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STATISTICAL ANALYSIS TO IDENTIFY MAIN PARAMETERS AFFECTING WWQI – A STUDY ON STP HANUMANGARH, RAJASTHAN

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ABSTRACT

The present study aims to identify the influential quality parameters affecting WWQI, a parameter used to evaluate overall quality of secondary treated water of STP, Hanumangarh. Waste Water Quality Index (WWQI) was calculated using several measured physicochemical parameters of secondary treated water. The study was carried out for one year period and the parameters were measured fortnightly following standard methods. Each measured parameter was compared with its standard permissible limit as prescribed by BIS-2296. The calculated values of WWQI reflected that secondary treated wastewater was of good quality. The correlation matrix used has approved the influence of pH, COD, BOD, Na^+ and Mg^{2+} on WWQI with correlation coefficient (r)>0.5. These five parameters were examined using multiple linear regression analysis. R, R^2 and adjusted R^2 values of applied regression model reveal its utility and relevance and p-value indicate significance of the regression model. Considering significant parameters, regression equations were developed using MS-Excel software to predict WWQI and used to check degree of match. The results revealed that out of five parameters only three parameters pH, BOD and Na^+ are statistically significant with p-value < 0.05, so are sufficient to predict treated water quality. The analysis provides an easy and rapid way to estimate as well as to monitor the water quality providing one step ahead towards treated water quality management.

Keywords: Secondary Treated Waste Water, Waste Water Quality Index, Correlation coefficient, linear regression equation

INTRODUCTION

India is sufficient rich in surface and ground water resources except some parts of the country and is also blessed with ice-covered Himalayan peaks. Population growth, irrigation water demands to meet food requirements, industrialization etc. have resulted in water demand hike and pollution of water resources (Mohmmed, 2006). The projected water demand by the year 2030, is to be twice the available supply as per the report released by union minister for water resources. It will lead to severe water scarcity for hundreds of millions of people and an eventual 6% loss in country's GDP (www.dailypioneer.com, 10 July, 2018). All governments have started to mitigate these effects by rain water harvesting, desalination, water location transfers and waste water treatment. Out of these, waste water treatment is a green and sustainable short term and long term solution to water crisis. It will resolve the issue of overused as well as polluted water resources. In Rajasthan sewage generation in urban areas is 3185MLD whereas treatment capacity available (including proposed) is only 1195MLD (sulabhenvis.nic.in). Rest wastewater is contributing to environment pollution directly or indirectly. To control contamination of receiving water bodies and to make wastewater fit for reclamation; it should be adequately treated (Wastewater, The Untapped Resource, 2017). Rajasthan state sewerage and wastewater policy-2016 has been framed to use every drop of water in an efficient safe manner. The main objective of wastewater treatment is to produce an effluent suitable for reuse in irrigation in accordance with WHO guidelines as a minimum requirement. Reuse of treated wastewater for other purposes shall be subject to appropriate specifications. Most of the secondary treated waste water in this agriculture belt of Rajasthan finds use in irrigation. So, quality assessment of treated wastewater for applicability in irrigation and seasonal variation of final effluent is of utmost importance as it will affect the quality and quantity of crops being irrigated with treated waste water (TWW). As part of our research program, the present study on public concern issue of wastewater management with reference to STP Hanumangarh will help to meet potential benefits of water reuse.

Water Quality Index (WQI) represents certain level of water quality (poor, good, excellent etc.) in terms of a single numerical value that reflects composite influence of various water quality parameters (Bordelo, 2006). Waste Water Quality Index (WWQI) used for secondary treated water quality enables easy and rapid assessment of water reuse for agriculture or recreational purposes as well as comparison of various wastewater treatment processes (Verlicchi *et al*., 2011; Jamshidzadeh *et al*., 2020). WWQI is computed from following expressions (Ramakrishna *et al*. 2009).

$$WWQI = \sum q_i W_i / \sum W_i \quad (1)$$

Where, q_i represents the quality rating for each of the water quality parameters used in the index and is given by

$$q_i = 100 (V_i - V_{10}) / (S_i - V_{10}) \quad (2)$$

V_i is measured value of the i^{th} parameter in water sample, V_{10} is the ideal value of this parameter in pure water and S_i refers to acceptable limit as given in Indian standard (IS- 2296).

W_i is unit weight for the i^{th} parameter

$$W_i = k/S_i \quad (3)$$

k is constant of proportionality and is assumed unity for the sake of simplicity.

Different quality parameters are correlated with each other and combined effect of their interrelationship determines the water quality. Correlation analysis establishes the nature of the relationship between the variables thereby providing a mechanism for prediction or forecasting. Correlation coefficient nearer to +1 or –1 shows the probability of linear relationship between the variables x and y (Mulla *et al*., 2007; Draper, 1966). Regression equations are developed for the parameters having significant correlation coefficient and can be used successfully to estimate the concentration of other constituents. A systematic correlation and regression analysis of water quality parameters helps to quantify relative concentration of various pollutants and assess the overall water quality, necessary for implementation of rapid water quality management programs (Kumar and Sinha, 2010). Rastogi (2011) interpreted the Statistical Regression Analysis as highly useful tool for correlating different parameters with two fold advantages. First, correlation analysis finds out inter-relationship between different parameters. Second, it is easy to figure out the main parameters affecting the WWQI. Significantly correlated parameters in the regression equation are sufficient to draw required information thereby reducing laboratory work of measuring all the parameters. Regression analysis involves two types of variables-dependent variable and regressor or independent variables. The variable whose value is influenced is called dependent variable and the variables influencing the dependent variable are called explanatory (regressors) variables. The model equation used is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + e \quad (4)$$

This model should be free from (as assumptions of applying this criteria), Multi-colinearity (regressors are correlated), Heteroscedasticity (error variance is non-constant), and Auto correlation (error terms are correlated). Multiple Linear Regression has been successfully applied by Chenini et.al. (2009) for evaluation of ground water quality. Regression Equation was applied by Rene et.al. (2008) for prediction of water quality indices. In this study, WWQI is taken as dependent variable and measured parameters are considered as explanatory variables.

MATERIALS AND METHODS

Composite method of sampling was adopted for the research work. Sampling was done in the morning and evening time. Good quality narrow mouth screw-capped water bottles of two liter capacity made of polypropylene were used to collect the samples. Before sample collection bottles were rinsed thrice with water to be sampled and then filled completely to avoid any air bubble. The samples were collected fortnightly for one year period (February, 2020 to January, 2021) to record the data of all the seasons.

The collected samples were analyzed for various physicochemical parameters- temperature, pH, electrical conductivity (EC), chemical oxygen demand (COD), biological oxygen demand (BOD), total alkalinity (TA), total hardness (TH), total dissolved solids (TDS), chloride (Cl^-), sulphate (SO_4^{-2}), nitrate (NO_3^-), sodium (Na^+), potassium(K^+), magnesium (Mg^{2+}), fluoride(F^-) and calcium(Ca^{+2}) as per standard methods. Temperature and pH were measured at the sampling site. DO fixation was performed at the location itself by adding Manganese sulphate and Alkaline KI solution. The samples were stored at 4°C for determining other parameters. For sampling and testing the procedure described in standard methods IS 3025, APHA were adopted. All the reagents used were AR grade and double distilled water was used for solution preparation.

STUDY AREA

The selected site for the study is GB STP, Hanumangarh with capacity of 5.0 MLD started in 2018. The STP is located on 18 HMH Road, Near Shiv Bishnoi Dhani, Railway Ghaggar Bridge, Hanumangarh Town. Working on SBR (sequential batch reactor) technique, the catchment area of this STP is about 75% of town residential area.

RESULTS AND DISCUSSIONS

Waste Water Quality Index (WWQI): WWQI is calculated using measured values of physicochemical parameters (Table-1) and is presented in Table-2. The values are indicative of overall good quality water for restricted irrigation and non-potable uses.

Correlation Analysis: Karl Pearson Correlation coefficient (r) have been calculated between each pair of water quality parameters for the experimental data. The degree of line association between any two of the water quality parameters as measured by the simple correlation coefficient (r) is presented as 17 x 17 correlation matrix in Table-3. Positive correlation is obtained between 126 combinations (82.4% of the total number) and the rest 27 combinations (17.6 % of the total number) exhibit negative correlation. The parameters exhibiting correlation coefficients (r)>0.5 with WWQI were chosen for regression analysis. It was found that WWQI is significantly correlated with pH, COD, BOD, Na^+ and Mg^{2+} (r-value > 0.5). It shows that out of sixteen parameters taken only five parameters are significantly correlated with WWQI.

Multiple Linear Regression Analysis: To identify the main parameters affecting the treated water quality, Multiple Linear Regression (MLR) analysis was carried out using MS-Excel software. Correlation matrix shows parameters pH, COD, BOD, Na^+ and Mg^{2+} exhibit correlation coefficients (r) > 0.5 with WWQI. Taking WWQI as dependent variable and selected these five parameters as regressors, multiple linear regression (MLR) was executed. From Table-4, unstandardized coefficients for the equation intercept, pH, COD, BOD, Na^+ and Mg^{2+} as -58.1368, 11.6358, 0.0015, 0.7650, 0.1011 and 0.0518 respectively. These coefficients were replaced with the coefficients of equation-4 and Y predicted is presented in equation-5. Table 5 shows that the model fit with 98.5% of accuracy.

$$Y = -58.1368+11.6358\ X_1+0.0015\ X_2+0.7650\ X_3+0.1011\ X_4 + 0.0518\ X_5 \quad \text{....(5)}$$

Where, $Y= WWQI, X_1= pH, X_2 = COD, X_3 = BOD, X_4= Na^+, X_5= Mg^{2+}$

This model is fitted significantly as F=197.53 (Sig F: 0.0000) (Table 6). Findings of regression analysis depicts p-value for pH, BOD and Na^+ less than 0.05.Taking these three parameters, the regression analysis was again executed in order to develop a new equation. So, COD and Mg^{2+} are dropped, recalculated the WWQI, again fitted the regression model and got the regression equation as follows (Eq-6) with 98.74% of accuracy. (Table-8)

$$Y_{(E)} = -59.503 + 12.0469\ X_1 + 0.7722\ X_2 + 0.1023\ X_3 \quad \text{......................................(6)}$$

Where, $Y_{(E)}=WWQI$ *after dropping COD,* Mg^{2+}; $X_1= pH, X_2 = BOD, X_3= Na^+$

Each parameter has significant effect on WWQI, p-value of all the parameters less than 0.05 (Table 7). This model is fitted significantly as F=371.6 (Sig F: 0.0000) (Table 9). The graphical comparison for WWQI determined and predicted by two regression equations is shown in Figure-1. The scatter plot indicates the determined values almost match the estimated values which clearly approve the selected model.

Table - 1 Physico-chemical parameters of GB STP, Hanumangarh

Sample	Month	Temp.	pH	EC	COD	BOD	TH	TA	TDS	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	NO_3^{-}	SO_4^{-2}	Cl^{-}	F^{-}
HS1	February (1)	17.2	7.1	1060	97	40	294	262	634	82	9.3	56.0	37.4	5.0	36	62	0.33
HS2	February (2)	18.5	7.1	980	132	44	280	238	612	78	9.0	54.0	35.2	4.8	40	66	0.36
HS3	March (1)	20.6	7.3	1120	148	52	275	243	654	96	9.4	52.8	34.3	5.4	48	72	0.32
HS4	March (2)	21.9	7.5	1210	125	58	310	282	728	104	9.7	60.0	38.8	5.8	40	86	0.39
HS5	May (2)	25.3	7.8	1535	112	50	334	302	782	118	10.5	64.8	41.7	6.4	52	102	0.42
HS6	June (1)	27.5	7.4	1380	104	47	320	290	744	102	11.0	63.2	39.3	7.0	56	95	0.35
HS7	June (2)	28.2	7.2	1240	88	32	316	287	730	97	10.7	66.4	36.5	6.2	61	80	0.4
HS8	July (1)	27.6	7.1	950	76	30	296	268	708	84	10.2	64.0	33.0	5.3	68	72	0.33
HS9	July (2)	26.5	7.0	900	68	26	287	260	678	78	10.0	62.8	31.5	5.0	55	69	0.37
HS10	August (1)	25.1	7.1	842	82	36	284	256	570	73	9.2	60.8	32.0	4.5	53	62	0.31
HS11	August (2)	25.0	7.1	815	98	41	298	270	511	79	9.8	63.2	34.0	4.8	46	66	0.35
HS12	September (1)	24.0	7.2	720	102	45	304	275	480	82	10.0	60.0	37.4	5.4	32	60	0.28
HS13	September (2)	23.4	7.3	760	114	52	310	280	496	87	10.4	57.6	40.3	6.0	30	57	0.33
HS14	October (1)	22.0	7.5	840	117	52	316	286	540	92	10.8	58.4	41.3	6.4	34	52	0.27
HS15	October (2)	22.1	7.4	890	126	57	300	272	562	82	9.3	56.0	38.8	6.6	37	58	0.32
HS16	November (1)	20.0	7.4	950	132	60	292	278	584	87	9.8	54.8	37.6	6.0	40	63	0.28
HS17	November (2)	18.4	7.3	1020	137	61	285	282	617	96	10.6	52.8	37.1	5.8	42	67	0.34
HS18	December (1)	16.7	7.2	1080	140	57	278	263	627	102	8.8	51.2	36.4	5.4	45	72	0.3
HS19	December (2)	16.2	7.2	1124	150	62	297	270	680	107	9.4	54.8	38.8	5.0	48	78	0.35
HS20	January (1)	14.4	7.1	1200	124	55	280	264	704	98	9.2	52.0	36.4	5.5	43	82	0.32
HS21	January (2)	15.3	7.2	1140	116	50	288	276	672	90	9.7	53.2	37.6	5.3	40	70	0.34

***All parameters are expressed in mg/L except Temp., pH and EC. Temp. is expressed in °C. EC is expressed in µmhos/cm.**

Table - 2 Waste Water Quality Index (WWQI) of GB STP, Hanumangarh

Parameter	IS-2296 (S_i)	Unit Wt (W_i)	HS1 (qiWi)	HS2 (qiWi)	HS3 (qiWi)	HS4 (qiWi)	HS5 (qiWi)	HS6 (qiWi)	HS7 (qiWi)	HS8 (qiWi)	HS9 (qiWi)	HS10 (qiWi)	HS11 (qiWi)	HS12 (qiWi)	HS13 (qiWi)	HS14 (qiWi)	HS15 (qiWi)	HS16 (qiWi)	HS17 (qiWi)	HS18 (qiWi)	HS19 (qiWi)	HS20 (qiWi)	HS21 (qiWi)
Temp.	25	0.0400	2.75	2.960	3.296	3.504	4.048	4.400	4.512	4.416	4.240	4.016	4.000	3.840	3.744	3.520	3.536	3.200	2.944	2.672	2.592	2.304	2.448
pH	8.5	0.1176	0.78	0.784	2.353	3.922	6.275	3.137	1.569	0.784	0.000	0.784	0.784	1.569	2.353	3.922	3.137	3.137	2.353	1.569	1.569	0.784	1.569
EC	2250	0.0004	0.02	0.019	0.022	0.024	0.030	0.027	0.024	0.019	0.018	0.017	0.016	0.014	0.015	0.017	0.018	0.019	0.020	0.021	0.022	0.024	0.023
COD	100	0.0100	0.97	1.320	1.480	1.250	1.120	1.040	0.880	0.760	0.680	0.820	0.980	1.020	1.140	1.170	1.260	1.320	1.370	1.400	1.500	1.240	1.160
BOD	10	0.1000	40.00	44.000	52.000	58.000	50.000	47.000	32.000	30.000	26.000	36.000	41.000	45.000	52.000	52.000	57.000	60.000	61.000	57.000	62.000	55.000	50.000
TH	300	0.0033	0.33	0.311	0.306	0.344	0.371	0.356	0.351	0.329	0.319	0.316	0.331	0.338	0.344	0.351	0.333	0.324	0.317	0.309	0.330	0.311	0.320
TA	200	0.0050	0.66	0.595	0.608	0.705	0.755	0.725	0.718	0.670	0.650	0.640	0.675	0.688	0.700	0.715	0.680	0.695	0.705	0.658	0.675	0.660	0.690
TDS	500	0.0020	0.25	0.245	0.262	0.291	0.313	0.298	0.292	0.283	0.271	0.228	0.204	0.192	0.198	0.216	0.225	0.234	0.247	0.251	0.272	0.282	0.269
Na^+	200	0.0050	0.21	0.010	0.240	0.013	0.015	0.255	0.012	0.210	0.010	0.183	0.010	0.205	0.011	0.230	0.010	0.218	0.012	0.255	0.013	0.245	0.011
K^+	15	0.0667	4.13	4.000	4.178	4.311	4.667	4.889	4.756	4.533	4.444	4.089	4.356	4.444	4.622	4.800	4.133	4.356	4.711	3.911	4.178	4.089	4.311
Ca^{2+}	75	0.0133	1.00	0.960	0.939	1.067	1.152	1.124	1.180	1.138	1.116	1.081	1.124	1.067	1.024	1.038	0.996	0.974	0.939	0.910	0.974	0.924	0.946
Mg^{2+}	30	0.0333	4.16	3.911	3.811	4.311	4.633	4.367	4.050	3.667	3.500	3.556	3.778	4.156	4.478	4.590	4.311	4.178	4.122	4.044	4.311	4.044	4.178
NO_3^-	50	0.0200	0.20	0.192	0.216	0.232	0.256	0.280	0.248	0.212	0.200	0.180	0.192	0.216	0.240	0.256	0.264	0.240	0.232	0.216	0.200	0.220	0.212
SO_4^{-2}	400	0.0025	0.02	0.025	0.030	0.025	0.033	0.035	0.038	0.043	0.034	0.033	0.029	0.020	0.019	0.021	0.023	0.025	0.026	0.028	0.030	0.027	0.025
Cl^-	250	0.0040	0.10	0.106	0.115	0.138	0.163	0.152	0.128	0.115	0.110	0.099	0.106	0.096	0.091	0.083	0.093	0.101	0.107	0.115	0.125	0.131	0.112
F^-	1.5	0.6667	14.67	16.000	14.222	17.333	18.667	15.556	17.778	14.667	16.444	13.778	15.556	12.444	14.667	12.000	14.222	12.444	15.111	13.333	15.556	14.222	15.111
$\sum W_i$		1.0899																					
$\sum q_iW_i$			70.24	75.44	84.08	95.47	92.50	83.64	68.54	61.85	58.04	65.82	73.14	75.31	85.65	84.93	90.24	91.46	94.22	86.69	94.35	84.51	81.38
WWQI = $\sum q_iW_i / \sum W_i$			**64.45**	**69.21**	**77.14**	**87.59**	**84.87**	**76.74**	**62.88**	**56.74**	**53.25**	**60.39**	**67.11**	**69.09**	**78.58**	**77.92**	**82.80**	**83.92**	**86.44**	**79.54**	**86.56**	**77.54**	**74.67**

Table 3 - Correlation Matrix of Water Quality Parameters

	Temp.	pH	EC	COD	BOD	TH	TA	TDS	Na^+	K^+	Ca^{+2}	Mg^{+2}	NO_3^-	SO_4^{-2}	Cl^-	F^-	WWQI
Temp.	1.000																
pH	0.136	1.000															
EC	-0.062	0.461	1.000														
COD	-0.700	0.341	0.194	1.000													
BOD	-0.633	0.508	0.170	0.902	1.000												
TH	0.559	0.682	0.329	-0.246	-0.037	1.000											
TA	0.324	0.684	0.361	-0.104	0.208	0.840	1.000										
TDS	0.055	0.218	0.894	-0.044	-0.094	0.198	0.215	1.000									
Na^+	-0.154	0.649	0.807	0.472	0.516	0.426	0.542	0.638	1.000								
K^+	0.599	0.432	0.163	-0.325	-0.158	0.724	0.755	0.143	0.259	1.000							
Ca^{+2}	0.914	0.141	0.108	-0.766	-0.666	0.684	0.448	0.220	-0.028	0.593	1.000						
Mg^{+2}	-0.173	0.777	0.330	0.436	0.625	0.669	0.694	0.038	0.601	0.384	-0.084	1.000					
NO_3^-	0.276	0.745	0.382	0.153	0.338	0.672	0.728	0.212	0.498	0.634	0.197	0.713	1.000				
SO_4^{-2}	0.529	-0.167	0.405	-0.461	-0.560	0.062	0.016	0.642	0.149	0.210	0.555	-0.487	-0.054	1.000			
Cl^-	0.153	0.386	0.913	0.037	0.048	0.383	0.376	0.864	0.761	0.212	0.316	0.192	0.298	0.532	1.000		
F^-	0.292	0.192	0.632	-0.186	-0.243	0.386	0.254	0.674	0.407	0.219	0.476	0.038	0.078	0.448	0.701	1.000	
WWQI	-0.465	0.694	0.340	0.840	0.959	0.194	0.392	0.060	0.664	0.019	-0.469	0.737	0.493	-0.457	0.234	-0.020	1.000

Table 4 - Coefficients for regression analysis (a)

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-58.1368	17.1707	-3.3858	0.0041
pH	11.6358	2.9998	3.8789	0.0015
COD	0.0015	0.0366	0.0403	0.9684
BOD	0.7650	0.0904	8.4654	0.0000
Na^+	0.1011	0.0402	2.5112	0.0240
Mg^{+2}	0.0518	0.2112	0.2451	0.8097

Table 5 - Regression Statistics (a)

Multiple R	R Square	Adjusted R Square	Standard Error
0.9925	0.9850	0.9801	1.4579

Table 6 - ANOVA (a)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	2099.238	419.848	197.535	0.000
Residual	15	31.881	2.125		
Total	20	2131.119			

Table 7 - Coefficients for regression analysis (b)

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-59.5028	14.1520	-4.2046	0.0006
pH	12.0469	2.2213	5.4233	0.0000
BOD	0.7722	0.0352	21.9181	0.0000
Na+	0.1023	0.0365	2.8070	0.0121

Table 8 - Regression Statistics (b)

Multiple R	R Square	Adjusted R Square	Standard Error
0.9925	0.9850	0.9823	1.3722

Table 9 - ANOVA (b)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2099.1090	699.7030	371.5959	0.0000
Residual	17	32.0105	1.8830		
Total	20	2131.1195			

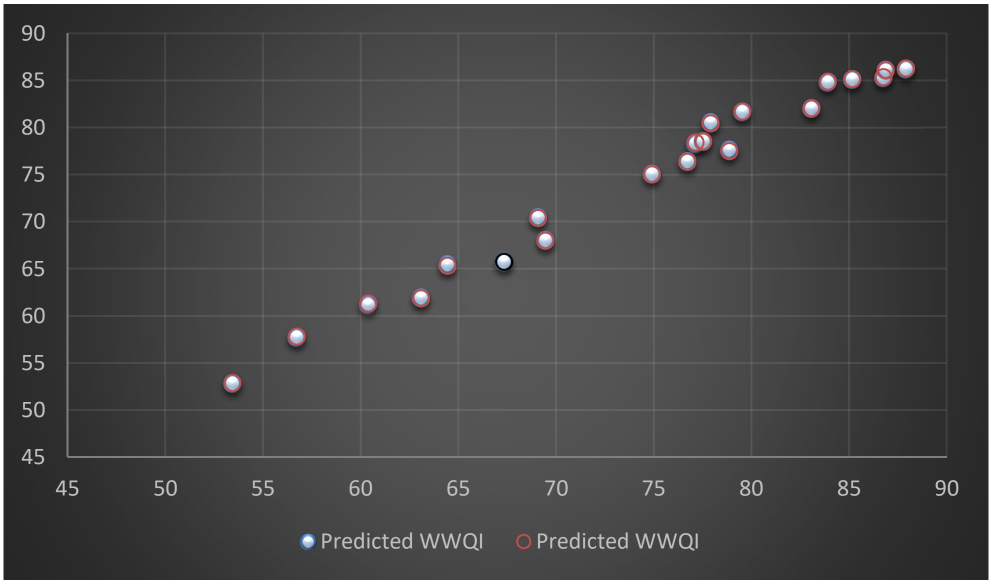

Figure 1: Comparison of WWQI predicted and determined

CONCLUSION

To determine the overall quality of secondary treated wastewater of GB STP Hanumangarh, WWQI was calculated using measured parameters. With the help of MS-Excel software interrelationship between different parameters was found using Karl Pearson correlation. From this analysis, it was found that WWQI is significantly correlated with pH, COD, BOD, Na^{+} and Mg^{2+} which means out of sixteen measured parameters, only five parameters are correlated with WWQI. Using these five parameters, two regression equations were developed with an accuracy of 98.83% and 98.74%. From regression analysis it is concluded that instead of analyzing all sixteen parameters, only three parameters pH, BOD, Na^{+} can provide results with sufficient accuracy of the order of 98%. This will definitely save much time, money and chemicals to carry tedious procedures of testing and determining each and every parameter.

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