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# An Analysis of Production Efficiency in Reverse Osmosis Drinking Water Plants in Faisalabad, Punjab: A DEA Approach

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**ABSTRACT**

The aim of present study was the estimation of technical, allocative and economic efficiencies in the production of safe and clean drinking water using reverse osmosis plant. Primary data was collected from the managers of 84 safe and clean drinking water plants in city Faisalabad. Non parametric or Data Envelopment Analysis (DEA) model was used to find technical, allocative and economic efficiencies. There exist technical, allocative and economic inefficiency in the business. Mean value of technical, allocative and economic efficiency was 0.680, 0.748 and 0.511, respectively. Medium plants were found to be more technical and economically efficient while small plants were allocatively more efficient. The determinants of production inefficiencies were also checked by using Tobit Regression Model. Results shows education of plant manager and water business experience has negative and significant impact on production inefficiency while age of manager has positive and significant impact.

**KEYWORDS:** Drinking water plant, DEA Model, Economic efficiency, Reverse Osmosis, Tobit Model

## INTRODUCTION

A natural process which involve the movement of a solvent like water from lower to higher solute concentration side with the help of semi permeable barrier until a chemical potential equilibrium level is achieved is called as osmosis as shown figure 1a. The osmotic pressure of the solution is equal to the pressure difference between the sides of membrane at equilibrium state. In order to reverse the direction of solvent like water, a pressure difference is applied which is greater as compared to osmotic pressure difference as shown in figure 1b. After this process water is separated and pure water flows from high to low concentration side. It is called as reverse osmosis or hyper filtration [1].

Fresh water sources supply safe drinking water but unfortunately these are only 2.5% of total availability of water on earth which is 1.4 billion cubic kilometers. Water that appropriate to drink without further treatment is below 1 percent of total available fresh water [2]. Safe water in sufficient quantity is not available to a large number of people. Water borne diseases put pressure on developing and developed countries. Migration due to high population is well observed in developing countries and responsible for increasing competition in God gifted resources like water and air in urban areas. Persons in urban areas are unwontedly spending significant money for treatment of water to fulfill drinking needs [3].

Khan and Javed [4] found that water availability in Pakistan was only 1200 cubic meter per capita in 2003 while it was 5600 cubic meter per capita in 1952. There was a deliberate increase in total public sector expenditure on water and sanitation. The share of this sector in GDP increases only 0.01% from 0.12% to 0.13% in last five years from 2000-01 to 2004-05. In Pakistan, infant deaths due to diarrhea were reported as 45 percent and the figure was 60 percent for infectious waterborne diseases. There were 25 to 30 percent gastro intestinal diseases. There is an increase in the industry and market of bottled water within short period. Unfortunately, a large number of mineral water companies are selling low quality and contaminated water. PCRWR is working in Pakistan as focal point agency to monitor quality of bottled water [5].

Bhattacharyya et al. [6] showed that utilities under private ownerships were working more efficiently while districts under self governing water were working less efficiently. Souza et al. [7] declared that public firms were working more efficiently as compared to privately owned firms but the gap in efficiency was shrinking with the passage of time.

It was found that the underground water of city Faisalabad was not recommended for drinking due to salinity. Water and Sanitation Agency (WASA) Faisalabad was established to supply safe drinking water to the citizens. WASA Faisalabad used different resources and supply nearly 88.5 Million Gallons per Day (MGD) water to met the water requirements [8]. WASA Faisalabad supplied inexpensive water but the supply was less

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than demand. Problems like old pipe lines, mixing of filthy water, low pressure of water, use of electric motor, availability in limited hours, load shedding forced people to private safe and clean drinking water plants. Water from private plants is available but it is expensive.

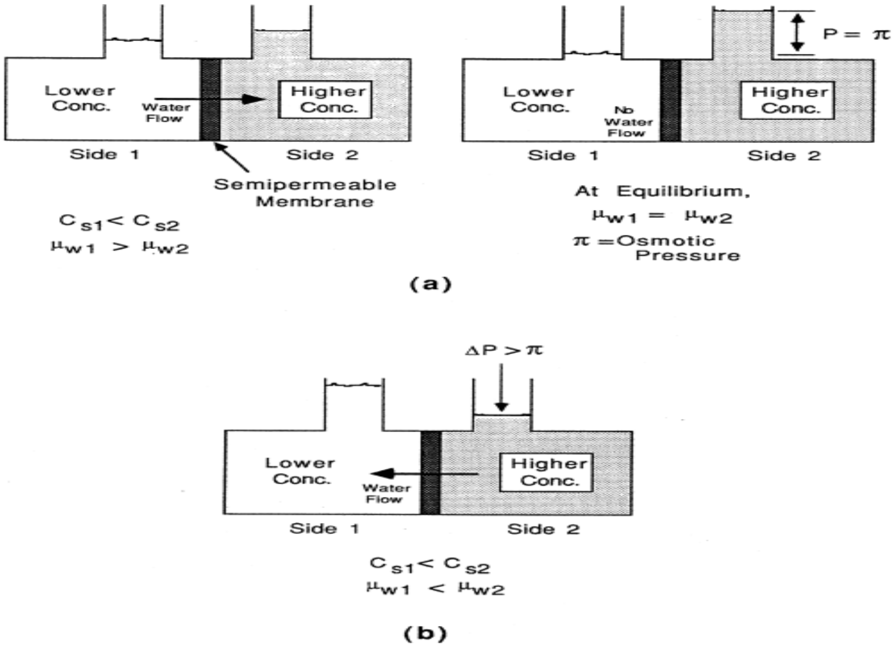


Figure 1: Flow chart of osmosis and reverse osmosis procedure [1]

Atikol and Aybar [9] calculated the cost of fresh water production in 1000 $m^3$/day reverse osmosis technology such as cost of electricity, cost of capital, cost of membrane replacement, cost of maintenance and chemical cost. The efficient and new plant showed a cost of 0.68\$/$m^3$ while the production cost was 0.86\$/$m^3$ for a similar plant outside the study area.

Shih et al. [10] examined the cost of production in case of water supply systems. They found that there was a 0.16% significant decrease in unit cost of water due to 1% increase in the production of water. Higher economies of scale was found in the cost of capital, outside cost and material cost but lower economies of scale was found in case of labour and energy cost. Feo et al. [11] estimated the cost involved in the desalination of $m^3$ of water in case of small reverse osmosis plant. Economy of scale was affected by optimum production cost. The cost was 1.5% less for efficient production as compared to normal production.

Hernández-Sancho and Sala-Garrido [12] checked the efficiency in case of waste water treatment plants which was used for reuse of water. They found the efficiency of large plants was higher than small plants. Liu et al. [13] demonstrated the efficiency in the use of energy by a reverse osmosis plant. The total input energy in the desalination of water was more as compared to thermodynamic minimal energy. For economical point of view, more energy was required in cross flow RO. They also compared the efficiency of energy with an ideal reverse osmosis plant.

However, no research study was found about the efficiency analysis of safe and clean drinking water plants based on reverse osmosis technology. The estimation of production efficiency is more preferable research area for developing countries which have the ability to raise the level of production but the adopting new technologies are very limited [14]. It is required to increase the economic efficiency of drinking water plants. High economic efficiency results in minimization of cost and increase in profit. Due to this, producers of safe and clean drinking water will increase which creates perfect competition in the market. We know that public welfare is maximized under perfect competition. Complete and updated information about the economic efficiency of safe and clean drinking water plants is still not satisfactory. Therefore, the present study was designed to check the economic efficiency in the production of safe and clean drinking water reverse osmosis plants. Moreover, the determinants of economic inefficiency were also checked.

## MATERIALS AND METHODS

Actual productivity of a firm as compared to its maximum productivity is known as efficiency while production frontier is used in order to find the actual productivity of a firm [15-16]. For the estimation of production frontier, two well-known approaches were used like stochastic frontier analysis (SFA) based on parametric procedure and data envelopment analysis (DEA) based on nonparametric procedure. DEA or nonparametric models are based on linear programming techniques. The distance between production frontier and actual data points was measured in order to calculate the efficiency of a firm. An increased distance between actual data points and production frontier pointed out the presence of inefficiency. The orientation is selected on the basis of quantities like inputs or output on which the control of manager was more [16]. The current study used input oriented DEA model because the owner of water plant has greater control over inputs as compared to output.

For technical efficiency estimation, DEA model was used which was based on variable returns to scale as well as constant returns to scale. DEA model based on constant returns to scale was preferable when each firm was working at optimal scale [17]. When all firms were not working at optimal scale than DEA model based on constant returns to scale was responsible for the problem in the measurement of technical efficiencies which were confounded by scale efficiencies. Therefore, Bankers et al. [18] used a DEA model based on variable returns to scale with the addition of convexity constraints. The current study used both models for the estimation of technical efficiency in case of reverse osmosis drinking water plants.

Primary data were collected from the owners of reverse osmosis drinking water plants in city Faisalabad. A sample size of 60 is considered as feasible for larger population if we want reliable results for decision-making [19], cited in [20]. The sample size for current study was 84 safe and clean drinking water plants in city Faisalabad. The plants were categorized in two types on the basis of plant capacity like 1000 liters per hour and 2000 liters per hour. Stratifies random sampling technique was adopted for the collection of primary data. In stratifies random sampling, the entire population is divided in different sub groups (like owner of small and medium sized reverse osmosis drinking water plants) and then a sample is randomly selected from each strata or sub group [21]. Managers of plants were asked about the production and input use in safe and clean drinking water. The owners of plants were interviewed with the help of comprehensive and pretested questionnaire. Data collected was entered, cleaned and analyzed to address the objectives. The software (s) of statistical and econometric analysis Microsoft Excel, DEAP 2.1 and Eviews 7 were used for data analysis.

**Empirical Models:**

Total revenue (Y) was used as output variable for technical efficiency estimation and was calculated by multiplying the quantity of safe and clean drinking water with market price. The inputs variables were number of membrane vessel ($X_1$), PP bottles ($X_2$), minerals ($X_3$), number of filters ($X_4$), labour ($X_5$) and electricity ($X_6$). Javed [14] used an input oriented DEA model based on constant return to scale expressed as:

min $_{\theta,\lambda}\theta,$

subject to

$$-yi + Y\lambda \geq 0$$
$$\theta xi - X\lambda \geq 0$$
$$\lambda \geq 0$$

Where:

$Y$ shows output matrix of N plants.

$\theta$ shows total technical efficiency of ith plant.

$\lambda$ represents Nx1 constants.

$X$ represent input matrix for N plants.

$yi$ shows total revenue of ith plant in Rs.

$xi$ shows the input vector of x1i,x2i,……x9i inputs of ith plant.

$x_{1i}$ shows number of membrane in ith plant.

$x_{2i}$ shows number of PP bottles used at ith plant.

$x_{3i}$ shows total mineral in kg used at ith plant.

$x_{4i}$ shows number of filters used at ith plant.

$x_{5i}$ shows the labour in numbers working at ith plant.

$x_{6i}$ shows the units of electricity consume at ith plant.

Javed [14] also used input oriented DEA model based on non increasing return to scale (NIRS) which was expressed as:

min $_{\theta,\lambda}\theta,$

subject to

$$-yi + Y\lambda \geq 0$$
$$xi - X\lambda \geq 0$$
$$N1^{/}\lambda \leq 1$$
$$\lambda \geq$$

Scale efficiency is simply the ratio between total technical efficiency ($TE_{CRS}$) and pure technical efficiency ($TE_{VRS}$). There exists scale or constant return to scale when its value is equal to 1 while there is scale inefficiency when its value is less than 1. Scale inefficiency was due to the existence of increasing or decreasing returns to scale. It was determined with the help of an additional DEA model based on non increasing returns to scale (NIRS).

According to [22], cited in [14], a cost minimization DEA model is used as a prerequisite in the calculation of economic efficiency. After that, economic efficiency is simply calculated by dividing minimum cost to actual cost. The same cost minimization method was used for current study which is expressed as:

$$\min_{\lambda,\, xi^E} wi\, xi^E$$

subject to

$$-yi + Y\lambda \geq 0$$
$$xi^E - X\lambda \geq 0$$
$$N1'\lambda = 1$$
$$\lambda \geq 0$$

Where:

$w_i$ shows the vector of input price $w_{1i}, w_{2i}, \ldots\ldots\ldots, w_{6i}$ of ith plant.

$X_i^E$ shows the cost minimizing vector of input quantities for ith plant.

N denote the total number of plants in the sample.

$w_{1i}$ shows the price of membrane vessel in Rs.

$w_{2i}$ shows the price of PP bottles used at ith plant in Rs.

$w_{3i}$ shows the price of mineral used at ith plant in Rs./kg

$w_{4i}$ shows the price of filter used at ith plant in Rs.

$w_{5i}$ shows the wage rate at ith plant in Rs.

$w_{6i}$ shows the price of electricity unit including all taxes and charges at ith plant in Rs.

Economic efficiency is calculated by dividing minimum cost with actual cost.

$$\text{Economic Efficiency} = \text{minimum cost/actual cost}$$
$$EE = wi\, xi^E / wi\, xi$$

Allocative Efficiency is simply a ratio of economic efficiency with technical efficiency.

$$\text{Allocative Efficiency} = \text{Economic Efficiency / Technical Efficiency}$$
$$AE = EE/TE$$

Software (s) like DEAP 2.1, Microsoft Excel were used for the estimation of total technical, pure technical, allocative, economic and scale efficiency scores.

A question arises about the reasons of difference in efficiency score irrespective of similar operating system of drinking water plants. In current study, different socioeconomic and plant-specific characteristics were selected to check their impact on technical, allocative, and economic inefficiency in the production of safe and clean drinking water. Efficiency scores were subtracted from 1 in order to find the inefficiency scores and their value falls between zero and one [23-25]. The scores of technical, allocative, and economic inefficiency were individually regressed on farm-specific and socioeconomic characteristics for the identification of inefficiency sources. A normal distribution does not observe for dependent variable in regression model. Krasachat [26] pointed out the non suitability of ordinary least square (OLS) because it gives biased parameters when inefficiency scores were regressed on plant-specific and socioeconomic characteristics. Therefore, a better option is the use of Tobit regression model [27].

The plant-specific and socioeconomic variables used in Tobit model were: schooling years of the plant owner, age of the plant owner, experience in water business, number of workers, number of water delivery vehicles, number of membrane vessel and number of filters per month. Tobit regression model used in current study is expressed as:

$$E_i = E_i^* = \beta_0 + \beta_1 Z_{1i} + \beta_2 Z_{2i} + \beta_3 Z_{3i} + \beta_4 Z_{4i} + \beta_5 Z_{5i} + \beta_6 Z_{6i} + \beta_7 Z_{7i} + \mu_i \qquad \text{If } E^* > 0$$

$$E = 0 \quad \text{if} \quad \text{If } E^* \leq 0$$

where

i denote the ith plant in the sample.

$E_i$ indicate the score of technical, allocative, and economic inefficiency at ith plant.

$E_i^*$ is the latent variable.

$Z_{1i}$ indicate the education of the ith plant owner in years.

$Z_{2i}$ indicate the age of ith plant owner in years.

$Z_{3i}$ indicate the water business experience of ith plant owner in years.

$Z_{4i}$ indicate the number of workers at ith plant.

$Z_{5i}$ represents the number of water delivery vehicles at ith plant.

$Z_{6i}$ represents the number of membrane vessels at ith plant.

$Z_{7i}$ represents the number of filters used in one month at ith plant.

ß's shows the unknown parameters to be estimated.

$\mu_i$ is the error term.

## RESULTS AND DISCUSSION

Total cost of reverse osmosis safe and clean drinking water plant was Rs. 378,593.63 for small plant while it was Rs. 546,994.50 for medium size plant. The expenses on laboratory were Rs. 67,343.75 for small plant while it was Rs. 130,500.00 in case of medium plant. The mineral cost was Rs. 3,570.52 per month a small plant while it was Rs. 5,961.25 per month for medium plants. Total variable cost was Rs. 58,965.01 per month for small safe and clean drinking water plant but it was Rs. 84,597.75 per month medium plant. Table 1 show the variable costs involved in the production of safe and clean drinking water. The total revenue was Rs. 6,191.92 per day in summer season for small plant and it was Rs. 3,095.96 per day in winter season for same kind of plant. The total revenue was Rs. 9,504.24 per day in summer season for medium plant and it was Rs. 4,752.12 per day in winter season for same kind of plant.

**Table 1: Average variable costs (Rs. /month) in the production of safe drinking water**

| Particular | Plant Size | | | |
|---|---|---|---|---|
| | Small R.O. plant (1000 liters per hour) | | Medium R.O. plant (2000 liters per hour) | |
| | Summer | Winter | Summer | Winter |
| Minerals (Rs.) | 3570.52 | 1785.26 | 5961.25 | 2980.63 |
| Filter Changing (Rs.) | 4817.11 | 2408.56 | 6576.50 | 3288.25 |
| Wages (Rs.) | 25157.96 | 25157.96 | 38590.00 | 38590.00 |
| Electricity Charges (Rs.) | 15675.00 | 7837.50 | 21350.00 | 10675.00 |
| Postage and Stationery (Rs.) | 1082.81 | 541.41 | 1375.00 | 687.50 |
| Telephone/Fax Charges (Rs.) | 1332.81 | 666.41 | 1635.00 | 817.50 |
| Repairing/Maintenance of Plant (Rs.) | 2329.69 | 1164.84 | 2650.00 | 1325.00 |
| Repairing/Maintenance of Vehicle (Rs.) | 1214.29 | 607.14 | 1585.00 | 792.50 |
| Transport Charges (Rs.) | 2628.57 | 1314.29 | 3425.00 | 1712.50 |
| Miscellaneous Expenses (Rs.) | 1156.25 | 578.13 | 1450.00 | 725.00 |
| Total Variable Cost (Rs.)/month | 58965.01 | 42061.50 | 84597.75 | 61593.88 |

Table 2 express the average value of total technical efficiency of safe drinking water plants is 0.680 with a minimum of 0.313 and a maximum of 1.0. It indicates 32% input reduction and 25.2% cost reduction if a plant is working at full efficiency level while output and technology remains unchanged. The average value was 0.963 in case of pure technical efficiency ranges from 0.614 to 1.0. The average scale efficiency was 0.712 in safe and clean drinking water plants ranging from 0.313 to 1.0. It is found that on 10.71% plants are scale efficient (SE=1) while other scale inefficiency was observed for 89.29% plants. The average allocative efficiency of drinking water plants is 0.748 lies between 0.453 and 1.0. The average value of economic efficiency was 0.511 ranges from 0.210 to 1.0. Mean value of all these production efficiencies are expressed in table 2. Results showed the existence of considerable allocative and economic inefficiency in safe and clean drinking water production.

**Table 2: Descriptive statistics of production efficiencies in drinking water plants**

| Efficiency | Mean | Maximum | Minimum |
|---|---|---|---|
| Technical Efficiency (CRS) | 0.680 | 1 | 0.313 |
| Technical Efficiency (VRS) | 0.963 | 1 | 0.614 |
| Scale Efficiency | 0.712 | 1 | 0.313 |
| Allocative Efficiency | 0.748 | 1 | 0.453 |
| Economic Efficiency | 0.511 | 1 | 0.210 |

Table 3 shows that majority of safe and clean drinking water plants have total technical efficiency between 0.51 and 0.60. Out of 84 plants, 14.29 percent plants have total technical efficiency more than 0.90. Majority of plants (84.52%) have pure technical efficiency within the range of 0.91 and 1.0. Only 5.95 percent plants have pure technical efficiency between 0.81-0.90. Majority of plants (25%) have scale efficiency between 0.51 and 0.60. Majority of plants (38.10%) have allocative efficiency within the range of 0.71 and 0.80. Only 9.52% plants have allocative efficiency more than 0.91. A large number of plants (28.57%) have economic efficiency within the range of 0.41 and 0.50. Only 4.76% plants have economic efficiency more than 0.91.

**Table 3: Frequency distribution of production efficiencies in drinking water plants**

| Efficiency Range | $TE_{(CRS)}$ | | $TE_{(VRS)}$ | | SE | | AE | | EE | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Freq. | % | Freq. | % | Freq. | % | Freq. | % | Freq. | % |
| 0.01-0.10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.11-0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.21-0.30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5.95 |
| 0.31-0.40 | 2 | 2.38 | 0 | 0 | 2 | 2.38 | 0 | 0 | 17 | 20.24 |
| 0.41-0.50 | 10 | 11.90 | 0 | 0 | 10 | 11.90 | 3 | 3.57 | 24 | 28.57 |
| 0.51-0.60 | 25 | 29.76 | 0 | 0 | 21 | 25.00 | 10 | 11.90 | 19 | 22.62 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **0.61-0.70** | 13 | 15.48 | 2 | 2.38 | 9 | 10.71 | 10 | 11.90 | 10 | 11.90 |
| **0.71-0.80** | 14 | 16.67 | 6 | 7.14 | 13 | 15.48 | 32 | 38.10 | 3 | 3.57 |
| **0.81-0.90** | 8 | 9.52 | 5 | 5.95 | 11 | 13.10 | 21 | 25.00 | 2 | 2.38 |
| **0.91-1.00** | 12 | 14.29 | 71 | 84.52 | 18 | 21.43 | 8 | 9.52 | 4 | 4.76 |
| **Total** | 84 | 100 | 84 | 100 | 84 | 100 | 84 | 100 | 84 | 100 |

All production efficiencies were also estimated with respect to plant size. Figure 2 shows the mean values of these efficiencies with respect to plant size. It is cleared that small plants had higher value of pure technical efficiency and allocative efficiency. Medium plants had higher value of total technical efficiency, scale efficiency and economic efficiency.

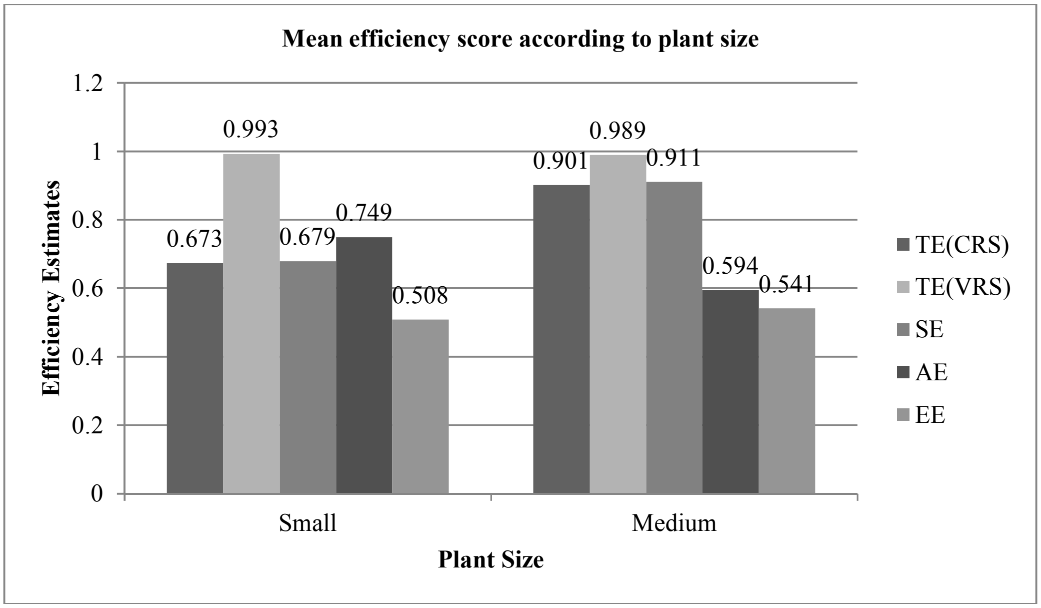


Figure 2: Production efficiencies with respect to plant size

Sources of production inefficiencies in safe and clean drinking water production are explored in table 4. The impact of age was positive and significant on all production inefficiencies. It shows that the inefficiency score increases with age and it might be due to the fact the younger plant owners has more education than older plant owner. The production of safe drinking water is a technical business and a younger manager quickly learns the technical knowledge. The coefficient of education was negative and significant in case of technical and economic inefficiency but it was positive and highly insignificant for allocative inefficiency. It shows that plant owner with higher education were less inefficient. An educated person has more awareness about latest technology which makes them efficient. The regression coefficient was negative and highly significant in case of water business experience and it shows that the experienced plant owners had less production inefficiencies. A person gain more technical knowledge due to experience. The impact of workers was highly insignificant in all kind of production inefficiencies. Production of safe drinking water is not a labour intensive activity but workers are necessary when a plant owner provide the facility of home delivery. The parameter of delivery vehicles was also highly insignificant. It shows the number of delivery vehicles have no significant impact on production inefficiencies. The regression coefficient was positive and significant in case of number of membrane used at plant. The primary purpose of using more membranes is the increase in the per hour quantity of clean water. Their impact was positive on production inefficiencies because the demand of clean drinking water is not much higher. Almost every person want to drinking safe and clean water but their less income is a hurdle in the purchase of safe and clean drinking water. Many people consume low quality water at low price. Many plant owners pointed out that they have the ability to produce more clean water because of more number of membranes but the demand was not high. Therefore, the impact of more membrane vessels was positive on production inefficiency. However, increase in number of membrane is very economical for a plant if the demand of safe and clean water is more. Plant owners also pointed toward increasing demand of safe water with the passage of time as a result of increase in awareness among the people.

**Table 4: Sources of production inefficiencies in drinking water production**

| Determinants | Technical inefficiency | | Allocative inefficiency | | Economic inefficiency | |
|---|---|---|---|---|---|---|
| | βi | p-value | βi | p-value | Bi | p-value |
| **Age (years)** | 0.007 | 0.000* | 0.002 | 0.001* | 0.007 | 0.000* |
| **Education (years)** | -0.037 | 0.000* | 0.002 | 0.513 | -0.021 | 0.000* |
| **Water business experience (years)** | -0.015 | 0.022* | -0.010 | 0.010* | -0.016 | 0.015* |
| **Workers at plant (No.)** | 0.027 | 0.143 | -0.007 | 0.569 | 0.011 | 0.574 |
| **Delivery vehicle (No.)** | 0.014 | 0.771 | -0.033 | 0.264 | -0.019 | 0.707 |
| **Membrane vessel in plant (No.)** | 0.168 | 0.000* | 0.238 | 0.000* | 0.313 | 0.000* |
| **Filter change (No./month)** | 0.009 | 0.042* | -0.008 | 0.007* | 0.001 | 0.891 |

* Significant at 5%

## CONCLUSIONS

It is clear that there exist technical, allocative and economic inefficiencies in safe and clean drinking water production. It means that the production of drinking water will be increase by using same level of inputs if the plants will work at efficient level. Increase in efficiency has positive impact on water production. So, increase in the production of water push the prices downward and low income consumer can purchase this valuable product. Sources of inefficiency indicate that the impact of education is negative on production inefficiency and shows that an educated plant owner was more efficient. Government should increase the technical awareness and knowledge of plant managers about latest technology and standard. It is also recommended that government should create awareness among water consumers that underground water is not fit for them. The existing plants have ability to increase their production to fulfill increased demand. Due to increase in production, producers feel it beneficial to reduce the prices and increase revenue. Moreover increase in the number of plants increase the competition. Increase in competition is good for consumers and results in quality improvement and reduction in price. Many plants have not standard laboratories to check the quality of water regularly. Establishment of stander laboratory is very expensive and it is difficult for a middle class producer to invest such a large amount. It is suggested that government should allow five water plants to set up a standard laboratory on sharing basis. Government should subsidize this sector because cost of production will be less to the producer and consumer will purchase quality product at low price. Government should also promote this business in rural areas.

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