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TRENDS IN HYDRO-CLIMATIC VARIABLES AND DISSOLVED OXYGEN OF THE RIVER PERIYAR, SOUTH INDIA WITH POTENTIAL IMPACTS OF GLOBAL WARMING

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Abstract: Rivers are of immense importance geologically, biologically, historically and culturally. They bring socio-economic and cultural identity to the land through which it is flowing. Any change in the characteristics of the river is bound to affect the living organisms depending on the river. Air temperature, surface water temperature, discharge, rainfall and dissolved oxygen of the river are interrelated hydro climatic variables. Any change in one aspect is bound to affect the other variable. Climate change is perceived globally as change in air temperature. Studies suggest that change in air temperature of the region has strong influence on surface water temperature of the river. Moreover, air temperature influences the rainfall of the region which in turn affects the discharge of the river. In this paper, the study has aimed to evaluate the changes in air temperature, surface water temperature, rainfall, discharge (flow) and dissolved oxygen during the last 30 years in Periyar River, the longest river in Kerala, from a climate change perspective. Trend analysis is done to the 30 year annual average data of hydro climatic variables (air temperature, surface water temperature, discharge, rainfall, and dissolved oxygen) of the river to forecast scenarios for 2020, 2040, 2060, 2080, 2100. Statistical analysis, correlation and simple linear regression are performed on the secondary data to derive equations relating to hydro-climatic variables. Emission scenarios hypothesized for South Asian countries in Global Circulation model output given in the Intergovernmental Panel on Climate Change (IPCC) report 2007, is then applied in the equations so derived, to predict surface water temperature and discharge of the river.

Key words: Climate change, Hypothetical scenario, Hydro-climatic variables, River water quality, Simple Linear regression.

INTRODUCTION

The phenomenon called "Climate change" is one of the most researched topics in recent times. From a global perspective, climate change is usually perceived as an increase in average air temperature. Consequently the increase in the air temperature will have a definitive impact on the surface water temperature .Subsequently this change would cause changes in runoff, river flow, ground water storage, water temperature and discharge of the river.

The scientific consensus is that future increases in atmospheric greenhouse gas concentrations will result in elevated global-mean temperatures with subsequent effects on regional precipitation, evapo-transpiration, soil moisture and altered flow regimes in streams and rivers (Arnell, 2004; Wilby *et al*., 1994). Most of the chemical reactions and bacteriological processes are dependent on temperature and they run faster at high temperatures, increasing the growth rates. The direct impact of an increased temperature will hence be on dissolved oxygen (Cox and Whitehead, 2009). Climate change results in deterioration of water quality in terms of reduction in dissolved oxygen concentration, high levels of which are needed to sustain aquatic life. These adverse effects will worsen with changes in river flow and increased pollutants. Changes in air temperature and rainfall can affect river flow and river water temperature, the primary variables that influence water quality. Therefore, in this article an attempt is made to assess the impacts of climate change on dissolved oxygen in the Periyar river under different emission scenarios.

Periyar River is one of the longest flowing rivers in Kerala, South India; with a catchment area of 5398 Sq.km. The river plays an important role in the cultural, political and socio-economic aspects of the people in central Kerala. Major tributaries of the river are Muthirapuzha River, Mullayar River, Cheruthoni River, Perinjamkutti River, and Edamala River. Minor tributaries are Muthayar, Perunthuraiar, Chinnar, Cheruthony, Kattappanayar. The river is divided into two branches at the Eloor Island to join back at the Eloor ferry, further flowing down stream to join the Arabian Sea. Eloor- edayar belt is sprawling with small and large-scale industries, which discharge semi-treated and untreated effluents into the river. Samples are collected from Periyar river near the Eloor- Edayar belt. Green peace, India describes the lower Periyar as "a cesspool of toxins, which has alarming levels of deadly poisons like DDT, endosulfan, hexa and trivalent chromium, lead, cyanide, BHC" etc.The Central Pollution Control Board started national water quality monitoring in 1978 under Global Environment Monitoring System (GEMS) water program.

Here, in this article historical data retrieved from the water quality program of hydro-climatic variables are analyzed to predict future trends in the river. Water temperature data is then correlated and analyzed with the dissolved oxygen of the river to propose predictions for surface water temperature and discharge of the river for the future.

METHODOLOGY

Periyar River is one of the most polluted rivers in India. Dissolved oxygen in the river is found to be very low and fluctuating, due to discharge of effluents from semi-treated and untreated waste water from the nearby industries into the river. Around 500 small and large scale industries are there in the Eloor – Edayar belt which discharge pollutants daily into the river. Inhabitants in the Eloor Island depend on the river for drinking, agriculture, and other domestic purposes. This disastrous condition of the river has made the life of the people miserable. A committee named Local Area Environment Committee (LAEC) was formed during 2005 as an order from the supreme court of India to monitor the effluent discharge from industries into the river. Since then, LAEC has been monitoring the river. Even then, we could observe that the condition of the river is

Fig. 1. Showing the sampling site

deteriorating day by day. So, trend analysis and correlation and regression analysis of hydro-climatic variables and its forecasting will help in planning management strategies in reducing pollution of the river. Fig. 1 Depicts the study area with sampling locations.

Secondary data of variables from the Periyar River during 1980-2011 was obtained from the Kerala State Pollution Control Board, Indian Meteorological Department, Neeleswaram station of Central Water Commission, Kochi and Kerala State Hydrology Department, Thiruvananthapuram for surface water temperature, air temperature, discharge and rainfall respectively.

Studies show that dissolved oxygen in the water gets reduced with an increase in water temperature. In order to understand the relation between dissolved oxygen and hydro climatic variables in the river especially surface water temperature, primarily a trend analysis was performed for all the variables. Thirty years annual average data of surface water temperature, air temperature, discharge, rainfall and dissolved oxygen are used for analyzing the trend. 30years is taken as the time period and average annual data as the time unit. Difference of data between the first year and second year are recorded. Continuing in this manner, the recording for the difference in data between each time unit is carried out until the 30 year time period is over. Add all the data to get total for all the time units. Divide the sum total by the number of time units over the time period. The resulting data is used for predicting the surface water temperature, air temperature, rainfall, and discharge and dissolved oxygen for 2020, 2040, 2060, 2080, and 2100. This data is then subjected to correlation and simple linear regression statistical analysis using SPSS 6.1 software. The equations obtained from the linear regression analysis are used to predict values of surface water temperature and discharge of the river from the air temperature (emission scenario) hypothesized in GC model output in the IPCC report, 2007.

The Special Report on Emission Scenarios (SRES) scenarios, described in the IPCC report 2007 with SRES 2000 as the base, are grouped into four scenario families (A1, A2,B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios do not include additional climate policies above current ones. The emission projections are widely used in the assessment of future climate change and their underlying assumptions with respect to socio-economic, demographic and technological change, serve as inputs to many recent climate change vulnerability and impact assessments.

The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into 3 groups that describe alternative directions of technological change: fossil intensive (A1F1), non fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures towards a service and information economy. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

For each emission scenario, corresponding increase in air temperature is given in the IPCC report 2007. So, corresponding air temperature is introduced into the equations derived from simple linear regression for each scenario. From the equations derived, we can predict values for water temperature and discharge of the river for the year 2100.

Time series model of SPSS 6.1 software is used for projecting the surface water temperature, discharge and dissolved oxygen of the river for the next 100 years (Table 1).

RESULTS

Correlation analysis of the data collected suggests that dissolved oxygen is inversely related to water temperature i.e., higher the water temperature, lower the dissolved oxygen. But, surface water temperature is in turn affected by air temperature and rainfall of the region, and discharge of the river. Here, in this article in

Table 1. 30 year annual mean variation of Air temperature, Water temperature, Rainfall, Discharge and dissolved oxygen from 1980 to 2011

Year	Air Temp.	Water Temp.	Rainfall	Discharge	Dissolved Oxygen
1980	28.02	29.3		260.51	3.58
1981	27.81	31.1	287.5	305.71	7.05
1982	27.9	30.4	209.16	121.83	5.1
1983	27.91	29.6	218.3	181.0	6.67
1984	27.48	28.5	234.11	198.4	7.04
1985	27.67	30.3	242.3	207.4	6.63
1986	26.46	31.4	200.9	177.12	7.0
1987	28.41	28.8	212.05	153.5	6.66
1988	27.97	29.0		175.5	6.65
1989	27.54		222.11	240.42	6.5
1990	27.66	28.8	204.9	195.08	7.11
1991	27.86	28.6		314.2	6.55
1992	27.43	27.4		256.9	6.59
1993	27.53	27.4	228.2	199.89	6.84
1994	27.54	27.4	247.5	281.08	7.0
1995	27.61	26.5	277.49	211.98	7.17
1996	27.72	28.2	202.16	190.61	7.26
1997	28.02	28.7	217.11	207.95	6.8
1998	28.13	28.8	216.66	276.05	6.7
1999	27.42	24.9	215.64	181.8	6.84
2000	27.44	26.1	174.93	197.51	6.84
2001	27.49	26.5	259.69	217.27	6.62
2002	27.73	27.8	262.65	167.69	5.08
2003	27.91	28.3	182.15	146.84	5.41
2004	27.604	28.08	235.74	209.14	5.98
2005	28.69	27.9	266.1	294.02	5.7
2006	27.65	28.0	304.37	221.71	6.19
2007	27.7	27.75	308.73	317.04	5.54
2008	27.68	28.83	219.01	176.83	5.14
2009	27.96	28.0	234.65	210.75	6.04
2010	27.908	31.0		237.25	5.32
2011	27.8	29.0			5.6

order to project the variations of dissolved oxygen of the river by 2100, thirty years secondary data of air temperature, surface water temperature, rainfall and discharge are analyzed using statistical software SPSS 6.1.

Air temperature values are within the 27 and 29 degree Celsius range with one exception during 1986 where the temperature went below 27 degree Celsius (26.46). From the historical data analysis, air temperature shows an increasing trend. Water temperature of the river shows an increasing trend but lately, it is found to decrease through the years till 1999 where the annual mean temperature went below 25degree Celsius (24.95). After 2000, the temperature is found to increase. Precipitation of the region is found to be within 200 and 300mm range with highest mean rainfall recording during 2006-2007 period. We could infer from the graph that low rainfall in the river basin is recorded during 2000 and 2003 period (174.93 and 182.15 mm respectively). Generally there is an increasing trend for precipitation in the region. Stream flow shows (Graph 4) a zigzag variation over the years with lowest record during 1983, 2003 and 2004. Hydro-climatic variables are analyzed for the trend along these years. Analysis shows that water temperature (0.012 degree celsius/yr), air temperature (0.018 degree celsius/yr), rainfall (2.008 mm/yr) and discharge (1.169 m3/s/yr) shows an increasing trend while , dissolved oxygen (2.02 mg/l/yr) shows a decreasing trend. Results are given in the Table 2.

From the analysis of hydro climatic variables, scenarios are given in the Table 2. The analysis of hydro climatic variables, scenarios are given in the Table 3. Here for the current study, year 2000 is taken as the base value for the evaluation of different scenarios. The results obtained are given in the Table 4.

Table 2. Showing result of trend analysis of variables

No	Variable	Trend
1	Water temperature	+0.012degree Celsius/yr
2	Air temperature	+0.018degree Celsius/yr
3	Rainfall	+2.008mm/yr
4	Discharge	+1.169m^3/s per yr
5	Dissolved Oxygen	-0.065mg oxygen/l/yr

Table 3. Showing proposed hypothetical scenarios

Scenario	Water temp.	Air temp.	Rainfall	Discharge
Scenario 1	+.24	+0.36	+40.16	+23.38
Scenario 2	+0.48	+0.72	+80.32	+46.4
Scenario 3	+0.72	+1.08	+ 120.48	+69.6
Scenario 4	+0.96	+1.44	+160.64	+92.8
Scenario 5	+1.2	+1.8	+200.8	+116.9

Table 4. Showing results of proposed scenarios

Scenario	**Air temp.e**	**Water temp.**	**Rainfall**	**Discharge**
2000	27.44	26.1	174.93	197.51
Scenario 1	27.68	26.46	215.09	220.89
Scenario 2	27.92	26.82	255.25	243.91
Scenario 3	28.16	27.18	295.41	267.11
Scenario 4	28.4	27.54	335.57	290.31
Scenario 5	28.64	27.9	375.73	314.41

The relationship between hydro climatic variables of the river was studied by computation of correlation coefficients between them. The climatic and hydrological variables considered are precipitation, discharge, air temperature and water temperature. The correlation results show that there is a significant negative correlation of water temperature with rainfall & discharge. With a positive correlation between air temperature and water temperature, it is clear that there will be an increase in river water temperature, with increase in air temperature. Correlation of discharge and rainfall shows significance at 90% confidence level. Air temperature has a positive correlation with rainfall and discharge of river Periyar. Correlation analysis done with dissolved oxygen and water temperature gives a negative correlation between them. So it is apparent that, warmer the water lesser the oxygen dissolved in the river water.

Furthermore, to establish relation between variables, simple linear regression analysis was done between air temperature & water temperature, discharge & rainfall, rainfall& air temperature and equations are derived (Table 5). The regression equations are as follows;

Water Temperature = 22.858 + 0.202 x Air temperature ——1

Discharge = 5.167 + 0.880 x Rainfall ————2

Rainfall = -60.511 + 10.62 x Air temperature —3

International Panel for Climate Change (2007) has given different emission scenarios for South-Asian region. Based on their observation, they had suggested a respective increase in air temperature for different scenarios which is evaluated for 99 yr time period. These air temperature values for each emission scenario are used for prediction of surface water temperature of the river. Here, 2000 mean annual air temperature (27.42) is taken as the base temperature for calculating temperature change for each scenario. Similarly, equation relating rainfall and discharge (equation 2) was used to predict discharge of the river from the rainfall scenario. Rainfall data obtained from equation 3 for different scenarios is used in predicting discharge of river by equating in equation 2.

Here, we could observe that the water temperature and discharge are slightly higher than the one predicted through the trend analysis. A1F1 scenario, a world with rapid population growth and more fossil intensive economic growth scenario projects the highest increase in temperature both for air and water temperature. Here it can be observed that for the scenario (A1F1) where population growth increases, with slow economic and technological changes, the air temperature increases with a corresponding increase in water temperature. Similarly, Rainfall and discharge of the river is

Table 5. Change in Air temperature, water temperature, rainfall, and discharge for different scenarios (2100 yr.)

Scenario	Air temp.	Water temp.	Rainfall	Discharge
B1	29.24	27.9	250.01	225.17
A1T	29.84	28.5	256.38	230.78
B2	29.84	28.5	256.38	230.78
A1B	30.24	28.9	260.63	234.52
A2	30.84	29.5	267.00	240.12
A1F1	31.44	30.1	273.38	245.74

also observed to be on a steady rise for different hypothetical scenarios considered. Results obtained here ascertain the IPCC report of increased temperature and increased precipitation over south-Asia over the next 100 years. Air temperature predicted through trend analysis for the river basin by 2100 is 28.64, an increase of 1.2 degree celsius, while emission scenarios proposed in the IPCC report suggest an increase of 1.6-3.6 degree celsius that is, air temperature would be between 29-31 degree celsius. For water, the increase in temperature is by 1.8 degree Celsius (trend analysis) and the GC model scenarios predict an increase of 1.8- 4 degree Celsius. Graphical projection of thirty years observed data of surface water temperature, discharge and dissolved oxygen are done with the time series model of SPSS statistical software.

From the time series model graph below, we could forecast the water temperature to be 29 degree Celsius and discharge to be 250 m^3/s for the year 2100 (Fig. 2). From the Fig. 3, given below we could infer that the dissolved oxygen would be around 5.6 mg of oxygen/l by 2100.

Periyar River flowing through the Eloor-Edayar industrial belt is discharged with both semitreated and untreated industrial effluents. So, river flowing through this sector suffers an oxygen sag. Eloor – Edayar belt is thickly populated with inhabitants mostly depending on the river for their water needs, moreover, drinking water supply to the nearby Kochi city is supplied from the upstream of this river. From the analysis of different scenarios, we could infer an increase in surface water temperature of 1.8 to 4 degree Celsius by the next 100 year. There is a simultaneous decrease in dissolved oxygen (9.2%) i.e., dissolved oxygen will be 5.6 mg/l by

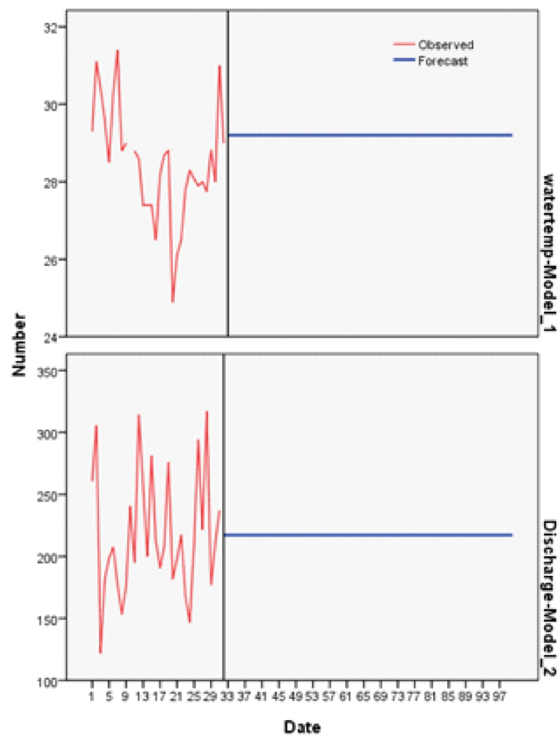

Fig. 2. Showing time series model for water temperature and discharge

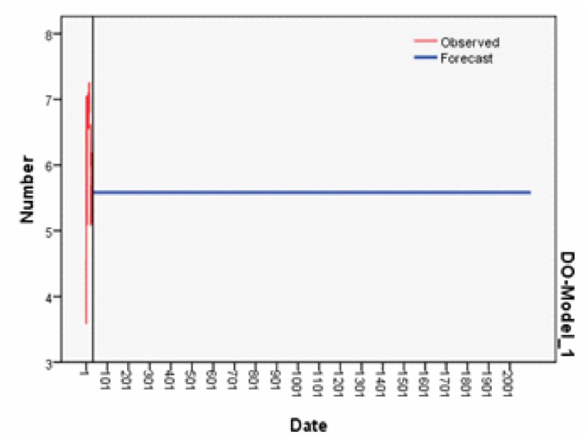

Fig. 3. showing time series model for dissolved oxygen

2100 if the water temperature is at 29 degree Celsius and industrial effluent discharge to the river remains at the present status. An increasing temperature has the most impact on de-oxygenation rate, resulting in decreased dissolved oxygen saturation concentration thereby reducing the dissolved oxygen in the river (Schnoor, 1996). Thus, lowering of dissolved oxygen in the Periyar River will further worsen the already polluted river. Currently the river receives around 25314 m^3/day of effluent discharge. As the water temperature increases, the rate of chemical reactions becomes higher, which in turn affects the biological activity, further lowering the dissolved oxygen in the river (water quality assessment: physical temperature). Time series graph (7 & 8) shows the water temperature to be at 29 degree Celsius, discharge of the river to be 250m^3/s and DO value to be 5.6 mg/l by 2100yr.

CONCLUSIONS

From the correlation analysis, we could find that all the hydro-climatic variables analyzed were positively correlated. In this article we have analyzed the increasing and decreasing trend of 30 year data of hydro climatic variables of the Periyar River. We observed an increasing trend for all the variables considered; air temperature, water temperature, discharge and precipitation. Based on the results from trend analysis, scenarios were proposed to predict air temperature, water temperature, discharge and rainfall by 2100. Linear regression equation obtained from the regression analysis was used to predict water temperature, and discharge of the river from the air temperature given in the emission scenarios of Global Circulation model output. Results from the scenarios of GC model output were compared with the scenarios of trend analysis. We could observe slight variation in discharge, rainfall, water temperature and air temperature. Time series model developed predicts the surface water temperature to be around 29 degree Celsius and discharge of the river to be 250m^3/sec by the year 2100.

30 year data of dissolved oxygen from the Periyar effluent discharge near Eloor showed a negative correlation with water temperature. Trend analysis done to dissolved oxygen, showed a decreasing trend, this is a consequent of effluent discharge to the Periyar River. Time series model developed for dissolved oxygen, water temperature and discharge, predicted the dissolved oxygen in the river to be 5.6 mg/l by 2100. In the IPCC report, it is predicted that the air temperature and precipitation of the South Asian region is bound to increase by 2100. This is in corroboration with our results from both trend analysis and simple linear regression. But Mathew (2009), in nature journal has pointed out that even though climate models indicate an increase in water temperature for tropics, investigations of ancient climates based on palaeodata have indicated cool temperatures or water temperature within the range of 28-32 degree Celsius during the supposed green house episodes. James Zachos (2003), analyzed sediments deposited on the sea floor during a period known as Paleocene-Eocene thermal maximum, found that a massive release of heat trapping green house gases is thought to have triggered the process of global warming. However, from our study, we could find that the air temperature of the Periyar River is increasing thereby, increasing the surface water temperature of the river. The precipitation and discharge of the river is found to increase with increasing temperature with reduction in dissolved oxygen. Thus, from our analysis we could reaffirm that climate change is a fact. So, strong measures should be made to curb the discharge of polluted effluents into the already polluted Periyar River. New management practices and paradigms that can accommodate changing conditions are needed. Efforts must be made to implement long term adaptation policies as an initial strategy and also to design new treatment systems to include climate change impacts.

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