394*	-.320	.135	-.422*	-.396*	-.093	-.406*	-.157	.192	-.474**	-.630**
	Sig. (2-tailed)		.002	.016	.645	.004	.017	.057	.431	.010	.017	.591	.014	.361	.261	.004	.000
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
pH	Correlation Coefficient	.505**	1.000	.301	-.191	-.420*	-.265	-.272	.009	-.534**	-.375*	-.125	-.498**	-.042	.356*	-.337*	-.515**
	Sig. (2-tailed)	.002		.074	.264	.011	.118	.108	.956	.001	.024	.469	.002	.806	.033	.045	.001
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SALINITY	Correlation Coefficient	.398*	.301	1.000	-.222	-.176	-.437**	-.407*	.071	-.448**	-.055	.037	-.089	-.283	-.317	-.612**	-.646**
	Sig. (2-tailed)	.016	.074		.193	.304	.008	.014	.681	.006	.748	.831	.607	.094	.060	.000	.000
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
DO	Correlation Coefficient	-.080	-.191	-.222	1.000	.044	.336*	.433**	.232	.387*	.175	.313	.115	.395*	-.043	.334*	.357*
	Sig. (2-tailed)	.645	.264	.193		.800	.045	.008	.172	.020	.308	.063	.504	.017	.805	.046	.033
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
PHOSPHATE	Correlation Coefficient	-.467**	-.420*	-.176	.044	1.000	.367*	.279	.098	.454**	.105	.474**	.180	.011	-.126	.298	.427**
	Sig. (2-tailed)	.004	.011	.304	.800		.028	.100	.570	.005	.542	.004	.294	.948	.465	.077	.009
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
NITRATE	Correlation Coefficient	-.394*	-.265	-.437**	.336*	.367*	1.000	.834**	.180	.349*	.188	.328	.213	.198	.174	.422*	.468**
	Sig. (2-tailed)	.017	.118	.008	.045	.028		.000	.294	.037	.272	.051	.213	.248	.310	.010	.004
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
NITRITE	Correlation Coefficient	-.320	-.272	-.407*	.433**	.279	.834**	1.000	.249	.346*	.205	.293	.205	.368*	.089	.395*	.450**
	Sig. (2-tailed)	.057	.108	.014	.008	.100	.000		.144	.039	.231	.083	.231	.027	.605	.017	.006
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
AMMONIA	Correlation Coefficient	.135	.009	.071	.232	.098	.180	.249	1.000	-.013	-.038	.161	-.025	.275	.191	.001	.108
	Sig. (2-tailed)	.431	.956	.681	.172	.570	.294	.144		.941	.827	.350	.884	.105	.264	.995	.531
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SILICATE	Correlation Coefficient	-.422*	-.534**	-.448**	.387*	.454**	.349*	.346*	-.013	1.000	.249	.228	.298	.423*	-.221	.704**	.627**
	Sig. (2-tailed)	.010	.001	.006	.020	.005	.037	.039	.941		.144	.181	.077	.010	.196	.000	.000
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
CHLA	Correlation Coefficient	-.396*	-.375*	-.055	.175	.105	.188	.205	-.038	.249	1.000	.236	.729**	-.187	.015	.406*	.420*
	Sig. (2-tailed)	.017	.024	.748	.308	.542	.272	.231	.827	.144		.165	.000	.275	.931	.014	.011
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
CHLB	Correlation Coefficient	-.093	-.125	.037	.313	.474**	.328	.293	.161	.228	.236	1.000	.323	.059	-.116	.057	.147
	Sig. (2-tailed)	.591	.469	.831	.063	.004	.051	.083	.350	.181	.165		.055	.732	.502	.741	.393
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
CHLC	Correlation Coefficient	-.406*	-.498**	-.089	.115	.180	.213	.205	-.025	.298	.729**	.323	1.000	-.034	-.073	.349*	.394*
	Sig. (2-tailed)	.014	.002	.607	.504	.294	.213	.231	.884	.077	.000	.055		.846	.670	.037	.018
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
FISHLARVAE	Correlation Coefficient	-.157	-.042	-.283	.395*	.011	.198	.368*	.275	.423*	-.187	.059	-.034	1.000	-.061	.487**	.444**
	Sig. (2-tailed)	.361	.806	.094	.017	.948	.248	.027	.105	.010	.275	.732	.846		.724	.003	.007
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
meancurrent	Correlation Coefficient	.192	.356*	-.317	-.043	-.126	.174	.089	.191	-.221	.015	-.116	-.073	-.061	1.000	.047	-.039

	Sig. (2-tailed)	.261	.033	.060	.805	.465	.310	.605	.264	.196	.931	.502	.670	.724		.787	.822
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
rainfall	Correlation Coefficient	-.474**	-.337*	-.612**	.334*	.298	.422*	.395*	.001	.704**	.406*	.057	.349*	.487**	.047	1.000	.862**
	Sig. (2-tailed)	.004	.045	.000	.046	.077	.010	.017	.995	.000	.014	.741	.037	.003	.787		.000
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
riverunoff	Correlation Coefficient	-.630**	-.515**	-.646**	.357*	.427**	.468**	.450**	.108	.627**	.420*	.147	.394*	.444**	-.039	.862**	1.000
	Sig. (2-tailed)	.000	.001	.000	.033	.009	.004	.006	.531	.000	.011	.393	.018	.007	.822	.000	
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

to have less river water flow. Estuaries being a mixed zone of freshwater and marine water have diverse organisms belonging to both groups. Hence during high tides, more saline waters enter into the estuaries which favours the growth of marine phytoplankton groups and hence attributes to high chlorophyll values. This was in agreement with Ratheesh *et al.* (2020) who divided the estuarine waters of Dakshina Kannada into 3 parts consisting of marine zone, estuarine zone and freshwater zone. Based on his study maximum chlorophyll concentration was observed to be at the estuarine zone while minimum along the freshwater zones throughout the study period along the Nethravathi Gurupura Estuary which is attributed to the relationship between saline waters, tidal regimes and chlorophyll concentration.

Dissolved oxygen concentration was observed to be ranging between 4.55-7.24 ±0.936 mg/l, maximum during the monsoon season (2014) and minimum during the post-monsoon season (2015). Sruthi and Rajashekhar (2014) and Mridula *et al.,* (2014) also observed maximum dissolved oxygen during monsoon season. Monsoon season is subject to high river flow and turbulent waters which is attributed to the high dissolved oxygen concentration during this season. Dissolved oxygen was negatively correlated to total suspended solids ($r = -0.417$, $p<0.05$). Generally, during the monsoons high freshwater river flow brings in highly loaded nutrients as well as pollutants which include domestic sewage effluents. This also gives birth to algal blooms and even high microbial load which is attributed to high TSS values during the post-monsoon seasons. This in turn leads to high consumption of dissolved oxygen. Higher DO values were correlated with lower ammonia concentrations ($r = -0.477$, $p< 0.01$). Sruthi and Rajashekhar, 2014 also observed lower DO values during the post-monsoon season.

Nutrients such as phosphate-P, silicate-Si, nitrite-N and ammonium-N concentration showed a similar trend, maximum concentrations were observed during the monsoons season. Phosphate-P concentration ranged from 0.016 - 0.0321 ± 0.06 mg/l, silicate-Si concentration ranged from 0.061 - 1.484 ±0.43 mg/l, nitrite-N ranged 0.006-0.192 ±0.042 mg/l, nitrate-N concentration ranged from 0.02-0.321± 0.06mg/l and ammonium-N concentration ranged 0.002 - 0.358 ± 0.07 mg/l. Minimum phosphate-P, nitrate -N and nitrite -N concentrations were observed in the pre-monsoon season while silicate and ammonium concentrations were observed in post-monsoon seasons indicating a nutrient-deficient oligotrophic condition. Phosphate-P concentration was highly significantly correlated with rainfall ($r = 0.513$, $p< 0.01$); river runoff ($r = 0.465$, $p<0.01$), silicate -Si ($r = 0.345$, $p< 0.05$); nitrate -N ($r = 0.558$, $p<0.01$) nitrite -N ($r = 0.399$, $p< 0.05$) and negatively correlating with salinity ($r = -0.452$, $p< 0.01$), water temperature ($r = -0.348$, $p< 0.05$), pH ($r = -0.369$, $p< 0.05$). High phosphate -P during the monsoon season could be due to organic load from domestic sewage as there are very few treatment plants. Similar trends in the nutrient concentrations were observed by Mridula *et al.* (2014), Sruthi and Rajashekhar (2014) and Ratheesh *et al.* (2020) (Table 2 b).

Unlike the Nethravathi-Gurupura Estuary, the Muki- Pavanje Estuary is comparatively less exposed to anthropogenic waters. The Mulki- Pavanje estuarine waters showed water temperatures to be in the range of 27.5-35.8±2.07 °C, the maximum observed during premonsoon (2015) and minimum during the post-monsoon season (2016). Salinity and pH ranged between, 0.4-34 ± 13.1 ppt and 6.62-8.13 ±0.43, with maximum observed during the premonsoon season and post-monsoon seasons respectively. Minimum salinity and pH were observed during the monsoon seasons of 2015 and 2016. Dissolved oxygen ranged from 3 - 8.64 ±1.37 mg/l. higher values of dissolved oxygen were observed (2016) due to the heavy river discharge of low saline waters during the monsoon season (Fig. 3 b). Overall dissolved oxygen was high during this season throughout the study period (Vijayakumar *et al.,* 2000). It may also be noted that the minimum salinity was also observed during this season.

Ammonia- N ranged between 0-0.26 ±0.05 mg/l, with maximum observed during the premonsoon season (2016) while minimum during the monsoon season. Nitrite- N and nitrate- N concentrations ranged between 0.001- 0.020 ±0.004 mg/l and 0.004-0.167 ±0.04 mg/l respectively. In both nitrite-N and nitrate-N concentrations, the maximum and minimum ranges followed a similar trend where the maximum concentration was observed during the onset of the monsoon season due to terrigenous input of river water as well as initial draining flushed from the upstream areas during this season as observed by De Souza (1977); Nair *et al.* (1984) and Prabha Devi and Ayakannu (1989). This was followed by lower values during the end of the monsoon season (Vijayakumar *et al.*, 2000). Phosphate- P concentration ranged between 0.009-0.254 ±0.06 mg/l. Maximum as well as minimum were observed during the monsoon season of 2016, with minimum during the onset of the monsoon and maximum during the end of the monsoon season. The levels of reactive silicate ranged between 0.008-3.878 ±1.14 mg/l again, maximum during the monsoon season (2016) and minimum during the premonsoon season (2014) which can be attributed to the river discharge (Anirudhan and Nambisan, 1990). The lowest silicate concentration during premonsoon seasons indicates complete utilization of the nutrient by the marine phytoplankton organisms for their survival (Mani *et al.*,1986; Sankaranarayanan and Quasim, 1969; Gowda and Panigrahy, 1992).

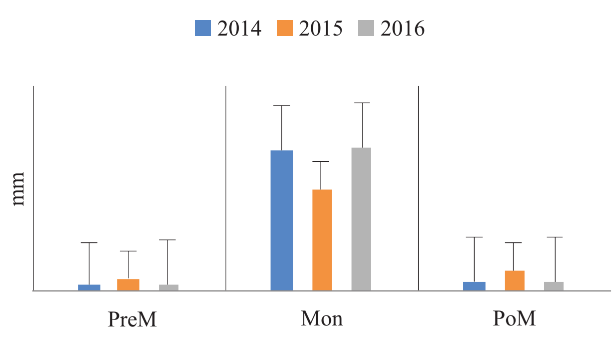

Fig. 3a. Average rainfall of Dakshin Kannada during 2014-2016 (mm)

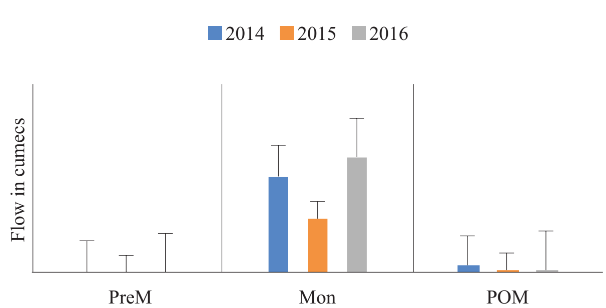

Fig. 3b. River runoff–Nethravathi Gurupura estuary during 2014-2016 (Flow in cumecs)

Influence on fish larval abundance

A total of 5982 (estuarine) and 5124 (nearshore) nos/ m^3 fish larvae belonging to 22 families were identified along the coastal waters of Dakshina Kannada during the period. The dominant ones belonged to the families Ambassidae, Clupiedae, Gobidae, Engraulidae, Lactaridae and Pomacentridae. Fish larval abundance was observed to be maximum during the post-monsoon season (1200 nos/m^3) along the estuarine waters. Whereas along the nearshore waters, maximum fish larval abundance was

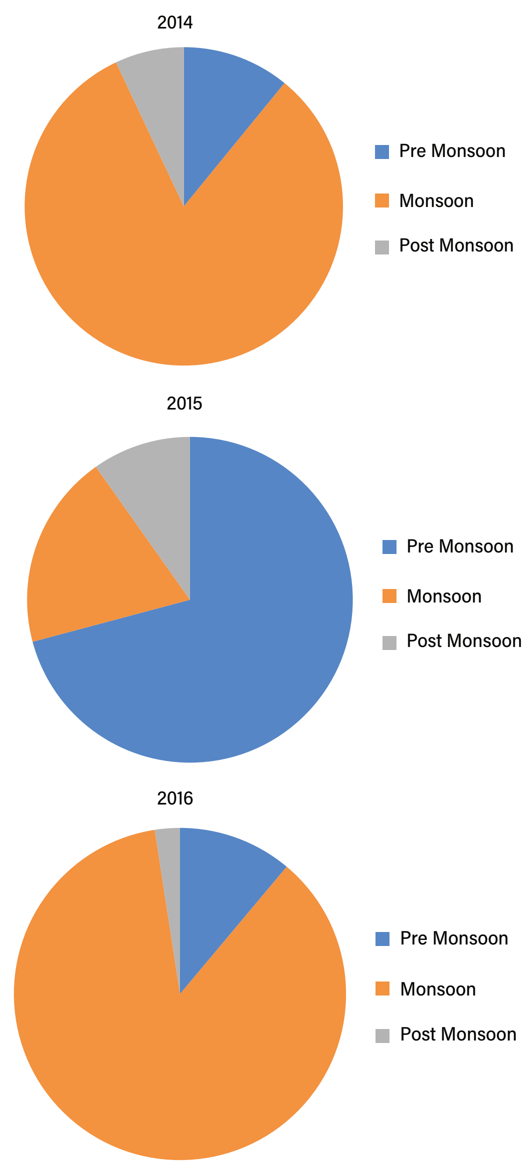

Fig. 4a. Seasonal availability of fish larvae along the Nearshore waters of Dakshina Kannada during 2014-2016 (%)

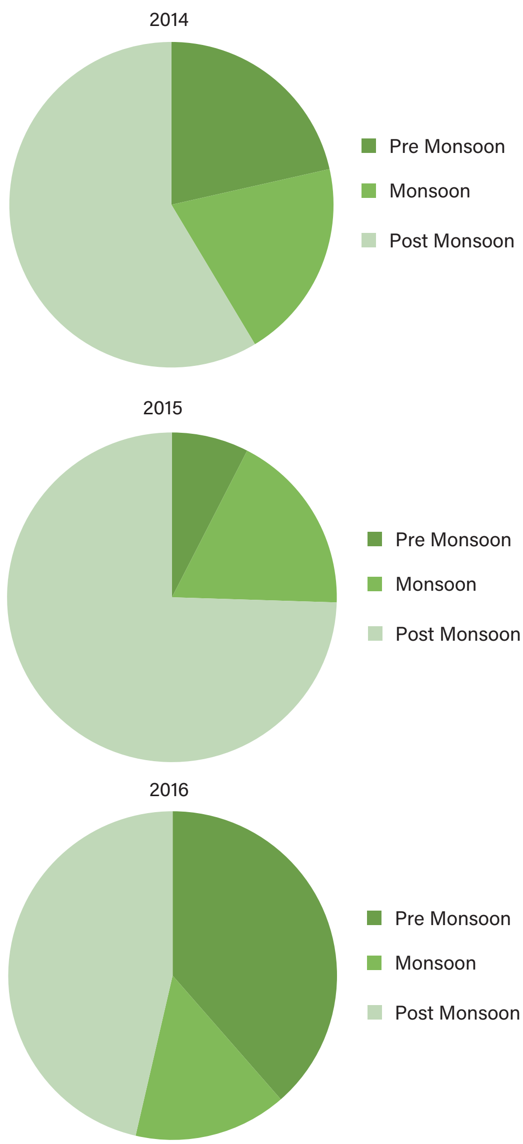

Fig. 4b. Seasonal occurrence of fish larvae along the estuarine waters of Dakshina kannada during 2014-2016 (%)

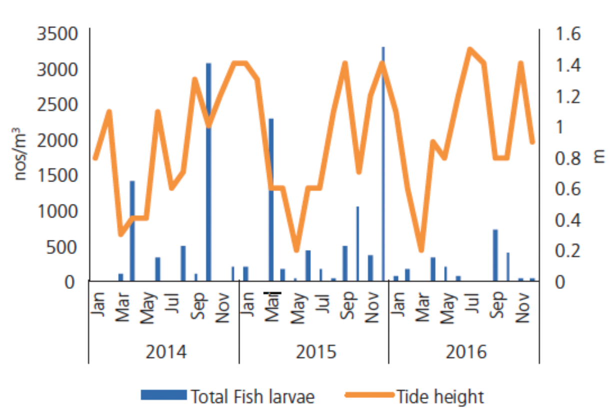

Fig. 5a. Monthly fish larval abundance and tidal variations observed along the Gurupur- Nethravathy estuarine waters of Dakshina Kannada during 2014-2016

observed during monsoon seasons (617nos/m^3) of 2014 and 2016, while in 2015 maximum fish larval abundance was observed during premonsoon (289 nos /m^3) season (Fig. 4 a and Fig. 4 b).

Along the nearshore waters, total fish larval abundance was found to be highly significantly positively correlating with rainfall ($r = 0.487$, $p < 0.01$), river discharge ($r = 0.444$, $p < 0.01$) and significantly correlating with dissolved oxygen ($r = 0.395$, $p < 0.05$). Coastal upwelling and the southwest monsoon rains bring in cool and nutrient-rich waters from the bottom and upstream rivers respectively (Table 2 a). A similar correlation was reported by Geider (1987), Geider *et al.* (1997) Susanto *et al.* (2006), and Nurdin *et al.* (2014) along the near shore waters. Fish larvae were positively correlated with silicate concentration ($r = 0.423$, $p < 0.05$), which also indicates the influence of river discharge along the nearshore waters.

Average mean rainfall was also highly negatively correlating with sea surface temperature ($r = -0.474$, $p < 0.01$), pH ($r = -0.337$, $p < 0.01$), salinity ($r = -0.612$, $p < 0.01$) and highly positively correlating with silicate-Si concentration ($r = 0.704$, $p < 0.01$), dissolved oxygen ($r = 0.334$, $p < 0.05$), nitrate -N ($r = 0.422$, $p < 0.05$), nitrite -N ($r = 0.395$, $p < 0.05$) and chlorophyll a concentration ($r = 0.406$, $p < 0.05$) along the nearshore waters.

Along the estuarine waters (Table 2 b) fish larval abundance was observed to be positively correlating with silicate concentration ($r = 0.367$, $p < 0.05$) and negatively correlating with pH ($r = -0.417$, $p < 0.05$). High silicate concentration is observed during the monsoon season and was found to be significantly correlating with mean rainfall ($r = 0.778$, $p < 0.01$). Retention and recruitment of fish larvae have been observed to be maximum when stable conditions exist within the coastal waters (Paris *et al.,* 2002). This

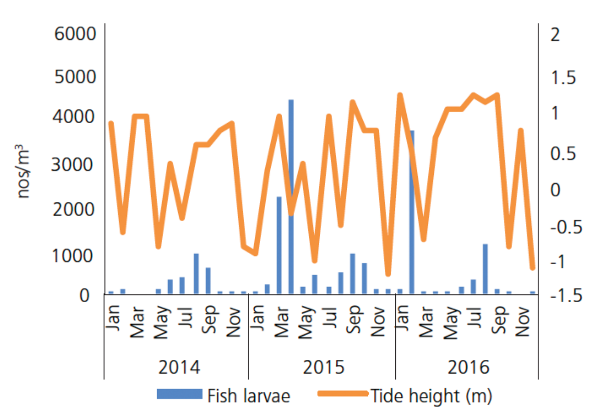

Fig. 5b. Monthly fish larval abundance and tidal variations observed along the Mulki Pavanje estuarine waters of Dakshina Kannada during 2014-2016

Table 2b. Correlation within physio chemical parameters and fishlarval abundance along the estuarine waters of Dakshina Kannada

Spearman's rho

AT	WT	pH	SALINITY	TSS	DO	BOD	PHOSPHATE	NITRATE	NITRITE	AMMONIA	SILICATE	CHLA	CHLB	CHLC	RIVERRUNOFF	TIDE	RAINFALL	FISHLARVAE		
AT	Correlation Coefficient	1.000	.813**	.315	.547**	.277	.095	-.080	-.551**	-.351*	-.415*	.055	-.402*	.296	.355*	.123	-.519**	-.100	-.493**	.200
	Sig. (2-tailed)		.000	.062	.001	.102	.582	.644	.000	.036	.012	.748	.015	.080	.033	.474	.001	.563	.002	.242
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
WT	Correlation Coefficient	.813**	1.000	.216	.489**	.341*	-.088	-.179	-.348*	-.298	-.353*	.095	-.341*	.410*	.418*	.299	-.439**	-.098	-.341*	.137
	Sig. (2-tailed)	.000		.205	.002	.042	.608	.297	.037	.078	.035	.583	.042	.013	.011	.077	.007	.568	.042	.425
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
pH	Correlation Coefficient	.315	.216	1.000	.742**	.734**	-.209	-.092	-.369*	-.381*	-.751**	-.202	-.633**	.262	.403*	.291	-.817**	-.197	-.713**	-.417*
	Sig. (2-tailed)	.062	.205		.000	.000	.220	.594	.027	.022	.000	.237	.000	.122	.015	.085	.000	.249	.000	.011
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SALINITY	Correlation Coefficient	.547**	.489**	.742**	1.000	.828**	-.259	-.311	-.452**	-.430**	-.695**	-.135	-.815**	.516**	.488**	.406*	-.852**	-.312	-.841**	-.220
	Sig. (2-tailed)	.001	.002	.000		.000	.127	.065	.006	.009	.000	.431	.000	.001	.003	.014	.000	.064	.000	.198
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
TSS	Correlation Coefficient	.277	.341*	.734**	.828**	1.000	-.417*	-.413*	-.186	-.324	-.554**	-.013	-.659**	.428**	.378*	.420*	-.814**	-.392*	-.703**	-.247
	Sig. (2-tailed)	.102	.042	.000	.000		.011	.012	.276	.054	.000	.939	.000	.009	.023	.011	.000	.018	.000	.146
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
DO	Correlation Coefficient	.095	-.088	-.209	-.259	-.417*	1.000	.288	.009	.001	-.003	-.477**	.288	-.237	-.160	-.250	.225	.234	.284	.258
	Sig. (2-tailed)	.582	.608	.220	.127	.011		.088	.960	.996	.987	.003	.088	.163	.352	.142	.188	.169	.094	.129
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
BOD	Correlation Coefficient	-.080	-.179	-.092	-.311	-.413*	.288	1.000	.181	-.008	.067	.025	-.018	-.500**	-.317	-.365*	.256	.465**	.244	-.102
	Sig. (2-tailed)	.644	.297	.594	.065	.012	.088		.291	.965	.698	.887	.918	.002	.059	.029	.132	.004	.151	.555
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
PHOSPHATE	Correlation Coefficient	-.551**	-.348*	-.369*	-.452**	-.186	.009	.181	1.000	.558**	.399*	.096	.345*	-.151	-.333*	.108	.465**	-.063	.513**	.155
	Sig. (2-tailed)	.000	.037	.027	.006	.276	.960	.291		.000	.016	.576	.039	.380	.047	.532	.004	.717	.001	.368
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
NITRATE	Correlation Coefficient	-.351*	-.298	-.381*	-.430**	-.324	.001	-.008	.558**	1.000	.389*	.148	.412*	-.287	-.248	-.111	.519**	.010	.411*	.227
	Sig. (2-tailed)	.036	.078	.022	.009	.054	.996	.965	.000		.019	.390	.013	.090	.145	.520	.001	.955	.013	.183
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36

NITRITE	Correlation Coefficient	-.415*	-.353*	-.751**	-.695**	-.554**	-.003	.067	.399*	.389*	1.000	.334*	.637**	-.199	-.214	-.196	.793**	.056	.766**	.235
	Sig. (2-tailed)	.012	.035	.000	.000	.000	.987	.698	.016	.019		.047	.000	.246	.209	.253	.000	.746	.000	.167
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
AMMONIA	Correlation Coefficient	.055	.095	-.202	-.135	-.013	-.477**	.025	.096	.148	.334*	1.000	-.045	.022	-.028	-.078	.193	.016	.136	-.055
	Sig. (2-tailed)	.748	.583	.237	.431	.939	.003	.887	.576	.390	.047		.793	.900	.871	.650	.259	.925	.428	.752
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SILICATE	Correlation Coefficient	-.402*	-.341*	-.633**	-.815**	-.659**	.288	-.018	.345*	.412*	.637**	-.045	1.000	-.199	-.195	-.225	.736**	.034	.778**	.367*
	Sig. (2-tailed)	.015	.042	.000	.000	.000	.088	.918	.039	.013	.000	.793		.245	.255	.187	.000	.842	.000	.028
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
CHLA	Correlation Coefficient	.296	.410*	.262	.516**	.428**	-.237	-.500**	-.151	-.287	-.199	.022	-.199	1.000	.671**	.811**	-.325	-.495**	-.274	-.157
	Sig. (2-tailed)	.080	.013	.122	.001	.009	.163	.002	.380	.090	.246	.900	.245		.000	.000	.053	.002	.106	.360
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
CHLB	Correlation Coefficient	.355*	.418*	.403*	.488**	.378*	-.160	-.317	-.333*	-.248	-.214	-.028	-.195	.671**	1.000	.553**	-.310	-.272	-.298	-.196
	Sig. (2-tailed)	.033	.011	.015	.003	.023	.352	.059	.047	.145	.209	.871	.255	.000		.000	.066	.108	.077	.252
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
CHLC	Correlation Coefficient	.123	.299	.291	.406*	.420*	-.250	-.365*	.108	-.111	-.196	-.078	-.225	.811**	.553**	1.000	-.233	-.422*	-.236	-.209
	Sig. (2-tailed)	.474	.077	.085	.014	.011	.142	.029	.532	.520	.253	.650	.187	.000	.000		.171	.010	.167	.220
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
RIVERRUNOFF	Correlation Coefficient	-.519**	-.439**	-.817**	-.852**	-.814**	.225	.256	.465**	.519**	.793**	.193	.736**	-.325	-.310	-.233	1.000	.158	.862**	.222
	Sig. (2-tailed)	.001	.007	.000	.000	.000	.188	.132	.004	.001	.000	.259	.000	.053	.066	.171		.358	.000	.194
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
TIDE	Correlation Coefficient	-.100	-.098	-.197	-.312	-.392*	.234	.465**	-.063	.010	.056	.016	.034	-.495**	-.272	-.422*	.158	1.000	.139	-.061
	Sig. (2-tailed)	.563	.568	.249	.064	.018	.169	.004	.717	.955	.746	.925	.842	.002	.108	.010	.358		.419	.726
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
RAINFALL	Correlation Coefficient	-.493**	-.341*	-.713**	-.841**	-.703**	.284	.244	.513**	.411*	.766**	.136	.778**	-.274	-.298	-.236	.862**	.139	1.000	.239
	Sig. (2-tailed)	.002	.042	.000	.000	.000	.094	.151	.001	.013	.000	.428	.000	.106	.077	.167	.000	.419		.160
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
FISHLARVAE	Correlation Coefficient	.200	.137	-.417*	-.220	-.247	.258	-.102	.155	.227	.235	-.055	.367*	-.157	-.196	-.209	.222	-.061	.239	1.000
	Sig. (2-tailed)	.242	.425	.011	.198	.146	.129	.555	.368	.183	.167	.752	.028	.360	.252	.220	.194	.726	.160	
	N	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36

stability is observed during the post-monsoon season once the coastal upwelling concludes along the coastal waters and most of the diatom and dinoflagellate blooms have been reported during this season (Krishnakumar and Bhatt, 2008). Tidal dynamics also is a strong driver of fish larvae abundance and assemblage composition in tropical waters (Joyeux, 1999; Teixeira *et al.,* 2009; Able *et al.,* 2017). Fish larvae were found to be abundant during high tide (Fig. 5 a and Fig. 5 b) although the Spearman correlation did not show any significant correlation between salinity and fish larvae. Along the Mulki Pavanje estuary (Table 2 c) also, fish larval abundance was positively correlated with water temperature ($r = 0.259$, $p<0.05$), tidal height ($r = 0.536$, $p<0.01$), silicate concentration ($r = 0.213$, $p< 0.05$) and phosphate concentration ($r = 0.407$, $p<0.01$).

Water Quality Index

The seasonal pattern of water quality along the nearshore waters was rated Fair (Table 3) as per USEPA (2012) rating during premonsoon while Poor WQI was observed during the post-monsoon. Good WQI was observed in 2015 compared to that in 2014 and 2016 during the premonsoon season and post-monsoon. The Nethravathi - Gurupura estuary showed Poor water quality mainly during the premonsoon season throughout the study period and was Fair during other seasons. Unlike Nethravathi - Gurupura Estuary, Mulki Pavanje Estuary was rated Good and Fair during the premonsoon and post monsoon season respectively.

The premonsoon and post-monsoon seasons are observed

Table 2c. Correlation between physiochemical parameters and fish larval abundance along the Mulki Pavanje estuarine waters

	AT° C	WT ° C	pH	Salinity	DO	Phosphate	Nitrate	Nitrite	Ammonia	Silicate	Chl a	Chl b	Chl c	Rainfall	Total fish larvae	Tide height
AT° C	1															
WT ° C	0.715	1														
pH	0.159	0.324	1													
Salinity	0.061	0.290	0.638	1												
DO	-0.021	-0.187	-0.409	-0.512	1											
Phosphate	-0.047	-0.048	-0.061	0.152	-0.106	1										
Nitrate	-0.041	-0.236	-0.296	-0.546	0.373	-0.209	1									
Nitrite	0.090	-0.034	-0.019	-0.021	0.204	0.067	0.391	1								
Ammonia	-0.228	-0.259	0.108	0.327	-0.134	0.496	0.035	0.399	1							
Silicate	-0.067	-0.288	-0.664	-0.936	0.559	-0.039	0.570	0.150	-0.273	1						
Chl a	0.103	0.038	0.068	-0.257	0.416	0.023	-0.015	0.059	-0.065	0.239	1					
Chl b	0.041	0.216	0.024	-0.090	0.170	0.104	-0.096	0.087	-0.071	0.161	0.613	1				
Chl c	0.115	0.097	-0.034	-0.318	0.402	0.126	-0.061	-0.026	-0.150	0.324	0.930	0.703	1			
Rainfall	-0.136	-0.162	-0.203	-0.171	0.315	0.036	0.383	0.297	0.108	0.282	0.366	0.326	0.355	1		
Total fish larvae	0.160	0.260	-0.077	-0.192	0.081	0.408	-0.153	-0.276	-0.216	0.213	-0.101	0.047	0.112	-0.229	1	
Tide height	-0.112	-0.008	-0.023	-0.344	0.070	0.224	0.010	-0.100	-0.083	0.305	-0.018	0.110	0.110	-0.221	0.536	1

Table 3. WQI of the coastal waters off Dakshina Kannada

Year	Seasons	Nearshore stations			Estuarine stations		
		St 1	St 2	St 3	St 4	St 5	St 6
2014	PreM	Fair	Fair	Poor	Poor	Poor	Good
	M	Poor	Poor	Fair	Poor	Poor	fair
	POM	Poor	Fair	Fair	Fair	Fair	fair
2015	PreM	Good	Good	Poor	Poor	Fair	fair
	M	Poor	Poor	Fair	Fair	Fair	fair
	POM	Good	Good	Good	Fair	Fair	Good
2016	PreM	Fair	Fair	Fair	Poor	Fair	fair
	M	Poor	Poor	Fair	Poor	Fair	fair
	POM	Poor	Poor	Fair	Fair	Poor	fair

with low river flow, which could lead to less flushing of liquid wastes of anthropogenic activities. The nearshore shore waters are also highly influenced by estuaries. Hence, 2016 was rated Fair and Poor during all the seasons along the nearshore and estuarine waters. The mean rainfall (Fig. 3 a) clearly shows less rainfall during the premonsoon followed by the post-monsoon season. This in turn affects the runoff (Fig. 3 b) and is mainly responsible for the Poor and Fair water quality in estuaries. While it is the opposite in the case of the nearshore stations as the high runoff causes all the concentrated pollutants to be flushed off into the sea.

A study on identifying the nurseries and fish breeding sites along the Nethravathi-Gurupura estuary was carried out by Murugan and Usha (2018) and the outcome of this study showed a drastic decline in the breeding and nursery grounds, some of which eventually disappeared over the past few decades. The reason for this was attributed to the increased anthropogenic activities and pollution. Food availability and oxygen-rich waters were considered to be important factors responsible for breeding and nursery distribution (Lee *et al.,* 1977; Coull and Bell, 1979), but variations in the physicochemical parameters can disturb this as several fishes are known to use these estuaries as nurseries for breeding and feeding purpose. Hence there is a serious necessity to conserve our coastal waters which will also support a future sustainable fishery.

Conclusion

The study identified factors such as rainfall, river discharge, nutrients and dissolved oxygen that influenced fish larval abundance along the nearshore while in the case of estuarine waters, silicate concentration, water temperature and tides influenced fish larval abundance. High tides were favourable for the entry of adult as well as larval fish form to enter into estuaries for breeding and survival respectively as these estuaries provide breeding grounds and nurseries especially.

Acknowledgements

The authors are thankful to the Director, ICAR-Central Marine Fisheries Research Institute; Dr V. Kripa, Dr P. Kaladharan and L. K. Suvarna for their support for the completion of this study.

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OSCAR. Ocean Surface Current Analyses Real-time 2020. is a NASA funded research project and global surface current database. (http://www.oceanmotion.org/html/resources/oscar.htm)