



IMPACT OF WATER QUALITY (BOTTOM-UP) VARIABLES ON SPECIFIC GROWTH RATE OF PLANKTONIC BACTERIA IN THE RIVER CAUVERY AND ITS FOUR UPSTREAM TRIBUTARIES IN KARNATAKA.

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Abstract - The planktonic heterotrophic bacteria by their virtue of abundance, ability to use dilute substrate, high assimilation efficiencies and rapid growth rates represent significant resources available to support the next higher trophic level. The bacterial specific growth rates should relate closely to environmental factors regulating growth. Different combinations of bottom-up (water quality) factors control bacterioplankton dynamics and growth potential. Mid stream surface water samples from the rivers Lakshmanatheertha, Harangi, Hemavathy, Lokapavani and Cauvery were collected in a sterile glass bottles and were transported back to the laboratory on ice. Water samples were screened through Whatman GF/A (1.63 μ m nominal pore size) glass micro fibre filters. The SGR was calculated by taking only the abundance of bacterioplankton at the beginning (0 h) and at the end (48 h) incubation period. In result, the mean value of specific growth rate of heterotrophic bacteria was comparatively more and was also significantly different in the river Lakshmanatheertha (mean 0.0042, range -0.0009 - 0.009 h⁻¹). The significantly less SGR during summer season may be due to physiological stress caused by seasonal environmental changes, and grazing pressure. Further, mineral limitation of bacterioplankton occurs in summer due to elevated metabolic rates. In the present investigation temperature did not show any relation with the bacterial growth rate, suggests that substrate supply limiting bacterial growth in summer and its effect is probably temperature dependent. Calculations of Pearson's correlation coefficients ($p < 0.01$) and the study of regression analysis revealed that, several key environmental variables were potentially responsible for much of the SGR of bacterial variations, notable are Calcium, DO, CO₂, Rainfall, Conductivity, Total Anions of Strong Acids, and Chloride.

keywords - Specific growth rate, Bottom-up regulation, river Lakshmanatheertha, TASA, Bacterial abundance.

I.INTRODUCTION

Heterotrophic bacteria are considered as major remineralisers of dissolved organic carbon and nutrients in most aquatic ecosystems (Cole, 1999; Kritzberg E.S. et.al., 2005, Kirchman, 2015). And also play important role in nutrient cycling, decomposition and secondary production in the lotic environments (Mohamed.N.M, et.al, 2003). Degradation of organic matter contributes to the purification of the ecosystem and is therefore a major process controlling water quality (Servais and Garnier, 1993). Planktonic bacteria by their virtue of abundance, ability to use dilute substrate, high assimilation efficiencies and rapid growth rates represent significant resources available to support the next higher trophic level (Thomas, et.al., 1990, Fuhrman, 1999; Kirchman et al., 2009). As in other ecosystems, populations of riverine organisms are controlled by a variety of abiotic and biotic factors. The abundance and production of bacterioplankton is closely related to phytoplankton abundance. But, the bacterial specific growth rates should relate closely to environmental factors regulating growth (Coveney, 1995). Sinsabaugh, et al., (1997) examined the substrate supply from sources other than phytoplankton, which could support bacterial growth in rivers. Further, different combinations of bottom-up (water quality) factors control bacterioplankton dynamics and growth potential as described by Gasol, et al., (2002), and Simek, et al., (2005). There is evidence that physico-chemical factor in rivers, for examples, temperature, discharge and concentration of suspended solids (Goulder, 1980; Milner and Goulder, 1984; Yamakanamardi and Goulder, 1995, Sarmiento et al., 2010; Morán et al., 2015.) and inorganic phosphate (Mohamed, et.al., 1998; Castillo, 2000; and Castillo, et.al., 2004), influence the bacterial abundance, in turn are responsible for growth rate of heterotrophic planktonic bacteria. Further, heterotrophic bacteria are one of the most nutritious components, and also known to store Phosphate, especially inorganic polyphosphate (Makino and Cotner, 2004). The bacterioplankton and phytoplankton are considered to be competitors for dissolved mineral nutrients. Interestingly, the heterotrophic bacteria are thought to be superior competitors for phosphorus to phytoplankton as described in pelagic Oligotrophic environments

by Cotner and Biddanda, (2002); Šimek, et al., (2006). This scenario finds support in a collection of recent studies, clearly demonstrating limitation of bacterial growth by mineral nutrients (Vrede, et al., 1999; Chrzanowski and Grover, 2001). More recently, several investigators have demonstrated that, bacterial growth in aquatic ecosystems can be limited by the availability of nitrogen and phosphorous (Shiah and Ducklow, 1994), temperature (Yamakanamardi and Goulder, 1999; Rier and Stevenson, 2001, Morán et al., 2017, 2018). The most research on the population ecology of marine bacteria continues to be carried out in rich coastal and shelf waters. Very less information is available on the microbial ecology of lotic fresh waters (Sinsabaugh et al., 1997; Foreman, et al., 1998; Yamakanamardi and Goulder, 1999; Bergstein, et.al. 2000, Yannarell, et.al. 2003, Castillo, et.al. 2004, Kisand, et.al. 2005, and Harsha et.al 2009). Surprisingly very little is known about bacterial respiration and growth rate and their regulation in natural systems. Given the crucial and significant role of bacteria enough studies are lacking on the international scene in lotic fresh waters. To the best of my knowledge, there are no reports available on the microbial ecology of lotic water ecosystems using heterotrophic bacterial growth rate in India. This author is aware of only a limited number of studies that have quantified the specific growth rate, Yamakanamardi and Goulder (1999); Chrzanowski and Grover (2001); Carlson and Caron (2001); Šimek et al., (2006); and Harsha et al (2009). So far there are no studies reported on the specific growth rate of planktonic heterotrophic bacteria in river Cauvery and its important tributaries like Lakshmanatheertha, Harangi, Hemavathy and Lokapavani in Karnataka state, India. Hence, this investigation on the specific growth rate of planktonic bacteria was under taken. The main aims of the study were: 1] To compare and contrast the specific growth rate (k) of heterotrophic bacteria in the five water courses. 2] To test the hypothesis that the mean specific growth rate of heterotrophic bacteria in all the four upstream tributaries are similar to each other, but markedly different in the main river Cauvery. 3] To investigate the relationships between specific growth rate (k) of heterotrophic bacteria with other environmental variables in these five water courses. 4). To know, the potential control of mean specific growth rate of heterotrophic bacteria by relevant water quality (bottom-up or nutrient) variables.

II. MATERIALS AND METHOD

Sample Collection

For the study of specific growth rate of planktonic bacteria, mid stream surface water samples from the river Lakshmanatheertha, Harangi, Hemavathy, Lokapavani and Cauvery were collected in a sterile glass bottles (Schott-Duran, Germany) and were transported back to the laboratory on ice. The water samples were screened through Whatman GF/A (1.63 μm nominal pore size) glass micro fibre filters to remove micro zooplanktons which act as grazers. This filtration process does not reduce bacterial numbers although phytoplankton was largely removed (Yamakanamardi and Goulder, 1999, Harsha et al 2009). Approximately 505 ml of pre filtered sample was transferred to 1 litre sterile glass conical flask (Borosil India Ltd, Mumbai). Two replicate flasks were used for each site. All the flasks were closed with aluminum foil. A 5 ml aliquot was taken from each flask at zero time and fixed immediately with 0.2 μm filtered neutral formalin (2% final concentration). Then all the conical flasks were placed in an Environ-Orbit shaker (Lab-line Instrumentals, USA) running at river water temperature (water temperature which was mean of all the sampling sites) and 90 revolutions per minute. For the analysis of environmental variables, water samples were collected in a clean polytene bucket and transferred to 5 liter capacity polytene containers. Detailed methodology for analysis followed was based on APHA (1992) and as described and discussed in Yamakanamardi and Goulder (1999).

Evaluation of method.

On two occasions mid-stream surface water samples from all five sites were collected. Next, two 5 ml of aliquots were collected at 12, 24, 36 and 48 h and were fixed immediately with 0.2 μm filtered neutral formalin (2% final concentration) and were stained with Acridine orange stain. The bacterial abundance from these fixed samples was counted by using Epifluorescence microscopy. In this study, specific growth rate (as cells per cells per hour), was routinely calculated from direct counts of bacteria at beginning (0 h) and end of incubation for 48 h in GF/A filtered, un-supplemented natural water samples. Koch (1981) mentions use of the symbols K and μ for specific growth. Ducklow and Hill (1985); Fry (1990) however, preferred μ (h^{-1}) for specific growth rate. In the present work K (h^{-1}) is used to express the specific growth of bacterioplankton. The specific growth rate (k h^{-1}) of bacterioplankton was determined using the following two approaches- (1) From linear regression of \log_e cell concentration against time. A graph was plotted using concentration of acridine orange counts of bacteria at 12, 24, 36 and 48 hours against time, with the help of sigma plot 4.0 (Jandel Scientific Corporation, USA). Regression lines were fitted through the plotted data and it was found that there was significant linear regression ($P < 0.05$ to $P < 0.001$), Table 1. Hence, the growth was exponential over the 48 h incubation period in all the five rivers studied. The slope of the regression line gave specific growth rate (k) of bacterioplankton. (2) In routine determinations made at intervals over 24 months, two 5 ml aliquots were taken only at 0 and 48 h. In the preliminary determinations, SGR (h^{-1}) was obtained from linear regression of \log_e of the bacterial concentration against time where SGR equaled the regression coefficient. From direct counts of bacteria at 0 h and 48 h. Exponential growth was assumed and the Specific Growth Rate (k) of bacterioplankton was calculated using the following equation (Koch, 1981).

$$\begin{aligned} \log_e N_t &= \log_e N_0 + kt \\ \therefore \log_e N_t - \log_e N_0 &= kt \\ \therefore k &= (\log_e N_t - \log_e N_0) / t \\ \therefore k &= \log_e (N_t / N_0) = t \end{aligned}$$

Where, N_0 = is the concentration of bacteria at zero time (ml^{-1})

N_t = is the concentration of bacteria at 48 h (ml^{-1})

t = is the duration of incubation (h) and

k = Specific Growth Rate of bacterioplankton (h^{-1}).

Both the methods gave similar k values in that the second method was within the 95% confidence intervals around k obtained by the first method. It was therefore decided to use the second method for routine determination of Specific Growth Rate (k) since counts were needed only at 0 h and 48 h. This was therefore, an economical and quick method. Hence, in routine measurements 5 ml aliquots were collected from each replicate flask only at the beginning of the incubation at 0 h (N_0) and at 48 h (N_t).

III. RESULT AND DISCUSSION

The results from routine determination of the specific growth rate (k) of heterotrophic planktonic bacteria measured for all the five rivers studied are summarized in Table 2. The mean values with different superscripts are significantly different ($p < 0.05$) as shown by one-way ANOVA post hoc non-parametric Student-Newman-Keuls test (SNK test) is also shown in this table. Statistical analysis (Mean \pm SD and F&P values obtained through ANOVA test) of the season wise grouped data for comparison of all five water courses is given in Table 3. The interrelationship between the specific growth rate of bacterioplankton and other water quality variables were investigated by calculation of Pearson's Correlation Coefficients after \log_{10} transformation of all five water courses are given in Table 4. The mean value of specific growth rate (SGR) of heterotrophic bacteria was more and was also significantly different in the river Lakshmanatheertha (mean 0.0042, range -0.0009 - 0.009 h^{-1}) when compared to remaining four water courses studied, the specific growth rate bacterioplankton was similar in the rivers Harangi (mean 0.0024, range -0.0016 - 0.011 h^{-1}), Hemavathy (mean 0.0031, range -0.0024 - 0.011 h^{-1}), Lokapavani (mean 0.0030, range -0.0019 - 0.009 h^{-1}) and Cauvery (mean 0.0033, range -0.004 - 0.0105 h^{-1}) (Table 2). There was a mean growth rate of 0.0024 h^{-1} which equal to 0.06 bacterium per day in river Harangi, 0.0031 h^{-1} which equal to 0.07 bacterium per day in river Hemavathy, 0.0030 h^{-1} which equal to 0.07 bacterium per day in river Lokapavani and 0.0033 h^{-1} which equal to 0.08 bacterium per day in river Cauvery. In contrast, in the river Lakshmanatheertha, the mean specific growth rate of heterotrophic bacteria was 0.0042 h^{-1} which equal to 0.10 bacterium per day. This observation suggests that the river Lakshmanatheertha was more favorable to bacterial growth. The initial hypothesis that the four upstream tributaries are similar to each other in having similar mean SGR of heterotrophic bacteria, but are markedly different from that of main river Cauvery was rejected, because the mean SGR of heterotrophic bacteria in the river Lakshmanatheertha was more and was also significantly different than the remaining four watercourses studied. The low level of water, maximum anthropogenic activities, discharge of sewage and other effluents contamination, might have enriched the nutrient level, may be the reason for increased bacterial SGR in the river Lakshmanatheertha. Similarly, the nutrient rich in the water markedly stimulated the bulk of bacterioplankton production, as well as changes in the growth rate of planktonic bacteria as represented by Simek, et al., 2005; Jezbera, et al., 2005. Recently, several investigators have demonstrated that, bacterial growth in aquatic ecosystems can be limited by the availability of nitrogen and phosphorous (Shiah and Ducklow, 1994), substrate supply (Rivkin and Anderson, 1997), allochthonous DOC (Findley et. al., 1991; del Giorgio and Peters, 1994). The statistical analysis of the season wise grouped data revealed that, the SGR of heterotrophic bacteria did not show any seasonal variation, in all the five watercourses, except, in the river Harangi during the first year of study, the SGR of heterotrophic bacteria was significantly less in summer season than in the rainy and winter seasons (Table 3). This may be due to physiological stress caused by seasonal environmental changes, and grazing pressure from higher trophic levels (Callieri and Heinimaa, 1997). The non-algal sources of carbon are likely to be important in bacterial growth (Rier and Stevenson, 2001). Temperature and summer stratification are often considered primary mechanisms through which physical forces interplay with biological activities to regulate nutrient dynamics in the aquatic environments. An emerging view is that during summer, mineral limitation of bacterioplankton occurs; this may be due to elevated metabolic rates that drive the bacterial communities into nutrient limited states. Thus, the resources limitation more severely depressed the bacterioplankton growth during warm seasons (Chrzanowski and Grover, 2001). Utsumi, et al., (1994) suggested that the temperature is the limiting factor for bacterial specific growth rate in a swampy bog in Japan. Kirchman, et al., (1993) concluded that both temperature and substrate supply are important in controlling bacterial SGR in the sub arctic Pacific. Ducklow and Shiah (1994) demonstrated that the growth of bacteria was enhanced by substrate enrichment when bacteria were incubated at higher temperatures. Yamakanamardi and Goulder (1999) reported the SGR of heterotrophic bacteria in three lowland watercourses of England at constant temperature, as an indicator of deterioration in water quality. However, in the present study temperature did not show any kind of relation with the bacterial growth rate. This finding suggests that substrate supply limiting bacterial growth in summer and its effect is probably temperature dependent (Gurung and Urabe, 1999). The calculations of Pearson's correlation coefficients ($p < 0.01$) between SGR of heterotrophic bacteria and other water quality (Bottom-up) variables revealed that, the SGR was positively correlated only with rainfall in river Lakshmanatheertha, Dissolved Oxygen in river Harangi, Carbon-di-Oxide in river Hemavathy and with Carbon-di-Oxide, Chloride and Total Anions of Strong Acids in river Cauvery. The SGR was negatively correlated with Calcium in the river Lakshmanatheertha, and with Conductivity in the river Harangi. In the river Lokapavani, the SGR of heterotrophic bacteria was not correlated with any of the environmental variables (Table 4). Negative correlations between SGR and conductivity and Calcium suggested that higher concentration of these variables might have regulated the bacterial growth which is in agreement with the findings of Rier and Stevenson (2001). The extent of the potential dependence of SGR of heterotrophic bacteria on environmental (water quality) variables was further investigated by step-wise multiple regression analysis. The results of all the five rivers are given in Table 5. The regression analysis revealed that, several key environmental variables were potentially responsible for much of the SGR of bacterial variations, notable are Calcium, DO, CO_2 , Rainfall, Conductivity, Total Anions of Strong Acids, and Chloride. Further, only few (1-3) correlations were found to be affecting the bacterial SGR in the present investigation. However, there were no environmental variables entered the regression equation in the river Lokapavani with respect to specific growth rate. The heterotrophic bacteria and phytoplankton are considered to be competitors for dissolved mineral nutrients. Because, bacterioplankton and phytoplankton draw nutrients from the same dissolved pool (Chrzanowski and Grover, 2001). This scenario finds support in a collection of recent studies, clearly demonstrating limitation of bacterial growth by mineral nutrients (Brett et al., 1999; Vrede et al., 1999). Sinsabaugh, et al., (1997) examined, the substrate supply from sources other than phytoplankton could support bacterial growth in rivers. Further, several studies have shown that additions of inorganic nutrients can stimulate bacterioplankton growth directly (Le, et al., 1994).

Table 1. Table showing Specific Growth Rate (SGR) of aquatic heterotrophic bacteria ($k \text{ h}^{-1}$) values determined by linear regression.

Sampling Sites	Mean (Range)	F value	
River Lakshmanatheertha	1.380 (1.10 - 1.83)	12.19	P<0.05
River Harangi	1.124 (0.89 – 1.34)	6.253	P<0.05
River Hemavathy	1.142 (0.97 - 1.29)	7.525	P<0.01
River Lokapavani	1.528 (1.30 - 1.82)	9.192	P<0.05
River Cauvery	1.274 (1.09 – 1.45)	5.126	P<0.01

The \log_e transformed direct counts of bacteria at 0, 12, 24, 36, and 48h, of both the replicates, were used for linear regression analysis, hence n=10. Overall F and P values for each river are given. The regression coefficients of SGR of all the rivers were significantly different.



Table.2 Summary of Specific Growth Rate of heterotrophic bacterioplankton in the surface waters from Rivers Lakshmanatheertha, Harangi, Hemavathy, Lokapavani and Cauvery.

Bacterial variable	River Lakshmanatheertha		River Harangi		River Hemavathy		River Lokapavani		River Cauvery	
	Mean (Range)	CV%	Mean (Range)	CV %	Mean (Range)	CV%	Mean (Range)	CV%	Mean (Range)	CV%
SGR (Kh^{-1})	0.0042 ^b (- 0.0009 -0.009)	105	0.0024 ^a (-0 .0016- 0.011)	83	0.0031 ^a (- 0.0024 - 0.011)	71	0.0030 ^a (- 0.0019 - 0.009)	73	0.0033 ^a (- 0.004 - 0.0105)	79

Mean Values with different superscripts are significantly different (P<0.05, Student-Newman-Keuls test, after log₁₀ transformation). CV= Coefficient of Variation, SGR= Specific Growth Rate.

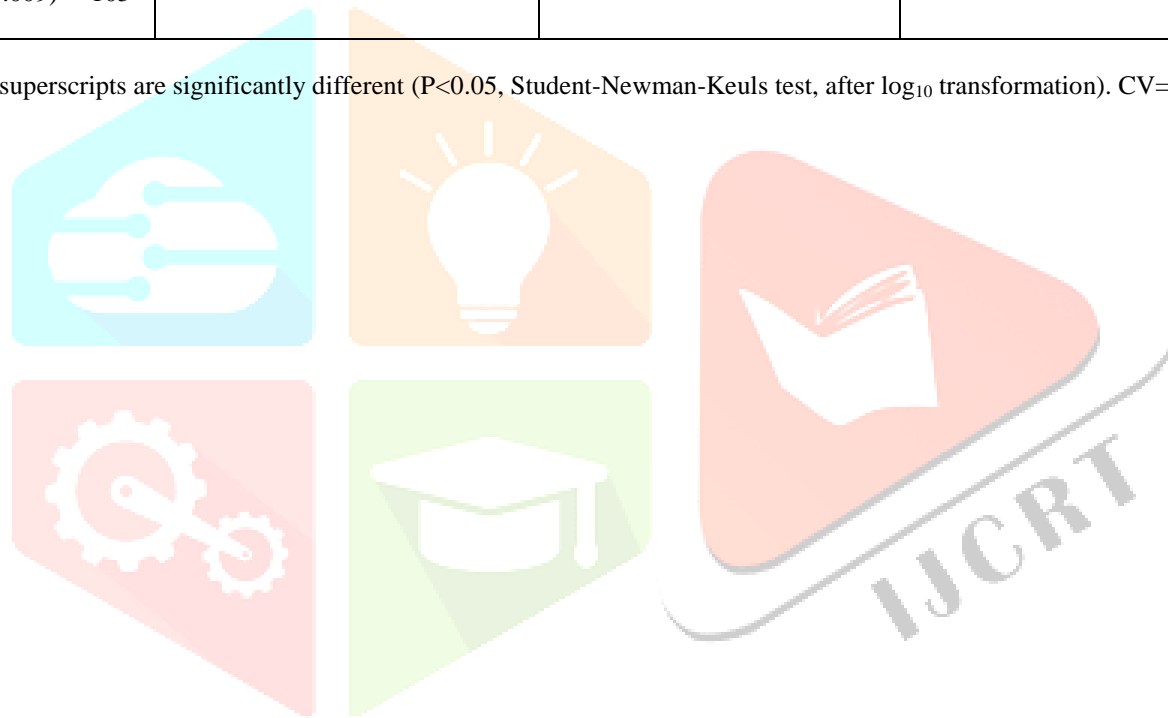


Table 3. Seasonal variation in the Specific Growth Rate of heterotrophic bacterioplankton.

Sampling sites	Pre-Monsoon (Summer)	Monsoon (Rainy)	Post-Monsoon (Winter)	F-value ¹	P-value ¹
River Lakshmanatheertha	0.0016 ^a ± 0.0010	0.0023 ^a ± 0.0013	0.0014 ^a ± 0.0014	1.2220	0.3131 ^{NS}
	0.0017 ^a ± 0.0018	0.0033 ^a ± 0.0038	0.0022 ^a ± 0.0024	0.7234	0.4968 ^{NS}
River Harangi	0.0007 ^b ± 0.0004	0.002 ^a ± 0.0014	0.0022 ^a ± 0.0011	5.7679	0.0093*
	0.0031 ^a ± 0.0032	0.0032 ^a ± 0.0023	0.0034 ^a ± 0.0016	0.0281	0.9724 ^{NS}
River Hemavathy	0.0019 ^a ± 0.0016	0.0025 ^a ± 0.0014	0.0028 ^a ± 0.0019	0.6269	0.5431 ^{NS}
	0.0033 ^a ± 0.0019	0.0031 ^a ± 0.0010	0.0051 ^a ± 0.0039	1.5383	0.2380 ^{NS}
River Lokapavani	0.002 ^a ± 0.002	0.0017 ^a ± 0.0012	0.004 ^a ± 0.0031	2.5846	0.0972 ^{NS}
	0.0039 ^a ± 0.0013	0.0039 ^a ± 0.0026	0.0024 ^a ± 0.0014	1.4792	0.2006 ^{NS}
River Cauvery	0.0011 ^a ± 0.0006	0.0019 ^a ± 0.0012	0.0027 ^a ± 0.0017	3.3512	0.0528 ^{NS}
	0.0038 ^a ± 0.0011	0.0064 ^a ± 0.0030	0.0041 ^a ± 0.0029	2.7428	0.0874 ^{NS}

Values are Mean ± SD, ¹value obtained from ANOVA post hoc nonparametric test. * = Significant, p<0.05, ^{NS} = Non Significant, p>0.05. Mean values with different superscripts are significantly different (p<0.05, Student-Newman-Keuls test).

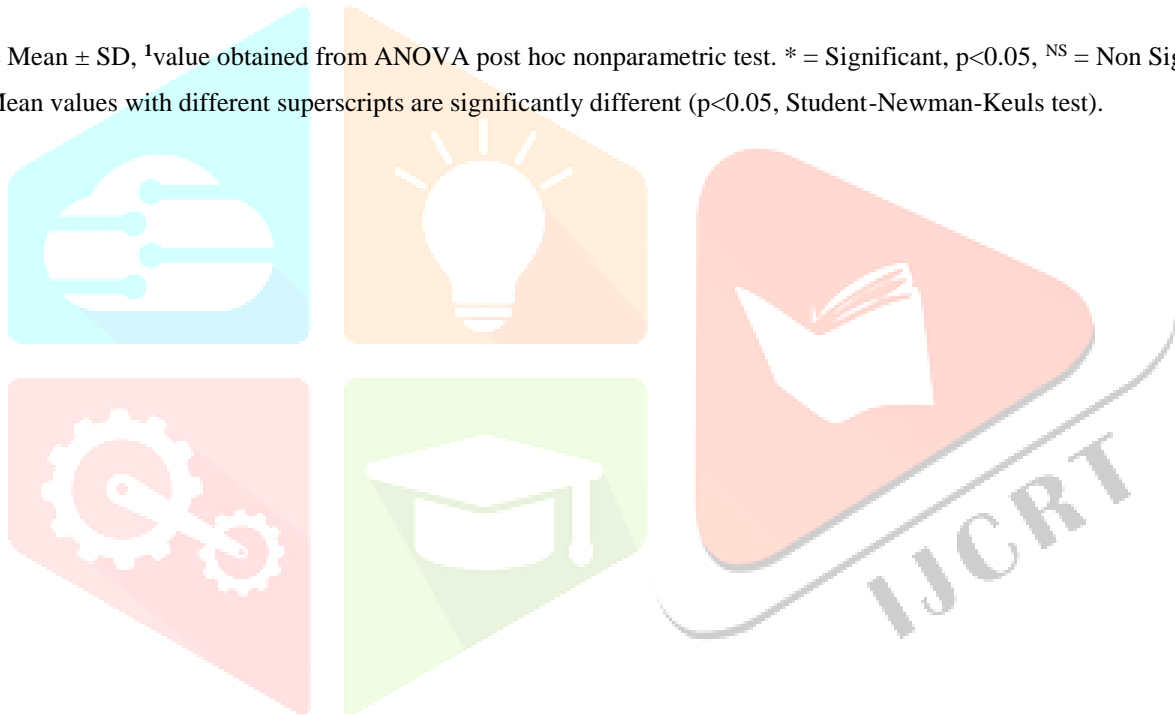


Table 4. Relationships between Specific Growth Rate (k) of heterotrophic bacteria and environmental variables, of river Cauvery and its four upstream tributaries.

Sampling Sites	Environmental variables																			
	pH(F)	pH(L)	Temp	Cond	Turb	SWV	RF	DO	BOD	COD	CO ₂	Cl ₂	NO ₃	SO ₄	TAS A	CAI	PO ₄	TSS	POM	Chla
River Lakshmanatheertha	NS	NS	NS	NS	NS	NS	0.29*	NS	NS	NS	NS	NS	NS	NS	NS	-0.41**	NS	NS	NS	NS
River Harangi	NS	NS	NS	-0.30*	NS	NS	NS	0.31*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
River Hemavathy	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.32*	NS	NS	NS	NS	NS	NS	NS	NS	NS
River Lokapavani	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
River Cauvery	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.55***	0.34*	NS	NS	0.37*	NS	NS	NS	NS	NS

pH (F) = pH measured in the field, pH (L) = pH measured in the laboratory, Temp= Temperature, Cond = Conductivity, Turb = Turbidity, SWV= Surface Water Velocity, RF= Rainfall, DO= Dissolved Oxygen measured in the Field, BOD= Biological Oxygen Demand, COD= Chemical Oxygen Demand, CO₂= Free Carbon di-Oxide, Cl₂= Chloride, NO₃=Nitrate, SO₄= Sulphate, TASA= Total Anions of Strong Acids, Cal= Calcium, PO₄= Inorganic Phosphate, TSS= Total Suspended Solids, POM= Particulate Organic Matter, Chl-a=Chlorophyll-a.

Table. 5. Results of stepwise multiple regression analysis between Specific Growth Rate (k) of heterotrophic bacteria and Environmental variables, in the river, Lakshmanatheertha, Harangi, Hemavathy, Lokapavani and Cauvery.

Sampling Sites	Environmental variables
River Lakshmanatheertha	CAL (-), ($R^2=0.17$, $F=9.71$, $P<0.05$), Rainfall (+).
River Harangi	DO (+), ($R^2=0.10$, $F=5.20$, $P<0.05$), COND (-).
River Hemavathy	CO ₂ (+), ($R^2=0.10$, $F=5.44$, $P<0.05$).
River Lokapavani	No environmental variables entered in the regression equation.
River Cauvery	CO ₂ (+), ($R^2=0.30$, $F=20.36$, $P<0.001$), Cl ₂ (+), TASA (+).

Environmental (independent) variables in the final regression equation ($P_{in}=0.05$, $P_{out}=0.1$) are shown: multiple coefficients of determinations (r^2) and overall F and P values for each equation are given in the parenthesis. Environmental variables which were not in the final equation but which are correlated ($P<0.05$) with the relevant Bacterioplankton variables are then listed in order of decreasing magnitude of correlation coefficient; the sign of the correlation is indicated in the parenthesis. The environmental variables were; COND=Conductivity, DO= Dissolved Oxygen, CO₂=Carbon di-Oxide, Cl₂ =Chloride, TASA= Total Anions of Strong Acids, CAL=Calcium.

IV. CONCLUSION

It was concluded that, the more and significantly different SGR of heterotrophic planktonic bacteria was noticed in the river Lakshmanatheertha than the remaining four watercourses studied. The increased nutrient level, pollution, sewage and other effluent contamination might be the reason. Similarly, the nutrient rich in the water markedly stimulated the bulk of bacterioplankton production, as well as changes in the growth rate of planktonic bacteria. The significantly less summer SGR of heterotrophic bacteria may be due to mineral limitation, the elevated metabolic rates during summer may drive the bacterial communities into nutrient limited states. Regression analysis revealed that the SGR tended to respond strongly towards environmental variables like, Calcium, DO, CO₂, Rainfall, Conductivity, TASA, and Chloride, which might have caused physiological stress which in turn regulated the growth rate in the present investigation. Thus, different combinations of bottom-up factors control bacterioplankton dynamics and growth potential. This study suggested that the SGR is potentially useful in detection of inhibition of heterotrophic bacteria, and potential loss of biopurification capacity, brought about by adverse water quality which may be related to natural process or to toxic pollution.

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