International Journal of Environment and Climate Change

Volume 12, Issue 12, Page 219-228, 2022; Article no.IJECC.93671
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Trend Analysis and ARIMA Models for Water Quality Parameters of Brahmani River, Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i121457

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/93671

Original Research Article

Received: 08/09/2022
Accepted: 16/11/2022
Published: 21/11/2022

ABSTRACT

Statistical trend analysis and time-series prediction model are widely used in water quality regulation. Using the Mann-Kendall test, trend analysis was performed on monthly time series. The monthly findings revealed that only the potential Hydrogen (pH) and Total Coliforms (TC) showed meaningful trends. Future values for the parameters which affect water quality have been predicted using the Autoregressive Integrated Moving Average (ARIMA) model. R-square, root mean square error, absolute maximum percentage error, absolute maximum error, normalised Bayesian information criteria, Ljung-Box analysis were used to validate the model. It has been found that the predictive models for potential Hydrogen (pH), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Total Coliforms (TC) are useful at 95% confidence limits. Also, the results showed that the pH values will be in the range of 7.2 to 7.5 and the predicted series were similar to the original series, providing a perfect fit. The DO (mg/l) ranges from 7.8 to 12.3 mg/l. BOD (mg/l) fluctuates continuously between 1.2 and 1.3 mg/l. The TC (MPN/100ml) values show reducing trend. The study show that the quality of water is deteriorating based on the trend for the parameters and needs managerial actions.

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Keywords: ARIMA; Mann-Kendall; water pollutants; forecasting.

1. INTRODUCTION

The Brahmani River, is one of the most significant peninsular river systems in India, the second-largest river in Odisha, and that is where the research is being undertaken. This mighty river during the monsoon, basically becomes stagnant pools of water held in steep gorges and potholes in the riverbed. On the banks of the river, one of India's major industrialised areas known for ore mining, steel production, power generation, cement production, and other related activities. A large number of pollutants are deposited by neighbouring companies, municipalities, and villages, therefore the river's intrinsic capability is unable to remove them, which is the primary reason why the water quality is deteriorating. These pollutants drain into the Bay of Bengal after passing through the southern districts of Sundergarh, Deogarh, Angul, Dhenkanal, Jajpur, and Kendrapara. Water is one of the most fundamental needs of the population, hence its safety needs to be considered before use. The current study seeks to determine the physico-chemical and bacteriological characteristics of the water quality across the Brahmani river.

Water is essential to the existence and health of both humans and ecosystems. To evaluate the performance of an assessment operation and provide better management and planning for water resources, evaluation of water quality characteristics is required. Potential Hydrogen (pH), Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD) are performance indices that typically represent the quality of water in any process industry. BOD and COD levels are significant indicators of water quality [1]. The BOD is an approximate measure of how much organic matter is present in a water sample that is capable of biochemical degradation. Although COD values are always higher than BOD values, COD measurements can be performed in a limited amount of time as compared to five days for BOD measurements [2]. However, it is very difficult to obtain continuous water quality data due to the scarcity of accessible space within the monitoring stations and the necessity of separate laboratory experiments. The presence of harmful chemicals in a sample may also affect microbial activity, resulting in a decrease in the reported BOD and COD values [2]. In order to manage the best procedures for water quality conservation, a number of water quality models, such as traditional mechanistic approaches, have been established. The majority of these models require a variety of input data, many of which are not readily available, making the process expensive and time-consuming [3].

In hydrology, analysing trends in water quality data is crucial for understanding how water quality parameters fluctuate, planning streams, and monitoring water quality measures. Understanding long-term fluctuations in certain water quality measures is one of six requirements for water quality monitoring [4]. Additionally, a trend analysis shows whether the measured values of a water quality metric have increased or decreased over time [5]. Gocic and Trajkovic [6] examined the trends of 12 indicators of the Nisava River's water quality from 2000 to 2004. In the current study trend analysis was performed on monthly time series data using Mann-Kendall test.

A time series is a group of data points that have been arranged chronologically. It is a collection of observations taken at a succession of equally spaced points in time *ie.*, discrete time data. These techniques analyse time series data to derive important statistics and data properties. Using a model and previously observed values, time series forecasting can be executed. Kurunc et al. [7] examined the Yesxilirmak River's stream flow and water quality parameters using time series analysis at the Durucasu monitoring station. Taheri et al. [8] used time series modelling to examine the quality of the Hor Rood River at the Kakareza station. The ARIMA (Autoregressive, Integrated, and Moving Average) model was found to be suitable for generating and forecasting river water quality. Hanh et al. [9] determined the influence of climate and hydrology on water quality of the lower Mekong River and reported that the predictions using ARIMA models were reliable in shorter period for some variables. ARIMA relies on past values of the series as well as previous error terms for forecasting [10]. Therefore, ARIMA models are relatively more robust and efficient in short-term forecasting [11].

Many works have been accomplished on hydrological components modelling using time series analysis and the efficiency and necessity of this kind of modelling as it takes into account the stochastic nature of hydrological processes.

Present study aims to apply ARIMA model on water quality parameters of Brahmani River.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is located in the Brahmani River, Odisha which is shown in the Fig. 1. The Brahmani River lies at 20^0.66'N to 23^0.35'N and 83^0.68'E to 87^0.30'E. The water from Brahmani River is increasingly being used for water supply in Odisha state. Therefore, the water quality level of Brahmani River is very important for the region. The water quality parameters data for the Brahmani River such as potential Hydrogen (pH), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Total Coliforms (TC) from 2017 to 2019 were gathered for the current study from the Pollution Control Board's official website in Bhubaneswar, Odisha (https://odocmms.nic.in). Four stations data on water quality were gathered *ie.,* Rourkela (D/S), Dhenkanal (D/S), Pattamundai, and Angul.

2.2 Mann-Kendall Test for Trend Analysis

Mann [12] described a nonparametric test for randomness against the trend. The test he described is a particular application of Kendall's test for correlation commonly known as Kendall's tau [13]. According to Mann the null hypothesis of randomness H_0 states that the data (X_1..., X_1) are a sample of n independent and identically distributed random variables. The alternative hypothesis (H_1) of a two-sided test is that the distribution of X_k and Xj are not identical for all k, $j \leq n$ with $k \neq j$. The test statistic S is defined as:

$$S = \sum_{k=1}^{n=1} \sum_{j=k+1}^{n} sgn\ (x_j - x_k) \qquad (1)$$

$$Sgn(x_j - x_k) = \begin{cases} -1 & if\ (x_j - x_k) < 0 \\ 0 & if\ (x_j - x_k) = 0 \\ +1 & if\ (x_j - x_k) > 0 \end{cases} \qquad (2)$$

Where x_j and x_k are the annual values in different years j and k, j>k, respectively. If n<10 then the value of |S| is compared directly with the theoretical distribution of S that is derived by the Mann–Kendall test. At some probability level, H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S having the probability less than α/2. A positive (negative) value of S indicates an upward (downward) trend [14].

For n≥10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0$$

$$Var\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)\ (2t_p + 2)\right] \qquad (3)$$

Where, q is the number of tied groups and t_p is the number of data values in the p^{th} group. The standard test statistic Z is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(s)}} & ; if\ S > 0 \\ 0 & ; if\ S = 0 \\ \frac{S+1}{\sqrt{Var(s)}} & ; if\ S < 0 \end{cases} \qquad (4)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. To test for either an upward or downward monotonic trend (a two-tailed test) at α level of significance, H_0 is rejected if $|Z| > Z_{1-\frac{\alpha}{2}}$, where $Z_{1-\frac{\alpha}{2}}$ is obtained from the standard normal cumulative distribution tables. The Kendall's τ values are calculated as Eq. 5.

$$\tau = 2\frac{S^*}{z(z-1)} \qquad (5)$$

In which S* denotes Kendall’s sum, computed as S* = A-B, where A represents the number of chances when the difference of x_b to x_a is greater than zero and B represents the number of chances when the difference of x_b to x_a is less than zero.

2.3 Autoregressive Integrated Moving Average (ARIMA)

ARIMA is a statistical analysis model that uses the time series data to forecast future trends. It retains a form of regression analysis seeking to predict future movements and the random walks seemingly taken by examining the differences between values in the series instead of using the actual data values. The differenced series have lags referred to as “auto-regressive” and forecasted data lags are referred to as “moving average”. This model is represented as ARIMA (p, d, q), where p represents the order of auto-regression, d shows the degree of differencing, q shows the order of moving average.

Inclusion of Autoregressive and moving average processes is more favour for achieving greater flexibility of actual time series data which starts to the combination of autoregressive and moving average processes denoted as ARMA (p,q).
ARMA (p,q) is indicated by

$$\emptyset(B)y_t = \theta(B)\varepsilon_t \qquad (6)$$

Where

$$\emptyset(B) = 1 - \emptyset_1 B - \emptyset_2 B^2 - \cdots \emptyset_p B^p \qquad (7)$$

And

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \qquad (8)$$

In which,

B - the backshift operator express by B(y_t) = y_{t-1}.
p – order of AR
q – order of MA

Box-Jenkins [15] Autoregressive Integrated Moving Average model developed by including “differencing” in the ARMA model which indicated by ARIMA (p,d,q) which is written as

$$\Delta^d Y_t = C + \phi_1 \Delta^d Y_{t-1} + \cdots + \phi_p \Delta^d Y_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} \qquad (9)$$

In which, ε_t ~ N (0, σ^2).

2.4 Methods of Forecast Evaluation

The modelling capacity of several models was studied in this research using two typical performance metrics. They are the Root Mean Squared Error (RMSE) and the Root Mean Square Percentage Error (RMSPE). These are measured using the following equations.

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{n}} \sum_{\mathrm{t}=1}^{\mathrm{n}} (\mathrm{y_t} - \hat{\mathrm{y}}_\mathrm{t})^2} \qquad (10)$$

$$\mathrm{RMSPE} = \sqrt{\frac{1}{\mathrm{n}} \sum_{\mathrm{t}=1}^{\mathrm{n}} \frac{(\mathrm{y_t} - \hat{\mathrm{y}}_\mathrm{t})^2}{\mathrm{y_t}}} * 100 \qquad (11)$$

Where,

- $\mathrm{y_t}$ – original price at $\mathrm{t^{th}}$ time
- $\hat{\mathrm{y}}_\mathrm{t}$ – forecasted price at $\mathrm{t^{th}}$ time
- n - the amount of forecasts

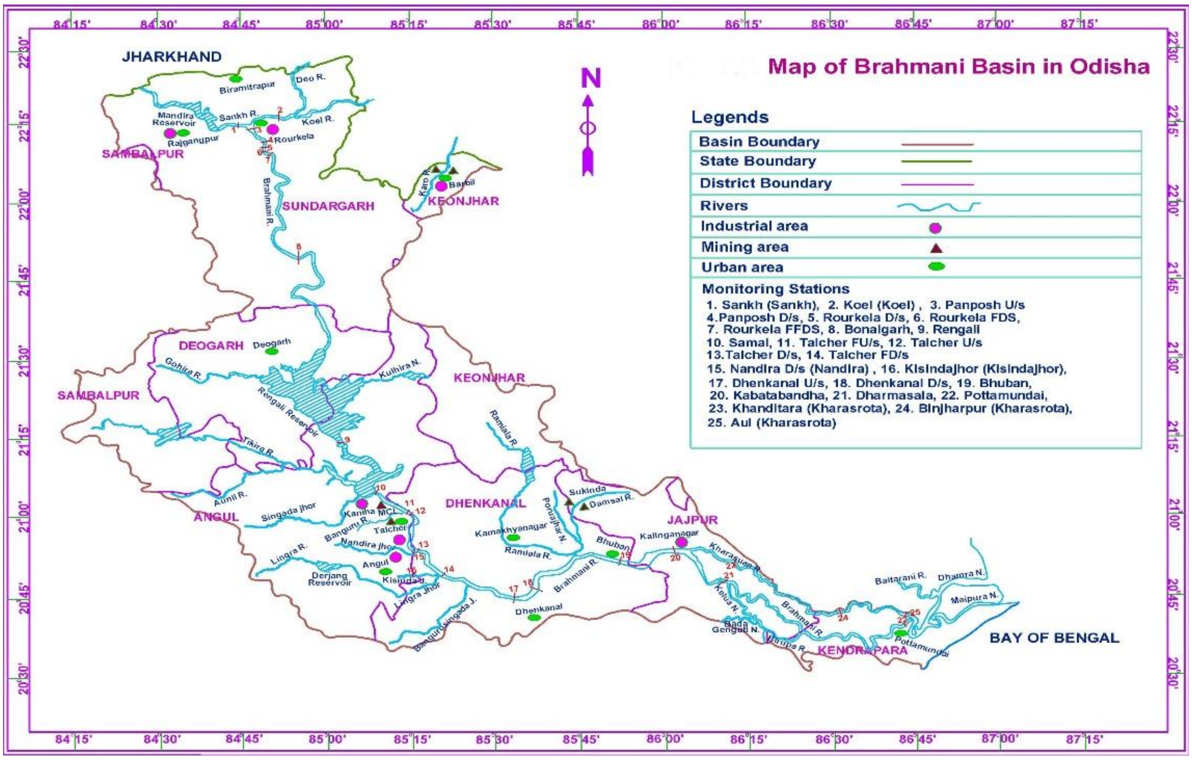

Fig. 1. Map of Brahmani river basin in Odisha

3. RESULTS AND DISCUSSION

The Table 1 depicts the summary statistics for average monthly values for Brahmani River. The pH levels, which range from 6.5 to 8.4, are within the acceptable range. The highest pH value was 8.4 in Dhenkanal (D/S), Pattamundai, and Angul, and the lowest was 6.5 in Rourkela (D/S). From 4.1 mg/l to 10 mg/l, the DO (mg/l) value is observed. The smallest DO value was 4.1mg/l in Rourkela (D/S), and the maximum DO value was 10 mg/l in Pattamundai. The BOD value lies between 0 and 6.5, with Rourkela (D/S) recording the highest (6.5 mg/l) and Pattamundai the lowest (0 mg/l). It is necessary to have a TC level of less than 5000 MPN/100 ml but the Brahmani River contains disturbingly high levels of coliforms, especially at Rourkela (D/S), where 92000 MPN/100 ml was observed with a minimum of 45 MPN/100 ml. The water quality parameters pH, DO, and BOD are all within acceptable limits, although TC deviates marginally.

The value of skewness is range from -0.44 to 1.69 and kurtosis is range from -0.53 to 3.15. For pH, skewness was -0.44, negatively skewed and kurtosis was -0.53 indicating platykurtic shape, respectively. For DO, skewness was 0.53, rightly skewed and kurtosis was -0.43, platykurtic shape. Skewness and kurtosis for BOD was -0.12 and -0.41, negatively skewed and platykurtic shape, respectively. For TC, skewness was 1.69, rightly skewed and kurtosis was 3.15 indicating leptokurtic shape respectively, indicating data were from a population with a non-normal distribution. Similar findings were found in previous relevant studies [16].

3.1 Trend Analysis Using Mann-Kendall Test

The dataset does not follow a normal distribution, indicating a non-parametric form of the test. For both the average monthly data of the Brahmani River from 2017 to 2019 and station-specific monthly data for the four essential monitoring stations, the non-parametric Mann-Kendall test is utilised for trend detection. Table 2 offers Mann-Kendall's test with the calculated test statistics and the corresponding p-value. P-values below 0.05 are regarded as significant; at these values, the null hypothesis would be shown to be false. The absence of a trend in the currently available data is the null hypothesis for this inquiry.

The p values for BOD and TC at station Angul were below the significant level, indicating that a trend existed in the data. The Kendall values for BOD and TC were -0.203 and -0.362, respectively, indicating a decreasing trend in the data. The p values for the remaining variables, pH and DO, were higher than the significant level, indicating that no trend existed. For the Dhenkanal station, pH and DO's p values are below the level of significance, and their Kendall values, which are -0.369 and 0.301, respectively, show that pH and DO are trending downward and upward, respectively. BOD and TC p values for the Pattamundai station were below the significant level, and their Kendall values were, respectively, -0.314 and -0.381, indicating that there is a trend in the data. However, pH and DO p values were above the significant level, indicating that there is no trend. The p values for pH and TC in the case of Rourkela were less than significant, indicating the existence of a trend. pH and TC both have Kendall values of -2.23 and -2.80, indicating a decreasing trend in the data.

Results of the Mann-Kendall test for the Brahmani River's average monthly data from 2017 to 2019 are shown in Table 3. The p values of both pH and TC were significant, *ie.*, 0.011 and 0.001 respectively, which amply demonstrated the existence of a trend. Since pH and TC have Kendall values of -0.295 and -0.474, respectively, there is a downward trend in the data. There is no trend for BOD and DO since the p values were determined to be non-significant, 0.753 and 0.474 respectively. Similar results were also obtained in [17,18] where Mann Kendall Trend Analysis accurately identifies the trends.

3.2 ARIMA

On the average water quality characteristics of the 2017–2019 data, the ARIMA time series model is fitted. The D-F test is used to assess the data using null hypothesis H_0, which indicates that there is a unit root in time-series data, and alternative hypothesis H_1, which indicates that there is no unit root, indicating that the time-series data is stationary. The calculated p-value for the D-F test for the time-series data for each water quality metric is larger than 0.05, which allows H_0 to be accepted and confirms that stationarity is attained by differencing. The p and q values were calculated using a plot of the ACF and PACF. Following that, estimates for RMSE, MAE, BIC, and R^2 were made for various combinations of the ARIMA. Based on the least value of RMSE, MAE, BIC, and R^2, the optimal model was chosen. Table 4 showed that all the chosen ARIMA models for the water quality parameters were highly significant since their fit statistic measures were significant, indicating that the models were well-fit. Therefore, the best fit for pH time series is ARIMA (1,1,1), followed by ARIMA (2,2,5) for DO time series, ARIMA (1,1,1) for BOD time series, and ARIMA (3,1,1) for TC time series. The Ljung-Box test is applied to the residuals of the fitted models. The results showed that all P-values exceeds 0.05 which indicates acceptance of models accuracy at 95% significant levels (Table 5). The goodness-of-fit test of the optimum ARIMA models showed non-significant autocorrelations in the residuals of the model.

Table 5 lists the various ARIMA model variables for the Brahmani River's water quality factors. The time series analysis shown here includes the Ljung-Box, RMSE, MAPE, MAE, and BIC for the best-fit ARIMA models. The observed and anticipated values, along with upper and lower limits, were graphically shown for diagnostic verification of all the chosen models (Fig. 2-5). This shows that pH forecasted values follow a decreasing tendency. Forecasted values for DO indicate an upward trend. Forecasted values for BOD show an ongoing trend, while those for TC show a downward trend. With the aid of the ARIMA model, the water quality values for the year 2020 were predicted with a 95% confidence interval shown in the Table 6, and it was discovered that the pH value will be between 7.5 and 7.2. The DO mg/l ranges from 7.8 to 12.3 mg/l. BOD mg/l fluctuates continuously between 1.3 and 1.2 mg/l. The rate at which oxygen is reduced decreases with decreasing BOD. The TC (MPN/100ml) values shows decreasing trend, which will be good for the water in the Brahmani River [19].

Table 1. Descriptive statistics

Parameters	pH	DO mg/l	BOD mg/l	TC MPN/100ml
Minimum	7.11	6.61	0.73	955.00
Maximum	8.15	8.48	2.08	27233.33
Mean	7.67	7.34	1.44	7113.28
SD	0.27	0.50	0.34	5846.57
Kurtosis	-0.53	-0.43	-0.41	3.15
Skewness	-0.44	0.53	-0.12	1.69
CV	3.55	6.81	23.76	82.19

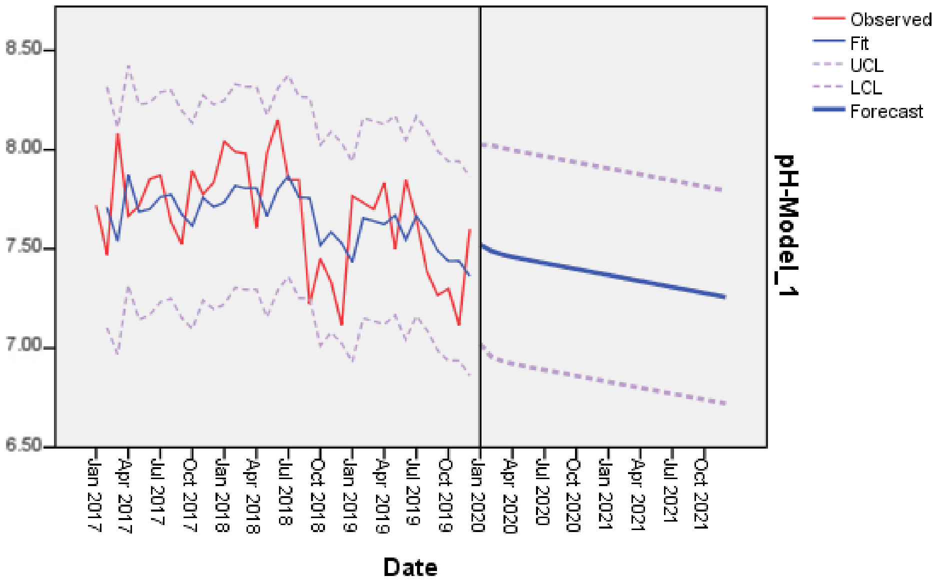

Fig. 2. Observed data and ARIMA [1,1,1] model prediction of pH

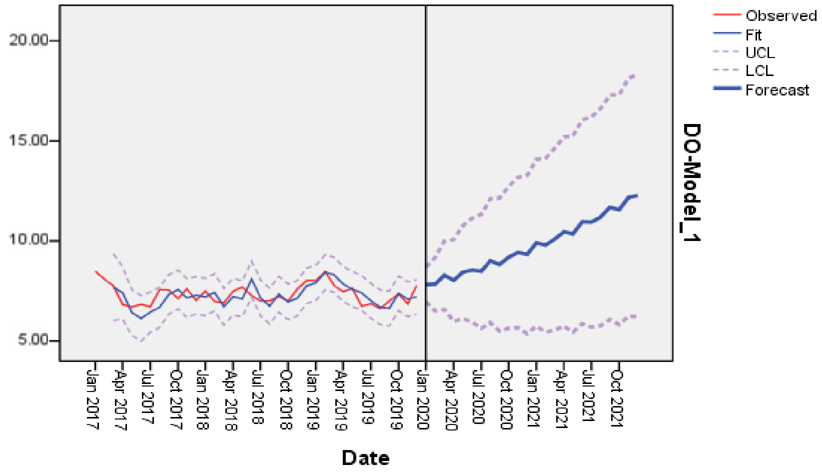

Fig. 3. Observed data and ARIMA (2,2,5) model prediction of DO mg/l

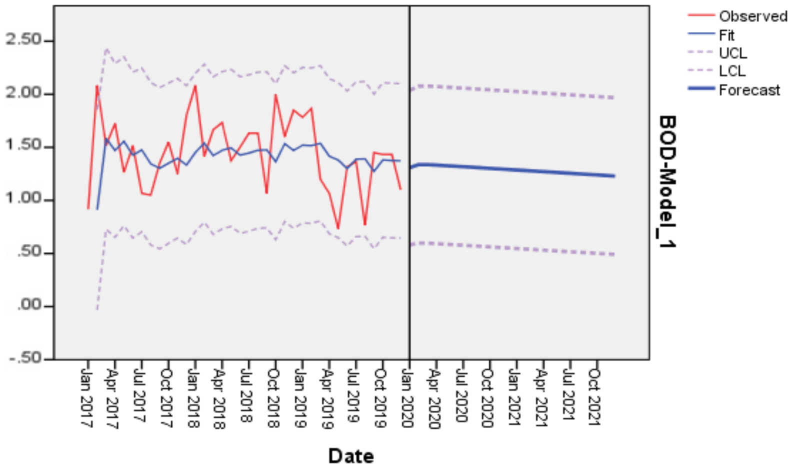

Fig. 4. Observed data and ARIMA (1,1,1) model prediction of BOD mg/l

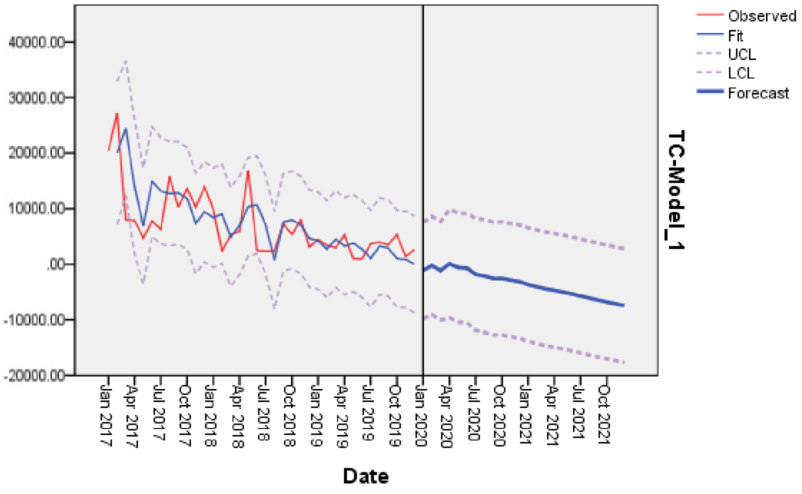

Fig. 5. Observed data and ARIMA (3,1,1) model prediction of TC MPN/100ml

Table 2. Results of the Mann-Kendall test for station wise monthly data from 2017 to 2019

Station	Water Quality Parameters	S	Z	Kendall-tau	p-value	Results
Angul	pH	4.30	0.57	7.011	0.565	No Trend
	DO mg/l	-57.01	-0.76	-0.093	0.443	No Trend
	BOD mg/l	-124.01	-1.68	-0.203	0.002	↓ Trend exists
	TC MPN/100ml	-216.25	-2.97	-0.362	0.002	↓ Trend exists
Dhenkanal	pH	-228.00	-3.10	-0.369	0.001	↓ Trend exists
	DO mg/l	185.24	2.51	0.301	0.011	↑ Trend exists
	BOD mg/l	2.50	0.33	4.182	0.470	No Trend
	TC MPN/100ml	-177.12	-1.58	-0.188	0.113	No Trend
Pattamundai	pH	6.57	0.06	9.678	0.945	No Trend
	DO mg/l	-63.65	-0.84	-0.101	0.397	No Trend
	BOD mg/l	-193.15	-2.62	-0.314	0.008	↓ Trend exists
	TC MPN/100ml	-233.00	-3.17	-0.381	0.001	↓ Trend exists
Rourkela	pH	-165.00	-2.23	-0.266	0.025	↓ Trend exists
	DO mg/l	-133.00	-1.52	-0.181	0.126	No Trend
	BOD mg/l	2.74	0.35	4.330	0.722	No Trend
	TC MPN/100ml	-206.25	-2.80	-0.337	0.004	↓ Trend exists

Table 3. Results of the Mann-Kendall test for the average monthly data

Water Quality Parameters	S	Z	Kendall-tau	p-value	Result
pH	-186	-2.52	-0.2957	0.0117	↓ Trend exists
DO mg/l	-24	-0.31	-0.0383	0.7538	No Trend
BOD mg/l	-57	-0.76	-0.0909	0.4453	No Trend
TC MPN/100ml	-299	-4.05	-0.4749	<0.001	↓ Trend exists

Table 4. Goodness of fit statistics of different ARIMA models for water quality parameters

Parameters	Model	R^2	RMSE	MAPE	MAE	BIC
pH	(1,1,0)	0.092	0.267	2.714	0.208	-2.435
	(1,1,1)	0.201	0.255	2.686	0.205	-2.430
	(1,1,2)	0.201	0.259	2.716	0.208	-2.298
DO mg/l	(2,2,4)	0.186	0.454	4.565	0.331	-0.855
	(2,2,5)	0.190	0.461	4.555	0.330	-0.719
	(2,2,6)	0.169	0.476	4.601	0.333	-0.555
BOD mg/l	(1,1,0)	-0.401	0.405	23.577	0.314	-1.605
	(1,1,1)	-0.233	0.386	20.989	0.283	-1.600
	(1,1,2)	-0.262	0.396	21.651	0.285	-1.444
TC MPN/100ml	(3,1,0)	0.188	5156.055	75.401	3405.190	17.502
	(3,1,1)	0.256	5016.875	75.623	3343.543	17.549
	(3,1,2)	0.255	5106.125	74.859	3368.776	17.686

Table 5. Best fit ARIMA models of water quality parameters at a 95% confidence interval

Statistics	pH	DO mg/l	BOD mg/l	TC MPN/100ml
ARIMA model	(1,1,1)	(2,2,5)	(1,1,1)	(3,1,1)
Ljung-Box Q	13.235	6.865	13.210	13.012
P-value	0.655	0.810	0.657	0.526
RMSE	0.255	0.461	0.386	5016.875
MAPE	2.686	4.555	20.989	75.623
MAE	0.205	0.330	0.283	3343.543
BIC	-2.430	-0.719	-1.600	17.549

Table 6. Monthly forecasted water quality parameters values

Month	pH	DO mg/l	BOD mg/l	TC MPN/ 100ml
Jan-20	7.52	7.82	1.30	-1118.09
Feb-20	7.48	7.83	1.33	-217.28
Mar-20	7.47	8.28	1.33	-1173.69
Apr-20	7.45	8.02	1.33	105.12
May-20	7.44	8.44	1.32	-601.85
June-20	7.43	8.54	1.32	-690.84
July-20	7.42	8.48	1.31	-1817.69
Aug-20	7.41	9.01	1.31	-2111.70
Sep-20	7.4	8.81	1.30	-2584.16
Oct-20	7.39	9.18	1.30	-2556.98
Nov-20	7.38	9.42	1.29	-2867.78
Dec-20	7.37	9.32	1.29	-3142.25

4. CONCLUSION

The study described in the paper gives a statistical analysis of changes in the factors relating to water quality, and it also develops a model to forecast the concentrations of various indicators in the following years. The M-K test is used to analyse historical data on water quality. The results of the M-K test reveal that some water quality parameter data from various stations have a trend. The ARIMA model was used to make predictions and by evaluating the goodness of fit statistics, the ARIMA (1,1,1), ARIMA (2,2,5), ARIMA (1,1,1), and ARIMA (3,1,1) models proved to be the most effective at forecasting future water quality parameters. The water quality parameters pH, DO, and BOD are all within acceptable limits, although TC deviates marginally.

ACKNOWLEDGEMENT

The author wishes to thank Odisha state pollution control board for providing data used in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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