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Analysis of the Operational Deficiencies Originating in Design at Wastewater Treatment Plants: A Case Study of the Islamic Republic of Iran

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Abstract: Considerable investments have been made in establishing wastewater treatment plants (WWTPs). However, evaluation of the performance of plants during recent years, when more WWTPs have become operational, shows that effluent quality criteria were not met in many instances. Preliminary assessment of the operational problems of WWTPs in Iran disclosed that numerous factors affect this issue of effluent quality. One reason is the lack of planning knowledge among the local consulting engineering companies, which causes design-related deficiencies. Lack of national standards as well as of practical design manuals are also significant factors. In this study, the effects of the design-related deficiencies on operational practices are investigated in 20 WWTPs around Iran. This is followed by the implementation of solutions in real models that match the most recent innovations in this regard. Consistent methods are then discussed for correcting these deficiencies. It was found that 68% of the operational deficiencies arise from design deficiencies. These are, accordingly, considered in the scope of the solutions presented in this work. The distinctive solutions presented in this study prevent the repetition of the same defects in new designs. Scientific methods for rectifying the detected deficiencies are developed in this study. The results are aimed at supporting experts who undertake the role of rehabilitating WWTPs in the country, through the correction of various deficiencies, so that the final goal of conserving the environment is met. The findings are compared with those of some related national and international works for the purposes of further clarification.

Keywords: Design-Related Deficiencies, Islamic Republic of Iran, Operational Deficiencies, Statistical Analysis, Wastewater Treatment Plants

INTRODUCTION

Recently, WWTPs have become one of the indispensable requirements of life, the lack of which results in irreparable losses of life and property, along with a threat to the valuable environment. In Iran, as a result of the rise in population and numerous causes of environmental pollution, consequent on the discharge of raw wastewater into the environment, legislators have designated funds for establishing WWTPs. The population coverage of the sewage systems (both collection and treatment) was almost above 30% at the end of 2008 (IWA, 2008).

The maximum treatment capacity of under-operation WWTPs is estimated to be 565 Mm^3/a (NWWC, 2008a), whilst the associated theoretical design capacity was considered to be 696.33 Mm^3/a; thus, 131.33 Mm^3/a representing the equivalent of a population of about 1,800,000, could not be brought into operation. This is because the WWTPs were under-designed, which happened as a result of the existence of design deficiencies- contradicting the

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designer's claim with regard to the planned coverage population of the design. At the end of the 1970s, it was found that operability, flexibility and maintainability of the designs are the factors affecting the effluent quality of the WWTPs (EPA, 1978). Zeferino et al. (2012) reported that the use of a decision support system for the planning of regional wastewater systems can provide a more accurate view of the decisions to make given the uncertain variables.

A study carried out by Nadafi et al. (2008) monitored 33 WWTPs and showed that for between 2 to 14 cases, the BOD factor frequently violated the required effluent quality. Another study by Badalians and Salehi (2007) showed that, in addition to the design factors, the absence of the well-known TPM system caused deviation from the acceptable effluent quality. The design deficiencies have led to calls for upgrades, which have resulted in the obligation to put extra funds into corrections (Aidin et al., 2011). Sludge bulking, which has been reported in 40% of WWTPs of the country, results from the choice of a completely mixed flow regime instead of a plug flow regime, and has caused effluent violations at most of the under-operating WWTPs in Iran (Takdastan and Azimi, 2009). The monthly average of BOD_5 and TSS was violated in between three and seven instances at the 20 under-operating WWTPs that were investigated in this study. The existing Iranian effluent standards for BOD and TSS are 30 mg/l and 40 mg/l, respectively (NEPO, 1999).

Niemann and Orth (2001) showed that by rainfall forecasts, the treatment plant can be prepared in advance, to some extent, to cope with the storm flow of a rainfall event; thus, taking these measures can help improve the effluent quality. Hannu (2010) showed that Finnish municipal WWTPs could improve their efficiency and control by investing in new instrumentation and modern process modelling tools; the necessity of applying these instruments is disclosed in this study as well. The benefits of the dynamic model for the evaluation of the efficiency of the WWTPs are that the future behaviour of the WWTP can be simulated, enabling more realistic designs, as shown by Gehring et al. (2010).

The distinguishing feature of the work is that, in contrast to the popular method of other researches, when the effluent criteria of a wastewater treatment plan are violated, the study does not only focus on the biological causes; rather, it seeks the design-related causes, thus guaranteeing improvement of the effluent criteria on condition that the design deficiency is alleviated according to the suggestions presented in this work.

MATERIALS AND METHODS

The methodology applied in this study comprises three main parts, namely: field activities (data collection through personnel interview); theoretical analysis; and development of methods for identifying and correcting the deficiencies. These interviews resulted in a list of deficiencies. The design deficiencies, as well as other causes that have a subsequent effect on the operation practices, have been categorized according to their sources, in order to statistically analyse them. These factors have been categorized under seven categories, each attributed to three sources, including administration, design and construction works. Statistical factors for the identified deficiencies, including standard deviation, skewness and covariance, have been calculated using Excel software. A flowchart is developed, based on which the designers can easily prevent the common design deficiencies appearing in new designs.

According to the statistics for 2008, the population of the urban area in Iran was estimated at 48,800,000 inhabitants. The annual growth rate of the population is estimated as 1% (NWWC, 2008a). By applying the forecasting method for estimating the population in order to obtain the design capacity of the WWTPs, as introduced by Sullivan et al. (1999), the population in 2018 is forecasted to amount to 53,905,000 inhabitants.

Taking into account the number of existing under-operation WWTPs, as well as the under-construction ones listed in Table 1, and applying the trend analysis method with due attention to the type of WWTP, it can be concluded that the first ranking with regard to tendency is allocated to the activated sludge WWTPs, whilst the second ranking is allocated to the aerated lagoons. The third ranking is obtained by stabilization ponds (Figures 1 and 2). After investigating the tendency of various types of WWTPs, as well as the increase of the capacity of under-operation and under-construction WWTPs, the categorized findings were considered and discussed to find suitable methods of correction. This approach benefited from the international researches which have examined similar deficiencies at WWTPs over many years of operation. Logic models were then developed to ensure a more accurate identification and correction of the deficiencies as well.

RESULTS AND DISCUSSION

Frequency Analysis of the Detected Deficiencies Considering Their Category

According to Table 2, it can be understood firstly that 35% of the observed deficiencies are attributed to planning, which can result in operation-related deficiencies in general, whilst 33% of all the observed deficiencies in this research are attributed to the deficiencies associated with the operation of liquid treatment facilities, which can be caused by design, administration or establishment issues. Finally, 13% of the all observed deficiencies are attributed to management strategies which could lead to effluent quality violations in different forms.

It can be found that inappropriate supervision of the construction work, as well as the limited technical capabilities of the contractors selected for constructing the WWTPs, have caused 5 % of the all observed deficiencies (Figure 3).

Table 1. Under-construction and under-operation WWTPs in Iran (NWWC, 2006, 2008b).

Item	Under-Operation		Under-Construction	Under-Operation
	2004	2006	2008	
Sum of under-operation /construction	51	90	133	223
Total design capacity *	338	696.33	945.30	1,641.63
Total design population	4,874,000	9,493,000	12,948,000	22,441,000
Number of activated sludge	23	35	76	111
Number of aerated lagoons	7	25	40	65
Number of stabilization ponds	19	29	16	45
Number of other plants	2	1	1	2
Capacity of activated sludge systems*	136.600	372.200	583.400	955.6
Capacity of aerated lagoons*	32.320	149.120	212.400	361.52
Capacity of stabilization ponds*	80	174.900	148.700	323.6
Capacity of other plants* (e.g. trickling filters)	0	0.110	0.800	0.91

*****Capacities in Mm^3 / a

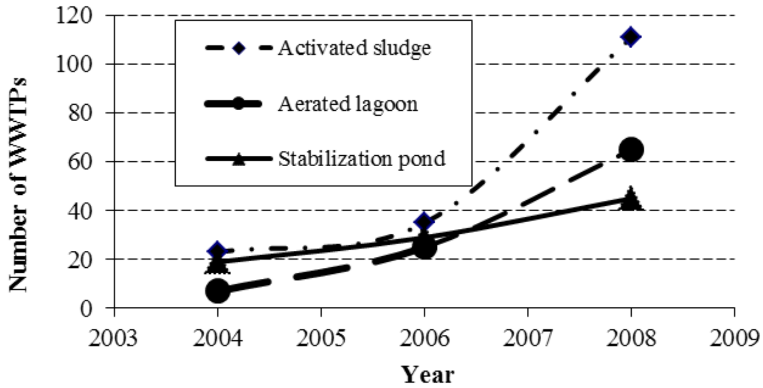

Fig. 1. Tendencies for different systems in terms of number.

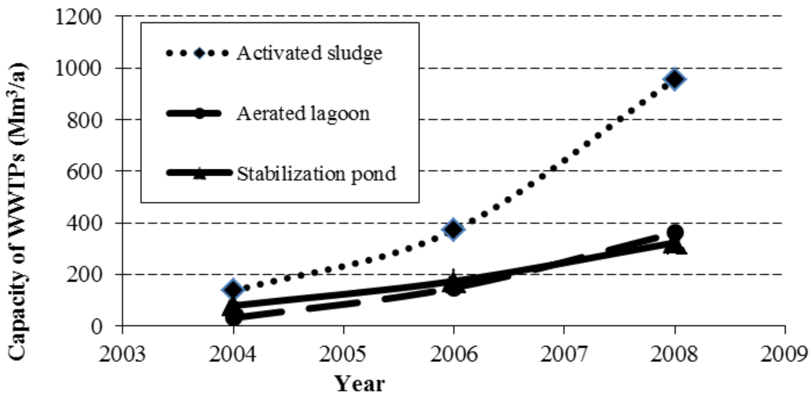

Fig. 2. Tendencies for different systems in terms of capacity.

Table 2. Number and frequency of the deficiencies detected by each category.

Item	Category of Deficiency	Number of Observed Deficiencies	Percentage of Total
1	Planning	61	35%
2	Management strategies	23	13%
3	Operation of liquid treatment unit	57	33%
4	Operation of sludge treatment unit	20	11%
5	Instruments of the WWTPs	5	3%
6	Establishing of WWTPs	9	5%
	Total	175	100%

Fig. 3. Sample of unsuitable construction work (unbalanced V-notch) (Amirtaimour, 2008).

Analysis of the Effects of Deficiencies Considering Their Sources

Table 3 considers the origin of the deficiencies. It can be concluded that 68% of all deficiencies are design-related, whilst 22% and 10% of the all deficiencies are administration and construction-related, respectively.

In the six categories, those with notable effects, along with associated interpretations, are as follows:

For the category of planning, the design-related deficiencies, with 88.5%, and the administration-related ones, with 11.5%, possess the largest and the second-largest share, respectively. This proves that, as expected, in addition to the source of design, the management strategies influence the planning procedures which lead, in turn, to design-related deficiencies. One studied case is that of forcing designers to choose drying beds for sludge drying in cold and rainy regions because of their low cost- in accordance with the administrators' desires regarding cost savings- where a mechanical dewatering performs much more efficiently (Figure 4).

Figure 5 shows the categorized distribution of the observed deficiencies.

Analysis of the Relationship between Total Deficiencies and the Design-Related Ones Detected in the WWTPs of Iran

Table 4 shows the distribution of different deficiencies for the 20 examined WWTPs. In order to investigate the relationship between the total observed deficiencies and the ones originating in design, Table 5 was developed to extract the statistical parameters to help discuss the probable relationship.

Table 3. Different deficiencies observed, divided by category and source of deficiency.

Category	Number and Frequency of Observed Deficiencies						Deficiencies	
	Source of Deficiencies							
	Construction Work		Design		Administration			
	%	No.	%	No.	%	No.	%	No.
Planning	0 0	0	40* 88.5**	61	16 11.5	8	31	69
Management strategies	0 0	0	5 26	8	47 74	23	14	31
Operation of liquid treatment unit	77 21.5	17	36 67.5	54	18.5 11	9	36	80
Operation of sludge treatment unit	9 8	2	11 68	17	12.5 24	6	11.5	25
Instruments of the WWTPs	0 0	0	3 66.5	4	4 33.4	2	3	6
Establishing of WWTPs	14 27	3	5 64	7	2 9	1	4.5	11
Total	100	22	100	151	100	49	100	222
Percentage of the whole	10%		68%		22%		-	

*Upper figures in terms of source of deficiency, ** Lower figures in terms of category of deficiency

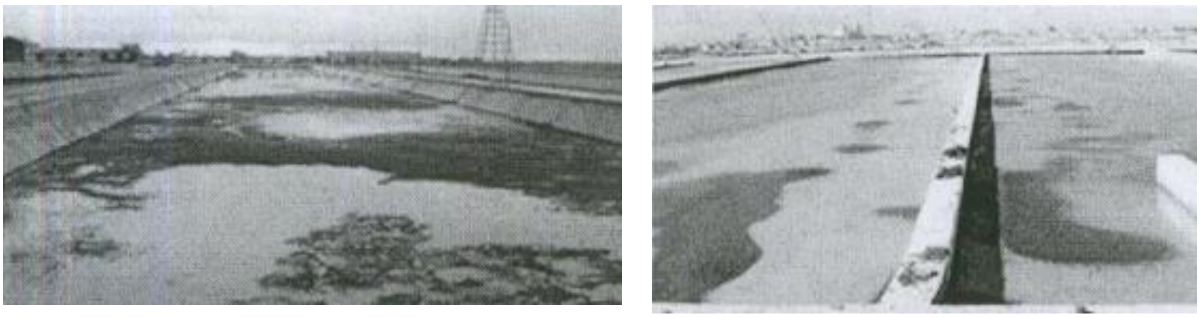

Fig. 4. A drying bed's incapacity in cold (left) and rainy (right) conditions (Moradhasseli, 2011).

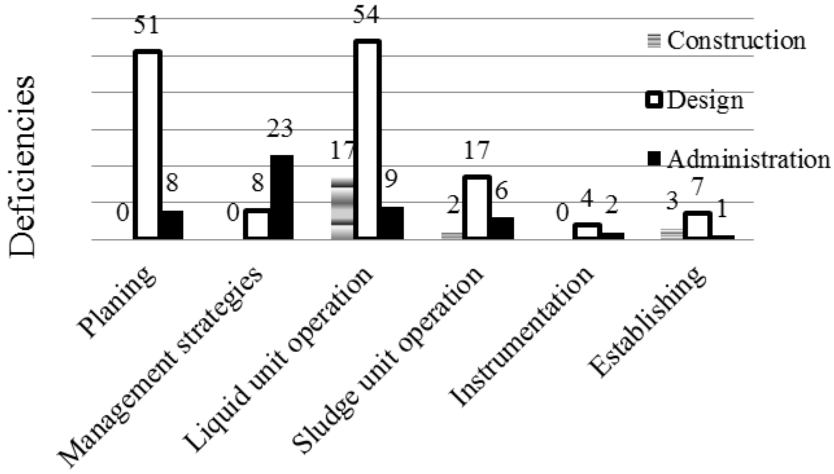

Fig. 5. Number of detected deficiencies, classified by category and source of deficiency.

Table 4. Distribution of the various deficiencies at the 20 studied WWTPs.

Plant ID	Number of Deficiencies Considering Their Source			Total Observed Deficiencies According to The Source
	Design	**Administration**	**Construction Work**	
1	5	3	2	10
2	7	1	0	8
3	9	3	2	14
4	6	3	2	11
5	7	2	2	11
6	5	4	3	12
7	8	1	3	12
8	5	2	3	10
9	9	2	0	11
10	6	3	0	9
11	5	2	1	8
12	9	2	0	11
13	8	3	0	11
14	7	3	1	11
15	9	3	0	12
16	11	1	0	12
17	8	4	0	12
18	7	3	2	12
19	9	1	0	10
20	11	3	1	15
Total	151	49	22	222

Table 5. Statistical factors for the total deficiencies and those originating in design.

Parameter	Total Deficiencies	Design Originated Deficiencies
Total	222	151
Standard deviation	1.713	1.877
Average	11	8
Skewness	0.177	0.205
Covariance	1.845	

According to Table 5, covariance between the total observed deficiencies and the ones originating in design is 1.854, which indicates that there exists a relationship between the two factors. Furthermore, the skewness factor for the total observed deficiencies is 0.177, which confirms that the distribution is normal (Figure 6). Hence, it is concluded that the average number of total deficiencies that can be detected in the WWTPs of Iran is 11, with a standard deviation of 1.7. In the case of deficiencies originating in design, the calculated skewness is 0.205, and therefore this distribution can also be considered normal (Figure 7). In this case, it can be concluded that the average number of design-related deficiencies that could be detected at the WWTPs in Iran is eight, with the related standard deviation of 1.877.

Developing Logical Methods for Identifying and Correcting the Deficiencies

In order to accurately identify and correct the deficiencies in WWTPs, it was understood that a logical model specifically developed for this purpose could guarantee the achievement of this goal (Figure 8).

More Frequently Identified Deficiencies Considered For Correction in the Study

When the design deficiencies with negative effects on the operation of WWTPs were detected, some of the more frequent ones were chosen to be discussed in detail for corrections. These are presented below:

- Low oxygenation capacity of surface aerators has resulted in lower efficiency (Figure 9). This can be alleviated by replacing the surface aerators with diffusers (Mousavi, 2011).

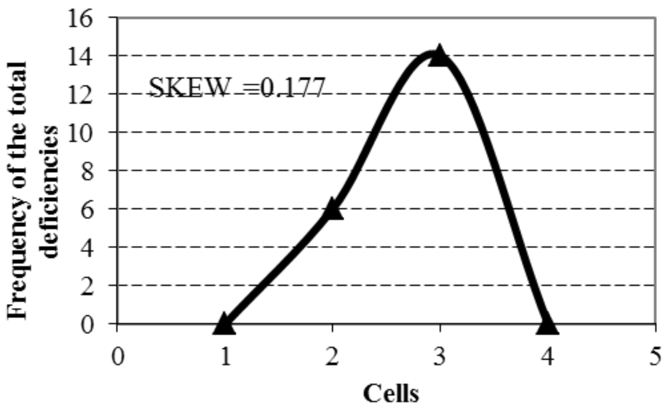

Fig. 6. Frequency distribution of the total deficiencies observed.

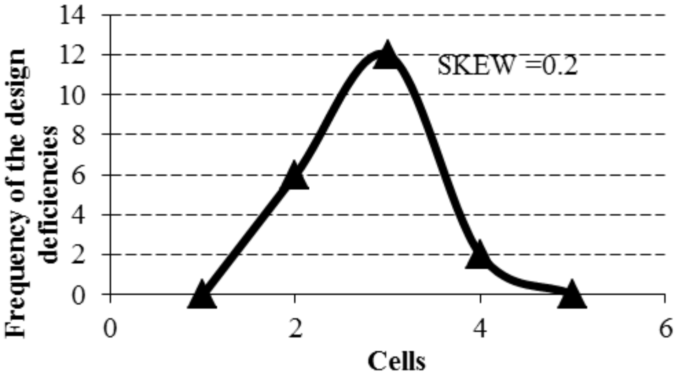

Fig. 7. Frequency distribution of the observed deficiencies originating in design.

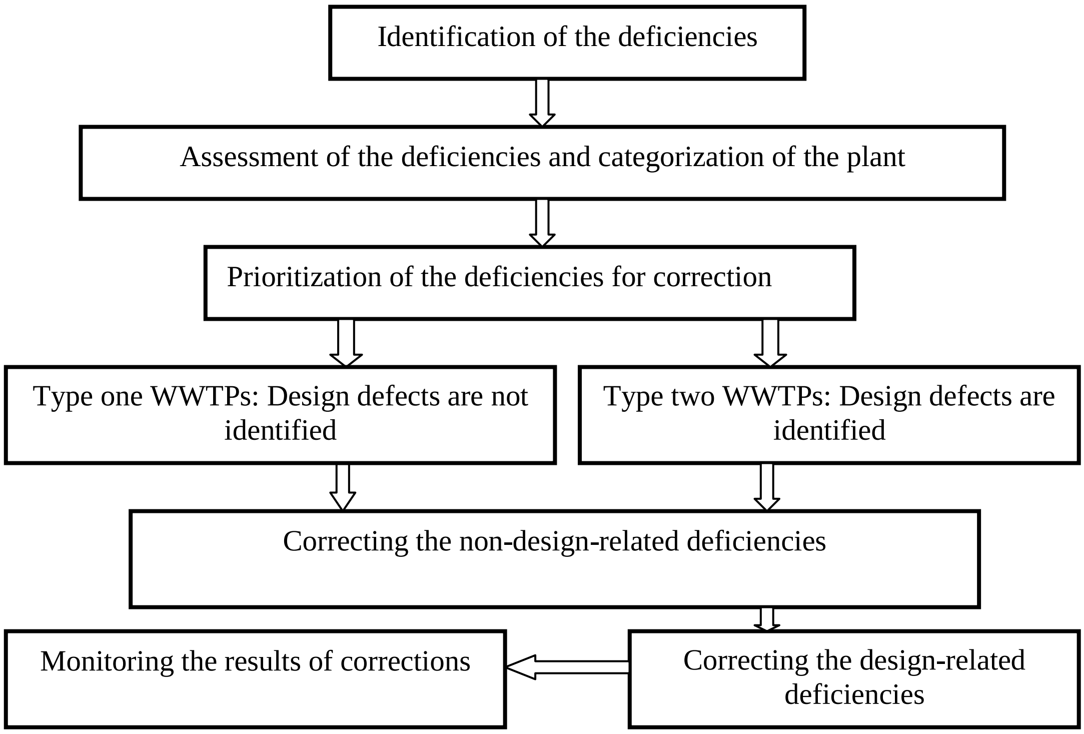

Fig. 8. Logical model for identifying and correcting the deficiencies at WWTPs (in part adapted from Diagger and Buttz, 1998).

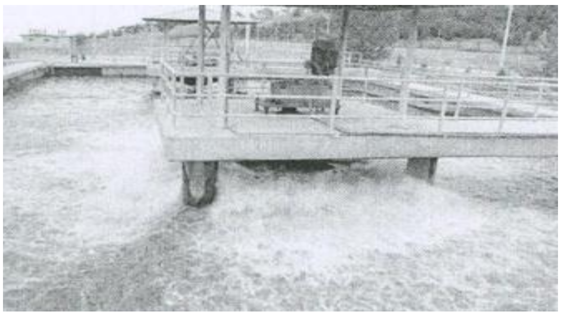

Fig. 9. Surface aerators cause lower BOD removal efficiency.

- Not paying attention to the effect of winter temperature has resulted in low efficiencies (Rahimi et al., 2006). In these cases, benefiting from deeper aeration tanks will help by greatly improving the efficiency (Qasim, 1999). Sludge bulking as a result of the existence of both filamentous bacteria and a completely mixed flow regime can be alleviated by installing a biological selector ahead of the aeration tank (Figure 10).
– High amounts of phosphorous in the effluent as a result of conducting detergents to the WWTPs result in eutrophication, which can be improved by benefiting from the A2/O system (ATV-DVWK, 2000).
– Excessive secondary clarifier hydraulic currents can contribute to the loss of solids at the effluent weir, resulting in periodically high effluent SS. This can be improved by installing a mid-radius baffle (Figure 11).
- Benefiting from the dynamic modelling tool for predicting the behaviour of the plant will result in minimizing some design deficiencies (Skrjanc, 2010).
- Dimensioning the wastewater treatment plants is not accomplished by taking into account the real qualitative and quantitative parameters. This will have a great effect on the efficiency of the plant (Moradhasseli and Mohamadi, 2013).
- Inaccurate choices of flow measurement device (Parshal Flume) have resulted in wrong measurement of the flow, causing serious operational problems (Moradhasseli and Mohamadi, 2012).

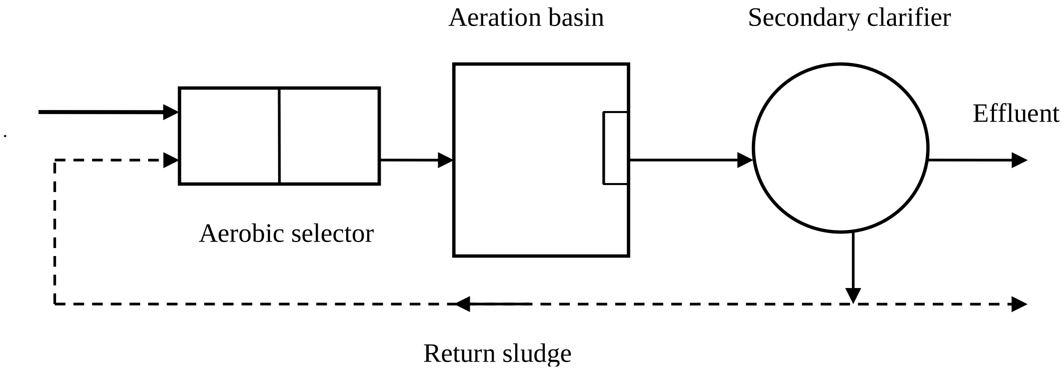

Fig. 10. Location of a biological selector in an activated sludge WWTP (Metcalf and Eddy Inc., 2003).

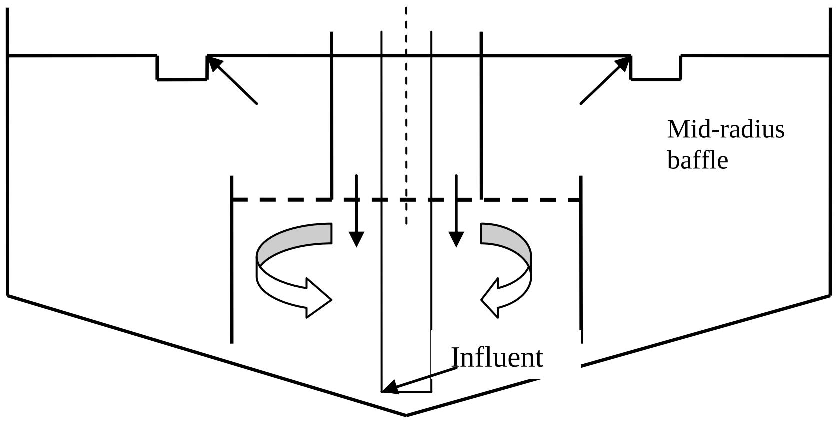

Fig. 11. Mid-radius baffle installed in a circular clarifier (EPA, 1984).

CONCLUSIONS

The main causes of the violation of the effluent quality in the 20 studied WWTPs in Iran have been recognized in this study. Among them, those originating from design deficiencies need to be assessed in detail to achieve corrections that also result in the prevention of pollution of water-receiving bodies, which is the main objective of erecting the WWTPs. It is understood that while these numerous design deficiencies exist, WWTPs cannot be operated consistently. A logic model for identifying and correcting the deficiencies is necessary to guarantee accurate removal of the deficiencies. From the statistical point of view, the number of design deficiencies identified in the investigated WWTPs follows a normal pattern. Considering the high frequency of the design deficiencies identified in the study, some points are discussed for correction, as outlined in the case studies. It is suggested that these corrections be implemented in the existing WWTPs and also considered in the new designs or upgrades. It was found that 68% of the operational deficiencies arise from the design deficiencies, and therefore methods for correcting them are discussed in this study. Besides this, it was found that 22% of all deficiencies are administration-related, whilst 10% of all deficiencies are construction-related. In the studied WWTPs, an average of eight design deficiencies were identified, with a standard deviation of 1.877. In addition, 35% of deficiencies observed were attributed to planning, 33% of deficiencies were associated with the operation of liquid treatment facilities, and 13% of all observed deficiencies were attributed to management strategies which could lead to effluent quality violations in different forms.

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ABBREVIATIONS

A2/O = Anaerobic Anoxic Oxic
ATV-DVWK = Deutsche Vereinigungfür Wasserwirtschaft, Abwasser und Abfall
BOD = Biological Oxygen Demand
EPA = Environmental Protection Agency
F/M = Food to Micro Organism
IWA = International Water Association
Mg/l = Milligram Per Litter
Mm^3/a = Million Cubic Meters per Annum
NEPO = National Environment Protection Organization
NWWC = National Water and Wastewater Company
RUB = Ruhr Universitaet Bochum
SKEW = Skewness
SS = Suspended Solids
TPM = Total Productive Maintenance
TSS = Total Suspended Solids
WWTPs = Wastewater Treatment Plants

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