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Network Directional Distance Function for Measuring Performance of Water Utilities in Malaysia

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ABSTRACT

Evaluating the performance of water supply services is crucial in many countries. Performance indicators (PIs) are often used to check how well water management is working. One important PI is the percentage of Non-Revenue Water (NRW), which shows how much water is being lost and how efficiently the utility is using water. Lower NRW percentages reflect better performance. NRW happens while delivering the water supply to the consumer; hence, NRW can be classified as an undesirable output in the water supply process. One type of Data Envelopment Analysis (DEA) model that directly considers the undesirable output factor is the Directional Distance Function (DDF) model. Recently, researchers have expanded the DEA and DDF models into network structures. Since the process of supplying the water services can be expressed as a network process, this study attempts to use the Network Directional Distance Function (NDDF) to measure the water utilities' performance that incorporates NRW as the undesirable output factor. Additionally, it proposes an alternative performance indicator for benchmarking Malaysian water utilities. The study used 2015-2016 data from the Suruhanjaya Perkhidmatan Air Negara (SPAN) on 14 Malaysian water utility providers. Results show that only Johor and Pulau Pinang were consistently efficient under both DDF and NDDF models. The NDDF model provided clearer efficiency rankings, identifying three efficient states across both years, whereas the DDF model found five in 2015 and seven in 2016. These findings suggest that NDDF enhances performance evaluation and ranking, helping authorities benchmark top-performing utilities for better water service management in Malaysia.

1. INTRODUCTION

Adequate supply of clean water is very crucial because water is a basic human need. To meet the basic needs of the peoples in the best way, the authorities in the main will give full attention for the management

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of the water supply services to meet the demands of all citizens. Therefore, all aspects in managing water supply services, especially the performance of the water utilities in providing cleaned and treated water need to be monitored. Globally, the problem of water loss is an issue that is taken seriously, and the authorities try to manage and reduce it as best as possible. In some countries and as well as Malaysia, water loss is regularly termed as Non-Revenue Water (NRW).

NRW can be described as the volume of cleaned and treated water that is produced by a water utilities' treatment plant and then supplied to the consumer but lost during the process which makes it lossmaking. Technically, NRW is computed as the difference between the water produced by a water treatment plant with the customer's billed amount (González-Gómez et al., 2011). The performance of water supply management can be signalled by its level of NRW. Lower level of NRW shows efficient water utilities' management. Furthermore, higher NRW will affects the revenue collection and weakened the sustainability of water utility operations. Therefore, performance measures should give credits to outstanding water utilities that have successfully managed in reducing their NRW level. Consequently, it is crucial to incorporate the NRW in the performance measures of water utilities. However, the performance indicators regarding NRW set by the authority is only concentrating on an NRW target rate. Despite that, there is no consensus on the indicator that should be applied to determine the NRW target rate (González-Gómez et al., 2011). Thus, a more appropriate method should be investigated to identify effective indicators related to NRW in the efficiency of the water sector. To address the need for reducing NRW rates, it can be treated as an undesirable output within the water supply system.

The evaluation of management efficiency in water utilities has utilized a variety of methods and models. These approaches range from straightforward performance indicators to more sophisticated mathematical models based on production frontiers. Such methodologies enable authorities to benchmark the efficiency of water utility management. Among these, the most used non-parametric frontier model for assessing the performance of water industry companies is Data Envelopment Analysis (DEA). A variant of DEA model that directly incorporates undesirable outputs was developed by Chung et al. (1997) and is known as the Directional Distance Function (DDF).

Another concern in the performance measurement of water service industry is the existing of linking activities among internal divisions or stages in the operations of water supply services (Kamarudin et al., 2015). These linking activities among internal divisions should be regarded and resolved by using network DEA (NDEA) (Färe & Grosskopf, 2000). As a variation of the DEA model, the DDF can also be adapted to a network structure, referred to as the network DDF (NDDF) (Fukuyama & Weber, 2010). Consequently, this study utilizes the NDDF model to suggest alternative performance indicator for benchmarking the efficiency of water utility management.

2. LITERATURE REVIEW

Various methods and models have been used to measure the performance of management of water utilities. Basically, most water utility authorities rely on simple performance indicators (PIs) to assess the performance of providers within the water services sector. Alternatively, Data Envelopment Analysis (DEA) is the most commonly used method for assessing performance in the water industry, first introduced by Byrnes et al. (1986) and subsequently adopted by many others (Romano & Guerrini, 2011). DEA is a non-parametric frontier model for measuring the relative efficiencies of a set of comparable units. DEA technique can deal with multiples performance measures in a single integrated model to set a best practice frontier for benchmarking (Russell, 1985). There are more studies around the world on the performance of the water supply services sector using the DEA model such as in USA (Lambert et al., 1993), Mexico (Anwandter & Ozuna, 2002), Spain (Garcia-Sanchez, 2006), Palestine (Alsharif, et al., 2008) and many others.

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As for studies in water industry, DDF was first used in Picazo-Tadeo et al. (2008), that features bad qualities in water supply service as undesirable output. Their research also considered NRW as one of the bad qualities that is produced together when delivering the water to customer. NRW also used as undesirable output in Kumar (2010), and stated that besides improving their service delivery, water utilities should credit the utilities that successfully reduced their NRW level. In Malaysia, water utilities recognize the challenge of reducing NRW in economically sustainable ways. Between 2000 and 2017, the average NRW in the country showed a slight decrease. Including the NRW in efficiency analyses is crucial, as it enables governments and regulators to assess policy decisions for water utilities, particularly when developing regulatory reform policies and promoting awareness of the need for NRW reduction (Goh & See, 2023). Research by Kamarudin et al. (2016) and See and Ma (2018) has demonstrated that neglecting NRW as an output measure (considered an undesirable output) can lead to inaccurate evaluations of water utilities, given its negative impact on water service delivery.

To account for the internal structure or operating network of a process, Färe and Grosskopf (1996) were the first to introduce the network DEA (NDEA) model. The NDEA model is applied when both inputs and outputs are involved in measured units that exhibit a network or stacked structure, as opposed to the single-structured approach of conventional DEA (often referred to as a black box). NDEA has since emerged as a significant area in the advancement of DEA-based models (Cook et al., 2010). Fukuyama and Weber (2014) explored different DEA model approaches for networks that incorporate undesirable outputs and extended the DDF model to create the NDDF model. As per mentioned earlier, water supply service operation can be expressed as a network structure, thus this study employed NDDF model which signifies a network production technology incorporated with the undesirable output factor. It is hope that this study is relevant in providing essential information to water utilities to improve their business practice, particularly in finding the best initiative to reduce the NRW level.

3. METHODOLOGY

3.1 Two-stage Network Production for Water Utilities

Water supply services operations can be expressed as a two-stage network structure, where in the first stage, raw water is treated and cleaned in the water treatment process (Division 1) and then, from the treatment plant, cleaned water is distributed to customers (Division 2). This study is also to highlight the issue of NRW. During the distribution process, the customer will be billed according to the amount of water consumed. The amount of water billed to consumers based on usage generates revenue to water utilities or service providers is called authorized consumption water. But, during this process, water utilities are also faced with water losses (NRW), which is the difference between water from the treatment plant with the authorized consumption of water. Water utilities aim to maximize revenue by minimizing water losses (NRW). Concisely, authorized water consumption or revenue can be classified as desirable output while NRW is classified as undesirable output of the water supply system.

The structure of operations for common water supply service can be depicted in a two-stage network framework as in Fig. 1. From past literatures in See (2015), the selection of inputs, intermediate products, desirable and undesirable outputs is concluded. In the water treatment process (Division 1), inputs such as operation costs (OPEX) and raw water are utilized to produce a volume of cleaned and treated water. Then the output from Division 1 is used as input to water distribution process (Division 2). This variable is called intermediate product. Pipe Length is a new input for Division 2. These inputs produce revenue generated from water delivered along with NRW as undesirable output.

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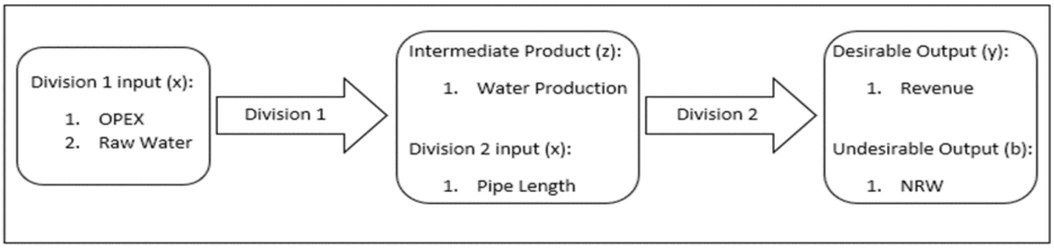

Fig. 1. Two-stage network production for water utilities

This study continues the work of Kamarudin et al. (2018; 2020), utilizing the same data gathered from the Suruhanjaya Perkhidmatan Air Negara (SPAN) as documented in Malaysian Water Industry Guide 2017 (MWIG, 2017). Table 1 and Table 2 show data set for 14 Malaysian water utilities in each state for year 2015 and 2016 respectively. The units for the variables; Pipe Length is in Kilometre (KM), OPEX and Revenue are in Malaysian Ringgit (RM). As for Raw water, Water production, and NRW are in Million litres per day (MLD). The water utilities for 14 states in Malaysia are the decision-making units (DMUs) in this study.

Table 1. Data set for 14 Malaysian water utilities for 2015

Water Utility	OPEX (RM)	Raw Water (MLD)	Water production (MLD)	Pipe Length (KM)	Revenue (RM)	NRW (MLD)
Johor	762,297	1,711	1,619	21,374	935,675	436
Kedah	269,374	1,411	1,315	11,942	294,000	614
Kelantan	88,545	476	454	7,152	98,729	222
Labuan	25,957	74	73	506	22,015	22
Melaka	162,879	668	519	4,913	191,593	93
Negeri Sembilan	214,116	865	752	8,524	236,446	264
Pulau Pinang	202,362	1,047	1,014	4,346	312,163	202
Pahang	267,936	1,198	1,129	13,585	153,585	596
Perak	222,153	1,321	1,289	11,457	367,020	382
Perlis	23,238	229	220	1,885	40,054	124
Sabah	406,253	1,314	1,229	13,868	281,293	677
Sarawak	210,894	1,268	1,268	12,005	256,411	423
Selangor	1,748,476	4,807	4,675	27,831	2,094,734	1,497
Terengganu	121,225	653	603	8,389	127,920	192

Table 2. Data set for 14 Malaysian water utilities for 2016

Water Utility	OPEX (RM)	Raw Water (MLD)	Water production (MLD)	Pipe Length (KM)	Revenue (RM)	NRW (MLD)
Johor	899,324	1,737	1,661	21,764	1,054,067	450
Kedah	292,535	1,471	1,361	12,002	307,322	637
Kelantan	100,555	501	471	7,452	117,940	232
Labuan	29,262	74	72	511	30,212	22
Melaka	195,469	737	510	5,032	228,070	95
Negeri Sembilan	262,897	897	779	8,659	276,661	253
Pulau Pinang	201,353	1,155	1,054	4,401	346,274	227

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Pahang	259,503	1,208	1,111	13,709	170,638	532
Perak	244,725	1,393	1,317	11,550	380,671	402
Perlis	39,172	260	230	1,897	31,414	148
Sabah	434,691	1,221	1,221	14,533	309,422	634
Sarawak	180,966	1,328	1,328	12,292	263,785	479
Selangor	1,794,207	5,088	4,807	28,191	2,040,494	1,547
Terengganu	121,624	682	616	8,363	133,429	189

3.2 Network Directional Distance Function (NDFF)

The main objective to measure the efficiency is to see how far the output can be increase based on the input or how much input can be reserve after certain output have been produced (Kao, 2017). Data Envelopment Analysis (DEA) is used to measure the efficiency in operation. DEA measures the performance of the decision-making unit (DMU) where the multi-inputs is used for producing multi-outputs (Charnes et al., 1978). It can be said that if the DMU is on the efficient boundaries, then it can be concluded that the DMU is efficient. The non-efficient DMU can be clearly shown by looking at the gaps in performance of DMU that is not efficient with the efficient boundaries (Fukuyama, & Weber, 2010).

A standard traditional DEA model only considers a one-stage process. In most productions, the process of creating the output from the input requires a more than one stage process whereby the processes are referred to as sub-DMU or division. Ignoring a division in measuring the performance of the DMU can produce an inexact result (Kao, & Hwang, 2008). Furthermore, Kao (2017) stated that the two-stage DEA is a very basic form of network DEA (NDEA). As for instance, in the two-stage process, the input of the first division produces the intermediate product which will then be used as an input in the second division to produce the final output. Later, DEA is modified to treat the undesirable output directly in the model by Chung, et al. (1997) and is called Directional Distance Function (DDF) model. Inspired by Chambers et al. (1998), DDF model is used when researchers need to expand the desirable output or good output and reduce undesirable outputs or bad outputs based on the direction vector given. Based on Chung et al. (1997) and Fukuyama and Weber (2010), formulation for calculating the DDF efficiency scores (β_o) for DMUo are as in Eq. (1).

$$
\begin{aligned}
&\text{Max } \beta_o \\
&\quad \text{Subject to} \\
&\qquad \textstyle\sum_{n=1}^{N} \lambda_n x_n \le x_o \;; \\
&\qquad \textstyle\sum_{n=1}^{N} \lambda_n y_n \ge y_o + \beta g_y \;; \\
&\qquad \textstyle\sum_{n=1}^{N} \lambda_n u_n = u_o - \beta g_u \;; \\
&\qquad\quad \lambda_n \ge 0; n = 1, 2, \dots, N
\end{aligned} \tag{1}
$$

where:
n = a DMU (N = number of DMUs)
λ = an intensity vector
x = an input
y = an desirable output
u = an undesirable output
g_y = direction vector of desirable output
g_u = direction vector of undesirable output

The DDF and NDDF model seeks for the extension based on g_y direction for desirable output and reduction based on g_u direction for undesirable output. The proportion β increases the desirable outputs and reduces the undesirable outputs by the direction vector of g at the same time. A DMU is efficient when β_o score is zero and indicates inefficiency when $\beta_o > 0$. For this study, the selected directional vector g is

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taken as (0, y, u) which y and u are observed DMU's desirable and undesirable output values. While $g_x = 0$, defined the inputs are constant and search for the maximum extension in desirable outputs and reduction in undesirable outputs. This means, when β_o is multiplied by 100%, it gives the maximum percentages to expand the desirable outputs and to decrease the undesirable outputs. For example, if percentage of β_o is 10%, that means, all desirable outputs will be expanded while all undesirable outputs will be reduced by 10%.

Next, the Eq. (1) is modified according to Fukuyama and Weber (2014), to address the two-stage network structure as shown in Fig. 1. Formulation for calculating the NDDF efficiency scores (β_o) for DMUo are as in Eq. (2) below.

$$\begin{aligned}
&\text{Max } \beta_o \\
&\quad \text{Subject to} \\
&\qquad \textstyle\sum_{n=1}^{N} \lambda_n x_n \leq x_o \ ; \\
&\qquad \textstyle\sum_{n=1}^{N} \lambda_n y_n \geq y_o + \beta g_y \ ; \\
&\qquad \textstyle\sum_{n=1}^{N} \lambda_n u_n = u_o - \beta g_u \ ; \\
&\qquad \textstyle\sum_{n=1}^{N} z_n(\lambda_n^1 - \lambda_n^2 \geq 0 \ ; \\
&\qquad\quad \lambda_n^1, \lambda_n^2 \geq 0; n = 1, 2, ..., N
\end{aligned} \tag{2}$$

where:
λ^1 = an intensity vector for stage 1
λ^2 = an intensity vector for stage 2
z = an intermediate product and the rest are similar as presented in the Eq. (1).

The optimal target point for the desirable and undesirable output for DMUo can be computed as $y_o + \beta^* g_y$ and $u_o - \beta^* g_u$ where the asterisk superscript indicates an optimal solution to Eq. (2). All the values for input-outputs and intermediate product variables are coded and executed under LINGO 20.0 software to obtain the efficiency scores for both Eq. (1) and Eq. (2).

4. RESULTS AND DISCUSSIONS

This study uses output-oriented DDF model (Eq. 1) and two-stage NDDF model (Eq.2) to determine the efficiency score for all the DMUs. Our primary concern is to increase revenue and alleviate NRW level while all other inputs will be maintained. DDF model is a single stage process, therefore, there are no intermediate product variables involved. Input variables are OPEX, raw water, and Pipe Length. Meanwhile, output variables are Revenue and NRW. Results of DDF model are for comparison purposes. Table 3 and Table 4 shows the optimal β^*(efficiency score) for DMUs by the DDF and the NDDF models respectively, together with the changes and their optimal target points for corresponding desirable (Δy_o^* and y_o^*) and undesirable outputs (Δu_o^* and u_o^*) for year 2015.

Table 3. Results of DDF model for year 2015

Water utility	**β^* DDF**	**Rank**	**Δy_o^* DDF**	**y_o^* DDF**	**Δu_o^* DDF**	**u_o^* DDF**
Johor	0.00	1	0	935,675	0	436
Kedah	0.43	12	126,770	420,770	-264	349
Kelantan	0.42	11	41,425	140,154	-93	128
Labuan	0.27	7	6,101	28,116	-6	15
Melaka	0.02	6	3,912	195,505	-1	91
Negeri Sembilan	0.28	8	68,138	304,584	-76	187
Pulau Pinang	0.00	1	0	312,163	-0	202

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Pahang	0.78	14	120,654	274,239	-468	127
Perak	0.00	1	0	367,020	-0	382
Perlis	0.00	1	0	40,054	-0	124
Sabah	0.67	13	190,037	471,330	-457	219
Sarawak	0.31	9	80,908	337,319	-133	289
Selangor	0.00	1	0	2,094,734	-0	1,497
Terengganu	0.41	10	52,883	180,803	-79	112

A DMUo is said to be efficient when the value of efficiency score (β_o) is calculated to be 0 and inefficient if the value is $\beta_o > 0$ (Fukuyama, & Weber, 2014). Value of β_o, computed from Eq. (1) is called efficiency score for the DMUo. Column 2 shows the optimal efficiency score β^* for each DMU. There are five efficient DMUs which are Johor, Pulau Pinang, Perak, Perlis and Selangor. From the scores in column 2, all the DMUs can be ranked according to descending order value. Those with a value of 0 are ranked as the highest or first. The ranking value for each DMU is shown in column 3. From the efficiency score value, if multiplied by 100%, it gives the percentage of maximum expanding of the desirable output and decreasing of the undesirable output. It indicates the changes should be made by the DMUs if they want to become efficient. For example, DMU Kedah efficiency score is 0.43 which is 43% of Revenue needs to be increased while 43% of the present of NRW level should be decreased.

The value in column 4 shows the Revenue amount that should be increased or retained by the corresponding DMUs. When we deduct the present value of Revenue for each DMU with the corresponding value in column 4, optimal target (projection) points (y_o^*) for Revenue are computed as depicted in column 5. For column 6, the values specify the required decreased level of NRW (Δu_o^*) for the DMU to become efficient. As for column 7, it is the optimal target point of NRW level (u_o^*) for each DMU. For instance, DMU Johor is an efficient water utility, no changes are needed whether to increase the Revenue or to decrease the NRW level. While Pahang, that ranked last, need to increase their Revenue by RM120,654 to achieve optimal value of RM 274,239. At the same time, Pahang needs to decrease their NRW level by 468 MLD to achieve a level of 127 MLD. Table 4 below shows the result of the NDDF model for the year 2015.

Table 4. Results of NDDF model for year 2015

Water utility	β^* NDDF	Rank	Δy_o^* NDDF	y_o^* NDDF	Δu_o^* NDDF	u_o^* NDDF
Johor	0.00	1	0	853,527	0	426
Kedah	0.60	10	176,842	467,433	-362	233
Kelantan	0.63	11	62,488	160,898	-139	80
Labuan	0.39	6	6,391	22,632	-7	12
Melaka	0.05	4	9,518	193,810	-5	96
Negeri Sembilan	0.48	7	90,218	278,166	-128	138
Pulau Pinang	0.00	1	0	278,504	-0	182
Pahang	0.77	14	117,859	270,915	-452	135
Perak	0.35	5	125,553	475,886	-135	243
Perlis	0.75	13	25,646	59,665	-91	29
Sabah	0.69	12	155,590	380,098	-428	189
Sarawak	0.48	8	128,279	391,884	-185	195
Selangor	0.00	1	0	2,023,915	-0	1,545
Terengganu	0.50	9	62,570	186,509	-94	93

Meanwhile, Table 4 displays the results of NDDF model for year 2015. From column 2, it shows only three DMUs are efficient, which are Johor, Pulau Pinang, and Selangor. Like findings from DDF

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model, but, for NDDF, Perak and Perlis are portrayed as inefficient. The ranking distribution in column 3 is quite similar with DDF models for all DMUs. Columns 4 and 5 show the changes (Δy_o^*) and optimal target points (y_o^*) of each DMU for Revenue, meanwhile columns 6 and 7 give the information for the changes (Δu_o^*) and optimal points (u_o^*) for NRW. Compared to findings from DDF model, the efficiency score is slightly increased for NDDF model. It indicates the bigger percentage of changes is needed for inefficient DMUs to become efficient.

Next, results and findings for year 2016 of DDF model and NDDF model are shown in the Table 5 and Table 6.

Table 5. Results of DDF model for year 2016

Water utility	**β^* DDF**	**Rank**	**Δy_o^* DDF**	**y_o^* DDF**	**Δu_o^* DDF**	**u_o^* DDF**
Johor	0.00	1	0	1,054,067	0	450
Kedah	0.53	11	165,137	472,459	-342	294
Kelantan	0.00	1	0	117,940	0	232
Labuan	0.06	8	1,912	32,124	-1.3	20
Melaka	0.00	1	0	228,070	0	95
Negeri Sembilan	0.27	9	76,635	353,296	-70	182
Pulau Pinang	0.00	1	0	346,274	0	227
Pahang	0.76	13	130,415	301,053	-406	125
Perak	0.00	1	0	380,671	0	402
Perlis	0.78	14	24,788	56,202	-116	31
Sabah	0.65	12	202,624	512,046	-415	218
Sarawak	0.00	1	0	263,785	0	479
Selangor	0.00	1	0	2,040,494	0	1,547
Terengganu	0.40	10	54,233	187,662	-76	112

Findings for year 2016 of DDF model in Table 5 denotes seven efficient DMU which are Johor, Kelantan, Melaka, Pulau Pinang, Perak, Sarawak, and Selangor. Column 3 represents the ranking for all the DMUs for that year. Likewise, Table 3 and Table 4, columns 4 and 5 show the changes and optimal target points of each DMU for Revenue, meanwhile columns 6 and 7 give the information for the changes and projection level for NRW for individual DMU.

Table 6. Results of NDDF Model for Year 2016

Water utility	**β^* NDDF**	**Rank**	**Δy_o^* NDDF**	**y_o^* NDDF**	**Δu_o^* NDDF**	**u_o^* NDDF**
Johor	0.00	1	0	1054067	0	450
Kedah	0.66	12	204,471	511793	-423	213
Kelantan	0.65	10	76,720	194660	-150	81
Labuan	0.07	5	2,274	32486	-1.6	20
Melaka	0.00	1	0	228070	0	95
Negeri Sembilan	0.37	6	103,499	380160	-94	158
Pulau Pinang	0.00	1	0	346274	0	227
Pahang	0.76	13	130,415	301053	-406	125
Perak	0.42	7	163,087	543758	-172	229
Perlis	0.83	14	26,310	57724	-123	24
Sabah	0.66	11	204,871	514293	-419	214
Sarawak	0.62	9	165,347	429132	-300	178

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Selangor	0.01	4	23,826	2064320	-18	1,528
Terengganu	0.54	8	72,787	206216	-103	85

In the meantime, Table 6 reveals the results of NDDF model for year 2016. Like 2015, there are only three efficient DMUs for 2016. Only Johor, Melaka, and Pulau Pinang are the efficient ones. If compared to DDF model findings, DMU Kelantan, Perak, Sarawak, and Selangor are inefficient in NDDF model. Column 3 shows the ranking distribution for 2016 using NDDF model. Columns 4 and 5 display the changes (Δy_o^*) and optimal target points (y_o^*) of each DMU for Revenue, as for columns 6 and 7 present the information for the changes (Δu_o^*) and optimal points (u_o^*) (projection level) for NRW. Like 2015, the efficiency score is slightly increased for NDDF model compared to efficiency score in DDF model in 2016. Similarly, for inefficient DMUs to make improvement, bigger changes are required.

From the results, we can conclude DMU Johor and Pulau Pinang are the most efficient water utilities. It shows that the management of water utilities Johor and Pulau Pinang are best at utilized their resources in producing higher revenue and at the same time, trying their best to reduce the NRW level. Findings from 2015 and 2016 is quite comparable in term of the ranking and percentage of changes for both the DDF and NDDF models.

5. CONCLUSION AND RECOMMENDATIONS

This study is to be reasoning for any comparison between the DDF and NDDF approaches. It also determines for any advantages in applying the NDDF approach in evaluating the performance of water utilities particularly in Malaysia. The NDDF approach has been employed to benchmark water utilities operations as there are two serial divisions related, namely the water treatment process and water distribution process. A dataset of 14 states representing water utilities in the years 2015 and 2016 have been computed and compared for both DDF and NDDF approaches. This brings to conclusion that the DDF approach for evaluating water utilities' performance has deduced unfair evaluation as compared to the two-stage NDDF approach. We can say that the NDDF approach discloses a higher improved percentage needed to the recent operation points than DDF approach does. Hence, the NDDF approach proves to be more reliable as it is more comprehensive rather than just attributing all the factors (inputs and outputs) in a single accumulated process.

Furthermore, findings from this study can be used as guidelines for continuous improvements in water utilities' management practice. This is because, projected potential reduction level of NRW can be regarded as the best initiative to decrease the NRW level. A possible continuation of this study is to evaluate the stage efficiencies of water utilities operation processes. This can be a subject of interest as it will help the water utilities' management to determine which subsequent process should be given priority and study to further improve the performance of inefficient water utilities.

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7. CONFLICT OF INTEREST

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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8. AUTHOR'S CONTRIBUTIONS

Norbaizura Kamarudin: Conceptualisation, methodology, writing the original draft, handling data analysis; **Zuraida Khairuddin**: Conceptualisation, methodology, writing the original draft; **Nur 'Ainina Awang:** Reviewing and editing the original draft, conducting validation; **Nur Rasyida Mohd Rashid:** Reviewing and editing the original draft, handling data analysis; **Zuraidah Derasit**: Reviewing, validation and editing.

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