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CASE STUDY

Application of Decision Making Tool to Determine Effluent Quality Index of Existing Sewage Treatment Plants

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Abstract Water is one of the most essential resources for living and is utilized for different purposes including domestic, industrial, and agricultural and other such applications. The water supplied from city municipalities is primarily used for domestic purposes with about 80% of the supplied water being considered as being generated into wastewater. The scarcity of water in different parts of the world and particularly in developing countries has led to potential reusability of the generated wastewater. However, the reusability of the generated wastewater is significantly dependent on the efficiency of the treatment plants for the treated effluent to be deemed fit for different applications. The efficiency of the existing sewage treatment plant can be determined using the parameter effluent quality index (EQI). It is an important tool which tells the quality of effluent generated by the treatment plants and hence it's potential for reuse for different purposes. It is determined by assigning suitable weightage to different parameters of wastewater for determining the final effluent quality. As such, this paper uses EQI approach to evaluate existing sewage treatment plants in Himachal Pradesh.

Keywords Domestic effluent quality index · Effluent treatment plant · Wastewater reuse · Parameters · TOPSIS

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Introduction

Water as a natural resource is consumed for different purposes including its use as in domestic, industrial and agricultural fields. Increase in urbanization has led to rapid deterioration of existing water supply resources and along with this increased contribution of generation of wastewater. Hence, there is an immediate need of urban water management and planning to meet the needs of the increasing population and also to explore the possibility of reusing the wastewater generated for different purposes by treating it so as to save the water supply from freshwater sources [1, 2]. Wastewater is defined as the fouled water received when the freshwater is supplied to a society and it completes serving the purpose. In particular, the domestic wastewater generated has large amounts organic material which may prove detrimental if allowed to go unchecked and discharged into surface stream proving hazardous to human health and environment [3, 4]. Further, various water borne diseases can arise from improper treatment of the generated domestic wastewater and hence one of the possible proposed solution is proper treatment of wastewater and making it fit for reuse [5].

The reuse of effluent from wastewater treatment plants for different fields is an interesting but difficult practice. However, proper implementation can lead to the better management of water resources and can save non-renewable sources of water leading to sustainable development and can solve the problem of water scarcity [6].

In the above context, several studies have been conducted to determine the different methods for reclamation of wastewater. As such, one of the most preferred ways for ascertaining the efficiency of treatment systems is the multi-criteria concept of decision making which helps in determining different and best possible alternatives of performing the same task in different approaches [7, 8].

There exists substantial scientific literature for water supply systems [20, 23, 24, 27, 28], but there is definitive lack of information regarding the management of existing wastewater treatment systems in developing countries like India. The lack of appropriate sanitation system severely affects the human health and the surrounding environment [24]. Developing countries like India face crucial challenges in wastewater management. Although, being the water-rich country, it is facing crisis due to the increased urbanization [27]. The major cause behind this problem is mainly due to the discharge of sewage from cities and towns which lead to degradation of the available water resources. Hence, it is imperative to increase the performance efficiency of the existing sewage treatment plants including up-gradation of treatment systems to improve the quality of effluents as per the standards given by the effluent quality standards [23].

Multiple criteria decision making approach is used in many fields of management, engineering and has proved to be a beneficial tool for decision making. One of the fields where it has been extensively used is in environmental research where it has proved highly beneficial in taking decisions without possible harmful effects to the environment. The basic principle involves assigning suitable weightage by methodological experts of that field. The survey is performed and the decisions are combined to reach one decision which is to be applied to the task without harming the environment [9]. This technique has also been applied successfully for determining the functioning of the treatment plants generated. Multiple criteria technique is used to select the best technology for treating the wastewater. Environmental indicators and economic indicators are evaluated using fuzzy logic formulation. The indicators are provided with appropriate weightage on the basis of importance of application in area of treatment. This is particularly important as the final wastewater treatment technology must be affordable, sustainable and acceptable by environment and society [10].

Various studies have been performed regarding the use of multi-criteria decision making approach on determining the efficiency of wastewater treatment plants and to control water pollution using multiple criteria decision making (MCDM) techniques. Successful applications of this technique have been carried out in Iran wherein such water source systems were identified and effects due to each source of pollution on water sources were reviewed and analyzed. Simple additive weighting (SAW) and analytical hierarchy structure (AHS) were two of the MCDM tools used wherein expert opinions and engineering judgments were performed to analyze the deficiency in data. Based on the discussions, various projects for reducing pollution were categorized. [11, 12].

However, use of other alternative MCDM techniques has also been successfully utilized. For example, TOPSIS and AHP methods of fuzzy approach were used to select appropriate and best method to be used for wastewater treatment. Advance wastewater treatment technologies can be used as alternate to conventional type treatment technologies. TOPSIS fuzzy logic method is used to evaluate 10 treated wastewater sites in South Korea in the watershed region [13]. This approach was applied to 6 domestic sewage treatment processes which are currently used in India [14]. Further, TOPSIS has been utilized for applying disinfection technologies to treated wastewater for its reuse in Spain wherein the reported literature mentions the use of TOPSIS method to six possible alternatives for disinfecting the treated wastewater for its reuse [15]. The weightage to the different parameters to be considered is carried out using the Delphi technique [16].

A study [17–19] conducted evaluated the efficiency of sewage treatment plant in Delhi which concluded that the proper operation and maintenance of the plants is required so as to achieve the high efficiency in order to meet up the effluent discharge standards as prescribed by the authorities. The overall process of treatment plant is the removal of pollutants [20, 21]. A recent report by Central Pollution Board [22] evaluated the performance of 152 sewage treatment plants (STP) spread over 15 states, and it was revealed that around 66% of the STP's were utilizing the treatment capacity. It is evident from such studies that a significant volume of wastewater is not subjected to any treatment and is directly disposed into surface water bodies leading to its deterioration. It has been reported that the management of wastewater treatment systems is not only of major concern for developing countries but also for developed countries [23, 24]. It has often been mentioned that performance evaluation of different treatment systems is of high significance in deciding which treatment technology should be implemented to achieve the highest efficiency results. However, in reality it is complicated to select one appropriate technology among the various available processes as all the processes have their unique advantages and their disadvantages [23, 25]. Hence, in recent years, the conventional wastewater treatment technologies are being replaced with the advance wastewater technologies because of their higher efficiency reports. Nevertheless, the problem arises when evaluating the efficiency of the existing treatment system based on conventional systems and their selection for up-gradation to advanced wastewater treatment technologies or to improve the existing system of the conventional treatment. In such cases, the decisions are often based on the outcomes of application of multi-criteria decision tools.

A study [26] discussed that multiple criteria decision making tools proved beneficial in accessing environmental, social and economic decisions for selecting the best technology for wastewater treatment. Hence, the selected decision making tool should have beneficial scope for the both social and economical aspects also considering the environmental characteristics. The use of such decision making tool is of significant interest to scientific community in this aspect [23, 27, 28]. The main purpose of using such decision criteria tools is to determine the performance of the existing sewage treatment plants so that appropriate measures can be taken for the up-gradation of the treatment systems to increase the efficiency. Similarly such use of decision making tools has been used in developing countries [20, 29] wherein various treatment technologies like compact extended aeration, conventional activated sludge, conventional extended aeration, rotary bio-disk reactor and peat bed reactor were evaluated. The study concluded that those existing treatment plants using conventional treatment processes like activated sludge process and extended aeration processes were found to be having the highest performance. The higher efficiency in functioning of the treatment plant is indicative of adequate elimination of biological and inorganic constituents which causes the pollution of environment as well as human health. A similar study conducted in Indian context [30] measured the efficiency of the two sewage treatment plants in Bangalore, using activated sludge process and reported that both the treatment plants were incapable to treat the high amount of dissolved solids thereby having low performance efficiency. Performance analysis of sewage treatment plants helps us in determining the treatment efficiency of the plants which in turn makes it easy to identify those plants with poor performance needing the up-gradation [28, 31, 32].

The study focuses on the evaluation of the sewage treatment plants in Himachal Pradesh [32]. The state of Himachal Pradesh, located in the northwestern part of the Himalayas, lies in the northern part of the country covering an overall area of 55,673 km^2. The state is connected by five major streams of Beas, Sutlej, Yamuna, Chenab and Ravi, which drains into Yamuna and finally enters into the Ganges river system. Himachal Pradesh has population of 0.56% of the total population of India, with 89.97% living in rural areas and rest 10.03% living in urban areas [33–36]. The major source of drinking water of the state is based on these five major streams which connects the whole of the state (NRDWP, 2013). Further, the treated effluent is also discharged into the tributaries or by-streams of such rivers and is governed by the effluent disposal standards as prescribed by CPCB [37].

Presently, there exist about 66 sewage treatment plants in the state of which only 55% are operational (36) and the remaining ones are either in construction or non-operational phase. Several small-scale plants are operational in the state [32]. This is similar to earlier reported literature wherein various small-scale sewage treatment plants operate in rural areas of European countries like Greece, out of which only a few are working properly [20, 38]. Small-scale wastewater treatment plants are also studied in rural areas of Korea which were designed for the removal of organic and suspended matter only [39].

Of the working 36 plants, we selected 24 (67% of functioning plants) existing treatment plants *which were in fully functional conditions and had similar parameters of measurement*. Of the 24 treatment plants selected for the study, 33% are under capacity 1 MLD, 63% are between 1 and 5 MLD and remaining are greater than 5 MLD and operate on the extended aeration system. The location details of the selected treatment plants (24) for the study have been shown in Fig. 1, and their treatment capacity in MLD has been presented in Table 1.

Materials and Methods

Characteristics of STPs Evaluated

As water supply system is important in providing hygienic drinking water society, sewerage system is also important for the effective transport of sewage to the treatment plants before its disposal to the water bodies [32]. The state of Himachal Pradesh is divided into four major zones covering an overall of twelve districts (Irrigation and Public Health Department, Himachal Pradesh). The majority of sewage treatment facilities of Himachal Pradesh work on the principle of the extended aeration system. The sewerage system is maintained by Irrigation & Public Health (I&PH) Department [32]. In practice, combined sewerage system which carries both domestic wastewater and storm water is used in the study locations. More and more emphasis is laid by government to connect adequate number of households to the sewerage network as 90% of the entirety population inhabit in rural areas [32]. All the treatment facilities discharge indirectly or directly into Beas, Satluj, Ravi, Chenab and Yamuna which are also drinking source for the state. So before discharging the domestic wastewater, it has to be treated to maintain hygiene [32].

The selected 24 treatment plants work on the extended aeration principle as described diagrammatically in Fig. 2. In practice, the hydraulic retention time (HRT) varies between 15 and 22 h for the selected 24 STP's considered for the study. This is slightly less than the operating HRT of treatment plants considered for Delhi [17–19]. The selected STPs were studied for period of 12 months from

Fig. 1 Location of STP's in Himachal Pradesh

September 2016 to August 2017 [32]. The parametric results of the influent and effluent samples were collected from the STP sites. The majority of the treatment plants were working below their design capacities due to the lack of connecting sewerage networks from different households to the STPs is being considered to be main reason [32, 39].

Sampling and Analysis

The samples were collected from the twenty-four sites, and the influent and effluent samples of the STPs were collected from the testing analysis carried out at the sites [32]. The major parameters tested before the disposal of effluent were total suspended solids (TSS), biochemical oxygen

Table 1 Capacity for treatment of selected STP's in Himachal Pradesh

Serial number	STP	Capacity (< 1 MLD)
1	NIT Hamirpur	0.27
2	Palampur	0.35
3	Khaliyar	0.40
4	Kangra Zone II	0.63
5	Hamirpur Zone III	0.68
6	Arki	0.70
7	Dhalli	0.76
8	Kunihar	0.90
Capacity varying between 1 and 5 MLD		
9	Sujanpur	1.20
10	Ghumarwin	1.20
11	Nagrota Bagwan	1.34
12	Hamirpur Zone II	1.35
13	Tanda Medical College	1.40
14	Kangra Zone I	1.68
15	Jogindernagar	1.74
16	Jwalamukhi	2.38
17	Bhootnath	2.50
18	Lankabaker	2.57
19	Solan	2.90
20	Hamirpur Zone I	3.13
21	Sundernagar	3.55
22	Ragunathka Padhar	3.83
23	Sanjauli Malyana	4.44
Capacity greater than 5 MLD		
24	Dharamshala	5.15

demand (BOD_3), chemical oxygen demand (COD), pH, and dissolved oxygen (DO). The tests in the laboratory were conducted as per the Standard Methods for the Examination of Waters and Wastewaters [40]. The results were analyzed on daily basis for period of 12 months. Table 2 highlights the potential reuse of the treated wastewater.

Determination of Efficiencies

Many studies [28, 29, 31, 32] have utilized the concept of general efficiencies for reporting working conditions of treatment plants. For example, a study carried out in Madrid, Spain, to determine the functioning of the existing treatment plants, utilized important parameters TSS, ammonia concentration, BOD and COD wherein the general efficiency was computed as the average of the removal efficiency of these parameters [29].

For a similar study conducted in Indian context in Delhi to determine the overall efficiency of the treatment plants, the parameters considered were turbidity, BOD and fecal coliforms [15–17]. Both the studies tend to utilize all the categories of parameter selection depending upon the parameters tested for effluent quality disposal. A similar methodology is used to determine overall actual efficiencies and overall standard efficiencies of the STPs studied for the state of Himachal Pradesh, India. The methodology used is similar to the study carried out by [29] with the only exception that since ammonia was not tested at any of the study locations, the efficiencies were determined on the basis of *TSS*, *BOD*$_3$ *and COD*.

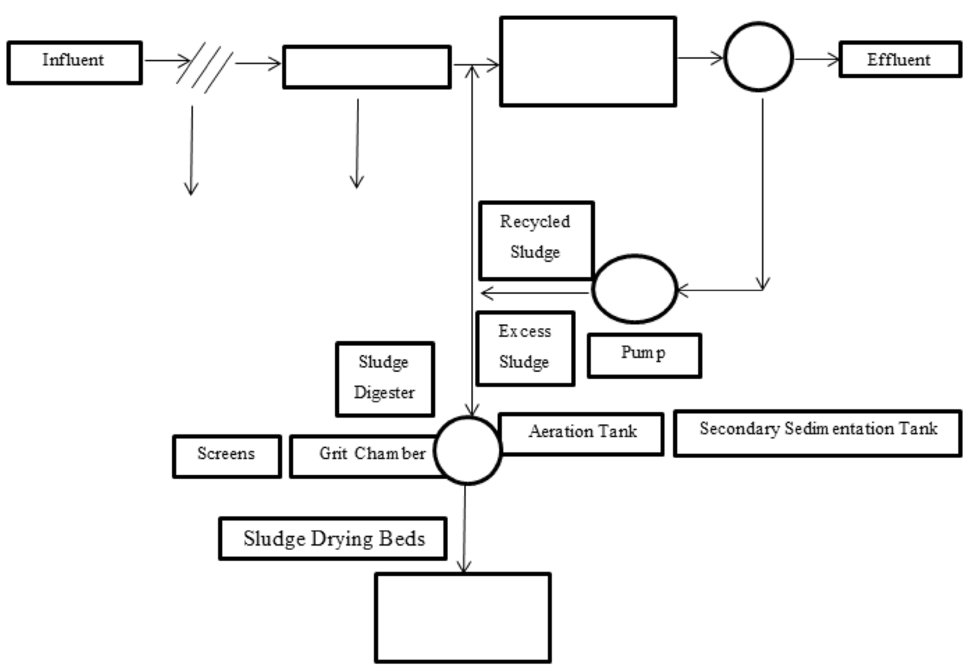

Fig. 2 Flow sheet of extended aeration process

Table 2 Permissible limits for the effluent reuse in different fields [16]

	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Fecal Coliform	NH_4 (mg/L)	PO_4 (mg/L)	pH	TDS (mg/L)
Agricultural limitations	100	200	100	400	50	15	6–8.5	1500
Recreational Limitations	5	10	30	400	0.02	1	6–9	750
Industrial Reuse	30	75	30	200	2	4	6–9	1000
Surface Water Disposal	30	60	40	400	2.5	6	6.5–8.5	1500
Ground Water Disposal	30	60	40	400	1	6	5–9	1500

Hence, the efficiency was determine using equation as mentioned below

$$EG_a = \frac{1}{3}[E_{TSS} + E_{BOD_3} + E_{COD}] \quad (1)$$

where EG_a is the overall *general actual efficiency* (%), E_{TSS} is the actual average TSS removal efficiency (%), E_{BOD_3} is the actual average BOD_3 removal efficiency (%) and E_{COD} is the actual average COD removal efficiency (%). Further, *general standard efficiencies* of the treatment plant were also determined based on the influent and effluent parameters considered of all the treatment plants and were compared with general efficiency [32]. The general standard efficiency is also calculated using Eq. (1) but uses the CPCB discharge standard as the effluent value to determine the efficiency of the selected parameters.

$$EG_s = \frac{1}{3}[E_{TSS} + E_{BOD_3} + E_{COD}] \quad (2)$$

The overall efficiency (EG_a) is the indictor which is considered as an important tool which supports policy makers to focus on the policy making efforts which further helps in designing effective policies to monitor progress toward the objective of the policies. The overall efficiency of the treatment plants is calculated by considering TDS, TSS, COD and BOD.

The efficiency of the treatment plant is also based on the quality of effluent produced often categorized as the effluent quality index. Effluent quality index is based on Delphi and TOPSIS method in which all the parameter of influent and effluent values are converted into an index by assigning suitable weightage to the parameters [32]. Effluent quality index is very useful in determining the quality of the effluent and the area where the effluent can be reused. The effluent quality index of the various sites is calculated and compared with the effluent quality index obtained from the standard parameters. The weightage attributed to the parameters are defined in Table 3.

The value of EQI is obtained from the expression:

$$EQI = \sum(0.767 * I_{BOD} + 0.0767 * I_{COD} + 0.0885 * I_{TSS} + 0.1344 * I_{pH})/0.3763 \quad (3)$$

Table 3 Weightage assigned to each parameter using TOPSIS method [16]

Parameter	Weightage
BOD	0.0767
COD	0.0767
TSS	0.0885
pH	0.1344

where EQI is the effluent quality index of influent and effluent. I_{BOD} is the sub-index of BOD obtained from rating curves, I_{COD} is the sub-index of COD obtained from rating curves, I_{TSS} is the sub-index of TSS obtained from rating curves, I_{pH} is the sub-index of pH obtained from rating curves.

Results and Discussion

To check and have a knowledge regarding the efficient working of the sewage treatment plants, the performance analysis is being performed [32]. The wastewater contains huge quantity of macrobiotic, inorganic and toxic matter which are dangerous for aquatic, human and environment life. So before discharging the wastewater to the streams, rivers and other water bodies, it needs to be treated. The purpose of wastewater treatment plant is to produce such quality of effluent that it is fit for reuse. For obtaining such kind of effluent, performance analysis is being performed [32].

Characteristics of the Influent Wastewater

The BOD_3/COD ratio for untreated municipal wastewater varies from 0.3 to 0.8. The BOD_3/COD ratio of 0.5 or more indicates high biodegradability of the influent sewage by biological treatment [32]. As the drainage pattern is combined sewer system, the precipitation water is also discharged to STPs along with wastewater [32]. For "NIT Hamirpur," the BOD_3 varies from minimum 90 mg/L to maximum of 190 mg/L, COD varies from minimum

100 mg/L to maximum 480 mg/L, TSS varies from minimum 195 mg/L to maximum of 365 mg/L [32].

The values of BOD_3 at “Palampur” ranges from 190 to 360 mg/L, COD ranges from to 430 mg/L and TSS ranges from 224 to 304 mg/L. At “Khaliyar,” BOD_3 ranges from 134 to 459 mg/L, COD ranges from 164 to 1056 mg/L and TSS ranges from 150 to 186 mg/L. “Dhalli” and “Sanjauli Malyana” has high amount of COD values ranging from 620 to 960 mg/L and 640–2667 mg/L [32]. High COD indicates the presence of toxic substances. TSS at “Sanjauli Malyana” is also high ranging 200 mg/L to 1450 mg/L [32]. “Tanda medical college” receives influent from the Rajiv Gandhi Medical College and Hospital. Hospital and residential waste with storm water feeds the treatment plant. The COD ranges 440 mg/L to 596 mg/L.

General Overall Efficiency Approach (EG)

The detail ranking of STP’s on the basis of actual general overall efficiency is given in Table 4. The ranking to the STPs is provided on the basis of general removal efficiency obtained from the actual influent and effluent data sets [32].

According to the basis of general overall efficiency approach, “STP Kunihar” with 0.9 MLD capacity is ranked 1st with the actual general removal efficiency of 90.78%. “NIT Hamirpur” having capacity 0.27 MLD has the lowest actual removal efficiency of 57.29% [32]. Both the plants are working on the same technology, i.e., Extended aeration process [32]. The difference being the aerators in “STP Kunihar” aerators provided with vertical mechanical surface aerators, and at “NIT Hamirpur,” inclined surface aerators are provided at the sides of the tank [32].

The comparison of the standard and actual general overall efficiencies has been presented in Table 4 and Fig. 3. The overall actual efficiency should always be greater than the overall standard efficiency. The maximum EG_a was observed for “Kunihar,” i.e., 90.78%. “Palampur,” “Khaliyar,” “Kangra Zone III,” “Dhalli,” “Ghumarwin,” “Nagrota Bagwan,” “Jogindernagar,” “Bhootnath,” “Lankabaker,” “Dharamshala” shows actual efficiency of more than 80% [32]. The final ranking of the efficiency of the treatment plant has been represented in Table 5 which presents both individual and the combinative rankings. Combinative rankings are grouping of those percentage efficiencies used in individual rankings that have no statistical significance and can be attributed to outlying errors. For example, the performance efficiency for Jogindernagar (88.61%) and Dharamshala (88.09%) is individually ranked 2nd and 3rd in the system but on closer evaluation the percentage values have no statistical significance and the functioning may be combined to give an overall 2nd ranking.

Table 4 Comparison of standard and actual general overall efficiencies for the 24 sewage treatment plants

STP	Standard general overall efficiency (EG_s)	Actual general overall efficiency (EG_a)
NIT Hamirpur	49.94	57.29
Palampur	61.00	80.94
Khaliyar	54.07	84.13
Kangra Zone II	52.23	83.41
Hamirpur Zone III	49.45	76.08
Arki	60.60	74.15
Dhalli	72.61	81.52
Kunihar	71.76	90.96
Ghumarwin	55.06	86.88
Sujanpur	54.27	84.39
Nagrota Bagwan	64.57	87.42
Hamirpur Zone II	50.07	73.27
Tanda Medical College	58.09	84.21
Kangra Zone I	−23.17	75.13
Jogindernagar	66.68	88.61
Jwalamukhi	50.16	76.25
Bhootnath	61.60	81.32
Lankabaker	69.44	86.49
Solan	56.00	78.89
Hamirpur Zone I	45.35	80.67
Sundernagar	55.28	80.96
Ragunathka Padhar	65.43	81.52
Sanjauli Malyana	80.71	69.76
Dharamshala	63.77	88.09

The general standard efficiency of “Kangra Zone I” is found to be negative value of 23.17 [32]. This is because the characteristics of the influent sewage feeding the STP are less than the effluent standards. “Sanjauli Malyana” shows the EG_s more than EG_a. This indicates the effluent produced by the STP is not meeting the discharge standards.

Physical and Chemical Removal Efficiency

All the STPs in Himachal Pradesh were designed to generate the effluent with BOD_3, COD and TSS values less than 30 mg/L, 250 mg/L and 100 mg/L [37]. Overall actual efficiency is generally measured with the help of these parameters [32]. High physical removal efficiency of 93.94% is observed at “Dharamshala” with extended aeration process followed by “Nagrota Bagwan” with the physical removal efficiency of 93.47%. “Jwalamukhi,” “Arki” and “NIT Hamirpur” has low physical removal efficiency of 69.53%, 61.36% and 57.64% [32].

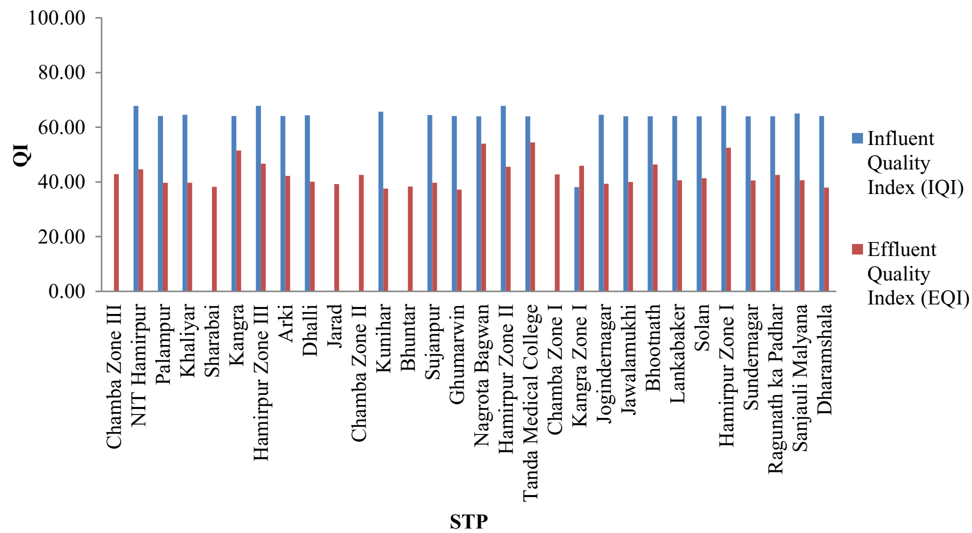

Fig. 3 Influent and effluent quality index yearly variation

Table 5 Ranking to the STPs on the basis of actual general overall efficiency (EG_a)

Serial no.	STP	Actual general overall efficiency (EG_a) in %	Ranking	Combinative rankings
1	Kunihar	90.78	1	1
2	Jogindernagar	88.61	2	2
3	Dharamshala	88.09	3	
4	Nagrota Bagwan	87.42	4	3
5	Ghumarwin	86.88	5	4
6	Lankabaker	86.49	6	
7	Sujanpur	84.39	7	5
8	Tanda Medical College	84.21	8	
9	Khaliyar	84.13	9	
10	Kangra Zone II	83.41	10	6
11	Dhalli	81.52	11	7
12	Ragunathka Padhar	81.52	12	
13	Bhootnath	81.32	13	
14	Sundernagar	80.96	14	8
15	Palampur	80.94	15	
16	Hamirpur Zone I	80.67	16	
17	Solan	78.89	17	9
18	Jwalamukhi	76.25	18	10
19	Hamirpur Zone III	76.08	19	
20	Kangra Zone I	75.13	20	11
21	Arki	74.15	21	12
22	Hamirpur Zone II	73.27	22	13
23	Sanjauli Malyana	69.76	23	14
24	NIT Hamirpur	57.29	24	15

All the other treatment plants, except these three, showed good and moderate physical removal efficiencies. Physical removal efficiencies from “Palampur” to “Jogindernagar” vary from 86.80 to 90.62% [32]. As all the plants employ extended aeration process, the total suspended solids removal efficiency varies from 57.64% at “NIT Hamirpur” to 93.94% at “Dharamshala.”

The chemical removal efficiencies consist of BOD_3 and COD removal efficiency. STP “Bhootnath” shows the highest BOD_3 removal efficiency of 95.44% followed by “Lankabaker” with 92.97% removal efficiency [32]. The extended aeration proves best as most of the STPs are working well in removing BOD_3. The BOD_3 removal efficiency ranges from 95.44% at “Bhootnath” followed by “Jwalamukhi” with 92.58% and the least at NIT Hamirpur with 61.13% [32].

Extended aeration shows good COD removal efficiency ranging from 89.24% at “Kunihar” followed by 77.12% at “Kangra Zone III.” “Tanda Medical College” has more removal efficiency of 79.03% than “Sanjauli Malyana” with 66.61%. Most of the STPs have removal efficiency ranging from 70 to 85%. “NIT Hamirpur,” “Kangra Zone I” and “Hamirpur Zone II” show relatively less removal efficiency of 52.29%, 59.09% and 59.67% [32].

Seasonal Variation

The seasonal variation among the standard (EG_s) and actual (EG_a) overall efficiency of STPs in autumn, winter, summer and monsoon seasons is given in Figs. 4, 5, 6 and 7, respectively. Factors affecting the general efficiency of STPs are aeration, temperature, pH, flow treated. The present study shows that extended aeration is performing best. STP at “Kunihar” is the best overall performer with the overall efficiency of 90.78% [32]. “Nagrota Bagwan”

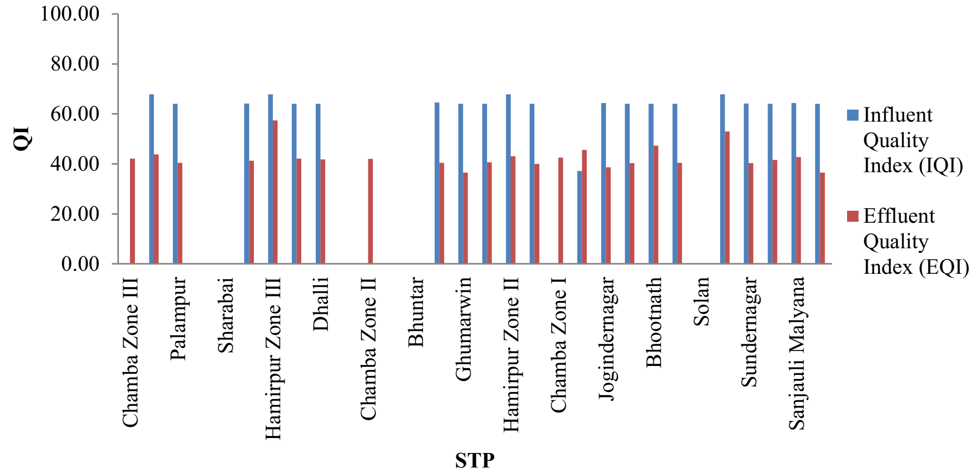

Fig. 4 Variation of influent and effluent quality index in autumn season

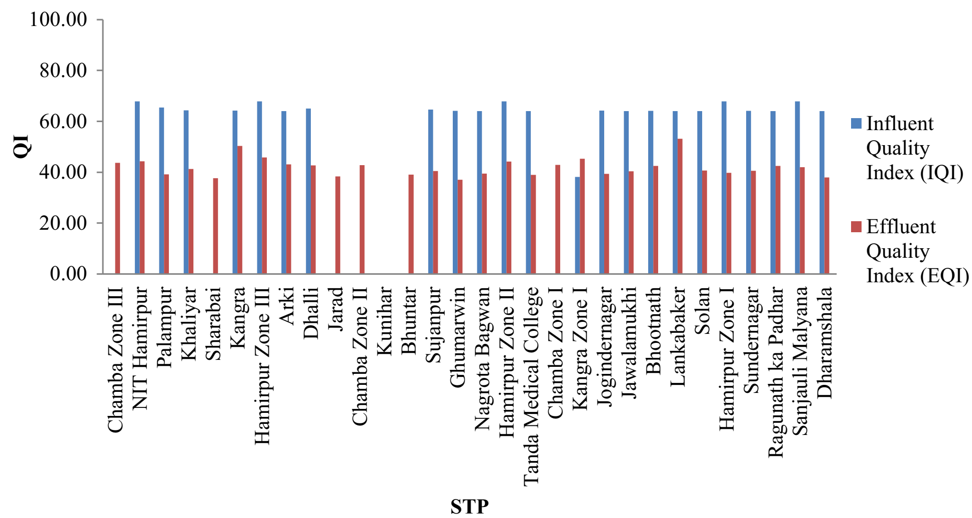

Fig. 5 Comparison of influent and effluent quality index in winter season

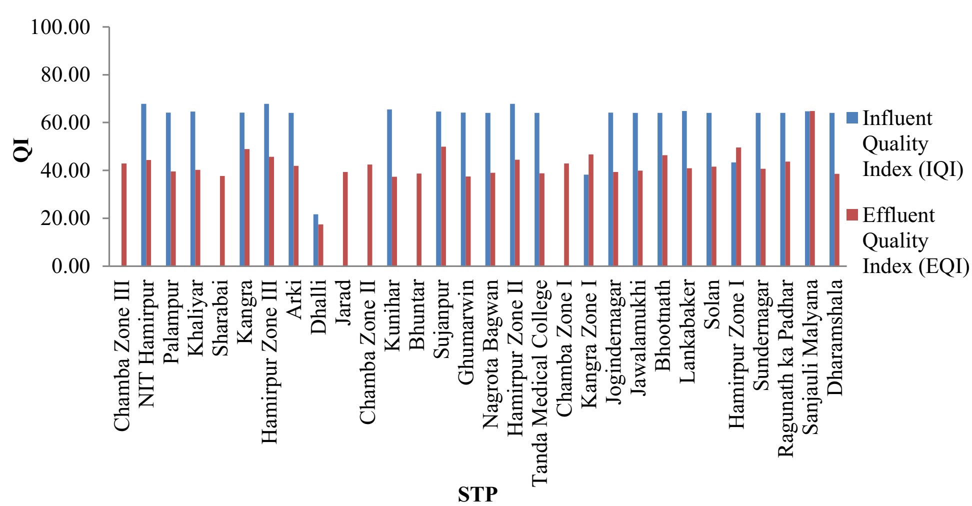

Fig. 6 Comparison of influent and effluent quality index in summer season

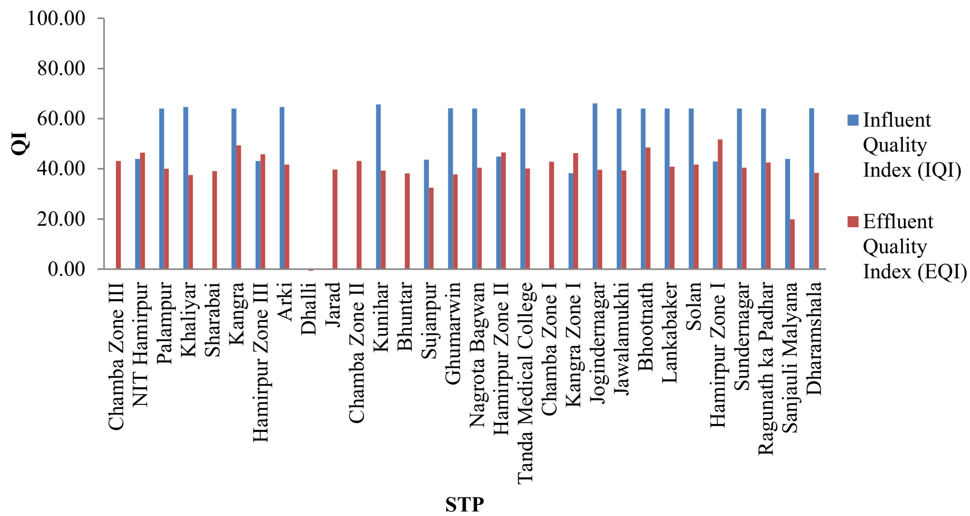

Fig. 7 Comparison of influent and effluent quality index in Monsoon season

with Diffused Aeration System is better in removing total suspended solids with efficiency of 93.47% than "Solan" and "Dhalli" using the same technology with 71.77% and 75.74%. This implies that "Nagrota Bagwan" performs better in removing the TSS than all other STPs studied. One of the key problems with "Dhalli" and "Solan" using Diffused Aeration Process is foam formation and hence resulting in average removal of TSS [32].

In STPs where mechanical aerators are use as extended aeration process, "Dharamshala" performs better with the overall TSS removal of 93.94%. "Jwalamukhi" proves best in removing BOD_3 with 92.58%, while COD and TSS removal efficiency is quite low, i.e., 65.90% and 69.53% [32].

As there is a combined sewer system, the storm water drains into these STPs resulting in low performance of the STPs studied as the sometimes during rains, certain STPs gets flooded and overloaded and the aeration system is not able to provide sufficient amount of oxygen as required [32]. The hydraulic retention time (HRT) also gets reduced due to the overflow condition resulting in effluents of low quality, and hence, the low TSS removal is observed due to low sludge retention time (SRT).

On an overall aspect, seasonal analysis showed no significant variation with performance of each STP in different seasons being almost similar. However, it is noted that the results obtained in monsoon and winter seasons are slightly greater in comparison to summer and autumn, and this is due to the increased rainfall, thereby increasing the flow in the treatment plants, and the increased flow reduces the efficiency of the treatment plant to provide effluent of good quality.

Effluent Quality Index Approach

Effluent quality index is the best method for estimating the superiority of the effluent discharging from the treatment plant [32]. The estimation helps in understanding the field in which the effluent from the treatment plant can be reused to save water sources.

It is seen that pH has more weightage than BOD, COD and TSS. pH is considered as the most essential factor because the value of pH depicts the nature of the wastewater [32]. As wastewater contains organic and inorganic components, the wastewater can be acidic or alkaline in nature. The right pH must be maintained for the apt working of the microorganisms [32].

Table 6 gives the ranking of the STP's on the basis of EQI approach. Out of twenty-four STPs considered, "STP Ghumarwin" shows the best results, means its effluent water can be used for recreational use. The least EQI value is obtained for "STP Tanda Medical College" as 54.43 signifies that the effluent wastewater can be used for agricultural purposes [32].

Critical Discussion on Existing Scenario of Performance Evaluation of Sewage Treatment Plant in Himachal Pradesh

The paper discusses the determination of efficiencies of 24 existing treatment plants in Himachal Pradesh utilizing the concepts of Actual general efficiency, Standard general efficiency and effluent quality index methods. The methods used are generally part of the multi-criteria decision making tool. It is important to note that the ranking criteria using the above tools are different. While rankings determined on general efficiency are based on higher values, they are classified on lower values using effluent quality

Table 6 Ranking of STPs on basis of EQI

STP	Effluent quality index (EQI)	Ranking
Ghumarwin	37.23	1
Kunihar	37.60	2
Dharamshala	37.92	3
Jogindernagar	39.34	4
Sujanpur	39.68	5
Palampur	39.75	6
Khaliyar	39.75	7
Jawalamukhi	39.97	8
Dhalli	40.06	9
Sundernagar	40.53	10
Sanjauli Malyana	40.64	11
Lankabaker	40.64	12
Solan	41.39	13
Arki	42.22	14
Ragunathka Padhar	42.57	15
NIT Hamirpur	44.59	16
Kangra Zone I	45.88	17
Hamirpur Zone II	45.57	18
Bhootnath	46.35	19
Hamirpur Zone III	46.63	20
Kangra Zone II	51.46	21
Hamirpur Zone I	52.51	22
Nagrota Bagwan	54.03	23
Tanda Medical College	54.43	24

index methods. Further, the ranking results obtained using both the methods are not same and therefore the selection of the methodology primarily depends on the purpose of the assessment. The general efficiency method uses two techniques to determine the efficiencies, one based on actual influent and effluent values of the treatment plant (actual general efficiency) and other to the actual influent and standard disposal value guidelines as per CPCB disposal guidelines (standard general efficiency). In contrast, the effluent quality index methods are assessed only on the effluent quality having no inputs from the influent entering into the system. Further, the results obtained show that using the two different methods two different ranking sets are observed which justifies that there exists no best or any particular method for determining the efficiency. The suitability of applicability of the methods depends on the outcome required. However, in essence it can be concluded that majority of the existing treatment plants were performing below par as determined from the study. Hence, in this context it is proposed to install advanced wastewater treatment technology to increase the efficiency of the treatment systems.

Table 7 Defined threshold for reuse [16]

Recreational reuse	26
Industrial reuse	48
Ground water disposal	53
Surface water disposal	56
Agricultural reuse	71
More treatment needed	>71

It was further noticed that majority of the treatment plant were performing below their designated capacity. This could be mainly attributed to lack of sewer pipe connections between septic tanks of individual households and the located treatment plant. This was mainly due to hilly terrain conditions existing in the state leading to difficulty in layout of pipelines.

Few other important features have been noticed while carrying out the study. This includes the lack of suitable treatment plants at higher altitudes within the state due to extreme climatic conditions, thereby proving no such facilities. There is an immediate need to install sewage treatment plants fitted with heating mechanisms to operate in these areas.

Finally, the calculated EQI shows that majority of the treatment plants (20) lie between the values of 26 and 48 signifying that majority of effluents from treated plant are suitable for reuse and the effluent quality lies between being used for recreational purposes and industrial reuse (classified on basis of Table 7). Of the 20 plants having EQI values lying between 26 and 48, it is observed that 12 of the treatment plants have EQI greater than 40, thereby suggesting that with slight improvement in the efficiency of the treatment system, the majority of the effluent wastewaters can be used for industrial reuse. Only 2 treatment plants meet the criteria for groundwater disposal but proper care and further assessment needs to be carried out before disposal to groundwater. Finally, none of the treatment plant has the treatment efficiency for disposal of the treated effluent for surface water disposal. For the effluent generated from the treatment plant for agricultural use, the efficiency of the existing treatment plants needs to improve significantly.

Conclusion

Performance analysis was carried out on twenty-four of existing STP's in Himachal Pradesh in order to evaluate the efficiency of sewage treatment plants (STP) for treating sewage water. The treated effluents of some plants were not up to the prescribed standards of the Central Pollution Control Board (CPCB) and Himachal Pradesh Pollution Control Board (HPPCB). As per the new norms of CPCB, all the STP's studied needs up-gradation to meet the new effluent standards. So there is a dire need to implicate strict provisions to check the tests performed and apparatus used as the results are not suitable. Further, majority of the plants test only about 5–6 effluent parameters which are not sufficient enough to meet the ambient effluent quality, so there is a requirement of testing more parameters which enables us to discharge wastewater effluent into the stream, river and other water bodies, as there water bodies are home for aquatic life and its water is worn in a lot of fields.

Mostly designed treatment plants do not meet their design capacity because maximum households have septic tanks which are not linked with the sewer lines carrying sewage to treatment plants. So Irrigation and Public Health department needs to keep a check on linking each and every house with the sewage line.

Another important aspect is that at the upper regions of Himachal Pradesh there are no treatment plants due to extreme cold conditions leading to the death of the microorganisms. However, there is a definitive need of new treatment plants in this location wherein their construction should be facilitated by installation of heaters or blowers in the aeration tanks to maintain the temperature required as temperature is very important factor for microorganisms to decompose the organic matter and to produce the satisfactory effluent.

On the basis of above results, proper measures are to be taken to check the working and operations of the STPs studied. Tertiary treatment is also mandatory as the maximum efficiency obtained is 90.78%. Most of the STPs effluent discharge does not meet the new effluent standards as the water is discharged into streams which are used as source of water supply. There is urgent need for up-gradation of STPs as these STPs still run on the old discharge standards.

Advance technologies like MBBR, SBR, etc., should be adapted to increase the efficiency of the STPs as these technologies are in trend and their effluent discharge parameters meet the new effluent discharge standards prescribed by Board. The effluent from these sewage treatment plants can also be used for different sources such as irrigation, drinking water sources after conventional treatment, propagation of wildlife fisheries. Different water quality standards are set up for the reuse of wastewater so that there is reduction of environmental pollution and save drinking water sources.

Experienced and trained working staff is to be employed to check the working and operation of STPs. Maximum households are not connected with the sewerage system, so government must pay more attention to connect maximum to maximum households to the sewerage network so that the STPs work on their designed capacities as most of them are underutilized.

Finally, on the basis of existing classification for reuse purpose, none of the treatment plants are working effectively for disposal of the treated water to surface sources and can be majorly used for agriculture and industrial uses.

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Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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