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# Effect of Leaders Related Attributes on the Efficacy of Tea Smallholding Development Societies in Sri Lanka

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## ABSTRACT

The Tea Smallholding Development Societies (TSHDS) are farmers' organisations (FO) established under the legislative act in tea-growing rural areas of Sri Lanka. They are largely non-for-profit voluntary organisations. They were expected to work on the development, resource, welfare, economic and market-related matters of tea smallholders. However, currently, the tea smallholding sub-sector seems stagnant as per some key indicators and that questions the interventions made by TSHDS to the lives of tea growers. Other than the collective action, there can be number of factors affect the efficacy of a FO. The present study attempted to find out the contribution of the leaders' attributes to the efficacy of TSHDS. From seven major tea smallholders' districts of Sri Lanka, 120 sampling units were selected for the study by adopting a stratified random sampling technique. Cross-sectional surveys were conducted to collect the data with the help of several questionnaire schedules. Data were analysed employing various statistical tools like descriptive analysis, cluster analysis, factor analysis, chi-square, Man- Whitney test, log-linear analysis. The majority of TSHDSs poorly provide multipurpose services to their members. Their market orientation is weak. Certain attributes of the leaders of TSHDS affect the efficacy of TSHDS. Although the attitudes of most TSHDS leaders were not negative, some other factors appeared to moderate the effect of attitude. The level of external linkages maintained by TSHDS greatly affects the efficacy of TSHDS and competent leaders guide TSHDS in establishing linkages with other organizations.

**Keywords:** *Tea smallholders, Famer organisation, leadership, linking capital and multipurpose activity*

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## INTRODUCTION

Like many voluntary organisations, the farmer organisations (FO) are predominantly non-profit organisations. FO is an entity that represents the farmers in a given geographical area and mainly deals with the agriculture enterprise-related needs of the members (Esham, 2012). Production and profitability of small farmers have been limited due to certain reasons. FOs emerged to combat some of such issues, like low capital, resource scarcity, lack of knowledge on agricultural technologies and exploitation in the marketplace faced by small-scale farmers(Barham & Chitemi, 2009; Spileman & Bernard, 2009; Trebbin, and Hassler, 2012). Therefore, it is an essential entity to empower the rural farmers, poverty alleviation and eventually uplift their living standards. Usually, a FO has well-defined membership, and its principal function is to provide service to the members (Stockbridge et al., 2003). A FO has an organised structure and a purpose for gathering and attempt to achieve a standard set of objectives. In short, forming a FOs can be understood as collective effort initiated by farmers to combat problems affecting them.

Many scholars have shown that collective action necessarily beneficial for the individuals of the voluntary organisation (Grootaert, 2001; Gillson, 2004) and the level of achievement of the expected goals would greatly determine by the level of collective action within the group (Olson, 1965; Ostrome 2000). Studies have shown that collective action is critically contribute to the performance of FOs (Uphoof et al., 1990; Uphoof & Wijerathna, 2000; Athukorala, K. 2006; Esham & Usami, 2007; Yapa et al., 2022). Further, Mahindapala (2023) found that Collective action has stronger relationship with the efficacy of Tea Development Societies (TSHDS). In addition to collective action, literature has shown that several factors can influence the efficacy of FOs.

According to the results of some studies conducted in locally, FOs' decline has been attributed to poor leadership, poor attitudes, cultural and religious ideological conflicts, political influences, structural factors and inefficiency of the relevant government officials appointed to serve them (Gerragama et al., 1999; Rajarathna, 2007). Moreover, Farmer companies (FC) were introduced to commercialise the FOs and resolve the issues which could not be succeeded by the traditional mode of FOs. However, these FC also could not produce the expected results for various reasons, such as political influence, poor management skills, lack of dignity of the board of directors, poor monitoring and mistrust between management and member farmers (Senanayake, 2002; Esham & Usami, 2007). According to the agrarian service act in 1958 (later repealed by act no.58 of 1979), these FOs and FCs are not the independent organisations and have some attachment with the government. Hence, in a way, it can also be argued that state intervention (dependency on state) and poor leader related attributes are the real reasons behind their failures. Further, the links maintain by the FOs with other external agencies also help to overcome their deficit of physical capital (Amarasinghe & Bavinck, 2007).

According to statistics published by the Tea Controller's Department and the Tea Smallholding Development Authority (TSHDA), the area held by the tea smallholdings has doubled in the early 1990s compared to 1978. With the rapid expansion of the tea small holdings, the TSHDA alone could not cope with the service demanded. Under such circumstances, the government took steps to establish Tea Small Holding Development Societies (TSHDS) by a legislative act (No. 36 of 1991). On the other hand, this emergence indicates a failure of the public sector and the market. (Anheier; (2005). The expected purposes of TSHDSs were (i) To contribute to the development of tea smallholdings, (ii) to provide marketing facilities for growers' production, (iii) to promote the economic and welfare activities of members and (iv) To facilitate the members in the area of credits.

The government expected TSHDSs to take rural leadership and carry out appropriate social and commercial activities to develop the smallholdings. However, several indicators such as productivity, tea production, replanting rate, income of tea growers, technology adoption indicate a shortfall in achieving the expected objectives by the TSHDSs. (Mahindapala et al. 2019a; Mahindapala et al. 2019b; Mahindapala et al. 2019c; Mahindapala et al. 2020a; ILO, 2018; TSHDA, 2005 - 2020). It implies that the organisations initiated to address the key problems of tea smallholders are in crisis. This study attempted to find out the leaders related factors that contribute to the efficacy of TSHDS. Based on the literature discussed in the above following conceptual framework was derived to provide the guidance in the methodology (Figure 1).

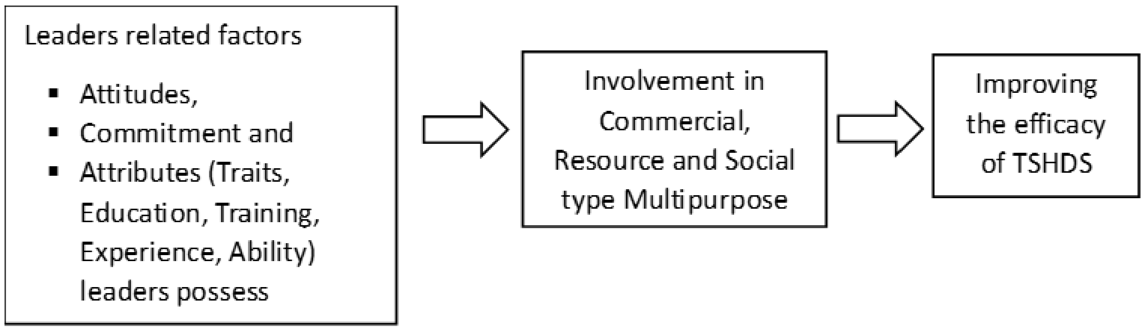


**Figure1**: Conceptual frame of the study

**METHODOLOGY**

The contribution of the variables in figure 1 were preliminary confirmed through a qualitative study – Focus Group Discussions held with the Tea Inspectors, A key extension entities of tea smallholders (Mahindapala 2020b).

In this study the following hypothesis were tested

$H1_0$;There is no association between efficacy index and leaders-related attributes (Education, Knowledge, Experience, Age, Training, Attitudes, Personality traits, Commitments, organizing ability)

$H1_a$ There is an association between efficacy index and the above leader related attributes

**Sampling Technique:**

The unit of analysis of this study was TSHDSs and among the registered TSHDSs (about 1340), 1200 TSHDS were found to be lasted as per the statistics available in TSHDA as of 2017. From that sampling frame, 120 sampling units (from seven major tea smallholders' districts of Sri Lanka) were selected by adopting a stratified random sampling technique. The basis of the stratification was the basic operating level of the TSHDS. (As per the TSHDA records, these TSHDSs had been grouped into several categories based on the functionality of the TSHDSs and hence, the sample was drawn in a stratified manner to ensure the variability in the sample). Further, an equal number of sampling units were drawn from each stratum and they were selected randomly within the strata.

**Research strategy**

A cross-sectional survey was carried out using structured interviews with several questionnaire schedules to collect the data with respect the various variables indicated in Figure 1. Table 1 describe the purpose of the different questionnaire schedules.

**Table 1:** Purpose of different questionnaire schedules

| Questionnaire No. | Research participant and technique | Purpose in brief |
|---|---|---|
| Questionnaire 1 (Q1) | Main Officers (President, Secretary, Treasurer)Collectively (face to face interview) | To collect the data on level of engage in different Multipurpose Services/Activities (MPA)and to work out the efficacy index |
| Questionnaire 3 (Q3) | Main Officers separately (self-completion questionnaire in the presence of researcher) | To collect the data on Leaders' related property (knowledge, education level, training, attitude, time spent on society affairs) and links with other organisations |
| Questionnaire 4 (Q4) | Tea Inspectors and Senior Tea Inspectors<br>(self-completion) | Collect the data on personality traits of Leaders |

The questionnaire related to MPA contained a set of closed-ended pre-coded questions intended to assess the involvement of the TSHDSs on the MPA (See annexure 1 for type of MPA and its sub-levels). Each of the functions was assessed by giving 0-10 scores based on the level of engagement in the activities. Data (behavioural type data) were collected through face-to-face in connection with the activities conducted in 2019.Certain information regarding the activities by referring to the records. In some cases, the study depended heavily on the recalling ability of respondents, and a 'more than one interviewee' approach was adopted to collect data. On the other hand, data and variables were behavioural in type (not perceptional), thus the technique adopted was compatible. Such types of practice have been adopted in other studies (Bryman, 1999; Pahl, 1990). The overall efficacy of TSHDSs were estimated using the relative importance factors related to each function, which have been established in a previous study (Mahindapala et al, 2021) (see Anexture1) and the score values obtained in the present study. The overall efficacy index (EI) is calculated as follows (Mahindapala et al. 2022, see page no 20-21)

$$EI = (X1.S1) + (X2.S2) + \ldots\ldots\ldots\ldots\ldots\ldots (X11.S11)$$

Where X1…….X11 = Relative importance factors in relation to different functions (Anexture1)

S1………. S11 = Scores levels for related to different functions.

Data were collected with respect to the different leader related attributes as per the research strategy outlined in annexure 2.The attitude level of leaders was obtained on a 1-5 scale concerning 16 questions and a mean value was calculated.

To estimate the linking capital, the number of links and frequency of interaction with outside organisations concerning each of the three key leaders were examined, and real data were converted to a 1-5 Likert like scale during tabulation.

The questionnaires were submitted to four expert personnel on the related subjects to check the validity (Content and construct validity), and they were pilot tested before being used. Data were triangulated by interviewing the respective Tea Inspector of the region and two-three ordinary members of the respective society and reviewing the records.

**Statistical Analysis**

Descriptive and cluster analyses were done to evaluate and categorise the TSHDS according to the multipurpose efficacy, and Mann- Whitney test was also performed to confirm the variability among the clusters. The associations between different independent variables and efficacy index are evaluated using chi-square test and log linear analysis. The factor analysis is also done as a data reduction technique. (The statistical software used was SPSS version 25).

## RESULT AND DISCUSSION

1. Clustering the TSHDS based on the performance of the MFA

Cluster analysis was performed using 120 observations based on the score values obtained for different functions. In this analysis observations have been separated to 4 different clusters (at 7.66 distance level) based on the level of implementation of MFA (Figure2). Out of the four clusters, one cluster comprise of most poorly performing (89) TSHDS, which has least centroid values for all the functions considered. Hence, the factors affecting multipurpose capacity should also be reflected in these clusters. Most importantly responses to external interventions (dependency level on state) will also be varied among these clusters.

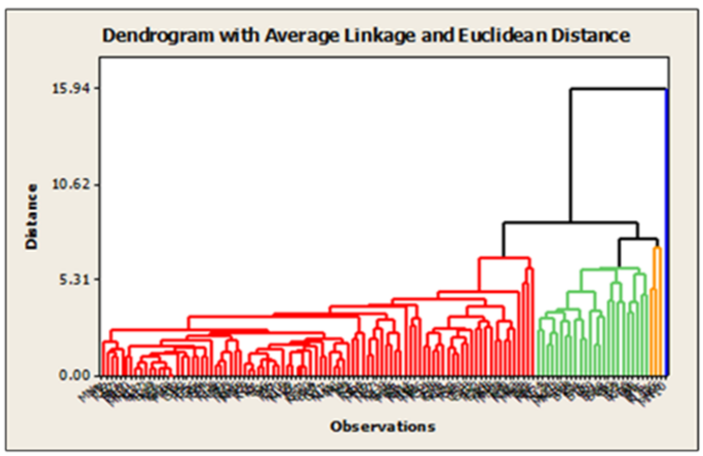


**Figure 2:** Dendrogram of cluster analysis.

Cluster 1 appeared to have large variability from the rest of the clusters. Thus, a comparison was made between cluster 1' (least performing cluster) and Clusters 2' (relatively moderately performing cluster) using Mann- Whitney test. Cluster 2 showed significantly higher performance over cluster 1 in commercial activities and almost all the other activities at the levels of $p<0.001$, $p<0.05$, and $p<0.1$ (depending on the type of activities). This difference caused, may be due to some characteristics shared collectively by the relevant group. In addition to the above variability, clusters 3-4 also have shown a significant variability over cluster 2 with respect to six variables, including market-related activities, financial support, welfare and for-profit activities, as illustrated in Table 2

**Table 2:** Comparison between clusters 2 and 3& 4

| | Mean rank | | |
|---|---|---|---|
| **Variable** | **Cluster2** | **Cluster 3 & 4** | **p-value** |
| Marketing related activities | 12.33 | 26.63 | 0.08 |
| Welfare | 12.25 | 23.25 | 0.011 |
| Financial support | 12.35 | 23.5 | 0.09 |
| Other for-profit activities | 12.74 | 21.25 | 0.049 |

In conclusion, significant variability with respect to the efficacy can be seen among these clusters.

2. Overall Efficacy (Efficacy Index -EI)

The eleven functions (Annexure 1) considered may not be equally important to the TSHDSs. Hence, as mentioned in the methodology, a relative important factor was estimated for each of the functions. Taking into consideration of relative importance, the overall efficacy index (EI) was calculated for each TSHDS and values were summarised in Figure 3

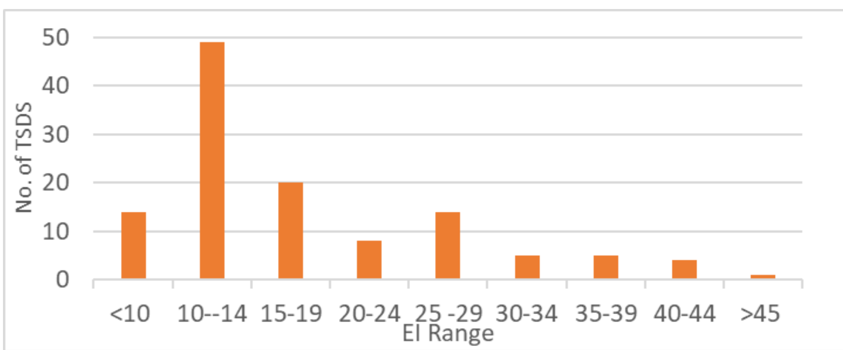


**Figure 3:** Variability of Overall efficacy/EI of TSHDS.

Results of the clustering and EI index are compatible. About 93% of the observations comes under cluster 1 have less than 20 EI value while 96% of the observations grouped into clusters 2, 3 and 4, respective value more than 25. The EI value ranges from 6.63 to 56.46. Therefore, there must be a reason for the that kind of variability and which should be investigated. One of the reasons uncovered was level of collective action (Mahindapala et al. 2023). However, in addition to the collective action there can be some other reasons. Nevertheless, it is also worth noting that efficacy of TSHDSs was limited to some degree may be due to common cause(s) affecting all TSHDSs.

**3. Leader- related Factors**

First, different variables under this are discussed using descriptive statistics, and then their relationship to the efficacy is examined.

### 3.1. Status of the TSHDS in Relation to the Leader-related Factors

As per the constitution, the main action coordinating body of the TSHDS is the executive committee. Thus, certain attributes possessed by the leaders may have contributed to the efficacy of TSHDS, and nine such attributes were considered.

#### 3.1.1. Educational level

The educational status of the committee members is given in Table 3

**Table 3:** Education level of the main leaders of TSHDSs

| Education level | Main leaders (n=351) | | Average leaders' education level for TSHDS n=120 |
|---|---|---|---|
| | Number | % | % |
| No schooling | 5* | 1.4 | 0 |
| Up to grade 5 | 6 | 1.7 | 2 |
| Grade 6- O/L | 56 | 16 | 9 |
| O/L qualified | 141 | 40.2 | 55 |
| A/L qualified | 139 | 39.6 | 34 |
| Degree | 4 | 1.1 | 0 |

*Those who are covering the duties in the absence of leaders

Out of 351 main leaders of 120 TSHDSs, about 40.2% of leaders passed the GCE (O/L) examination, and 39.6% were GCE (A/L) qualified. The lower education categories and higher education categories were relatively low.

#### 3.1.2. Knowledge level

The rural communities -especially the farmers, gain knowledge not only through formal education but also through informal /non-formal means as well. Therefore, the leaders' knowledge level on FOs-related aspects was assessed and given in Table 4. Accordingly, the majority of the leaders obtained moderate to low marks level. Therefore, most TSHDS leaders have a moderate and low level of knowledge of the essential functions of FOs. Although 19% of leaders have fairly high knowledge, they were from different TSHDSs, and their other fellow leaders have poor knowledge, the mean value becomes low.

**Table 4 :** Knowledge level of the main leaders of TSDSs on FOs functional aspects

| Marks level out of 15 | Main leaders (n=349) | | Mean for TSHDS |
|---|---|---|---|
| | Number | % | % |
| 0-3.5 | 7 | 2 | 0 |
| 3.6-6.5 | 120 | 34 | 31 |

| | | | |
|---|---|---|---|
| 6.6-9.5 | 152 | 44 | 62 |
| 9.6-12.5 | 68 | 19 | 8 |
| 12.6-15 | 2 | 1 | 0 |

#### 3.1.3. Mean Experience and Age Level of TSHDS Leaders

TSHDS leaders' experiences, (i) in tea cultivation, (ii) as members of the tea society and (iii) on the executive committee were also considered (Table 5). About 82% of TSHDS have main leaders with a mean experience level of more than 20 years of tea cultivation, while 48% of TSHDS have leaders with more than a mean experience of 10 years as a member. Further, 45% of the TSHDS have main leaders whose mean experience in the committee was more than 6 years, of which half of the TSHDS have main leaders who have served in the committee average of more than 9 years. Moreover, more than 80% of the leaders were more than 50 years old. The young (age below 35 years) tea smallholders were hardly seen in the leadership.

**Table 5:** TSHDS by the mean experience of leaders and age.

| Experience and age of leaders | | | | | | |
|---|---|---|---|---|---|---|
| **Mean leaders' Experience of TSHDS in different activities/roles** | | | | | **Mean age of leaders** | |
| **Category (years)** | **Tea cultivation** | **As a member** | **Category (years)** | **As a committee** | **Age category** | **% TSHDS** |
| 5< | 0% | 22% | 3< | 29% | 25-35 | 0% |
| 5-10 | 2% | 41% | 3-6 | 26% | 36-50 | 19% |
| 11-15 | 3% | 41% | 6-9 | 18% | 51-65 | 67% |
| 16-20 | 13% | 13% | 9-12 | 19% | 66-75 | 14% |
| 20< | 82% | 3% | 12< | 8% | | |

#### 3.1.4. Vocational Training Exposure of TSHDS Leaders.

Among the leadership (Chairman, Secretary, and Treasurer), the majority have not undergone any vocational training and only about 13% have undergone related training (to their business activities), for more than 3 months period (Table 6). Moreover, those who obtained more than 3 months were from different TSHDSs, and therefore mean training level of the TSHDS was low in the majority of the cases.

**Table 6**: Level of the training exposure received by TSHDS leaders.

| Duration of training | % of main leaders received | % of TSHDS based on mean values |
|---|---|---|
| No training | 46.7 | 82 (both no training and less than 1month training) |
| 1- 30 days | 40.5 | |
| 1-3Months | 2.6 | 16 |
| 4-12 months | 2.6 | 2 |
| 1-2 year | 3.6 | 0 |
| >2 year | 4.0 | 0 |

### 3.1.5. Commitment of the TSHDS Leaders

TSHDS leaders' commitment level was measured through their engagement in TSHDS affairs. The mean time spent on society affairs of the three main TSHDS leaders was stated in Table 7. The mean time spent by the majority of key leaders on TSHDS activities was less than 5 hours per week, with only 8% of key leaders in TSHDS spending more than 15 hours per week. It was found that some TSHDS have one out of three leaders working hard, and the rest of them are not so, and the mean time spent in such cases was not high.

**Table 7:** Level of commitment of the main leaders by.

| | **<5 hrs./week** | **5-10 hrs./week** | **10-15 hrs./week** | **15-20 hrs./week>** | **>20 hrs./week** |
|---|---|---|---|---|---|
| % of TSHDS have come under mean value | 51% | 31% | 10% | 4% | 4% |

### 3.1.6. Attitudes of the main leaders

The leaders’ attitudes on FOs-related matters were measured using 16 questions. The Cronbach's alpha value related to the responses were 0.711 (> 0.7), which confirms the internal consistency of the questions used. Attitude preliminary modifies the behaviour of the person. In that argument, the efficacy of the FOs can be influenced by the leaders' attitudes. The majority of the TSHDS have leaders with moderate attitudes towards the FOs' activities, and about 30% of the TSHDSs consist of leaders with favourable attitudes. Notably, the TSHDS with strong negative and strong positive attitudes holding leaders were lacking (Figure 4).

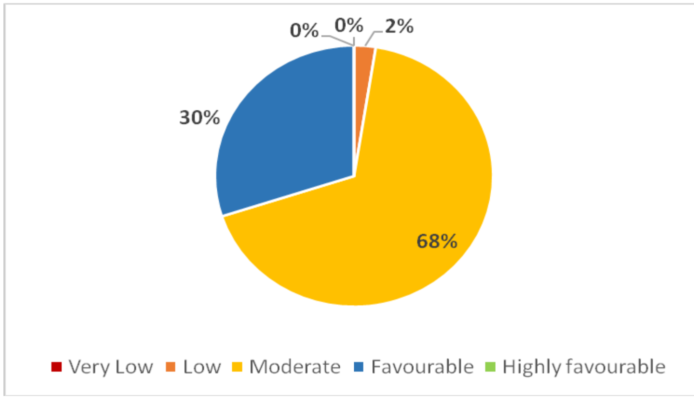


**Figure 4:** TSHDSs by leaders' attitudes

**3.1.7. Personality Traits Related to the Leadership of the Most Dominating leader of the TSHDSs.**

Extraversion, Conscientiousness and Openness to experience are the important traits out of main 'Big-five' personality traits that have been proven to have a relationship with leadership (Robbinsand Judge, 2007). The availability of these factors with the TSHDS leaders was assessed on a 1-5 scale by a set of questions. The relevance of the questions to each trait was confirmed through factor analysis. The internal consistency of the questions is at a satisfactory level (Cronbach's alpha value = 0.745). Figure 5 illustrates the availability of three traits and their average. Accordingly, about 40% of TSHDS's most dominant leaders have satisfactory levels of these three characteristics, while 25-30% of TSHDS leaders have moderate levels of these characteristics (3) (Figure 5). Among the traits, only conscientiousness personality traits were the most existing personality (32%) trait at a very high level (5) compared to the other traits. About 20% and 15% of TSHDS have leaders with low levels (2) of openness and extraversion personality traits, respectively. The combined average value for these three-personality traits was estimated, and 53% of TSHDS leaders have more than 3 value. The leaders are appointed through the members' vote; generally, it is not a thorough screening process. In this context, the presence of these characteristics is important to convince others of the ability of leaders so that members can choose a suitable person as a leader. Hence it is required to examine the relationship between the efficacy of TSHDS and the personality traits of the TSHDS leaders.

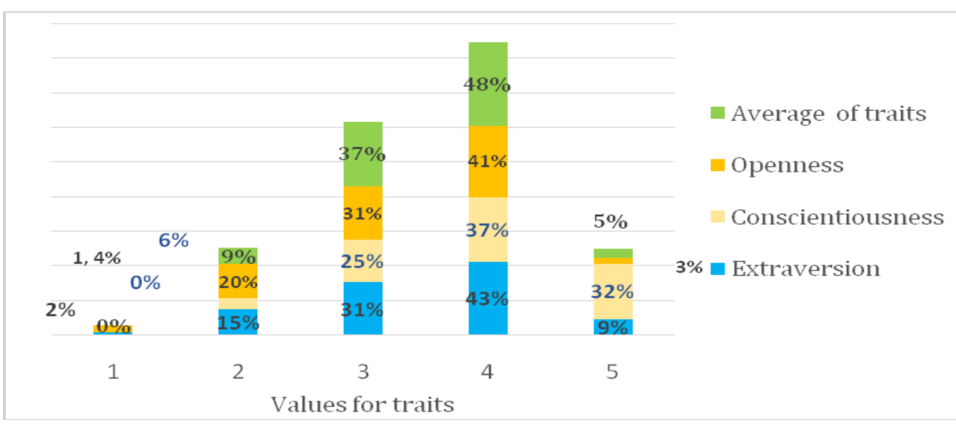


**Figure 5:** Availability of personality traits with TSDS leaders

**3.1.8. Leadership Ability is Based on Members' Perceptions.**

The members' perceptions of the main leaders' organising capability were measured using five statements (Cronbach's alpha value = 0.737). The mean score values of the leaders in different TSHDSs are summarized in Table 8

**Table 8:** Categories TSHDS by leadership capability level

| Leaders mean Score level | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| % of TSHDS | 0 | 19 | 54 | 27 | 0 |

Most of the TSHDS (54%) have moderately capable leaders based on the opinion of the members. On the other hand, very low or very highly capable leaders are not seen in any of the TSHDS studied.

**3.2. Relationship Between Leader-related Factors and Efficacy of TSHDS**.

Whether any association existed between the above-discussed leader-related factors and the efficacy of TSHDSs was evaluated using the chi-square test, and results are indicated in Table 9.

**Table 9:** Association between leader-related factors and efficacy

| Type of association | Chi-Square value | p-value |
|---|---|---|
| Efficacy X Mean Education level of leaders | 13.90 | 0.307 |
| Efficacy X Mean Knowledge of leaders | 20.071 | 0.01** |
| Efficacy X Vocational Training level of leaders | 8.855 | 0.355 |
| Efficacy X Mean Experience of leaders | 11.812 | 0.757 |
| Efficacy X Mean Age level of leaders | 3.146 | 0.925 |
| Efficacy X Mean attitudes level of leaders | 15.708 | 0.047* |
| Efficacy X Mean availability level of personality traits | 22.582 | 0.031* |
| Efficacy X Mean commitment level of leaders | 98.061 | 0.0001** |
| Efficacy X organising ability level of the main leader | 12.482 | 0.131 |

*Significance at $P<0.05$ level, ** significance at $p<0.01$ level

According to Table 9, there is no association at all between the Efficacy of the TSHDS and the educational level of the leaders, exposure to vocational training, experience in the tea society, and mean age level of the leaders. Further, it is surprising to notice that a significant association did not detect between the efficacy of TSHDS and the organising ability level of the leaders at 0.05 level. However, it existed at the 85% confidence interval. The capability of leaders was measured through the perception of fellow members. One's perception of the individual can be dependent on contextual factors. This means that contextual factors can distort reality to a certain extent. In addition, factors such as the perceiver's attitudes, interests, expectations and experiences are also influential. Such moderating factors may have acted to mask the relationship between the ability of the main leader and TSHDS effectiveness.

As indicated in the table 6, more than 80% of the society leaders have not undertaken vocational training for more than one month, and on average, no leader has received more than one-year period of vocational training. This means that the TSHDS has realised this level of achievement without such a component, which could be the reason for not showing an association between training and efficacy. On the other hand, TSHDS do not engage in processing and value-addition activities (except in one case) as done by many FPC in India and Japanese Agriculture cooperatives, and hence such professional qualifications are not critical for TSHDS unlike Indian farming companies and Japanese agricultural cooperatives. That could also be a reason for not having an association with efficacy. The experiences mostly matter for job performance and decision-making events (Rhodes, 1983). However, such a relationship too has not prominent in the TSHDS context as such kinds of business decisions are hard to arise as they are not market-oriented and hardly run as business entities. Although it was expected that organisations run by middle-aged leaders are expected to be performed well as the combined effect of both experience and energy, (McEvoy & Cassio, 1989) which has not been seen in this context. Moreover, the education level of the TSHDS leaders has not contributed to the effectiveness of the TSHDS. In the rural setup, formal education is not the only way to gain knowledge in farming in rural communities. Confirming this fact, the mean knowledge level of the TSHDS leaders has a positive association with the efficacy of the TSHDS. Along with the knowledge, mean time devoted to society affairs by the leaders has a positive association at $P<0.01$ level, while Attitudes of leaders and availability of leadership traits have shown a positive association with the efficacy at $P<0.05$.

Knowledge and attitude are the essential elements for behavioural change (Hanik, 1988). Here, behavioural change means implementing strategies to elevate the FOs to a status that can address the array of members' issues. The leaders need to have the right attitudes and a vision of the right direction to bring the TSHDS towards success. The vision develops through knowledge. Thus, that way, these two associations work to uplift the TSHDS. However, knowledge-efficacy associations were relatively strong (phi =0.409) compared to attitude–efficacy (phi=0.362). As leaders of voluntary organisations, their attitudes are at a certain basic level, which is why they intrinsically motivate common activities. On top of that, leaders with more positive attitudes would position the TSHDS at a relatively higher level. The leaders' commitment has a strong association (phi=0.904) with efficacy. Understandably, TSHDSs are pushed forward through leaders' commitment. This finding confirms the argument that arises in the preliminary study that 'some TSHDS survive due to leaders' (Mahindapala, 2020b). On the other hand, the reverse side of this phenomenon is also true – less committed leaders spoil TSHDS. This study showed that the presence of the personality traits in the most dominating leader has a bearing on efficacy. This is one of the leadership approaches, arguing that those who sufficiently enrich these three traits can direct the organisation towards success (Geier, 1967; Judge et al., 2000).

Finally, out of the nine features of the leaders considered, leadership, commitment, knowledge and attitudes are the important factors that influence the efficacy of the TSHDS.

### 3.3. Confirmation Through the Factor Analysis of Leader-related Factors

To further understand the behaviour of these factors considered, a Factor analysis (FA) was performed and Bartlett's test ($P<0.0001$) and KMO factor (0.574) indicated that it is reasonable to go ahead with FA. The varimax rotation has also been done to ensure fair loadings only on some of the variables with few factors. Based on the eigenvalues (>1), 3 components were identified, which accounted for 68% of the total variance (Table 10).

**Table 10:** Component Metrix of Factor

| | Component | | |
|---|---|---|---|
| Variables considered | 1 | 2 | 3 |
| The ability of the Main leader | .942 | | |
| Education | .928 | | |
| Commitment | | .740 | |
| Attitudes | | .695 | |
| Knowledge | | .617 | |
| Leadership-related Personality Traits | | .595 | |
| Experience | | | .900 |

Accordingly, factors that significantly contributed to the efficacy of TSHDS came under one component (2), indicating the uniformity of these variables. Therefore, the latent factor in this component is here argued as contributing to the efficacy.

The links maintained by the TSHDS with the other organisations were examined. Here the attention was drawn to the links initiated and maintained in voluntarily with private, public or voluntary organisations. Only 12% of TSHDS maintained satisfactory links with external entities. These external links are an asset to an organisation and are therefore considered 'Linking social capital' (Woolcock, 2001). When there is a shortage of physical capital, especially for a voluntary organisation like this, linkage capital can be used to improve the status of farmers. (Ostrome, 2000) Amarasinghe and Bavinck (2011)have shown that linking capital was successfully utilised to cope with the vulnerability and poverty of small scaled fishers attached to fisheries cooperatives. Therefore, leader-related factors (Based on the outcome of FA – Table 10, the composite mean value of related variables were used), Link with external organisation and efficacy were considered, and attempted to fit a log-linear model. Based on the $\triangle G^2$ value and p-value, a suitable model was selected. Accordingly following interaction terms were fitted to the model:

(Links X Efficacy) + (Leader related factors X Links) + (Leader related factors X Efficacy)

These results show that, while directly contributing to efficacy, leader-related factors could even influence the establishment of links with the other organization and thereby indirectly also contribute to the efficacy.

## CONCLUSION

The majority of TSHDS weakly engage in multipurpose service to address the broader needs of members. The market orientation of the TSHDSs is poor. The knowledge, attitude and commitment of leaders significantly affect the efficacy of TSHDSs. Furthermore, the combined effect of some of the 'Big-five' personality traits - particularly extraversion, conscientiousness and 'openness to the experience', of the most dominant leader in TSHDS was found to have a relationship with the efficacy of TSHDS. However, leaders' education qualification, experience, training and age has no significance relation with the efficacy of the TSHDS. Although the attitudes of most TSHDS leaders are not poor, some other factors appeared to be moderated the effect of attitude. As a result, there is a gap between attitudes and behaviour. This may be the reason for their low market orientation and lack of involvement in multipurpose activities.

The efficacy of TSHDS greatly influence by the level of the external link maintained by the TSHDS and the competent leaders drive the TSHDS to establish such links with the other organization.

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**ANNEXURES**

**Annexure 1:** Estimated relative important factors for different MFA

| Main Factor | Relative Importance factor | Sub-level Factors | Sub-level weightage |
|---|---|---|---|
| Need Identification | 11.82 | | |
| Extension | 11.41 | Advisory activities | 0.285 |
| | | Farmer training | 0.267 |
| | | Diagnose field problem | 0.245 |
| | | Monitoring /motivate farmers | 0.203 |
| Welfare activities | 7.59 | Educational aids | 0.213 |
| | | Death donation scheme | 0.265 |
| | | Medical support scheme | 0.202 |
| | | Recreation | 0.114 |
| | | Provide other livelihood support | 0.206 |
| Dealing with inputs and | 12.53 | Supply of Inputs | 0.57 |

| | | | |
|---|---|---|---|
| resources | | Supply of physical resources, machines, tools | 0.43 |
| Marketing of produce | 13.53 | Provide information | 0.229 |
| | | Handling of members primary products | 0.333 |
| | | Involve in Value addition | 0.240 |
| | | Marketing of value-added products | 0.198 |
| Financial support for members | 9.06 | Banking service | 0.237 |
| | | Sharing of profit/Bonus | 0.146 |
| | | Coordinating to obtained government subsidies | 0.229 |
| | | Providing Insurance service | 0.142 |
| | | Transport service | 0.176 |
| Joint field operations | 8.47 | | |
| Capacity Building | 8.41 | | |
| Involvement in natural Resource management and national/Common/Industry issues which have Broder level impact | 5.21 | Natural resource conservation and management programs and | 0.409 |
| | | Intervening in policy formulation | 0.313 |
| | | Acting as a pressure group | 0.278 |
| Adherence to administrative and financial procedures | 5.09 | Admin activities | 0.294 |
| | | Accounting | 0.264 |
| | | Auditing | 0.218 |
| | | Record keeping | 0.224 |
| Other for-profit activities | 6.88 | | |
| Total | 100.0 | | |

*(Source: Mahindapala et al., 2021).*

**Annexure 2:** The research strategy to measure the leader related attributes.

| No. | Attributes that possess by leaders | Research Strategy | Measurement |
|---|---|---|---|
| i | Knowledge level | A self-completing questionnaire was administered to three main leaders. Five questions related to operational aspects of FOs were stated in the questionnaire [Q3] to measure the knowledge. | Answers are evaluated, and 15 marks are given; Scaled into five categories. |
| ii | Exposer to professional training | Self-completing questionnaire[Q3]; Two questions asked (Q3) | Categorical data with five levels |
| iii | Education level | Self-completing questionnaire [Q3] | Categorical data with five levels |
| iv | Attitudes of leaders | Self-completing questionnaire; 16 combined statements directed to main officers. [Q3] | Likert scale with five levels consists of highly Agree – highly disagree (Likert, 1932); finally, to be worked out – the mean attitude scale. |
| v | Commitment | Self-completing questionnaire [Q3]; directed to main leaders. | The number of hours spent on society activities per week – to be categorised into five levels. |
| vi. | Experience of leaders | Above Questionnaire [Q3] | The experience was measured in three areas- Tea cultivation, as a society member, and as the main leader – to be converted into 5 scaled categorical data. |
| vii. | Presence of leadership characteristics of the most dominating leader (most relevant three big- five factors) | Asses based on the perception of the Tea Inspector in charge of the range by a questionnaire consisting of 10 questions related to Openness, Extraversion and Conscientiousness traits. [Q5] | Responses were measured using 5 Likert scales. Finally, the mean value was taken. |
| viii | Members' perception on organising ability of TSHDS leaders | This was evaluated by asking three questions from members in a separate questionnaire given to the members [Q4] | Likert scale with five level |

# A quality control assessment for digital x-ray radiography through pixel values based signal and noise characteristics.

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**ABSTRACT**

Quality of x-ray image is a major factor for the correct clinical diagnoses in radiology. A quality control (*QC)* programme for medical x-ray imaging is essential to preserve quality of the images. Implementation of an effective quality assurance programme to ensure the high quality of images is a responsibility of a medical physicist in the hospital. However lack of relevant, expensive QC tools has become a challenge to maintain the quality of medical x-ray equipment in developing countries such as Sri Lanka. This article presents a simple, low cost QC procedure to measure the quality of a digital x-ray detector and image reader in occasionally through the analysis of signal and noise of digital images. The mean of the pixel value within 5 mm x 5 mm region of interest (ROI) of a uniform digital image is used to estimate signal and standard deviation (SD) of pixel value within the ROI used to estimate noise. This study suggests good baseline tests for QC through the linear relationship of pixel value based signals versus ln [mAs] and SNR versus ln [mAs]. Stable signal, noise and SNR characteristics of an image will indicate stability of the quality of the imaging device. Then present experiment creates base line for signal and noise assessment for future analysis. Likewise signal to noise ratio (SNR) characteristics can be used to compare image performance between two equipment or two set up.

**Keywords:** Digital Radiography, Quality Assurance, Signal, Noise.

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**INTRODUCTION**

X-ray imaging is the most important technique in the diagnostic medicine to take two dimensional images of human body. When x-ray beam passing through the human body, depending on the electron density of tissue the photons undergo attenuation and the transmitted x-ray photons is collected at the detector as signals. Signals bring useful information of the patient anatomy described in beer's law (Guimaraeset al. 2009; Potts, 1987) and it is converted into a digital image by digital imaging system. Digital image is a matrix of pixels and pixel is the smallest controllable element of the image. Brightness of each pixel is denoted by pixel value. Pixel value represents the number of photons reached to the corresponding area of the detector (Johnston & Fauber, 2015; Vogelnest & Allan, 2015). X-ray machine has a control console to set the desired kVp (peak kilo voltage), mAs (milli amperes) or mAs (mA multiplied by the desired exposure time) for the x-ray tube and these factors influence the image quality as well as patient dose.

Brightness of pixels should be uniform in a recorded digital radiography (DR) image of a uniform object. However the fluctuations of the x ray photons reaching to the detector from point to point change the brightness randomly. This random variation in the brightness which is not related to the patient anatomy is produced in practice of the DR imaging even when the object is uniformed. This variation does not have a particular pattern and it gives a mottled, grainy, textured, or snowy appearance in the image. This random variation in image brightness is named quantum noise and it limits the detection of objects in the image (Johnston & Fauber, 2015; Gupta, 2013).

However all medical images contain some visual noise. Noise reduces the image quality; hence it is commonly used to describe the quality of images as well as equipment (Goyalet al., 2018).Then noise is a basic measure of image quality (Alsleem & Davidson, 2012).A set of noise measurements that is taken just after the installation of a machine can be used to establish baseline data set for QC of equipment. Base line data will be compared with the future data to analyse quality changes with the usage and aging of equipment.Signal to noise ratio (SNR) is a better way to compare the noise level of images. It is a measure the ratio of true signal to noise (Easton, 2009). Low SNR indicates high noise level related to the useful signal, as well as a high SNR indicates the low noise level. Therefore high SNR indicates high image quality(Easton, 2009; Vano, 2008)

Although medical physicists in the hospitals bound to assure the quality of diagnostic imaging systems, lack of relevant, expensive QC tools has become a great challenge to establish QC culture in developing countries such as Sri Lanka. This study introduces a simple, low cost QC procedure for digital detectors and image reader through the noise analysis of digital image. It will be a great solution for high cost QC tools and a good stimulator to establish a QC culture.

**MATERIALS AND METHODS**

DRX–3724HD tube type TOSHIBA KXO-50S general x-ray machine with Care stream Direct view Classic Computer Radiography (CR) system were subjected to this study. 30cm X 30 cm, 10 cm thick water phantom was placed on the top of a CR cassette and positioned on the couch. The setup was imaged with the settings of 80 kVp, because most x-rays used in medical imaging are between 40 and 120 kVp. 25 cm X 25 cm field size at 100 cm source to detector (cassette) distance (SDD) was set up for different mAs. Mean of the pixel values and standard deviations of the pixel value in a 5 mm x 5 mm, square shape ROI in phantom image area was recorded with the corresponding mAs using the software of the (CR) system. After erasing previous image using the software, the cassette was positioned at 100cm SDD and x-ray beam was blocked by placing a lead sheet( 10 cm X 10 cm X 0.66 cm) on the cassette. 5 cm X 5 cm of shielded area was exposed with 80 kVp with different mAs. Mean pixel value of a 5mm X 5mm ROI in the centre of shielded cassette area was recorded as offset pixel value.

**RESULTS AND DISCUSSION**

X-ray beam is a shower of x-ray photons and each individual photon is called quanta. mAs controls the quantity of x-ray photons produced by the x-ray tube. mAs setting of the x-ray equipment is directly proportional to number of quanta of the x-ray beam (Carroll & Quinn,2018). X-ray quanta reach to the object or the patient as well as to the image detector in a random pattern even when object (patient) is uniformed. The random pattern of the x-ray quanta fluctuates the image pixel values from pixel to pixel. Therefore mean of the pixel values within a small ROI in a uniform image is a close representation to the signals from the x-ray beam (Strauss & Rae, 2012).

mAs set up of a machine represents the number of x-ray quanta in the x-ray beam (Langland et al., 2002; Damulira et al., 2019). Hence the relationship between signals and mAs is linear for a given technique. However the experimental relationship between mean of the pixel value of a ROI in the phantom image and mAs settings was non-linear. Limitation of vacant trap holes in between the valance and conduction bands of the PSP crystal layer in the detector decrease the signal absorption for high mAs creates weak response of the detector or the laser light intensity of the image reader may not be enough to readout all trapped electrons during the reading process at high mAs (Rowlands, 2002)is responsible for the non-linearity. Figure 1, the best fit relationship between signals (mean of the pixel values of the ROI) versus ln[mAs] was a linear with the calculated correlation coefficient ($R^2$) value of 1.0. The relationship of signals vs mAs is only changed by the kVp, experimental set up as well as equipment failure or aging (Seibert, 2004). Therefore this test is a good baseline for QC and it will identify chronic failures of the equipment.

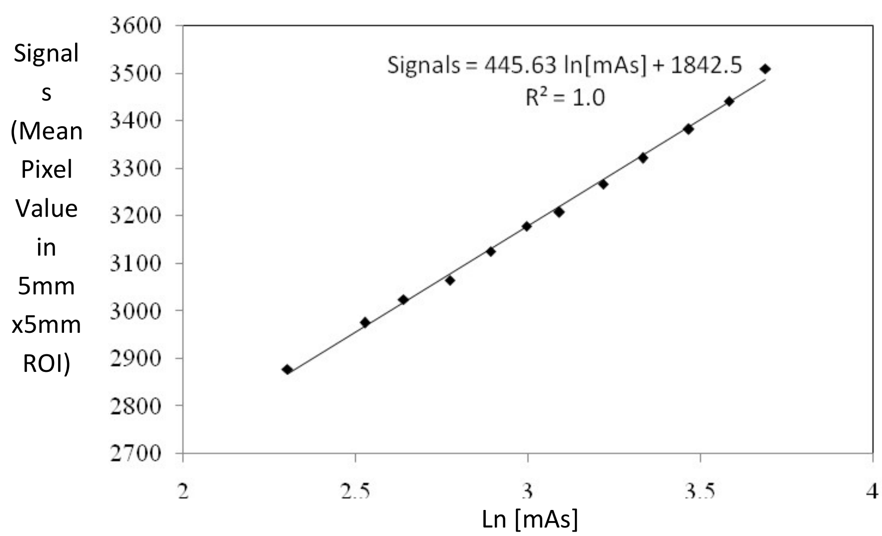


**Figure 1:** The graph of pixel value based signals versus ln [mAs] of the Direct view care stream CR system for 80 kVp at 100 cm SDD for 25 cm x 25 cm field size.

Signals come from variety of mechanical functions such as properties of cassette, image plate and electronic components, electrical and optical leakage, initial additionally to the x-ray quanta. These mechanical signals may contribute to the mean of the pixels values of the 5 mm x 5 mm ROI. They are not related to the exposure and anatomical structure of the patient and represented by offset pixel value (Scarfe & Angelopoulos, 2018). Offset pixel value is the mean of the pixel values in a5 mm x 5 mm ROI of an image which was taken by blocking direct x-ray flux to the detector. However to compare offset pixel value with different mA settings, exposure of 80 kVp was used with a 0.66 cm lead shielding. The amount of anatomical related signal was calculated by subtracting offset pixel value from the mean of the image pixel values within the 5 mm x 5 mm ROI. A small offset value (4) was recorded by the experiment and it is suggested that the signals from the mechanical errors of the equipment is not significant. However, the offset pixel value may be changed by usage and aging of the cassette, image plate and electrical components of the system with the time. Therefore repeatability and constancy of the offset pixel value are preferable evidences for quality of a DR system. The present off set value will be the baseline test for future comparisons.

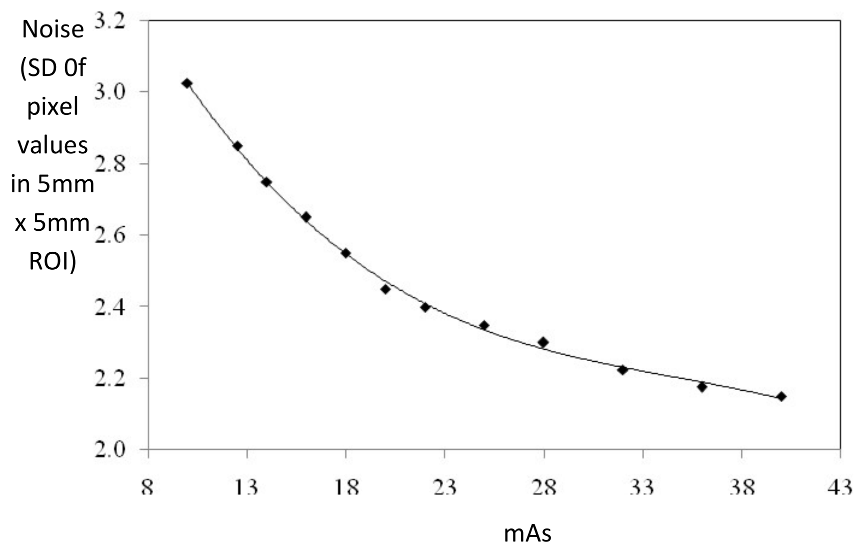


**Figure 2:** The graph of pixel value based noise versus mAs of the Directviewcarestream CR system for 80 kVp at 100 cm SDD for 25 cm x 25 cm field size.

Fluctuation of the image pixel values adds noise effect to the x-ray image. The noise appearance by the random pattern of the x-ray quanta is called x-ray quantum noise (Goyal, 2018). Although the structure of the film, intensifying screens, or digital receptors can introduce noise into images, the quantum noise is the most significant noise source in plain x-ray imaging applications (Penelope & Williams, 2008). The intrinsic fluctuation of the quanta or the pixel values can be determined by the standard deviation (SD) of pixel values within the ROI in the phantom image (Alsleem & Davidson, 2012).The SD of image pixel values of the small ROI in the phantom image was considered to quantifying the quantum noise from x-ray beam as in equation 1.

Noise = SD of the photon concentration of ROI = SD of the pixel values at ROI-(1)

The experiment data of noise was slightly decreased when increased mAs and taken low values with respect to the signal values as shown in figure2. These observations of noise indicate the high quality of the imaging device. As well as signal and offset value characteristic, noise variation with mAs creates a base line experiment to analyse the quality changes of the Instrument.

However, It is not impartial for comparing image quality using either signal or noise individually, since they have opposite behaviour. However SNR represents both signal and noise simultaneously. SNR is a better factor to analyse and compare the image quality of digital x-ray images (Chan et al.,1990).SNR vs ln [mAs] was shown in figure 3 and SNR was calculated by equation 2 using both pixel value based signal and noise values. SNR characteristic is important to compare image qualities of different imaging systems with same technique. As well as the behaviour of signal and noise with the mAs settings, the SNR vs mAs can be used as a baseline curves for QC.

SNR = Useful Signals / Quantum Noise ------- (2)

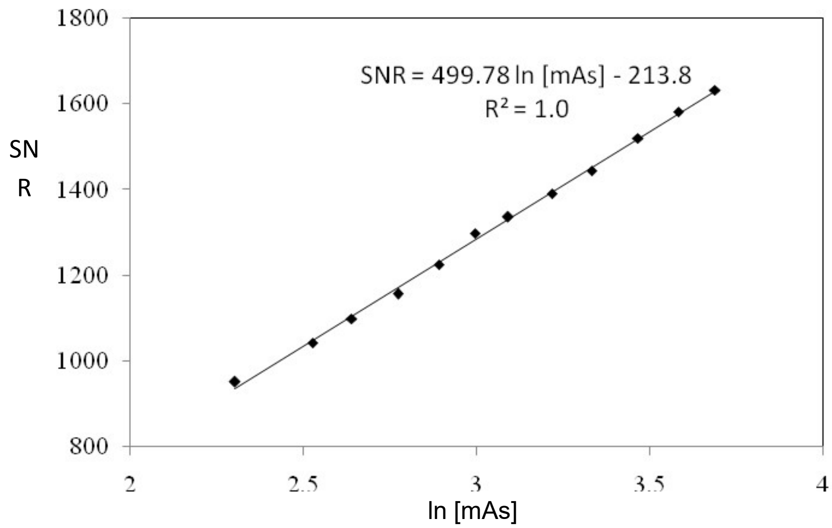


**Figure 3:** the graph of SNR versus ln [mAs].

**CONCLUSION**

Setup value of the mAs represents the number of x-ray photons called quantity of x-ray quanta from a x-ray tube. It governs the amount of useful signals with x-ray quanta which reaches to the image detector in medical imaging. Mean of the pixel values within a small ROI in an image of uniform water phantom is a close representation to the signals from the x-ray beam and SD represents the noise. Although signals are proportionately related to the mAs, linear relationship of signals (mean of the pixel values of the ROI) versus mAs is deviated by the weak response of the detector or the image reader at high mAs.However signals (mean of the pixel values of the ROI) versus ln [mAs] is linear with the calculated correlation coefficient ($R^2$) value of 1.0.This relationship is only changed by the equipment failure or aging for fixed 80 kVp and same experimental set up. It can be used as a baseline for QC and it will identify chronic failures of the detector and image reader. Noise is inversely related to the mAs, hence greater mAs increase the quality of the image. As well as the behaviour of signal, noise with mAs should not be changed for same set up of an instrument with time, if there is no equipment fault. The simple calculation method of SNR by using pixel values is a great measure of image performance. The relationship of SNR vsln [mAs] is linear with the calculated correlation coefficient ($R^2$) value of 1.0. Study of SNR introduces good baseline tests for QC as well as signal and noise analyses. As well as the SNR analyse by using pixel values of images will be a great measure of image performance between different x-ray equipment as well as different setups.

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# Verification of tangential breast treatment dose during 2D treatment planning

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**ABSTRACT**

This study presents a water phantom study of verification of tangential breast treatment dose calculations in a two-dimensional treatment planning system (TPS) at the Department of Radiotherapy, in a National hospital in Sri Lanka. Measurements were made using a 0.6 cc Farmer-type cylindrical ionization chamber with an electrometer in a breast phantom made of water field Perspex structure. The measured doses in the breast were compared with calculations made on a two-dimensional radiotherapy treatment planning software THERAPLAN®PLUS version 3.55 using the digitized breast phantom contour. Overall, the measurements obtained from the TPS had an accuracy of 5% compared to the direct measurements while most of the measurements lie within 3%. And dose in the chest wall was below the tolerance level of the lung and heart. Thus, it was concluded that TPS calculations and dose distributions are within the clinically acceptable accuracy level of international standards (ICRU report 50).

**Keywords:** Radiotherapy dose calculation algorithm verification, tangential breast irradiation.

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## INTRODUCTION

Radiation therapy uses ionizing radiation in the treatment of malignant cells with the aim of targeting a precisely measured dose of radiation to a defined tumor volume, sparing the surrounding healthy tissues and the critical organs as much as possible [1], [2]. According to the National Cancer Incidence and Mortality data of Sri Lanka, 31848 new cancer patients were recorded in 2019, within that 26 percent of female patients having breast cancer [3]. The epidemiology of breast cancer worldwide reports that every one million new cases of breast cancer occur representing 18 percent of all cancer cases [4].

Radiotherapy of breast cancer is difficult because of the complex geometry of the target volume, which includes the breast, the adjacent lymph nodes, and the presence of critical organs such as the lungs and heart [5], [6], [7]. Ideally, the dose distribution should be as homogeneous as possible to avoid areas of under dose or overdose, which can result in insufficient tumor control or late sequelae (unacceptable fibrosis) and poor cosmesis [8]. The critical parameters to verify treatment plans for breast radiotherapy are the accuracy of the dose calculation and the homogeneity of the dose distribution of the treatment plan [9], [10].

Three-dimensional (3D) Radiotherapy TPS are now common in radiotherapy departments offering improved accuracy and enhanced visualization in the radiotherapy treatment planning process [11], [12], [13]. However, the Department of Radiotherapy of this particular hospital uses a two-dimensional (2D) treatment planning system, THERAPLAN®PLUS version 3.55 (MDS Nordion, Canada). The use of radiotherapy is complicated by the complex geometry and large variability of the target volume for different patients. More accurate dose calculation from TPS could be expected, particularly by increasing the amount of treatment site data input. The absolute dose at the prescription point is of prime importance in radiotherapy treatment planning [14], [15]. Monitor units are calculated to this point and the dose distributions are relative to this calculated value [16], [17].

In this study, the accuracy of the radiation dose calculation algorithm employed in THERAPLAN®PLUS version 3.55 was evaluated for different conditions simulating tangential breast treatment. THERAPLAN®PLUS uses the Clarkson equation for the calculation of the relative dose at any point on the axis of a radiation beam and Pencil Beam spread function Data (PBD) in the calculation of the relative dose at any point [18]. A 0.6 CC Farmer-type cylindrical ionization chamber with an electrometer was used to measure the dose distribution at the axial mid-plane of the breast phantom made of Perspex structure filed with water. This study is an important part of quality assurance procedures to accurately validate a treatment planning system.

**MATERIALS AND METHOD**

Preparation of 2D Breast Phantom

The breast phantom shown in Figure 1 was prepared using Perspex sheets. The phantom was designed to simulate the 2D anatomical and radiological characteristics of a breast. It was a very effective model for measuring radiation dose and optimizing breast radiation therapy treatments.

**Figure 1:** Prepared Perspex breast phantom.

**Treatment Planning**

At the 2D treatment planning, a single patient contour at mid plane was acquired using lead wire, which is transcribed onto a sheet of graph paper, with reference points identified. In this study, the cross-section of the phantom's curved surface could be assumed as the patient's breast contour as shown in Figure 2. A transverse line registered the mid-transverse plane of the breast phantom. Planning Target Volume (PTV) and calculation point A to P were marked on the slice (Figure 2).

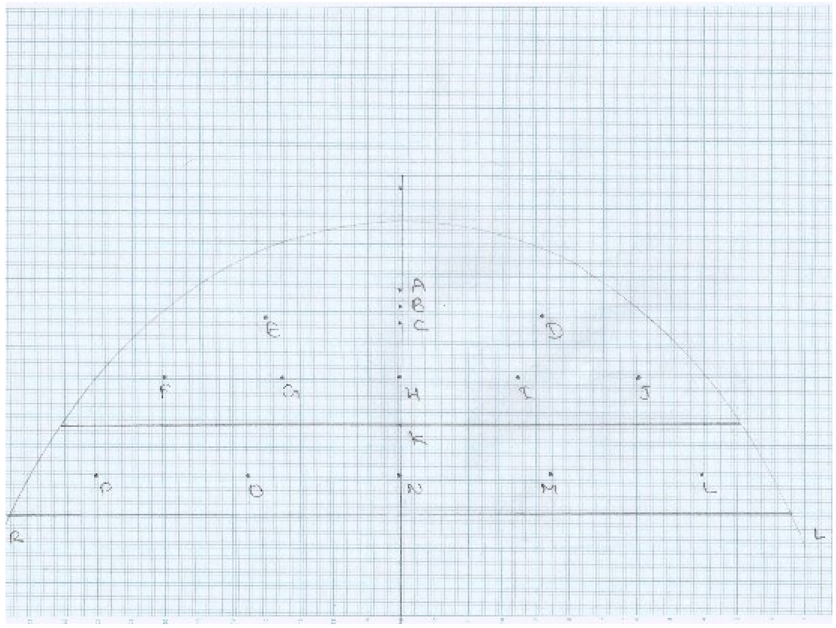


**Figure 2:** Cross section of the phantom's curved surface, PTV, and measurement points.

The contour of the phantom curved surface shown in Figure 2 was digitized by tracing the graph paper while identifying measurement points (Figure 3). The Radiotherapy department uses SSD, tangential fields, and compensating wedges technique for breast radiotherapy. In this exposure, a half-beam block and 30-degree wedges were used. In the treatment planning, a 30-degree wedge was used to compensate for the missing tissue. From this simulation procedure, a field size of 18 cm in length and 14 cm in width was used. A fraction size of 2 Gy as the prescribed dose was set at the normalized point A in Figure 2. The point A was selected to be two-thirds of the distance along the midline of the mid-transverse of the breast contour from the borderline of PTV to prepare uniform dose distribution. Percentages of doses at points A to P and monitor units for both beams were computed using the TPS.

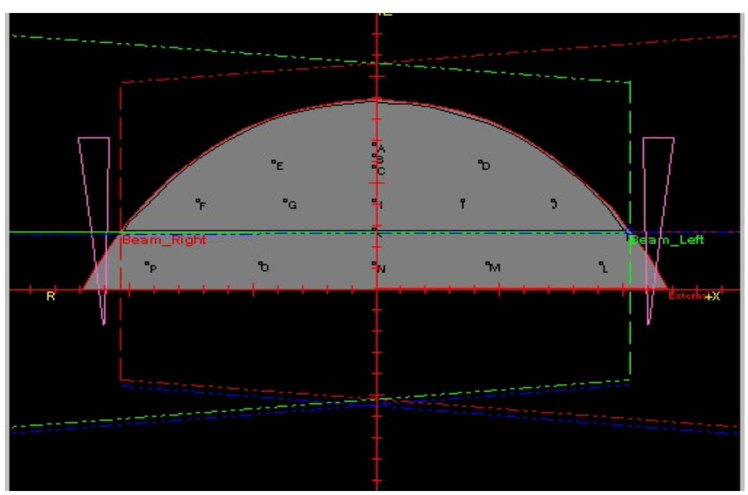


**Figure 3:** Screenshot - Beam arrangement of Breast Radiotherapy, Right and left fields with half beam blocks and wedges on TPS, THERAPLAN®PLUS.

**Dosimetry**

Measurement points A to P were determined and marked on the phantom using laser beams in the mold room. Quality Assurance (QA) tests were done to ensure the accuracy of the radiotherapy machine, before taking dosimetric measurements. The output calibration of the treatment machines was performed using a 0.6 CC ionization chamber (PTW Freiburg 30001-2125) and electrometer (PTW Freiburg UNIDOS T 10002) by following IAEA TRS 398 protocol in a standard 30 cm × 30 cm × 30 cm water phantom to ensure that machine output is same as the data fed to the TPS [19].

The breast phantom was placed on the treatment couch of the teletherapy machines (THERATRINIC 780 E, MDS Nordion, Canada) and aligned using laser beams. Machine parameters were set as gantry - 270o, collimator - 0o, field width - 14 cm, height - 18 cm with SSD - 80 cm for the right side beam, and for the left side beam gantry angle was changed to 90o. Half beam block and 30-degree angle wedges were used as planned by TPS, THERAPLAN®PLUS. The 0.6 CC ionization chamber was placed on point A marked at the midplane of the breast phantom and the phantom was exposed from both the right and left side. The dose of measurement at point A was measured using the 0.6 CC ionization chamber and the electrometer by following the IAEA TRS 398 protocol [19]. The same procedure was followed by changing the ionizing chamber positions, from points A to P to determine dose rates at each point.

**RESULTS AND DISCUSSIONS**

The plot of the calculated isodose line in the sagittal breast midplane using TPS, THERAPLAN®PLUS was shown in Figure 4. The plot of the dose distribution in Figure 4 shows that the dose was between 95% and 107 % of the prescribed dose in the PTV of the breast phantom according to ICRU recommendation [120]. Therefore, this beam arrangement with beam modifications which used half beam blocks and 30-degree angle wedges is suitable for radiotherapy treatment for a real breast cancer patient.

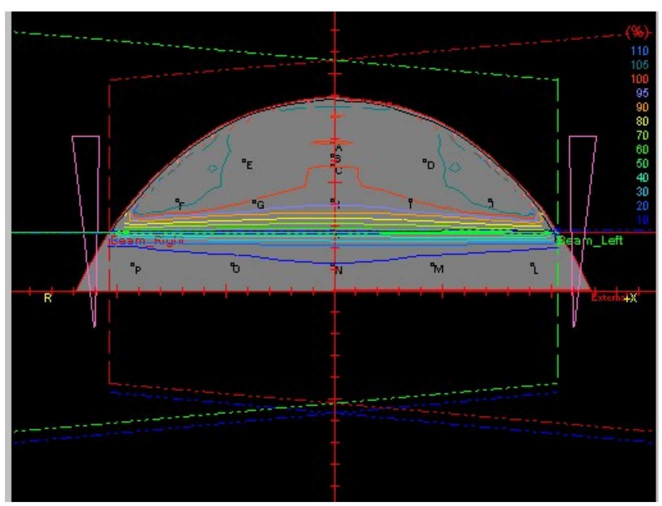


**Figure 4:** Screenshot – Dose distribution (Isodose line) in the breast treatment plan on TPS, THERAPLAN®PLUS.

The electron density of phantom-made Perspex and water are 3.24 x 1023 electrons/g and 3.34 x 1023 electrons/g respectively [21]. Basic dose distribution data are usually measured in a water phantom, which closely approximates the radiation absorption and scattering properties of muscle and other soft tissues [21]. Another reason for the choice of water as a phantom material is that it is universally available with reproducible radiation properties. The calculated doses derived from the TPS, THERAPLAN®PLUS were compared with the measured doses in the breast phantom. Each measurement point was analyzed for percentage difference using the following Equation [22].

$$\text{percentage difference} = \frac{(\text{measured dose} - \text{calculated dose}) \times 100}{\text{measured dose}}$$

The dose variation and percentage difference at different measurement points were shown in Figure 5 and 6. Overall, the measurements in the PTV area at points A, B, C, D, E, F, G, H, I, and J confirmed that the dose calculations are within an accuracy of, 5% while most measurements varied within 3%. The ICRU report 50 recommends target dose uniformity within +7 % and –5 % relative to the dose delivered to a well-defined prescription point within the target [20]. At points below the shielding area, dose difference percentages were also within the accuracy of, 5%. However, doses of points in the chest wall (below the half beam block shielding) L, M, N, O, and P were below 0.3 Gy per fraction. Compared to the values in the PTV area, it was a very small value and below the tolerance dose values of the lung and heart. Therefore, the treatment technique and calculations planned with TPS, THERAPLAN®PLUS were accurate according to ICRU recommendation. The overall results give confidence in the dose calculations for breast treatments.

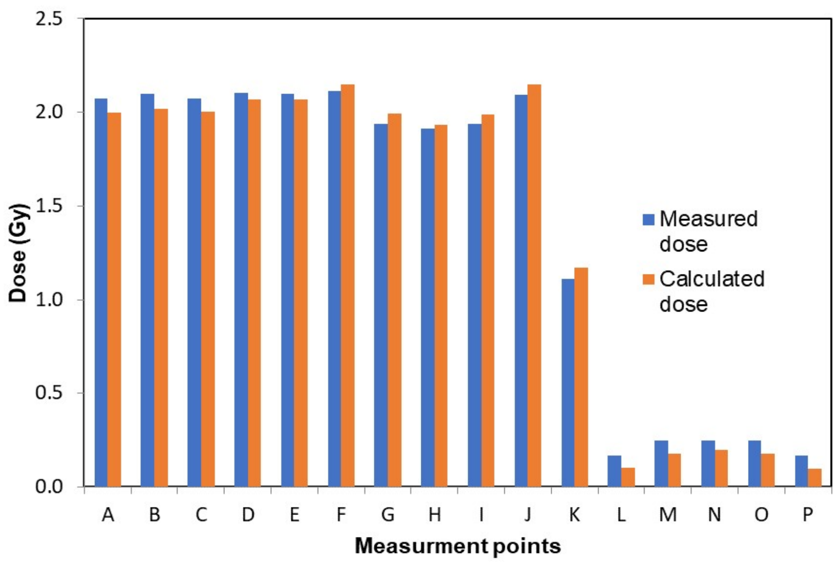


**Figure 5:** The dose variation at different measurement points.

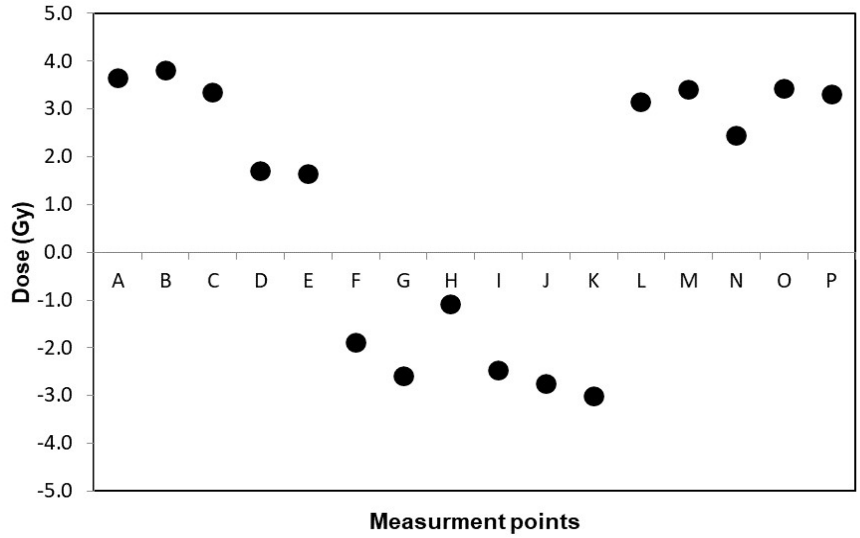


**Figure 6:** The percentage difference at different measurement points.

**CONCLUSIONS**

This work assessed the accuracy of monitor unit and dose distribution calculations performed by the THERAPLAN®PLUS version 3.55 planning system for a particular breast treatment by using a breast phantom and an ionization chamber. Overall, the measurements confirmed the dose calculations within an accuracy of 5% with most measurements lying within  3%. The overall results give confidence in the dose calculations for radiotherapy treatments by using the THERAPLAN®PLUS version 3.55 planning system.

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# Location Identification and Capacity Determination of Ocean Thermal Energy Conversion Power Plants in Sri Lanka

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**ABSTRACT**

In many parts of the world, renewable energy-based power plants are gradually replacing fossil fuel-based power plants. Intermittency is a major issue for most of the renewable power plants. But Ocean Thermal Energy conversion plants (OTEC) can generate electricity throughout the day. Such plants are possible in tropical countries where the temperature difference between the surface and the depth of the water is sufficient for electricity generation. In this research, a pre-feasibility study of OTEC plants was carried out. The paper discussed the main requirements for OTEC plant location, different types of plants and their suitability, operation, and key advantages of existing plants especially in the South Asian region. Temperature versus sea depth and the distance from the seashore to the plant location were considered in identification of the suitable locations of the plant. Based on the criteria, three sites were identified as the most feasible locations for OTEC plants in the country: Pasikudha, Trincomalee, and Dondara. Plant capacity at each location has been calculated considering the enthalpy diagram. Plant capacity of each location has been presented as a trend line equation considering the power generated by the plant and the auxiliary power of the plant. The results of the study revealed that maximum possible power output of all the three plants is limited up-to 6 MW.

**Keywords**: Ocean Thermal Energy conversion, OTEC plant capacity, Renewable Energy, Sea depth,

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**INRODUCTION**

The basic principle of electricity generation from OTEC is to capture the temperature difference between the surface of the seawater and the depth of the ocean to produce steam to spin the turbine. This concept was first mentioned in Science Friction by Jules Verne called "Twenty thousand Leagues under the Sea" published in 1870 (Kobayashi et al. 2001), (Fujita et al. 2018), (Vega 1999). The required temperature difference between the surface of the sea and the depth of the sea is mainly available in tropical countries around the globe (Ruiz et al., 2021), (Seungtaek et al.,2020). According to the World Ocean Atlas published by the United States National Ocean Centre in 2005, Sri Lanka is in a region that has about 22°C temperature difference between the surface and depth of the sea. Major advantage of OTEC power plants is their ability to generate electricity throughout the day. So, it does not have problem of intermittency that is the major drawback of renewables such as solar and wind.

Several studies have been carried out to investigate the feasibility of OTEC plants in South Asian region countries. Mohd Fahmie et al. carried out a preliminary design for constructing a 4 MW closed cycle OTEC power plant in Sabah, Malaysia (Fahmie et al. 2018). The study also included the OTEC plant potential in Malaysia is 100 MW. Jaswar Koto (Koto and Negara 2017) has studied the OTEC potential for electricity generation in Indonesia. Further, the study focused on the cost and performance of OTEC and showed that the plant cost beyond the capacity of 50 MW is much cheaper than the plant costs of smaller capacities. In the Philippines, a 10 MW OTEC plant has been in operation since 2008. In the world scenario, currently, there are two other power plants in operation. Since 2015, a 100 kW grid-connected closed-cycle OTEC power plant has been operating in the USA (Makai's Ocean Thermal Energy Conversion (OTEC) Power Plant, Hawaii 2020). A 100 W plant was built in Japan for demonstration purposes, and it has been in operation since 2013 (Okinawa OTEC Demonstration Facility 2023).

The operating principle of the OTEC plant is similar to the operation of any other conventional thermal power plant. The only difference is that the heat source used is the vertical temperature difference that exists in open tropical oceans. This temperature difference can be described as consisting of two layers separated by an interface. The upper layer of the seawater is heated by the sun and the temperature is mixed to depths of about 100 m because of the waves. The bottom layer consists of colder water of about 5°C formed at high latitudes. More often this temperature drop is gradual. The temperature difference between the upper and bottom layers can vary from 10 °C to 25 °C. The heat source and the heat sink required for a heat engine can be designed by that heat difference. The heat engine can be used to transform thermal energy into electrical. The temperature difference should be higher than 20°C to achieve net electrical power generation and good plant efficiency (Vega 2022).

The depth of the seabed with required temperature difference is one of the key parameters in deciding the feasibility of such a plant. Since submarine cables are used for cold-water transmission, the water at the selected depth should be accessible.

Different techniques have been proposed and experimented with to use a thermal gradient for electricity generation. At present, two systems are discussed mostly by their method of converting working fluid to vapor to spin the turbine (Etemadi et al. 2011): Closed Cycle and Open Cycle.

In the closed cycle OTEC process, warm seawater is drawn from the surface layer of the ocean into a heat exchanger (evaporator) to vaporize a liquid with a boiling point of about -30°C. Liquid propane and liquid ammonia have such low boiling points. The vapor drives a turbine that is connected to an electric generator. Exhaust vapor from the turbine is condensed in a second heat exchanger (condenser), which is cooled by deep seawater that is pumped from the deep ocean. The condensed vapor is then returned to the evaporator to complete a cycle. The operation of a closed-cycle OTEC plant can be modeled with the saturated Rankine cycle. In the past, the Rankine cycle preferred water as a working medium, and now most of the applications prefer to use the organic Rankine cycle having a working fluid with a low boiling point such as ammonia. OTEC's closed cycle operating mechanism is also based on the organic Rankine cycle since the temperature difference in OTEC is very small.

In an open-cycle OTEC system, the working fluid is warmed seawater itself. A fraction of the warm seawater is flash evaporated below its saturation value. Then, that steam is expanded through a low-pressure turbine that is coupled with a generator. The steam leaving the turbine is then condensed by cold deep seawater through a cold-water pipe (Vega 2013). There are some special conditions to be considered when planning an open-cycle OTEC plant. The system must be properly sealed to maintain the system in a partial vacuum ranging from about 3% to 1% atmospheric pressure. Components should be larger enough to prevent steam velocities to get dangerously high velocities because the specific volume of the low-pressure steam is larger than the pressurized warm water. Therefore, the designed plant may be larger in the open cycle process-based plants. In this process, the evaporator produces desalinated steam. Therefore, when the steam is condensed, fresh drinkable water can be obtained if a surface condenser is used.

The thermodynamic model and the operating principle of the open cycle OTEC heat engine, with its environment, can be stated as parallel to the Rankine cycle. In this condition, the role of the discharge pump and the non- condensable gas compressor is assumed as the role of the Rankine cycle pump (Vega 2013). There are three types of OTEC power plants based on the location of operation.

<u>Land-based plants</u>: Plants that are constructed in locations such as those with narrow shelves, steep (15C°-20C°) offshore slopes, and relatively smooth sea floors come under land-based power plants. Such plants prevent sophisticated monitoring and extensive maintenance associated with an open-ocean environment.

<u>Shelf-based plants</u>: Plants that are mounted to the continental shelf at depths up to 10,000 ft are known as shelf-based plants. A shelf-mounted plant is towed to the site and attached to the sea bottom. Such plants help to have closer access to the deep seawater and avoid turbulent surf zones.

<u>Floating power plants</u>: Floating OTEC plants are offshore plants mounted on a floating platform. Such plants are designed for large-capacity power plants. Stabilizing such plants has difficulties.

In the past, an OTEC plant was recommended for Sri Lanka after the analysis on bathymetry, thermal resources, resources, mixed layer depth, weather conditions, and sea & swell conditions and recommended (U.S. Department of Energy 1989), (U.S. Department of Energy 1979). Only a few studies were done on the feasibility of OTEC plant for Sri Lanka. The first preliminary study on the feasibility of the OTEC plant was carried out by Sri Lanka National Science Council (National Science Council 1980) in 1980 and the report concluded that such plants are technically feasible but economically not viable. This study was carried out forty years ago and the present status in the energy sector of the country has significantly changed. In 1994, the National Aquatic Resources Research and Development Agency (NARA) carried out a study on a conceptual design of OTEC in Sri Lanka. The study has proposed to have a floating-type OTEC power plant in the country. Meegahapola L et.al (Meegahapola et al. 2017) have discussed strategies and challenges of OTEC in Sri Lanka. The paper also discussed the financial aspects of such OTEC plants. The above studies were carried out for more than 10-15 years ago, and since then, the technology has been advanced and the equipment costs of such plants have been reduced (Kobayashi et al. 2001), (Seungtaek et al. 2020). In the meantime, the generation cost of fossil fuel-based power plants has been increased due to incorporating penalty costs for environmental effects (Choi et al. 2023, Holechek et al. 2022). More importantly, now the world is more concerned about environmental protection, and the prevention of greenhouse gas emissions. Therefore, the objective of this study is to identify locations and capacity of OTEC power plants in Sri Lanka.

## MATERIAL AND METHOD

### 2.1 Key Parameters for Site Location

The best possible location of the OTEC power plant is determined based on three parameters: Temperature Difference, The distance of the thermal gradient column from the shore, and Depth of the deep cold water

Temperature difference between the surface temperature and temperature of the layer at the depth of 750 - 1500 m is used for electricity generation. The minimum value of temperature difference that is required for energy conversion is 18°C.
The distance of the thermal gradient column from the shore is mainly responsible for the cost of the plant and therefore the unit cost. When the thermal gradient column is far away from the shore, both the costs of the piping system and cabling under the depth of the sea for power transmission become expensive.
Water pumps are required for pumping the water from the seabed. The power consumed by these water pumps depends on the depth of the cold water. This power is a major portion of the auxiliary power of the plant and hasa greater influence on the net power output of the plant.

### 2.2 Site Selection.

After studying data available in NARA (sea depth and distance from sea shore ) and in the report on "Overview of Ocean Thermal Energy Conversion" (Madhawa,2000), three potentially suitable locations were chosen for further analysis. Considering the temperature difference of surface water and the deep-sea water and the distance from the sea to the potential locations, three sites have been identified.
**2.2.1 Site 1**: Pasikudah - (7.9865N, 81.7614E): Pasikuadh is located 35 km northwest of Batticaloa district in the eastern province. The location is very famous for its beautiful beach. The temperature profile of the location is shown in Figure 1 (a). According to the graph shown in Figure 1((a), the temperature on the surface of the seawater is about 29°C, and at 500 m depth, the temperature becomes $10^0$C. This means the temperature difference of 19°C occurs even at a depth of 500 m. The distance from the seashore to the site is about 5.5 km as shown in Figure 2(a).
**2.2.2 Site 2**: Trincomalee- (8°36.10N, 31°17.43E): Trincomalee is located on Sri Lanka's northern coast. Stretching on either side of a narrow peninsular, it is flanked by some of the most idyllic white-sand beaches in Sri Lanka. The beach has been a tourist destination for many years. The proposed site is near Trincomalee Bay. The temperature profile of the seawater is given in Figure

1(b). As per the figure 1(b), site 2 (8°36.10N, 31°17.43E) has a surface temperature of about 27°C and a cold seawater temperature of about 6°Cat 1100 m depth. Since the temperature difference is about 21°C, Trincomalee Bay is suitable for an OTEC plant. The distance from Trincomalee Beach to the identified location is 35.1 km (Figure 2(b)).

**2.2.3 Site 3**:Dondra - (5.783333N, 80.50E) Dondra is a settlement on the extreme southernmost tip of Sri Lanka, in the Indian Ocean near Matara, Southern Province, Sri Lanka. As per the temperature profile shown in Figure 1(c), the surface temperature is about 29°C and the temperature at about 1300 m depth is about 6°C. The temperature difference of 23°Cexists at the distance. Therefore, the proposed site is also suitable to locate an OTEC plant. The distance between the location and Dondara is 18.1 km (Figure 2(c)).

The depth of the cold water has a greater influence on the cost of the plant. The cost is increasing with the deepening of the cold water. When the cold water is at a greater depth, it is required to have high-capacity water pumps. The cost of these water pumps and associated installation works becomes expensive. It is possible to build a low-cost power plant when the required temperature gradient is available at about 500 m-1500 m depth.

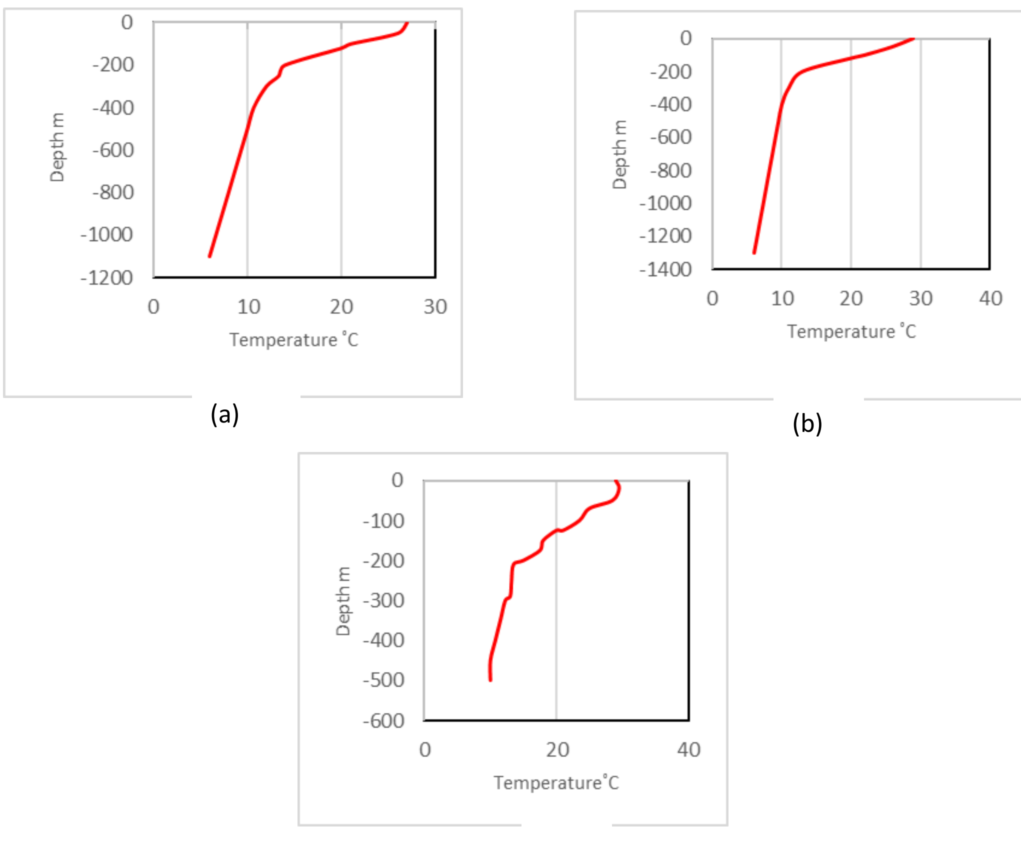
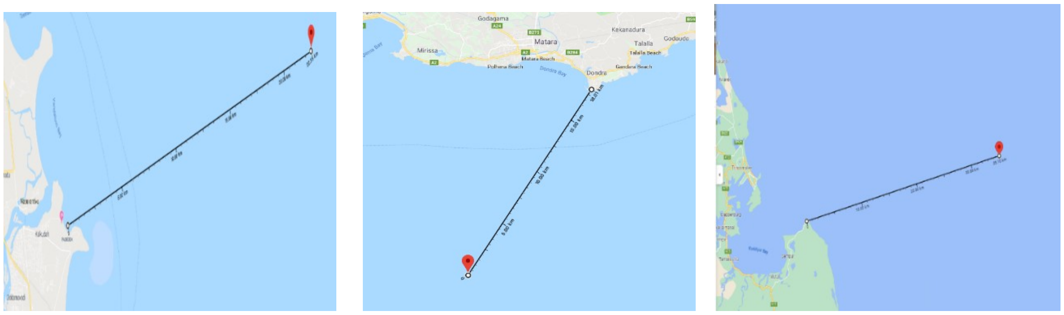



**Figure1:** Temperature versus depth of the sea of three locations (source: NARA)



(a) Pasikudah (b) Trincomalee (c) Dondara

**Figure 2:** Possible location for OTEC

In sites 1,2 and 3, the cold water of the required temperature is available at the sea depths of 500 m, 1000 m, and 1200 m respectively. This means all the three sites are suitable for the OTEC power plants.

### 2.3 Plant Type Selection

The distance from the seashore to the deep cold seawater extraction point would restrict the feasibility of an onshore plant. This is because of the increase of the capital cost for cold water pipes with the increase of the distance and associated reduction in thermodynamic efficiency. Considering the distance to the seashore from the selected sites (18.1 km, 22.5 km, 33.1 km) an offshore platform (floating) type plant has been proposed.

The selection between open-cycle and closed-cycle types of the plant depends on the required capital investment and the plant capacity. The cost for the main components of two types of plants based on their capacities is given in Table 1 (Seungtaek et al., 2020). As per the table, constructing an open cycle plant requires higher capital cost, therefore considering the predicted capacity of the plant closed cycle plant is recommended.

### 2.4 Plant Capacity calculation

In this study, plant capacities were estimated by considering only the temperature difference. The exact plant capacity can be determined after analyzing the characteristics of elements of the plant (condenser, evaporator, etc.), site parameters, environmental parameters, climatic parameters, etc. The plant capacity of a closed-cycle type plant was calculated using mathematical formulae and data from various sources. The T-S diagram is shown in Figure 03. The numbers indicated in the diagram and the status of the working fluid in the closed-cycle power plant shown in Figure 4 are the same. 2.4 Plant Capacity calculation.

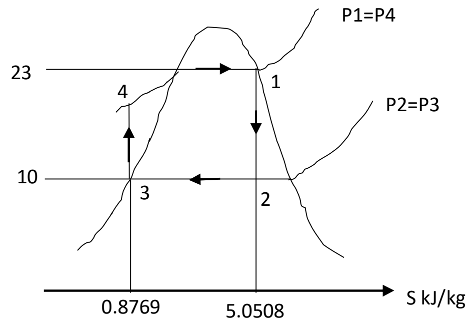



**Figure 3:** Enthalpy diagram

The total heat output from the evaporator after absorbing the heat of the warm seawater can be calculated using the equation (1) respectively (Yeh et al. 2005).

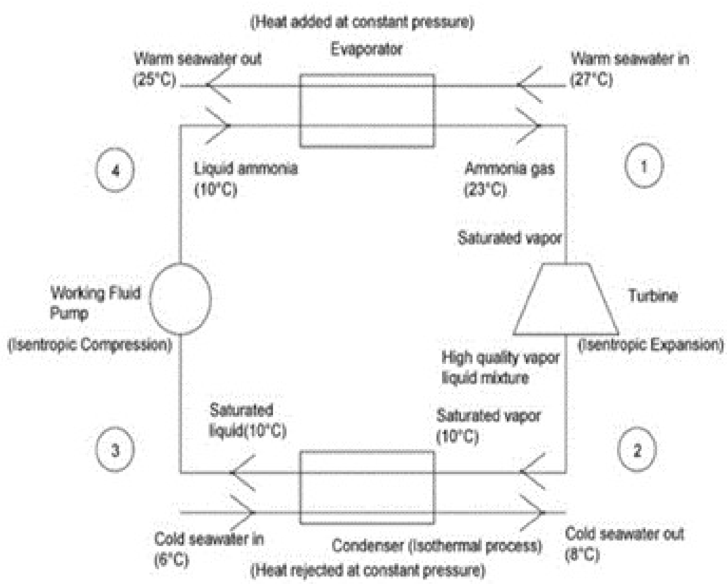



**Figure 4:** Closed-Cycle OTEC plant

$$Q_e - \dot{m}_{ws} C \Delta T_{ws} \qquad (1)$$

Considering the energy balance, the mass flow rate of saturated vapor can be calculated using equation (2) (Yeh et al. 2005).

$$\dot{m}_a = \frac{Q_e}{(h_1 - h_4)} \qquad (2)$$

Assuming that the expansion of saturated vapor of the working fluid into low pressure's mixture of saturated vapor and liquid happens is entropically, the working fluid that is leaving from the turbine is calculated using the equation (3) respectively (Engels et al. 2014)

$$x = \frac{(s_{g(at\ 10°C)} - s_{f(at\ 10°C)})}{s_{fg(at\ 10°C)}} \quad (3)$$

The enthalpy of the working fluid vapor at the turbine output is calculated using the equation (4) respectively (Engels et al. 2014)

$$h_2 = h_{f(at\ 10°C)} + x\, h_{fg(at\ 10°C)} \quad (4)$$

Since the enthalpy at the input and output of the turbine are known, total electric work resulting from turbine- generator unit is calculated using the equation (5) (Yeh et al. 2005).

$$W_{tg} = \dot{m}_a(h_1 - h_2)\eta_t\eta_g \quad (5)$$

### 2.4.1 Auxiliary power of the plant

The net output of the generator differs from Wtg given in equation (5) because of the plant's auxiliary power. Power consumption by the plant is mainly because of the pumps 'operations. The pumps are mainly required for three purposes: pumping of deep seawater to the condenser; pumping of the warm seawater to the evaporator; and pumping of the working fluid to the evaporator (Engels et al. 2014). These pumps are identified as cold seawater pump, working fluid pump, and warm seawater pump. The auxiliary power of the OTEC plants is high due to the power consumed by these pumps. The depth of the sea that has the required temperature difference has a greater impact on the capacity of the pumps and therefore the auxiliary power of the plant.

Power consumed by the working fluid circulating pump, warm seawater pump, and cold seawater pump are given in equations (6), (7), and (8) respectively (Engels et al. 2014).

$$W_p - v(P_4 - P_3)\dot{m}_a/\eta_{ap} \quad (6)$$

$$W_{wsp} = \frac{\frac{1}{2}\dot{m}_{ws}U_{ws}^{2}}{\eta_{wsp}} \quad (7)$$

$$W_{cp} = H_{(loss)}\dot{m}_{cs}\, g/\eta_{csp} \quad (8)$$

The net output power of the generator is calculated after deducting power consumed by the three pumps are given in equations (6), (7), and (8), This is given in equation (9)

$$W_n = W_{tg} - W_{ap} - W_{ws} - W_{cs} \quad (9)$$

## RESULTS AND DISCUSSION

Power output from the proposed three sites was calculated using the equations (1) – (9) and the data of the three sites are given in figures (2)-(4). The data relevant to the condenser, evaporator pipe, and parameters of the pumps were taken from Yeah et al (2005) (Yeh et al. 2005). These data are summarized in Table 1. Ammonia was chosen as a working fluid for all three sites. Enthalpy (h) and entropy (s) of the saturated ammonia (liquid-vapor) at 23 $^{0}$C and 10 $^{0}$C were obtained from the physical properties of the ammonia (Haar and Gallagher 1978). Accordingly, h1=h2=hg (23 $^0$C) =1461.933 kJ/kg; $h_3$=$h_4$=$h_f$ (10 $^0$C)=5.508 kJ/kg; $S_1$=$S_g$(23 $^0$C)=5.0508 kJ/kg; $S_3$=$S_f$(10 $^0$C)=0.8769 kJ/kg. As per the thermodynamic formula, the pressure at points 1,2,3 and 4 were: $P_1$=$P_4$=P(23 $^0$C)=943.96 $^0$C; $P_2$=$P_3$=P(10 $^0$C)=615.29 kPa. The volume at the fluid state was 0.0016 $m^3$/kg.

**Table 1: Seawater, turbine, and pump data of the proposed sties**

| Parameter | Dondra | Trincomalee | Pasikudah |
|---|---|---|---|
| **specific heat of the sea water (C)** | | 4.8 kJ/kg$^0$C | |
| **Warm seawater inlet temperature** | 27 $^0$C | 29 $^0$C | 29 $^0$C |
| **Warm seawater outlet temperature** | 25 $^0$C | 27 $^0$C | 27 $^0$C |
| **Cold seawater inlet temperature** | 6 $^0$C | 6 $^0$C | 6 $^0$C |
| **Cold seawater outlet temperature** | 7 $^0$C | 7 $^0$C | 7 $^0$C |
| **Desired ammonia temperature at the evaporator outlet** | 25 $^0$C | 25 $^0$C | 25 $^0$C |
| **Desired ammonia temperature at the condenser outlet** | 10 $^0$C | 10 $^0$C | 10 $^0$C |
| **Seawater pipe diameters(both)** | 1 m | 1 m | 1 m |
| **Turbine efficiency** | | 89% | |
| **Generator efficiency** | | 96% | |
| **Seawater pump efficiency (both)** | | 85% | |
| **Ammonia pump efficiency** | | 85% | |
| **The kinematic velocity of the seawater (K)** | | 1.83 x$10^{-6}$ $m^2$/s | |
| **$\xi$ Approximate pipe roughness** | | 20 mm | |
| **Cold seawater depth** | 1300 m | 1100 m | 600 m |

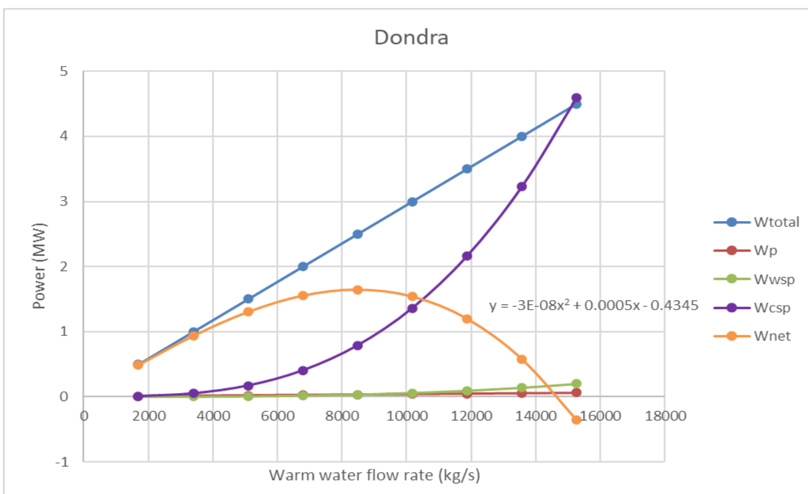
By using the above equations and the data, the variations of power (Wnet, Wtotal, Wp, Wwsp, Wcsp ) versus mass flow rate of warm seawater were plotted and shown in Figure 5

For the considered site parameters, the maximum power that can be generated was determined using the trend line equations for each site separately. The trend line equations and maximum net power output of respective sites are given in Table 2.

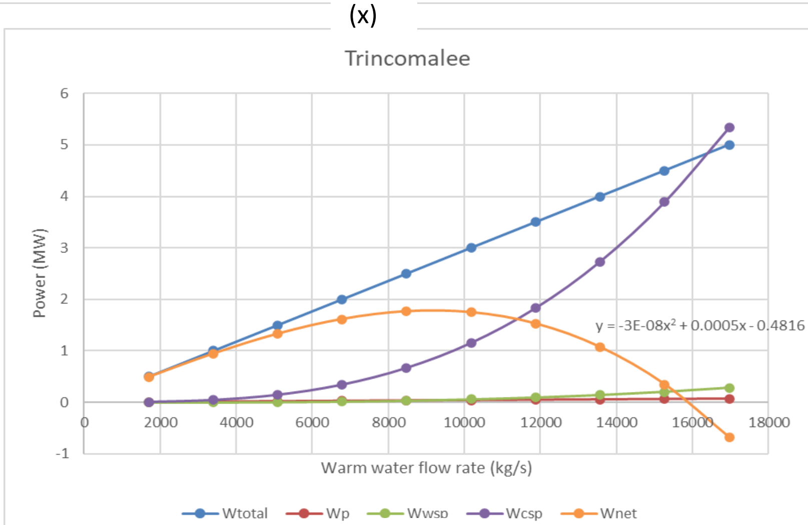
**Table 2:** Maximum power generation of proposed sites

| | Trend line equation | Maximum possible power output (MW) |
|---|---|---|
| **Pasikudah** | $y = -2 * 10^{-8}x^2 + 0.0005x - 0.6297$ | 2.49 |
| **Trincomalee** | $y = -3 * 10^{-8}x^2 + 0.0005x - 0.4816$ | 1.60 |
| **Dondara** | $y = -3 * 10\ ^{8}x^2 + 0.0005x - 0.4345$ | 1.65 |

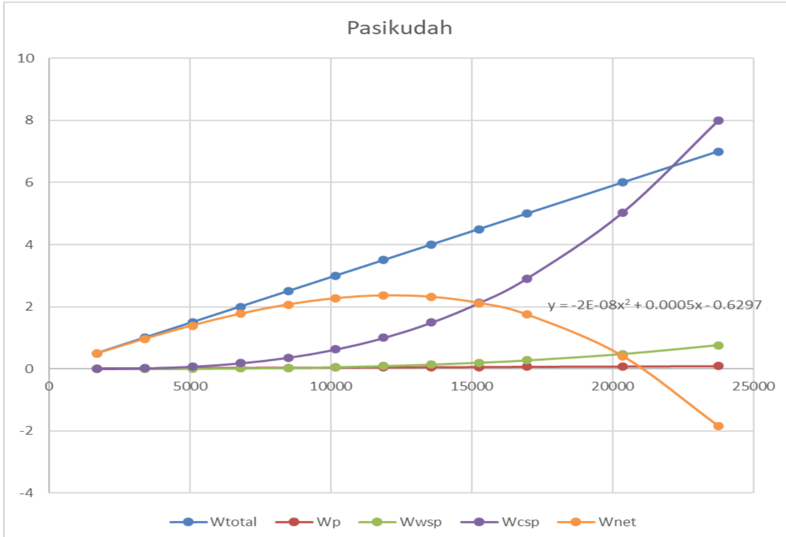
By considering all three outputs it can be determined that the Pasikudah site has the potential to generate electricity more than the other two sites. The reason is that the cold-water intake depth is shallower in the site than in the other two. The graphs also showed the impact of the depth of the cold water on the net output of the plant. When the depth of the cold water is greater the pump capacities and the power consumed by the pumps are higher.




(x)




(y)




(z)

**Figure 5 (x), (y), (z):** Power variation of the three sites with the warm water

Therefore, even though the power generated by the plant is high the net power output becomes less.

**CONCLUSION**

This study showed that the construction of OTEC plants in Sri Lanka is technically feasible. The results of calculations show that the maximum possible power output of these three plants is only 5.74 MW.

The main barrier to further increase of the power output is the power consumed by the pumps of the plant. It is possible to connect these plants to the distribution network and serve as distributed generators. The economy of such a connection depends on the proximity of the grid. This is because of the cost involved in transmission of the power generated by the plant to a substation (cost of the cables and accessories, cable laying under the sea etc.). Another option is to consider these plants to form microgrids. Microgrids are now increasingly used for providing electricity to distribution systems by utilizing available renewable sources of energy in respective areas or regions. All these three locations are very famous tourist destinations. OTEC can be used not only for electricity generation but to provide cool water and air conditioning which are very much required for the tourist hotels in the area., the tourist industry looks for state assistance due to energy and financial crisis. This study did not include details of the economic analysis of OTEC plants. However, recent studies have shown that the levelized cost of energy of low and medium-scale OTEC power plants is around 0.3 USD per kWh (Chenglong Xio and Raza Gufam, 2023). At present, the unit cost of energy from the diesel and furnace oil is a little higher than this value. However, it also should be considered that the lack of foreign currency to export the fuel and the environmental pollution due to the operation of diesel power plants. Therefore, OTEC power plants can be one of the candidates to meet the 100% power generation from renewable energy sources in the future.

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## NOMENCLATURE

| | | | |
|---|---|---|---|
| Q | The total heat flow $(kw)$ | U | Velocity$(m/s)$ |
| $\dot{m}$ | mass flow rate$(kg/hr)$ | W | Electric work$(kw)$ |
| c | Specific heat of seawater$(kJ/kg)$ | S | Entropy $(kJ/kg)$ |
| T | Temperature $(K)$ | x | The quality of ammonia vapor leaving the turbine |
| h | Enthalpy $(kJ/kg)$ | | |

## SUBSCRIPTIONS

| | | | |
|---|---|---|---|
| e | evaporator | p | Pump |
| *c* | Condenser | g | Gas |
| ws | warm sea water | f | Fluid |
| cs | cold sea water | a | Ammonia |
| tg | turbine generator unit | | |

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