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# Image Processing Based Quality Measurement System for the Manufacturing Process of Porcelain Plates

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**Abstract –** *This paper aims to introduce an Image processing-based non-contact diameter and thickness measuring system for the manufacturing process of porcelain plates.*

*The proposed system is designed to replace the manual process of quality assurance with a non-contact design that is more precise, time-efficient, and has effortless control. Seeing that the verification of acceptable tolerance levels in quality parameters (foot diameter, outer diameter, centre thickness & edge thickness) manually is time-consuming and erroneous, a more satisfactory system is designed to meet the stipulations.*

*Here in this design, the laser displacement method, triangulation principle and pixel scaling methods used to provide the necessary basis for the image processing analysis for thickness measurement, and edge detection algorithm for diameter calculations.*

*This system provides an improved error percentage variance of 0.01- 0.13 in outer diameter, 0.01-0.52 in the foot diameter and 0.18-1.38 in centre thickness measurement. Regardless the system can be used for similar applications where non-*

***Keywords*** *–Non-contact measurements, pixel scaling, CCD*

## 1 INTRODUCTION

This paper analysed the manufacturing process of porcelain products and identified the areas that can improve by applying vision-based measuring techniques to enhance to quality of products by reducing the drawbacks of the existing manual process.

The analysis is based on the data collected from the Dankotuwa Porcelain (Pvt) Ltd with the prime focus on **TYPE 520** plate model. From the statistical data, plate type 520 is the most defective plate item in the manufacturing process. According to company reports, the number of quality products versus the total production of porcelain varies between 60-75 % at the final production stage. At present, they employ a manual process where plates are selected on a random basis every ½ an hour where workers cut the plate (Refer Fig.1) through diameter axis and check the Outer diameter, Foot diameter, Centre thickness and Edge thickness of the plate using a vernier calliper. Further, the weight of the plate is measured using an electrical balance. The manual process does not yield a meticulous output as the process is time-consuming, inefficient and observer-dependent.

On the other hand, in the manual process quality parameters measurement take place in the biscuit stage (Fig.2). At this stage, it is impossible to recycle raw materials. By introducing an alternative approach to measure the quality parameters in, forming stage promotes easy recycling of defective products.

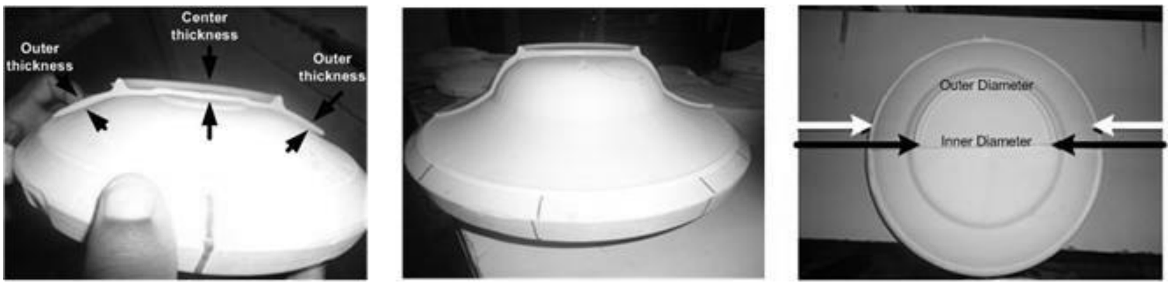


**Fig. 1. Quality Parameters of Plates**

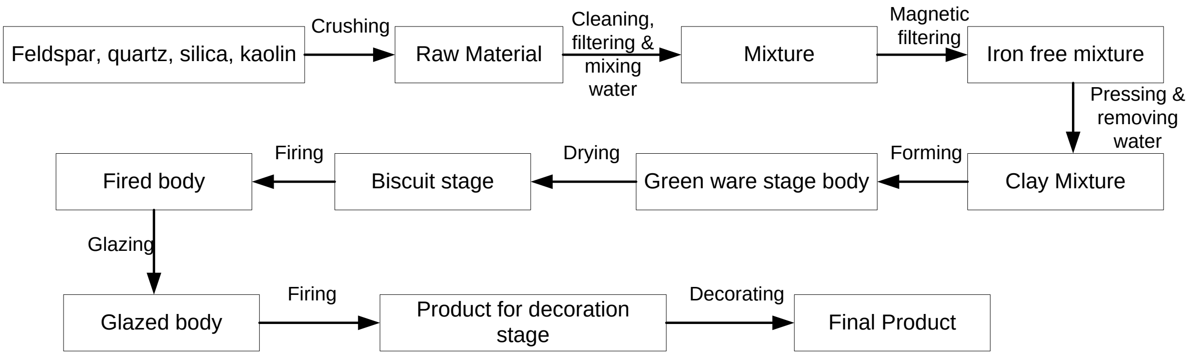


**Fig. 2. Manufacturing steps of porcelain plates**

Before the biscuit state, the product is extremely fragile. Therefore, the non-contact-based measurement system is required to do the quality parameter measurements. Vision-based systems widely used technology in many industrial applications. Even though is it established technology, the specific application needed to investigate and come up with unique solutions. Let us discuss few vision-based measurements application and research work.

Chenu-Chung (Chen *et al.*, 2008) explaining how CCD camera used for an area measuring while recording images simultaneously. It used the relationship between the pixel number and the distance to measure the area in large. Paper explain how to build the relationship between pixels and distance using the triangular method. Similar approached used in our proposed approach.

Chih Lu et al. (Lu, Wang and Chu, 2006)introduced a novel measuring system using a scan counter method via a CCD camera. In this method, measuring system, measure the distance between a CCD camera and an object, and to measure the projected area of the object. Two laser projectors are set on either side of a CCD camera and produce two parallel rays that project two bright spots on the object on the CCD. An external clock, which is generated by an extra oscillator, is used to measure the time interval between the two bright spots as the CCD scans the image. A circuit for counting the number of external clock pulses between the two bright spots is employed to calculate the interval between them in the video image. The most significant advantage of the proposed system is, it does not require highly complex hardware to process and processing time is less. It is an essential requirement for real-time application. Our approach using image processing techniques and required high processing power, and it takes considerable time to process.

The proposed system in (Lu, Wang and Chu, 2006) output distance from the CCD to image and calculate the surface area of the object. In our system, it is required to get the necessary measurements like the diameter and thickness of the plate.

To measure the thickness of a cable subpixel based image processing techniques has been introduced in(Wang and Zhao, 2011). The proposed method is more focused on the accuracy of the measurement as it used to take the precision measurement. Overall computational complexity is high in the proposed method. The proposed method not suites for our requirement as considered application requires a less complex computational algorithm for measuring parameters.

There are many vision-based measurements systems in the various application explain in (Wang and Wang, 2015),(Wang and Zhao, 2011),(Borkowski, 2002),(Wang *et al.*, 2007) and (Hwang, Park and Kim, 2010). In all these research work trying to solve application-oriented practical issues, which is needed to investigate case by case. Even though the same base principle is using, application-specific challenges require a novel approach to solve the problem. Hence, there are new research opportunities in vision-based applications.

Similarly, this study focused on an application-specific problem in the porcelain manufacturing process. The objective of this study is to replace the manual process of measuring quality parameters with a preeminent, efficient, automated system design to minimise the production wastage, time wastage and improve quality of production. The primary approach of the proposed methodology is a combination of Laser triangular method and image processing techniques.

## 2 METHODOLOGY

According to the quality targets, the details of the Plate **TYPE 520** with an acceptable range of variation in measurements are as follows.

**Table 1 Manufacturing product details of Plate model: 520**

| Measuring detail | Design value | Tolerances |
|---|---|---|
| Foot diameter | 187mm | +/- 1mm |
| Outer diameter | 300mm | +/- 1mm |
| Centre thickness | 5mm | +/- 0.5mm |
| Edge Thickness | 3mm | +/- 0.5mm |

Image processing approach is used to measure the quality parameters as the accuracy can maintain in the tolerance values, and it is proven techniques in non-contact measurements over ultrasonic systems—considered application required two types of measurements to be taken; Diameter and thickness.

### 2.1 Parameter Calculations

#### *2.1.1 Calculation of Plate Thickness*

For thickness measurements, Laser displacement method is used. If the angle between the Camera, laser and the line displacement is known, the component height calculated using simple trigonometric formulae (right-angled triangle).

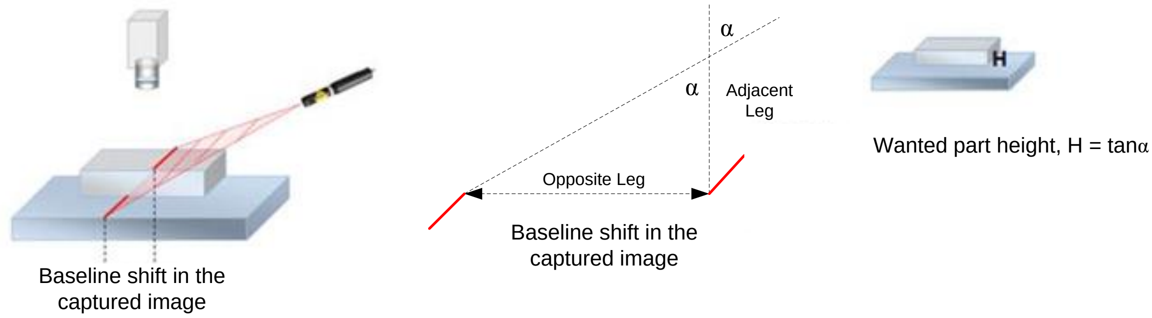


**Fig. 3. Thickness measuring & Calculation using the laser triangulation principle**

If the laser project on the object with a shallow angle (As shown in Fig. 3), even small differences in height cause a substantial displacement of the lines, even differences of tenths of millimetres can be detected easily without special effort, Fig. 4 shows a sample image of such displacement of the laser beam.

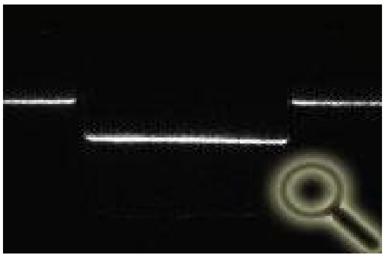

**Fig. 4. Image of a projected laser beam for thickness measuring**

The line displacement can be found by simply multiplying the pixel distance between two lines with a fixed constant. As the projection angle of the laser pointer (ϴ) is already known, plate thickness derived as a product of the tangent of the projection angle and line displacement.

$$Thinkness(Y) = X\ Tan\theta\ (1)$$

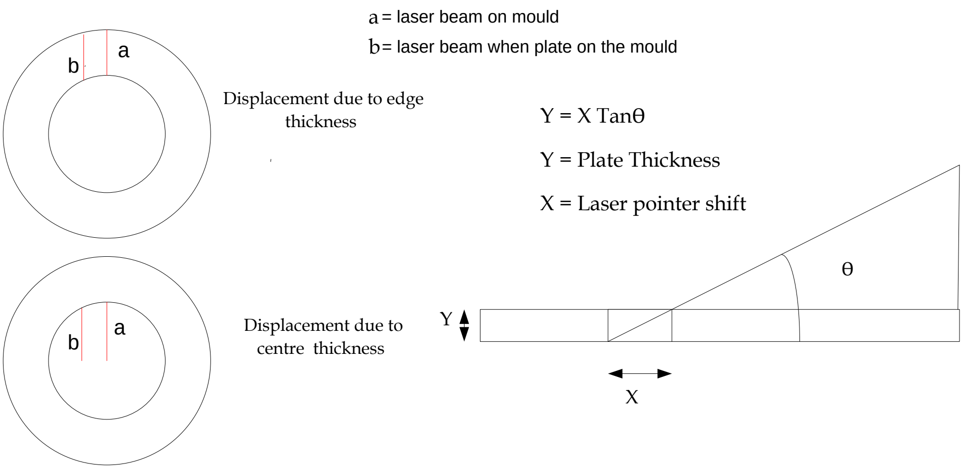


**Fig. 5. Thickness calculations using a laser pointer**

With this method, it is possible to find the centre and edge thickness of the plate. To find the edge thickness, it is needed to apply the laser beam parallel to the angle plate surface. Displacement of laser beams is appearing after adding two images taken mould only and mould with the plate. Plate thickness causes the displacement of the laser beams. In the practical setup, we are considered only centre thickness as the procedure is the same for the edge thickness.

#### *2.1.2 Calculation of Plate Diameter*

The edges of the captured images are detected by applying the edge detection algorithm(Canny, 1986) to the smoothened greyscale image. The relevant outer diameter & foot diameter are filtered out from the received set of diameter values (pixel values) procured using OpenCV inbuilt libraries. Similar to thickness measurement, outer diameter & foot diameter is obtained by multiplying the diameter values (pixel count) with a fixed constant.

#### *2.1.3 Calculation of the Focal Length of the Camera*

Even though the focal length of the Camera is specified, it is needed to find it experimentally in an application like image processing-based measurement calculations. As shown in Fig. 6, an object is mapped of the CCD chip through the camera lens. Since the CCD chip is two dimensions, we can find the value for focal length considering object height and width. Focal length can found using known parameters like object height, working distance and size of the CCD chip.

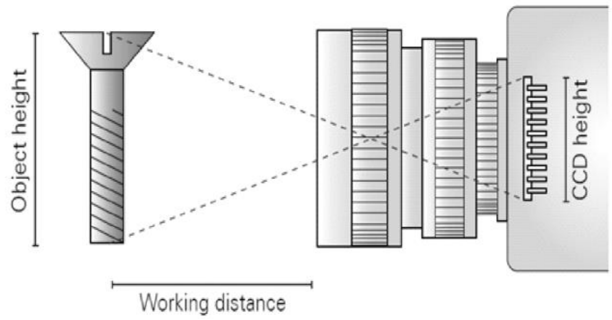


**Fig. 6. Method of calculating the focal length**

$$\text{The focal length of the height} = \frac{(\text{working distance} \times \text{CMOS height})}{(Object\ height + CMOS\ height)} \quad (2)$$

$$\text{The focal length of the width} = \frac{(\text{working distance} \times \text{CMOS width})}{(Object\ height + CMOS\ width)} \quad (3)$$

#### *2.1.4 Pixel Calibration for Distance Measurement, Calculation Technique*

Calibration involves determining the correspondence between pixel units and physical units. It allows measurements made in pixel units to converted to physical units by scaling factor. Four parameters need to measure in two dimensional CCD; pixel height, $h$; pixel width, $w$; the aspect ratio $r = h/w$; and pixel area, $a = h \times w$.

Furthermore, there are two methods of pixel calibration techniques; Length and Area-based measurements. Length based calibration technique has been used in this process as the measurements are the length of an object [15].

In the proposed method, the Camera is mounted perpendicular to the object in a fixed position. Fig. 7 shows how the object image focuses on the CCD sensor area. It is needed to find the relationship between pixel size and the object size. CCD pixel size and the calculated size is not necessarily the same. Therefore, let us define a new parameter, scaling factor. Since CCD is a two-dimensional, scaling factors should find for both x and y directions.

### 2.1 Calibration procedure – Length

In the calibration process, dimensions know objects needed to use as reference objects. Then no. of pixels will be counted using the algorithm. After that, the relationship between object dimensions and pixel count can found.
A circular-shaped object of known diameter has chosen. Let the known diameter of the calibration object to be *D,* and *W* is the pixel count.
The calibration parameters can then calculate as:

$$\textit{Pixel Scaling factor\_X (Px)} = Dx / Wx \quad (4)$$

$$\textit{Pixel Scaling factor\_Y (Py)} = Dy / Wy \quad (5)$$

x and y denote x-direction and y directions, respectively.

These equations valid only when H is the fixed and same type of plates.

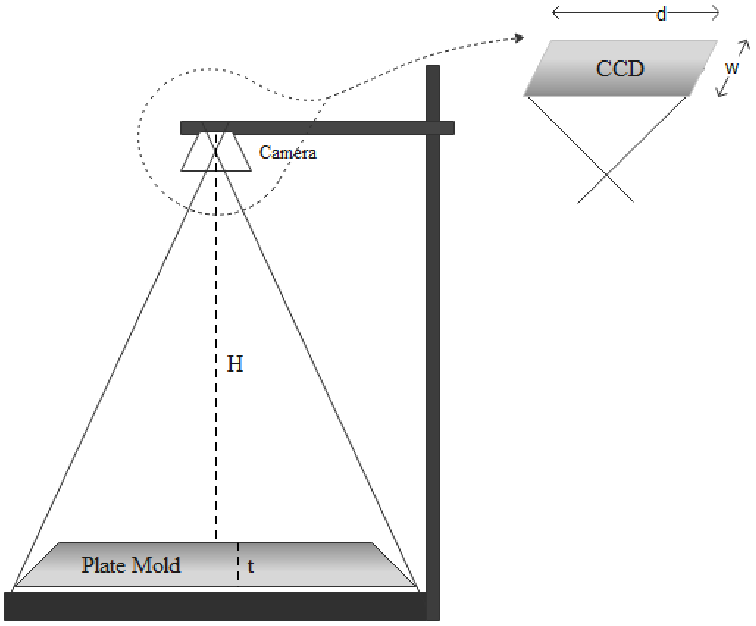


**Fig. 7. Scaling the object on the CCD plane**

The distance of Camera to foot diameter - (H+t)
The distance of Camera to outer diameter – H

*i.* ***Pixel to real values Conversion***

Plate Outer diameter – D0
Plate Foot diameter - Df

Measured values,

The pixel count of Outer diameter - NpixO

Pixel of foot diameter - NpixF

For a camera with a known pixel value mounted in the distance H from the object, the relationship between the number of pixels that represent X mm=N pix/L (mm).

$D_o = NpixO \times Px$ or $D_o = NpixO \times Py$ (6)

$D_f = NpixF \times Px$ or $D_f = NpixF \times Py$ (7)

From equation (5) and (6), plate outer diameter and foot diameter can find.

## 2.2 Image processing-based diameter, thickness detection and calculation Algorithms

Next, let us focus on image processing algorithms used in the proposed method.

### *2.3.1 Quality Parameter Measuring Process*

The first step of the process is to capture images of the mould. Then apply mixed on the mould and capturing an image with the plate by applying two laser sources described in 4.1. From these two images, we can apply the image processing algorithm to calculate the thickness measurements and diameter measurements. These data stored in a database, and it will compare with the given specification. If it is in the acceptable range plate is moved to the next steps, and if not, it will reject, and raw material will be recycled.

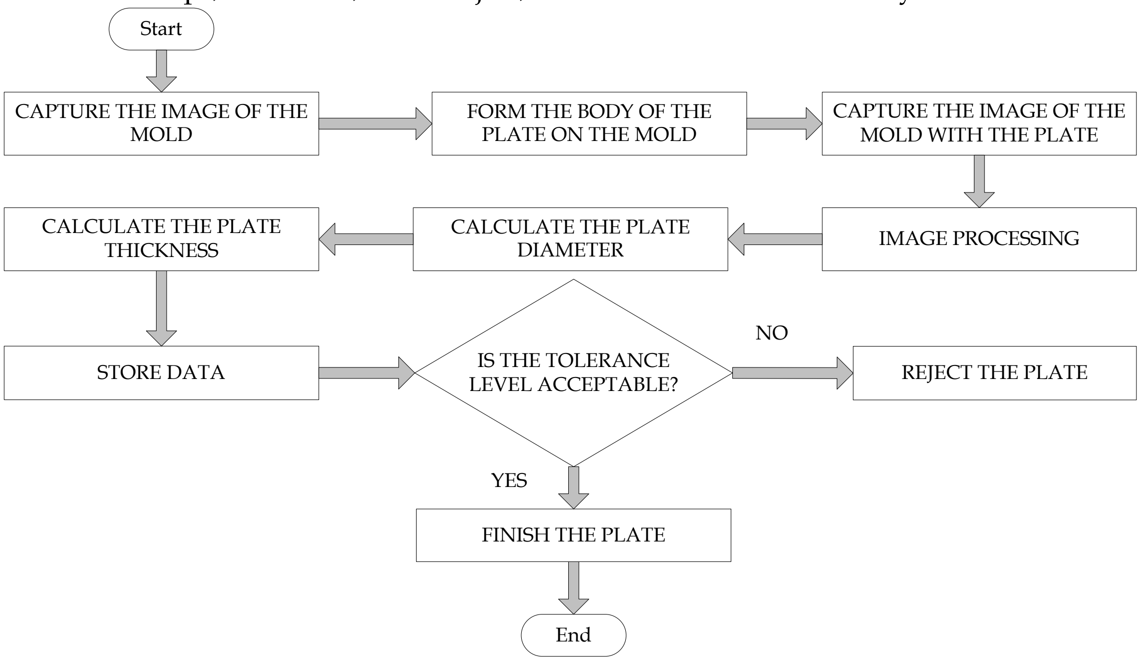


**Fig. 8. Flow Chart for Quality Parameter Measurement Process**

### *2.3.2 Image Processing Algorithm for Diameter Measurement*

For diameter measurements, contours of outer and foot diameters need to need to identify. As the first step, the algorithm threshold the image to filter the unwanted details. Then, it converts to black and white image to make the edge detection process easy. Edge detection and centre identifying algorithm explained in the next sections.

After identifying the centre, the diameter can calculate. Fig. 9 shows the process of calculating the diameter of the plate.

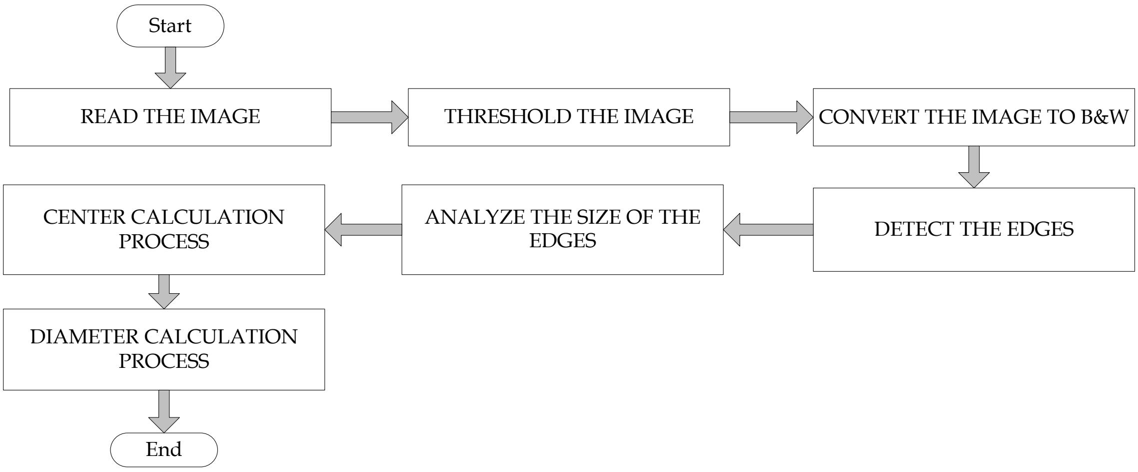


**Fig. 9. Flow Chart for Diameter Measurement**

### *2.3.3 Edge Detection Algorithm*

The edge detection algorithm is based on the Sobel operator. The algorithm is calculating the gradient of the intensity of the image. At each point, it finds the direction of the change from light to dark. It also finds the magnitude of the change. This magnitude corresponds to how sharp the edge is.

The algorithm can break down into its constituent steps.

a. Iterate over every pixel in the image.
b. Apply the x gradient kernel.
c. Apply the y gradient kernel.
d. Find the length of the gradient using Pythagoras' theorem.
e. Normalise the gradient length to the range 0-255.
f. Set the pixels to the new values.

### *2.3.4 Centre Calculation Algorithm*

The algorithm counts no. of pixels from left to right and right to left in the x-direction of the circle. The same procedure applied in the y-direction. From these values, it can calculate x and y coordinates of the centre.

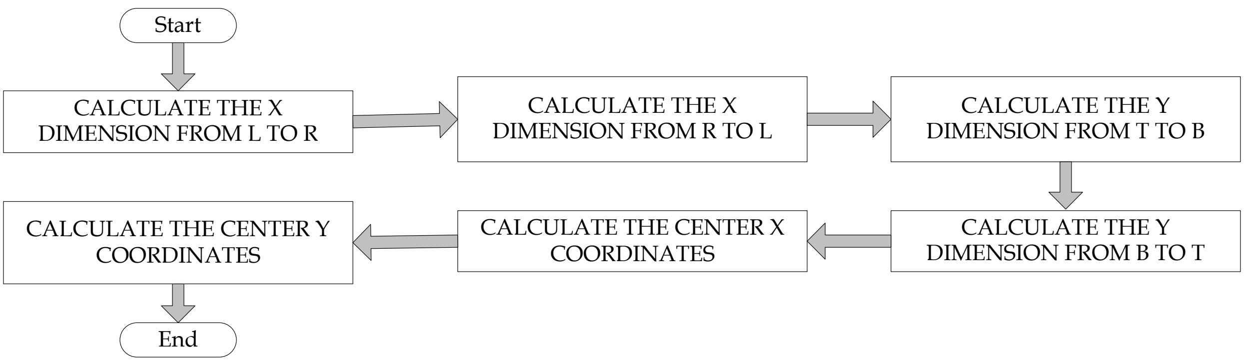


**Fig. 10. Flow Chart for Centre Calculation**

#### *2.3.5 Diameter Calculation Algorithm*

Once edges are detected, and centres of circles are known, diameters of circles can be calculated easily. The diameter calculation process is shown in Fig. 11.

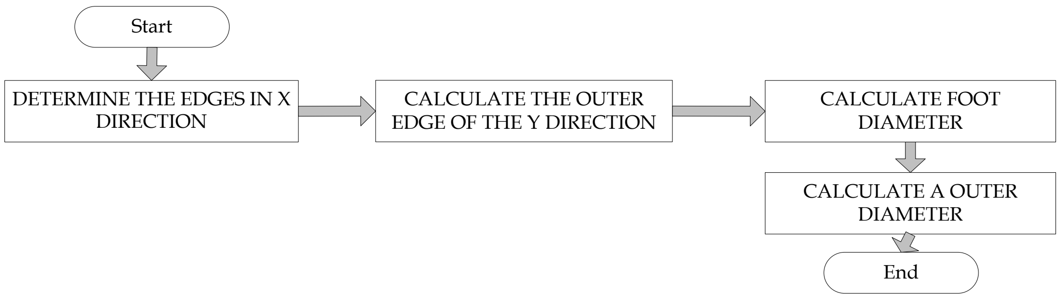


**Fig. 11. Flow Chart for Diameter Calculation**

## 3 IMPLEMENTATION AND TESTING

Implementation is being done in three steps.

1) Hardware implementation
2) Software implementation
3) Pixel scale conversion and System calibration

### 3.1 Hardware Implementation

The main components of the proposed system are CMOS camera and a single-board computer. A light source is applied to the Object (Porcelain plate on the mould) to capture uniform images by eliminating effect from background light sources. A laser light source is used to get the plate thickness using the triangulation principle. The single-board computer process images and results are shown in the LCD.

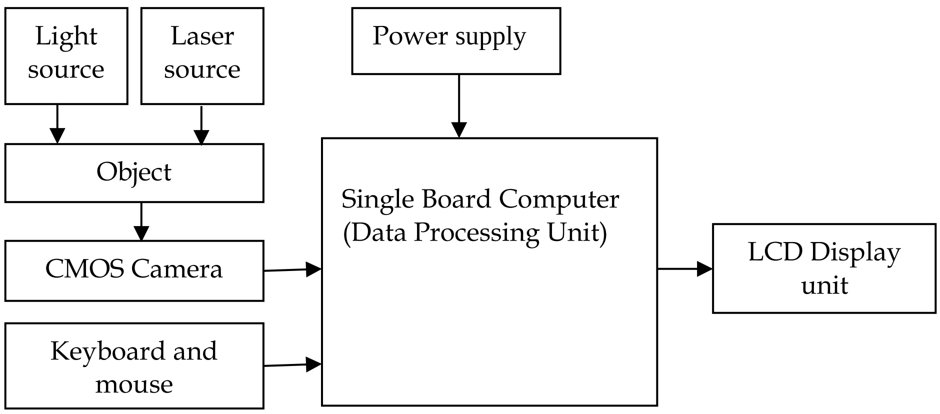


**Fig. 12. Block Diagram of the Proposed hardware setup**

Raspberry Pi Model B - ARM1176JZFS Processor is used as the central processing unit in the design. A 5-pixel camera module is used for detection, and a laser pointer of 532nm and 1mw power is employed.

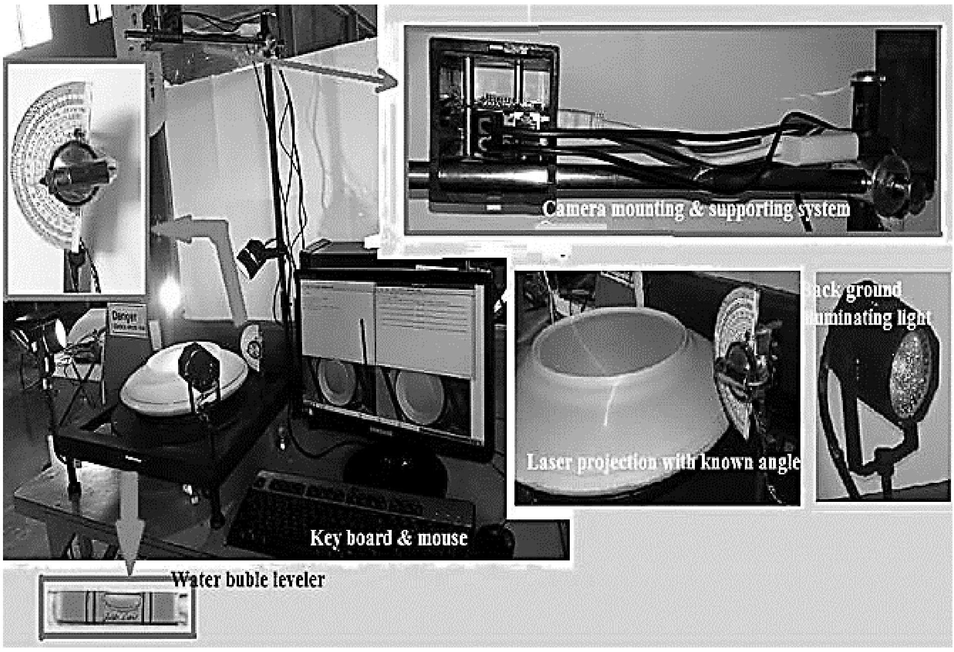


**Fig. 13. The hardware setup of measuring unit**

Hardware implementation is shown in Fig. 13. Setup equipped with a 1) lighting system to illuminate the object, 2) laser projectors with known angles to find the thickness of the plate using the pixel drift method, 3) camera module with Raspberry Pi board as the processor, 5) display and keypad. Water bubble leveller has been included to frame to adjust the frame to the horizontal level. Frame level affects the accuracy of the measurements.

### 3.2 Software implementation

Open-source computer vision and machine learning software library, OpenCV (Open-Source Computer Vision Library) are used for developing algorithms through Python programming language.

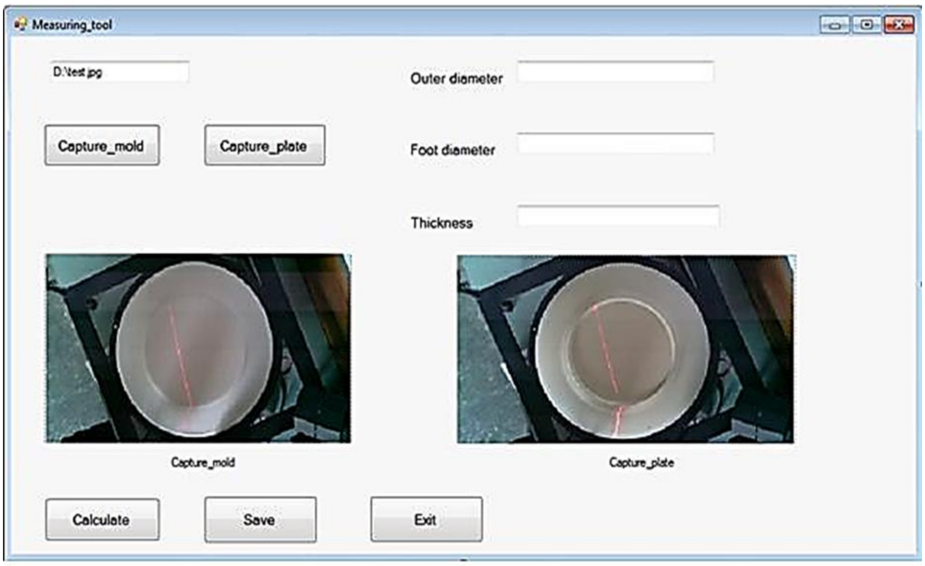


**Fig. 14. Laser pointers shift after adding two images**

**Fig. 15. Implementation of thickness calculation**

**Fig. 16. Implementation of diameter calculation**

Fig. 14 shows the software interface for the system. It shows the laser beam applied to mould and the plate. These two images added, and displacement of laser beams is calculated.

Laser displacement is shown in Fig. 15. Laser implement first calculated from pixel mapping, and after that, it converts to real object measurement by multiply by scaling factor. Fig. 16 shows the processed images for contour detection hence calculate the diameters of out and the foot diameter of the plate. These data are stored in the system for later analysis.

## 3.3 Pixel Scale Conversion and System Calibration

### *3.3.1 Pixel Calibration calculations*

Reference objects were made in a two-dimensional plane to find the scaling factors according to equation 4 and 5. Table 2 shows the scaling factors obtain for x and y directions—the average value selected as the scaling factor.

**Table 2 Pixel calibration**

| Length of Specimen ($Dx$) in mm | Pixel count ($Wx$) | The scaling factor ($Px$) in mm | Width of the specimen ($Dy$) in mm | Pixel count ($Wy$) | The scaling factor ($Py$) in mm |
|---|---|---|---|---|---|
| 400 | 947 | 0.4224 | 400 | 932 | 0.4291 |
| 300 | 711 | 0.422 | 300 | 699 | 0.4291 |
| 310 | 735 | 0.4218 | 310 | 723 | 0.4287 |
| 320 | 759 | 0.4217 | 320 | 745 | 0.4295 |
| 200 | 474 | 0.422 | 200 | 466 | 0.4291 |
| 250 | 593 | 0.4216 | 250 | 582 | 0.4295 |
| Average value | | 0.422 | Average value | | 0.4292 |

TYPE 520 plate has been used to verify the results.

Outer diameter – measurements taken on x directions,

The relationship between pixel value with real distance = 300.96mm / 712pix

$Px$ = 0.422 mm

Foot diameter – measurements were taken on y directions,

The relationship between pixel value with real distance = 187.78mm / 437pix

$Py$ = 0.429mm

In both approaches, nearly the same scaling factor values obtained.

## 4 RESULTS AND DISCUSSION

The results of the testing phase are as follows. These values obtained according to the equations (1),(6) and (7).

Predominantly measurement of distance and displacements is categorised into two as contact method and non-contact method. However, designing a quality measurement system for the manufacturing process of porcelain plates at the forming stage seek a non-invasive method with no external effect on the product. We have proposed a quality measurement system that employs Image processing. The primary purpose of this system is to replace the existing manual process with a low cost, efficient, automated system that requires minimal supervision.

In the design, the pixel dimensions of captured images are directly converted to the real scale of the plate, and measured values are displayed via an LCD and stored for further analysis. The results of the system show that developed design works with acceptable accuracy. However, for accurate analysis of the captured image, elimination of unnecessary noises, maintaining of a proper lighting system and precise surface levelling is crucial.

**Table 3 Observation from the proposed system**

| Plate number | Actual Reading (mm) | | | System Reading (mm) | | |
|---|---|---|---|---|---|---|
| | Outer diameter (mm) | Foot Diameter (mm) | Centre thickness (mm) | Outer diameter (mm) | Foot Diameter (mm) | Centre thickness (mm) |
| 1 | 300.5 | 188 | 5.58 | 300.46 | 187.90 | 5.56 |
| 2 | 302 | 187.5 | 5.06 | 301.73 | 187.47 | 5.13 |
| 3 | 302 | 187.5 | 5.30 | 301.73 | 187.47 | 5.27 |
| 4 | 301.5 | 188.5 | 5.30 | 301.30 | 187.68 | 5.27 |
| 5 | 300.5 | 189 | 5.58 | 300.46 | 189.18 | 5.56 |
| 6 | 303 | 188.5 | 5.06 | 303.41 | 187.68 | 5.13 |
| 7 | 302 | 187 | 5.54 | 301.73 | 187.04 | 5.55 |
| 8 | 302.5 | 187.5 | 6.02 | 302.15 | 187.47 | 5.99 |
| 9 | 301.50 | 189 | 5.54 | 301.30 | 189.18 | 5.55 |
| 10 | 303.5 | 188.5 | 5.06 | 303.8 | 187.68 | 5.13 |

**Table 4 Error vs measuring distances**

| Plate No. | Absolute Error Percentage (%) | | |
|---|---|---|---|
| | Outer Diameter(mm) | Foot Diameter(mm) | Centre Thickness(mm) |
| 1 | 0.01 | 0.05 | 0.35 |
| 2 | 0.08 | 0.01 | 1.38 |
| 3 | 0.08 | 0.01 | 0.56 |
| 4 | 0.06 | 0.43 | 0.56 |
| 5 | 0.01 | 0.10 | 0.35 |
| 6 | 0.13 | 0.43 | 1.38 |
| 7 | 0.08 | 0.02 | 0.18 |
| 8 | 0.11 | 0.02 | 0.49 |
| 9 | 0.06 | 0.10 | 0.18 |
| 10 | 0.08 | 1.43 | 1.38 |

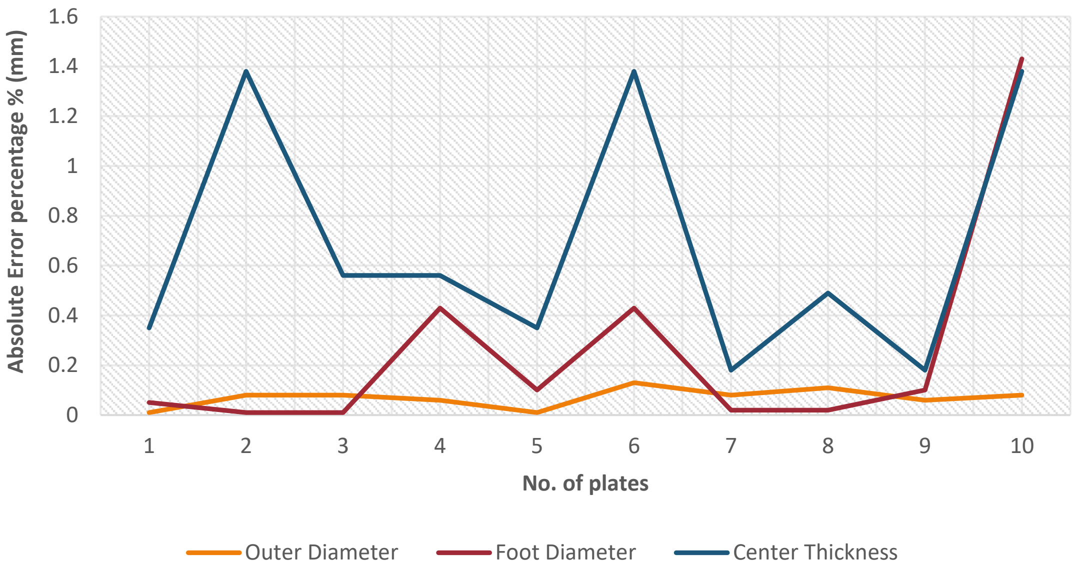


**Fig. 17. Error vs. measuring distances**

## 5 CONCLUSIONS AND RECOMMENDATIONS

With the help of the proposed design to the production line, product quality can be improved while reducing the energy loss and material wastage. In the proposed system, the main focus was the keep the accuracy of the system in the acceptable quality range and the keep the computation complexity minimum as possible. In the proposed system, we have used simple mathematics, and image filtering techniques to keep the computation simple. Hence, the processing time can be reduced. Processing time plays an important role in the industrial environment as it directly affects the production rate. However, the proposed system is a standalone system where plates should take off from the production line to do the measurements. Still, it saves time comparing to human measurements and saves the production cost as the testing in forming stages.

By use of a high-resolution camera, measuring accuracy can be increased as the pixel density of the image depends on the resolution of the Camera. Electro-Magnetic Interference caused by the vast amount of inductive load present in the factory environment must be avoided with the use of shielded cables for data communication. Raspberry pi and other electronic circuits should be covered in IP66 enclosure to prevent dust and moisture.

This system is tested only for plate type 520. In order to test with other plats, it is required to modify the base structure as the measuring plate is kept on the plate mould. It is a disadvantage of the system, and it can be improved by changing the mechanical structure where it supports different plate moulds. However, in this study, it was only focused on mechanical design.

Measurements are affected by the environmental lighting condition. In this study, an open mechanical design with a lighting system was used due to limited resources. It is recommended to use covered design with controlled lighting environment for minimising errors.

According to the error percentages, it is apparent that measurements accuracy is in the acceptable level of the factory quality standard. In addition, the following recommendations can be made for further improvements of the system

- The system should improve as a fully automated online system which can apply with the production line.
- System configuration with the network line to allow remote monitoring and access.
- Improvements in the user interface for smooth operation.
- Real-time isolation of defective products

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# Smart Automotive Side Mirror

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**Abstract -** *The side mirrors are fixed on the outside of motor vehicle for the driver to see areas behind and the sides of the vehicle. There are two types of mirrors, side-view mirrors, and rear-view mirrors. But still, there are some areas of the road which cannot be seen by the driver even with the assistance of these mirrors. These unseen areas are called 'Blind Spots'. Every driver is at risk of facing an accident simply because of the existence of these blind spots.*

*At present, there are many solutions proposed by the vehicle manufacturers to make these blind spots visible or to inform the state of these blind spots to the driver. These solutions could be broadly divided into Active monitoring systems and Passive monitoring systems. From literature, it was evident that these systems have not completely solved the issues related to blind spots, but partially. These solutions have proposed an artificial sense to the driver, and driver must pay additional attention, thus it distracts the driver's concentration and creates undue problems. Therefore, a better solution is needed.*

*This study has designed a smart side mirror, which automatically identifies the necessity and adjusts itself in order to visualize the blind spots to the driver. The solution is evaluated by a model in which the results justify the performance of the proposed system. The average response time is 2-3 seconds which is acceptable. The solution could be easily adapted to the existing power mirrors with simple modifications. Since almost all the vehicles with auto mirrors (except few luxury ones consists of in-built blind spot detection facility) in Sri Lanka could potentially adopt this system and minimize the blind spot risk. The vehicle manufactures could incorporate this option to their future vehicles which will be beneficial not only to the manufacturers, but also to the vehicle owners/drivers for safe driving.*

***Key Words*****:** *Side Mirror, Blind Spots, Product Design and Development.*

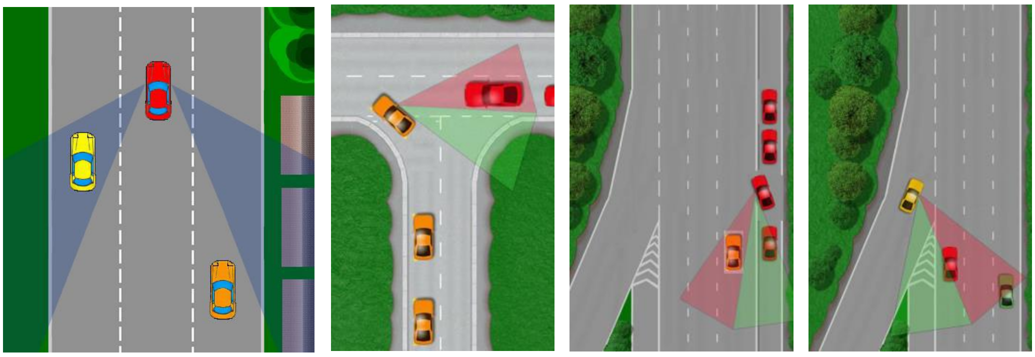
**Nomenclature**

*Subscripts*
*FOV*- Field of view.
*BoQ*- Bill of Quantities

## 1 INTRODUCTION

Side mirrors are found on the exterior of motor vehicles for the purposes of assisting the driver to observe the rear areas and the sides of the vehicle. In fact, a vehicle cannot safely drive without side mirrors (1A Auto, 2017). Side mirrors, also known as the wing mirrors, fender mirrors, door mirrors or outside rear-view mirrors, are mounted at the A-pillar on the front doors. They are equipped with either manual or remote (power mirrors) vertical and horizontal adjusters, to provide adequate coverage to the drivers of differing heights and seating postures. The remote adjusters may operate mechanically by means of bowden cables or electrically by means of geared motors.

A blind spot is an area around the sides of the vehicle that cannot be directly observed by the driver even with the assistance of side mirrors and rear-view mirror. Every driver is at risk of accident, simply because of these blind spots (Mathew et.al., 2018). The shaded areas in Fig.1(a) shows blind spots of both sides when the vehicle drives straight. Blind spots are usually occurring when entering to the main road from a by-road and leaving or backing out of a driveway lane or parking spots. Fig.1(b), Fig.1(c), and Fig.1(d) illustrates the blind spots when making a left-hand turn across two lanes of oncoming traffic, changing lane on the wide road and entering to highway lines, respectively.



(*a*) (*b*) (*c*) (*d*)

**Fig. 1. Blind spots to the drivers (blind spots are shaded in red in *b*, *c*, *d*)**

Blind spots of vehicles are more than an annoyance since they have cause serious accidents. The drivers must pay additional effort to check the blind spots. Blind spots can lead to, backing into objects or individuals, changing lanes interfering another vehicle, pushing another vehicle off the road into oncoming traffic, etc., and accidents caused by blind spots can lead to two or multi-vehicle accidents that result in property damage, minor to serious injuries, and fatalities (Shawky, 2019). Blind spots on larger cars are particularly dangerous to children. Every year, adults back into kids playing in their driveways, causing preventable serious injuries and deaths (Krist Law Firm P.C., 2018). Statistics from the National Highway Traffic Safety Administration show that nearly 840,000 blind spot accidents occur each year in the United States resulting in 300 fatalities, due to not properly checking the blind spots before changing lanes (Gordon & Partners, 2013). With the existence of new technological features, blind spots are still a worldwide problem. It is difficult to find written evidences of accidents occurred directly due to blind spots in Sri Lanka, which could be mainly due to the unavailability of a proper analysis or categorization of the accidence. However, there are ample evidences of considerable number of automotive accidents due to blind spots from other countries (Shawky, 2019; Krist Law Firm P.C., 2018; Gordon & Partners, 2013).

At present, many solutions have been introduced to make blind spots visible to the driver by using Active and Passive monitoring systems (Fernandez et al., 2013). These efforts have not provided a complete solution by addressing all the issues related to blind spots (Souders et al, 2016). These solutions demand much effort from the driver to visualize the blind spots which makes them ineffective, and some solutions distract the driver's concentration which eventually induce undue issues. Further, these solutions made an artificial sense for drivers, it demands additional attention of the drivers to refer those

(Souders et al, 2016). For a vehicle with blind spot monitoring options, mainly in luxury cars with options, the clients must pay extra, which many feels the cost is not compensates the benefit. In Sri Lanka it is hard to find a vehicle with those options, since the blind spots are not been evident as a cause of accident. But even though the accidents have not been categorized, blind spots could be one of the main causes for road accidents. Therefore, there should be a better solution to minimize the blind spots without any disruption to drivers and which are beneficial if the solution could also be adopted to existing mirror systems with minor modifications.

Hence it is a problem, requiring a right solution which eliminates the drawbacks of existing mirror systems, specially it enables driver to visualise blind spot with minimum effort and without distractions. Under this study a smart side mirror was developed. The existence of blind spots, characteristics of side mirrors, and existing solutions were analysed, and features of the end-product were recognized according to the views/needs of drivers (people who drives vehicles). Technical features of a vehicle related to real-time mirror angle adjustments were identified. The proposed system was evaluated by a model and further developments were proposed. If such a system is designed and developed to work with existing power mirrors with little modifications, the product will be greatly appreciated by many vehicle owners/drivers and it has high utility value for the customers

Throughout the study, the Product Design and Development techniques (Ulrich et al, 2012; Otto & Wood, 2009) were followed. The current Product Design and Development practices provide techniques which enable concept generation and select best solution leading to the development of the end product to a segmented market.

## 2 LITERATURE REVIEW

Nowadays, almost all auto manufacturers approach the problem of blind-spot detection. There are two main categories of blind-spot monitoring technologies, namely active and passive monitoring systems (Saboune, 2011).

***Active Blind Spot Monitoring Systems:*** A blind spot monitoring system uses electronic detection devices mounted on the sides of the vehical (often in the vicinity of the side mirrors or near the rear bumpers) that sends out either electronic electromagnetic waves (usually in the radar wavelengths) or takes computer-processed images with a digital camera. When one of these detectors notices another vehicle getting too closer, it indicates to the driver, by flashing a light in the driver's peripheral vision or by making audible sounds (beep sound) or both together, depending on how likely it looks that the driver steers the car into other vehicle (HowStuffWorks, 2018). The most advanced active monitoring systems steer the vehical back to the safety zone (Wu, 2012). Depending on the maker, the system of blind spot monitoring named differently; Ford, Lincoln, and Volvo call it as Blind Spot Information System (BLIS), Audi calls it Side Assist (SA), General Motors as Side Blind Zone Alert (SBZA), and Infiniti’s name it as Blind Spot Warning (BSW) (ExtremeTech, 2017; Tigadi et al, 2015, Hassan & Ariffin, 2013). The main target of these systems is to monitor blind spots and inform the driver when entering into adjacent lanes.

***Passive Blind Spot Monitoring Systems:*** This system consists of mirrors with less advanced monitoring features. Presently, lots of mirror attachments are used to see blinds spots, such as Fisheye mirrors, Aspheric mirrors and Panoramic rear-view mirrors, to reduce the size of a blind spot (UWM, 2016). Many car manufacturers will offer the alternative special convex mirror at the corner of a current external rearview mirror, which allows the driver to see the areas beyond the coverage of the normal side mirrors (HowStuffWorks, 2018). The passive blind spot monitoring systems also target to track and minimize the blind spots as much as possible.

Steering ratio and field of view are two important automotive kinematic features which have given special attention in designing the smart side mirror.

*Steering Ratio:* Steering ratio (ratio of the number of degrees the steering wheel turned vs. the number of degrees the front wheels turn) is an inherent design consideration, which gives the mechanical advantage to the driver in turning. If the steering wheel turned by 20° and corresponding front turn of front wheels is 1°, that gives a steering ratio of 20:1. For most modern cars, the steering ratio is in between 12:1 and 20:1. This, coupled with the maximum angle of deflection of the wheels gives the lock-to-lock turns for the steering wheel. For example, if a car has a steering ratio of 18:1 and the front wheels have a turn by 25°, then the steering wheel should turn by (25°x18) 450°. That is only to one side, so the entire steering goes from -25° to +25° giving a lock-to-lock angle of steering wheel of 900°, or 2.5 turns (Kong, 2015).

*Field of View:* FOV is the observable area to the driver through eyes or via an optical device as shown in Fig.2, while mean angles of FOV which driver could see are given in Table 1 (Reed et al, 2000).
In the context of optical devices and sensors, FOV describes the angle through which the devices can pick up electromagnetic radiation (Reed et al, 2000).
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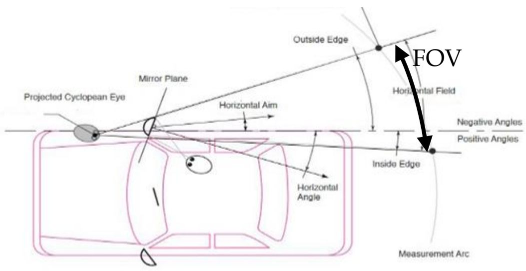



**Fig. 2. Field of View (FOV) of a vehicle optical device**

**Table 1 Angles of view**

| Mirror | | Angle |
|---|---|---|
| Left | Outside | $-21.1^{0}$ |
| | Inside | $2.2^{0}$ |
| Right | Outside | $-13.2^{0}$ |
| | Inside | $0.2^{0}$ |

## 3 METHODOLOGY

**Product Design and Development approach:** The Product Design and Development approach were studied (Ulrich et al, 2012; Otto & Wood, 2009) and process illustrated in

Fig. 3 was followed in this study. A product design, and development process is the sequence of steps/activities which adhered to initiate/conceive, design and commercialize a product. In this study, the commercialization part is omitted, but a cost analysis has been carried out.

***Mission Statement:*** The output of the planning phase is the project mission statement, which specifies the target market for the product, business goals, key assumptions, and constraints.

***Identifying Customer Needs (and Technical Aspects):*** The goal of this activity is to understand customers' needs and to effectively communicate to the product design and development team. The output of this step is a set of carefully constructed customer need statements, organized in a hierarchical list, with importance weightings for many or all the needs.

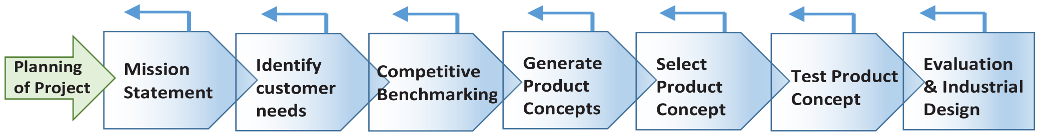



**Fig. 3. Product Design and Development process followed throughout this study**

***Competitive Benchmarking:*** In this phase it compares competitors' systems with assumed solutions for the problem.

***Concept Generation:*** The goal of concept generation is to thoroughly explore the space of product concepts that may address the customer needs. It covers Identification of limitations for solutions considering actual situations, decomposition of the complex problem into simple sub problems and listing solutions for each sub problem to generate the concept of product design. The result of this activity is several conceptual solutions.

***Concept Selection:*** Concept selection is the activity in which various product concepts are analyzed and sequentially eliminated to identify the most promising concept(s). The process usually requires several iterations and may initiate additional concept generation and refinement.

***Prototyping and Testing:*** Selected concept is tested by developing a model based on the selected design concept and tested to check whether it fulfills the design limitations, the aim and the objectives.

***Evaluation and Industrial Design:*** It was the final stage of the product design process that lists out the future works by evaluating the results from 'Prototype and testing' stage and concludes about the product as industrial design.

# 4 RESULTS AND DISCUSSION

## 2.1 Mission Statement

The mission statement shown in Table 2 was finalized after thoroughly investigation under the project planning stage.

## 2.2 Gathering Customer Needs

A questionnaire was administered, and planned discussions were conducted to gather customer needs.

***Questionnaire Administration:*** The questionnaire was designed and administered to gather user/customer information specifically drivers, and professionals who drive regularly. A Google Forum was established and s shared. Administration of the questionnaire through Google Forum is cost effective and easy to share with persons through mails and social media, and it is convenient to analyze and compile data. Incidence faced due to blind spots and the awareness regarding the blind spots among drivers were identified. Analyzed statistically the responses to make some decisions and conclusions. Customer needs were identified, ranked, and recognized the primary needs which directly affect the development activities.

**Table 2 Mission statement of Smart Side Mirror project**

| **Mission Statement: Smart Side Mirror Project** | |
|---|---|
| Production Description | • Car side view mirror which able to change the field of view angle dynamically in real time. |
| Benefit Proposition | • Avoid blind spots by modifying existing side mirror. |
| Key Business Goals | • Product which has the potential to compete in the market and with a cost-effective design. |
| Primary Market | • Car owners/drivers. |
| Secondary Markets | • Car manufactures. |
| Assumptions | • Car has inbuilt power mirror.<br>• Known steering ratio.<br>• Inputs can be read from sensors. |
| Stakeholders | • Owners /drivers<br>• Car manufactures<br>• Spare part dealers/repairing persons |

***Analysis of Survey Data:*** Conclusions were made from the data gathered from 72 respondents. The data were tabulated, and SPSS was used to analyse and sort out the customer needs and their priority levels.

***Limitations and Conclusions Based on the Survey:*** According to analyzed data, the solution (the end-product) should be developed within the following boundaries/limitations:

- The most important scenarios which the product should focus on are ***1.*** Entering the main road from a by-road and **2.** Entering to highway lanes**.**
- Use electrically operated side mirrors (power mirrors) with design features to automatically adjust the mirror to visualize the blind spots.
- Design for the light vehicles specifically for cars (sedan/hatchback), but it could be used with other vehicles such as Vans, SUVs, etc.

Further, it is understood that 32% of respondents have mirror attachments (passive systems), but still they are facing difficulties due to blind spots when, entering to the main road form a by-road (77.1%), entering to highway lines (55.7%), leaving or backing out of a driveway or parking spot (44.3%) and changing the track while driving on the wide straight road (41.4%). Therefore, it was obvious that the usage of mirror attachments is not a good solution for those blind spots issues, especially at entering the main road form a by-road and entering highway lines (55.7%). The mirror attachments have a slight positive effect when leaving or backing out of a driveway or parking spot and changing the track.
Almost all the respondents, 95.8%, including those who used mirror attachments have insisted having a system to avoid blind spots and 91.6% are preferred smart side mirrors to make blind spots visible.

### 2.3 Identify Customer Needs

The data gathered by questionnaires and discussions were effective. The customer needs/requirements were rated using a 1–5 scale and prioritized (refer Table 3). These were considered according to priority level.

**Table 3 Assessment of Customer needs**

| No. | Need | Relative importance |
|---|---|---|
| 1 | Light vehicle drivers need to avoid accidents due to blind spots. | 4 |
| 2 | Drivers need to see and verify side rear view of main road when entering to main road from a by road & entering highway line. | 5 |
| 3 | Drivers need to see and verify side rear of multilane highway road view when switching the track on a multilane highway. | 3 |
| 4 | Drivers like to have visualized system to see blind areas rather than using active blind spot detection systems. | 5 |
| 5 | Drivers feel better to view side rear view through the side mirror rather than using a camera display. | 4 |
| 6 | Side mirror able to dynamically change the angle quickly. | 5 |
| 7 | Side mirror able to back to initial state in a normal road drive. | 4 |
| 8 | The system is cost effective and easy to install. | 3 |
| 9 | Capable to use with existing power mirrors. | 2 |

The technical needs/specifications are identified and rated by 1–5 scale as in Table 4 to address rated customer needs in Table 3.

**Table 4 Technical needs**

| No. | Need | Relative importance |
|---|---|---|
| 1 | The time taken to move mirror from initial position to maximum angle. | 5 |
| 2 | Take steering angle. | 5 |
| 3 | Signal light condition (on / off). | 5 |
| 4 | Vehicle speed. | 4 |
| 5 | Configuration of initial mirror angle. | 4 |
| 6 | Vehicle length (length between front wheel to rear wheel) | 2 |
| 7 | Existing side mirror maximum moving angle. | 5 |
| 8 | Product price. | 3 |
| 9 | Existing mechanism of power mirror. | 4 |

### 2.4 Competitive Benchmarking

The proposed system was rated based on the weight of importance for systems on customer needs by comparing existing systems. The results are, active detection 30, passive detection 60, proposed system 103, as illustrated in Table 5. It could be confirmed that the proposed solution is comparatively more reliable.

**Table 5 Competitive benchmarking with weights of importance**: *Key (.)- Not perceived satisfaction of the need, (..) - Less perceived satisfaction of the need, (…) - Well enough perceived satisfaction of the need, (….) - Good perceived satisfaction of the need, (…..) - Greater perceived satisfaction of the need.*

| No. | Need | Imp. | Active detection | Passive detection | Proposed system |
|---|---|---|---|---|---|
| 1 | Light vehicle drivers need to avoid accidents due to blind spots. | 4 | .... | ... | .... |
| 2 | Drivers need to see and verify side rear view of main road when entering to main road from a by road & entering highway line. | 5 | . | . | .... |
| 3 | Drivers need to see and verify side rear of multilane highway road view when switching the track on a multilane highway. | 3 | ... | ... | ..... |
| 4 | Drivers like to have visualized system to see blind areas rather than using active blind spot detection systems. | 5 | . | ... | .... |
| 5 | Drivers feel better to view side rear view through the side mirror rather than using a camera display. | 4 | . | .. | .... |
| 6 | Side mirror able to dynamically change the angle quickly. | 5 | . | . | ... |
| 7 | Side mirror able to back to initial state in a normal road drive. | 4 | .... | .... | .... |
| 8 | The system is cost effective and easy to install. | 3 | . | ..... | .... |
| 9 | Capable to use with existing power mirrors. | 2 | . | ..... | .... |
| | **Weight of importance for systems on customer needs** | | **30** | **60** | **103** |

## 2.5 Concept Generation

The design concept generation was done as per the process illustrated in Fig. 4. Only the important segments of the concept generation are described under this section.

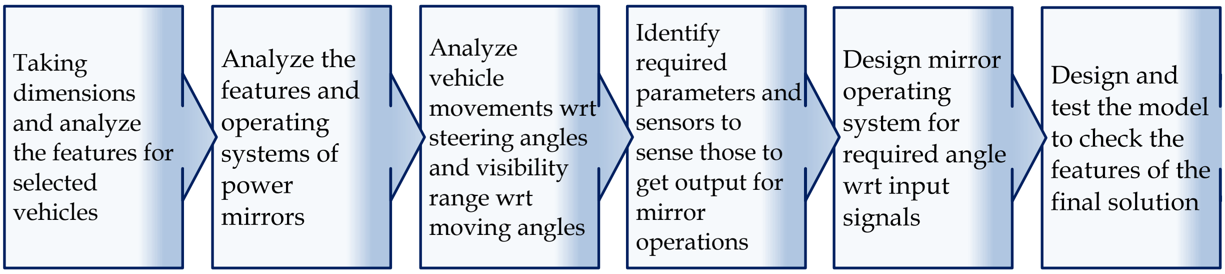



**Fig. 4. Concept generation process**

### *4.5.1. Testing for Concept's limitations*

Three experiments were conducted to analyse the correlation between, **1.** Vehicle speed and turning time, **2.** Movement of steering wheel turning angle, and **3.** FOV and operating angles of the mirror.

***Experiment 01 Time to take a turn and respective vehicle speed:*** The average time vehicle took to make a turn from by-road to the main-road were recorded (by stopwatch) and corresponding vehicle speed (from dashboard indicator) were observed and averaged form 10 trials. The mean value of time to take a turn was 5.5 *seconds* and the mean speed was 7.6 $km/h$.

***Experiment 02 Taking real time steering angle:*** The wheel turning angle was geometrically measured with respect to the movement of the steering wheel. On average, the turned angle of the front wheel for $360^0$ turns of the steering wheel is $20^0$, therefore the steering ratio is 18:1.

***Experiment 03 Taking real time FOV of side mirror at its minimum and maximum operating angles:*** **T**he minimum and maximum angles of FOV were considered as the minimum and maximum turning angles of the mirror. The minimum angle was $9^0$ and the maximum angle was $35^0$.

### *4.5.2. Limitations*

The total functions could be decomposed into main three folds, inputs, processing input data (system with functions), and adjust mirror angle accordingly (output) as illustrated in Fig 5. Inputs of the system are steering angle, vehicle speed, and signal light on/off.

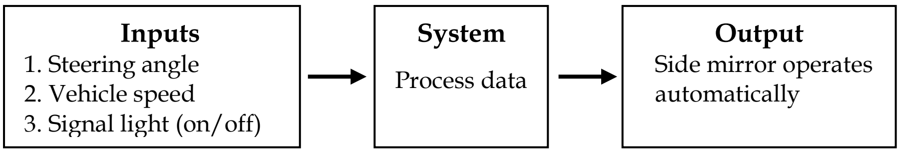



**Fig. 5. Representation of main folds of the development process.**

Real time experiments were conducted, and real-time data were collected to find input limitations.

***Steering angle and corresponding angles:*** The observations show that the maximum amount of steering angle to take a turn when entering to the main road and changing drive track of wide road is about 30°. Simultaneously with car tuning between 10° and 30° (if steering ratio 18:1 maximum steering wheel turning angle is between $180^0$ and $540^0$), the angle of side mirror changes its angle from initial value to maximum angle and when the steering wheel returns side mirror returns to the initial position simultaneously.

***Vehicle speed:*** Since the average speed of entering to the main road is 7.6$km/h$, the range of speed is considered as 0 -15$km/h$. The change of the side mirror should accommodate this speed.

***Turning indication by signal lights (on/off) is mandatory:*** when entering to the main road or change drive track, it is assumed that the driver turns on the signal lights. In the proposed system, the signal indication "ON", is mandatory to operate the system.

### *4.5.3. Concept Selection*

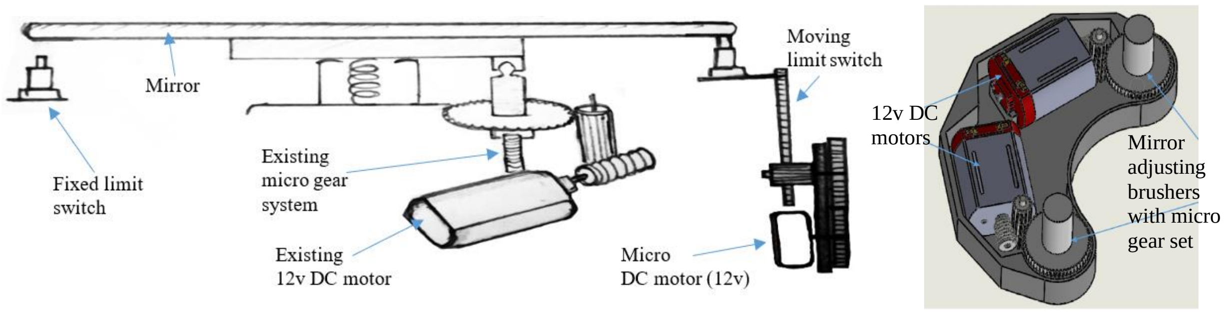
The concept combination table, given in Table 6. The main problems were identified and decomposed to sub-problems.

**Table 6 Concept combination table of sub-problems**

| Get vehicle speed | Get steering angle | Detect signal light condition | Change angle of mirror glass | Drive position changing system |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Read from OBD | Read from OBD | Read from signal light connection | Use existing power mirror system | Servo Motor |
| Use accelerometer sensor | Use a Gyroscope | Get signal light on/off condition from ECU | Separate modified attachment to existing power mirror | Stepper Motor |
| Read Wheel Rotation Speed | Use Encoder | | Replace mirror operating system | Normal DC Motor |
| Get Signals from ECU System | | | | |

The solutions were then proposed based on firm facts. Finally, the most effective and reliable solution (concept) was selected. Selections were done based on parameters such as ease of handling, ease of use, readability, accuracy, durability and ease of application. The selected combination of concepts to develop the final solution/end-product are shaded and connected by dotted lines in Table 6. The basic sketch representing the final concept along with the internal arrangement is shown in Fig.6.




(a) (b)

**Fig. 6. Sketch represent the final concept, (a) sketch of the component arrangement, (b) 3-D view of the inside arrangement**

### 2.6 Concept Design

After identifying the inputs, functions/sub-functions of the system (and implementation hardware and software, such as input sensors, controllers, actuators and feedback components, connectors, switches) and interaction each of them is illustrated in Fig.7, which gives an overall idea of how the final concept works.

By sensing the vehicle speed, steering angle, and the signal light on/off as inputs, the system identified the area needed to be covered or visualized, i.e. the angle of FOV. All three input requirements should be satisfied to operate the mirror. Then the DC motor (adjust the mirror angle) was actuated as per the controller program. The controller operates on two modes, the Auto mode, and Manual mode. Manual mode is to adjust the mirror to the home position as per the driver and the smart mirror function operates only in Auto mode. There were two limit switches, one is to accommodate the maximum rotation of the mirror and the other one is to accommodate the home position of the mirror. These limit switches transmit feedbacks to the controller. The system flow charts/algorithms of the final concept and the sub-system to adjusting home position are illustrated in Fig.8 and Fig.9 respectively. An existing power mirrors (with its operating mechanism) could be used with the proposed new operating system with minor modifications. The space inside is adequate to accommodate additional components.

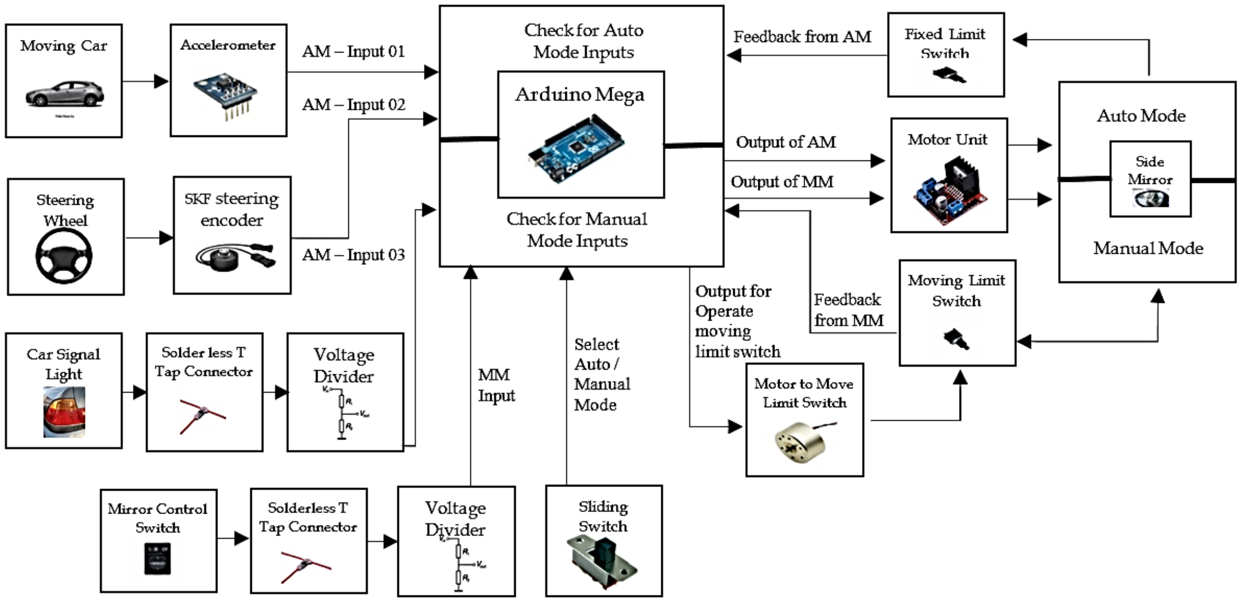



**Fig.7. Schematic diagram of design**

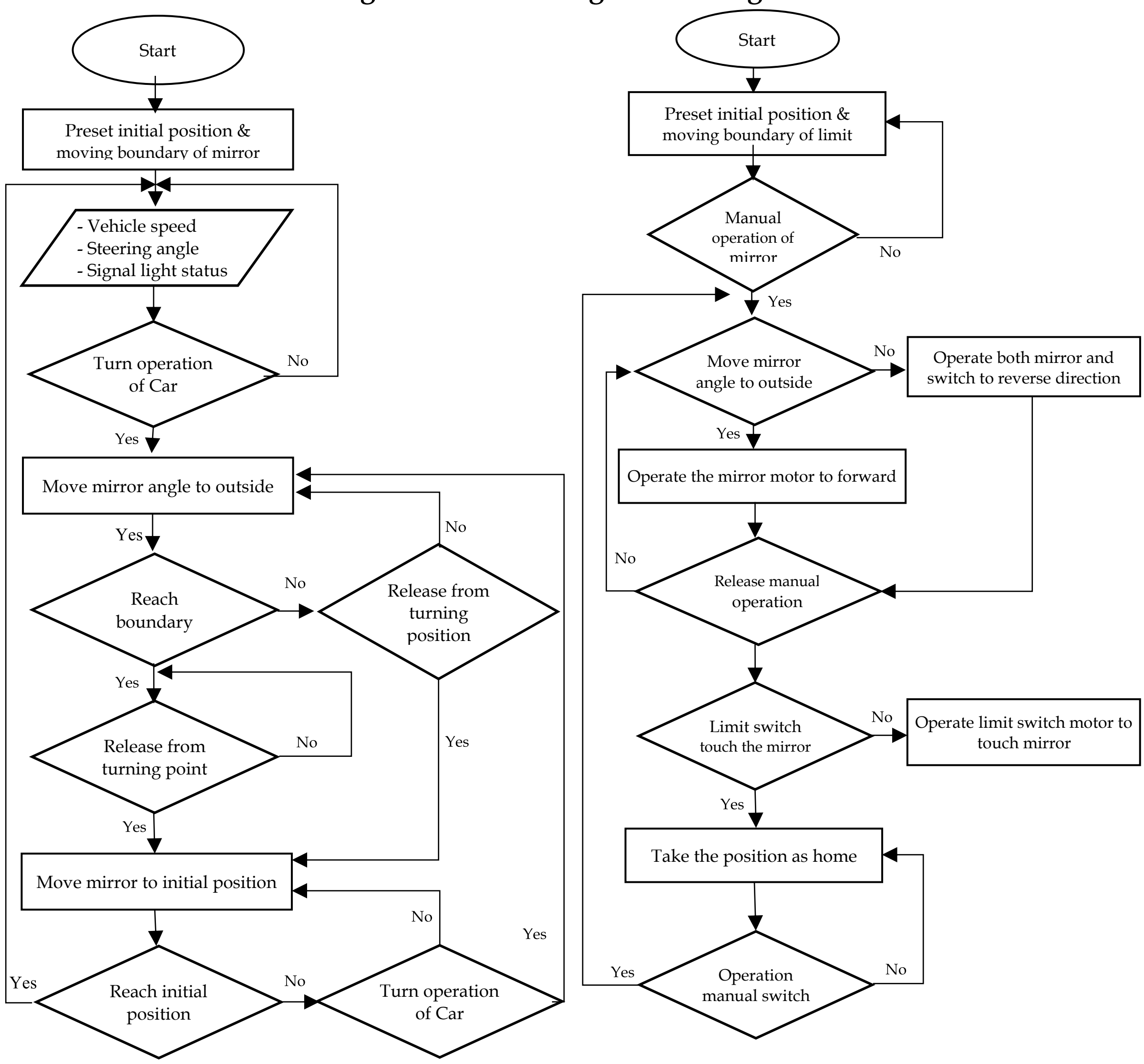


Fig.8. System flow Fig.9. Sub-System

## 2.7 Concept Testing and Development of the Model

The model was developed based on the concept table given in Table 7, which extracted from the final concept combination (refer Table 6).

**Table 7 Combination of sub-problems to develop the model**

| Get Vehicle Speed | Get Steering Angle | Detect Signal Light Condition | Change Angle of Mirror Glass | Select Auto & Manual Mode | Drive Position Changing System |
|---|---|---|---|---|---|
| Use inter-locking switch to make condition | Use Encoder to sense and feed angle variation as input | Use inter-locking switch to feed on/off condition as input | Separate modified attachment to existing power mirror with micro limit switches | Use Toggle switch to change the mode | Use DC Motors (FK-130RH) |

Fig.10 illustrates the operating sequesnce of the model. The working conditions and limits are identical to the final conceptual design. But some of the hardware components such as, the accelerometer and signal light on/off sensor were not included to the model, inserted the respective indication signals were provided by an interlocking switch. Also, due to practical difficulties (since the testing was not done with a vehicle it is impractical to use real vehicle conditions as inputs of model demonstration) a rotary encoder was used in place of steering encoder. The model's working principle, processing methods, and actuator operations, as well as response time, will be exactly as identical with the final concept (end-product).

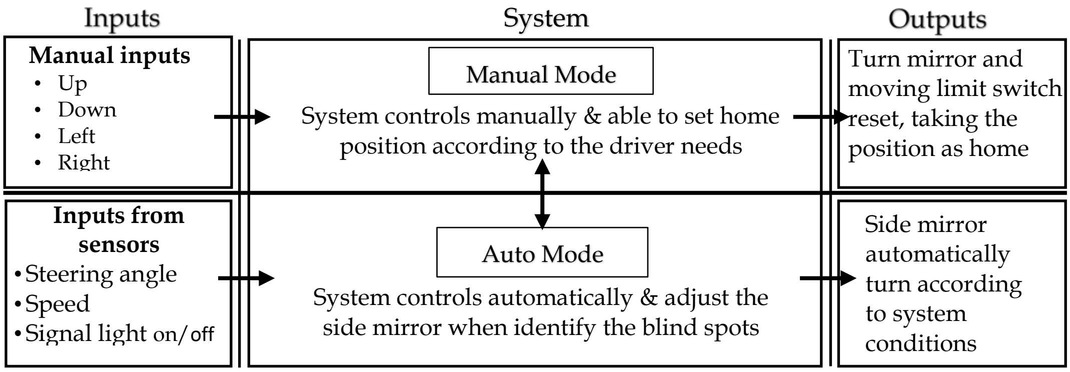



**Fig. 10. Working process of auto and manual modes**

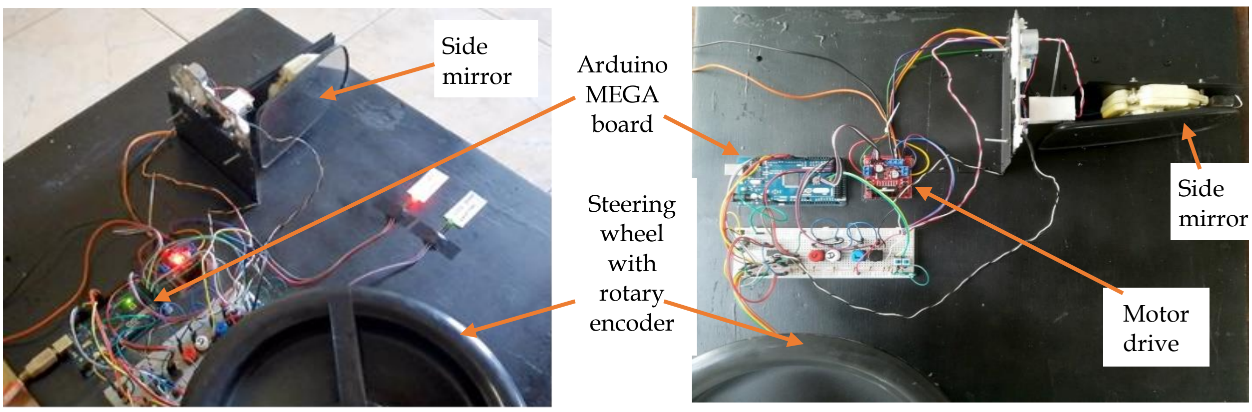


**Fig.11. Test model setup**

The arrangement of the test model along with the components are shown in Fig. 11, and the results are tabulatrd in Table 8. Referring Table 8, the experimental results show that the system accurately works in both manual and auto modes by complying with all the conditions as defined. In manual mode, the movements of the mirror could be obtained as the requirement of the driver irrespective of the signal light, vehicle speed, and steering angle status, which is the requirement. In auto mode (refer the shaded row) all the three conditions, the signal light (on), vehicle speed (<15$km/h$) and steering angle (180< α<540) should be satisfied to automatically adjust the angle of the side mirror (outwards as required). At this stage, the mirror cannot turn manually. The choice of selecting auto or manual mode is totally decided by the driver as per his convenience.

Real-time 'response-time' is critical in this design. The response time to rotate mirror (from starting position to the end position) is 2-3 *seconds* (average) which is less than 5.5 *seconds.* The response time to rotate the mirror back to the initial position is also 2-3 *seconds* (average), which is acceptable.

**Table 8 Results from experiments conducted by the test model** (√ - on, X - off)

| Manual mode | Auto mode | Signal light on/off | Speed <15km/h | Steering angle 180<α<540 | Can operate derection manually Yes(Y)/No(N) | | | | Mirror turning | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | In | Out | Up | Down | In | Out | Up | Down |
| √ | X | √ | √ | √ | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | √ | √ | X | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | √ | X | √ | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | √ | X | X | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | X | √ | √ | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | X | √ | X | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | X | X | √ | Y | Y | Y | Y | √ | √ | √ | √ |
| √ | X | X | X | X | Y | Y | Y | Y | √ | √ | √ | √ |
| **X** | √ | √ | √ | √ | **N** | **N** | **N** | **N** | - | √ | **X** | **X** |
| X | √ | √ | √ | X | N | N | N | N | - | X | X | X |
| X | √ | √ | X | √ | N | N | N | N | - | X | X | X |
| X | √ | √ | X | X | N | N | N | N | - | X | X | X |
| X | √ | X | √ | √ | N | N | N | N | - | X | X | X |
| X | √ | X | √ | X | N | N | N | N | - | X | X | X |
| X | √ | X | X | √ | N | N | N | N | - | X | X | X |
| X | √ | X | X | X | N | N | N | N | - | X | X | X |

## 2.8 Cost Analysis

The BoQ and costing for the developmet of a prototype based on the final conceptual design is given in Table 9. The total cost is Rs. 38,691.00 which is much less compared to an additional amount a buyer has to pay for a vehical with a blind spot detecting option. Assuming a profit margin of Rs. 10,000.00 (10% of the selling price) the product coud be marketable for a price around Rs. 50,000.00. However a comprehensive financial analysis needed to be performed.

**Table 9 BoQ and Cost of design**

| Component | Quntity (Nos. | Unit price (Rs.) | Total price (Rs.) |
|---|---|---|---|
| Micro DC motor | 1 | 250.00 | 250.00 |
| Motor Driver Module (L293D) | 1 | 350.00 | 350.00 |
| SKF Steering encoder (sensor) | 1 | 20,000.00 | 20,000.00 |
| Arduino Mega Board | 1 | 7,800.00 | 7,800.00 |
| Wires (Jumper) | 40 | 4.00 | 160.00 |
| Wires (Circuit connectors)/(m) | 1 | 85.00 | 85.00 |
| Limit switch (micro) | 2 | 450.00 | 900.00 |
| Resistores (10K) | 10 | 4.00 | 40.00 |
| Resistores (4.7K) | 2 | 4.00 | 8.00 |
| Resistores (6.8K) | 2 | 4.00 | 8.00 |
| Solderless T tap connector | 1 | 250.00 | 250.00 |
| Accelerometer | 1 | 650.00 | 650.00 |
| 3D printed mini scale rack & Wheel se | 1 | 3500.00 | 3500.00 |
| Vero Board 1344-Points | 1 | 150.00 | 150.00 |
| Toggle switch | 1 | 40.00 | 40.00 |
| Total overhead cost | | | 2,000.00 |
| Assembly (Installation) cost | | | 2,500.00 |
| **Total Cost** | | | **38,691.00** |

## 5 CONCLUSIONS

The design effort of Smart Side Mirror was conducted by adhering to the Product Design and Development methodologies. The aim and objectives of the study were achieved. The final concept is developed based on the critical needs and problems faced by vehicle drivers regarding the existence of blind spots. The final concept was tested by a model simulating real-time test procedure. There are differences in the model with respect to the developed concept (end products) but the operating principles were identical and test results justify the performance of the final concept. The most important parameter is the response time of the system, in which the average response time of the prototype was 2-3 *seconds* which is less than the practical average time when taking a turn, therefore the response time is acceptable. The cost analysis indicates that the amount that a car owner must be spent is worth compared to the risk involved with respect to Blind Spots. The results justify that the final concept is acceptable to produce as an industrial marketable product.
It was understood that the response time of the mirror could be further reduced by designing and replacing the existing cogwheel system of the mirror attachment. Furthermore, the accuracy and reliability could be enhanced by further verifying/cross-checking the operating input signals to the mirror, by using image processing devices such as a camera.
The prototype development takes more time and due to the time constraints, it is beyond the preview of this study, but it is recommended to conduct a prototype test with the real vehicle and to get confirmed the results of this study.

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# Capturing Rainwater for Urban Living

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**Abstract** – *Rainwater harvesting simply means that capturing rainwater for the usage of people. Sri Lanka has a long history of rainwater harvesting associated with ancient water harvesting systems. The existing practice of rainwater harvesting is mostly limited domestic purposes which is more effective and economical. Sri Lanka adopts rainwater harvesting policy and amends the acts and by-laws of implementing the same especially in the urban sector usage for better management of water resources. Thus, this research is focussed on identifying rainwater harvesting potential for non-potable use especially in buildings with large roof areas such as factory, public buildings, apartment complexes, etc. located in urban areas within the wet zone of Sri Lanka. Accordingly, monthly rainfall data from 1950 to 2014 for Colombo and Ratmalana have been analysed. A relationship between the probability of success and water demand for a given roof area has been developed. Results showed that for a roof area greater than 800 $m^2$ with a tank of 75 $m^3$ provide a minimum of 60% probability of success.*

***Keywords***: *Non-potable use, Rainwater harvesting, Urban area*

## 1 INTRODUCTION

With the beginning of civilization, people built their houses close to the natural water bodies such as lakes, springs etc. to fulfil their water requirements, which is the key to life. Rain is considered as a gift from God and our ancestors worshipped it. With an increase in population, people had to find alternatives, because they faced difficulties in drought seasons due to lack of water. This can be seen predominately in arid and semi-arid areas. Rainwater harvesting (RWH) is identified as one of the best solutions to overcome this problem.

Although close to three-fourths of our planet is made of water, not all of it is suitable for use. As a result of that, there is a constant shortage of water which is suitable for drinking, household use and industrial usage. Only 30 per cent of the total population was urban in 1950 and is expected to rise it up to 60% in 2030. However, between 1950 and 2018, the urban population in less developed regions were increased from 17% to 51% showing the higher level of urbanization in developing countries (UN, 2019). Unplanned and inadequately-managed urbanization may affect sustainable development in urban areas. Forest cover will be also reduced due to industrialization and the water pollution will also increase. This tends to a shortage of water soon and precautions should be taken to overcome this situation.

In the context of Sri Lanka, which a tropical island, is situated in between $5^0$ to $10^0$ North latitude and between $79^0$ to $82^0$ East latitude with a total of 65,610 $km^2$ land area. The average rainfall and the temperature of Sri Lanka vary from 900 mm to 6000 mm and $20^0$ to $34^0$ Celsius respectively (Department of Meteorology, Sri Lanka). The country experiences a variation of rainfall which covers both dry periods as well as excess rainfall periods throughout the year.

29% of the total population of Sri Lanka represents the urban population and only 67% of the same is supplied with pipe-borne water but not fully provided with 24-hour water supply (NWSDB, 2020). Thus, it is seen that the existing water supply is not adequate for the present rate of water consumption for domestic and day to day needs of the population, especially in urban areas. On the other, providing treated pipe-borne water for the increasing population is becoming expensive when considered with the high level of investment required and the operations and maintenance costs of improved activities in urban areas. In the light of this, Sri Lanka has achieved impressive progress in piped onto premises at the urban water supply coverage from 37% in 1991 to 67% in 2010 (Mcloughlin & Harris, 2013).

The National Water Supply and Drainage Board (NWSDB) is the sole public body responsible for water supply and sanitation facilities in Sri Lanka. NWSDB mainly divides the water supply schemes as urban and rural considering the consumption of water. Water supply schemes which have 1000 or more service connections are termed as urban water supply schemes (Ariyananda, 2007). Industrial and service sectors in Sri Lanka are mostly dependent on treated water supply provided by the NWSDB mainly, besides they use a small quantity of water pumped from groundwater and rivers. Also, the water tariff system in Sri Lanka provides water at low cost for domestic users while higher rate charges for commercial and industrial water users. At the current rate of water consumption, domestic and other water needs of the population concerning the water supply cannot be met with the current level of supply by NWSDB. Therefore, there is an urgent requirement to find different alternatives for water supply.

Although the groundwater is an alternative source of water supply it is not very suitable for direct usage in urban areas. The groundwater in urban areas is usually polluted due to the mixing of chemicals, acids and sewage. Also, the cost associated with pumping the groundwater is much higher than the existing tariff system. As Sri Lanka get sufficient rainfall throughout the year, domestic and industrial users can use RWH as an optimum method of getting water. Compared to groundwater, this is a cost-saving and less polluted way to fulfil the day to day water needs of domestic users as well as industrial users.

The rainwater harvesting projects were initially implemented in Badulla and Matara districts from 1995 to 1997 as a World Bank project especially focusing on drinking water at the domestic level (Dissanayake & Ranasinghe, 2018). Later RWH practices were gradually widespread in other areas and also extended the application towards public institutions too. Having identified the importance of water resource management and the availability of water for everybody, the Government of Sri Lanka (GoSL) assisted rainwater harvesting (RWH) projects. In 2005, the National Policy on Rainwater Harvesting and Strategy was adopted and rainwater harvesting was made mandatory for certain buildings under Municipal and Urban council areas (NRPS, 2005). Accordingly, legislations were amended to incorporate rainwater harvesting in the Municipal council and Urban Development Authority administrations (Gazette, 2007; Ariyananda & Wickramasuriya, 2009).

The application of rainwater harvesting in large housing projects, commercial and public buildings have been studied by Jayasinghe (2004), Gunatilake (2006) and Ariyananda & Wickramasuriya, (2009). Those findings explained that 50 – 70% of non-potable water demand can be supplied by using RWH with the incorporation of proper water treatment whenever necessary. It is noteworthy to examine the analysis by Lo & Koralegedara (2015) on the effects of climate change on RWH in Colombo under six different scenarios ranging from residential to non-residential. It further discussed the monthly water security of RWH systems with the selected scenarios. Thus, the main objective of this research is to provide a guideline of finding the success of the application of RWH for different water demands and a given roof size by analysing monthly rainfall data at Colombo and Ratmalana. As the research is mainly focused on urban living, only large tank capacities were considered.

## 2 METHODOLOGY

In the methodology, both quantitative and qualitative approaches employed for data collection and analysis. Field visits were carried out for several commercials, industrial, government and non-government bodies to collect data and information regarding the technologies used in their RWH systems and cost savings arise to those organizations as a result of implementing RWH system. Few experts in the RWH field were interviewed to identify the existing problems relating to the rainwater harvesting and to aware the currently used technologies, new techniques which can be used in this field, etc.

### 2.1 Rainfall Data

Colombo and Ratmalana urban areas are selected as the study area and monthly rainfall data was collected for the past 65 years from 1950 to 2014 at Colombo and Ratmalana meteorological stations.

### 2.2 Determination of catchment area and the runoff

The amount of rainwater collection depends on the rainfall intensity, catchment area and the runoff coefficient. The maximum amount of rainwater that can collect from the roof can be calculated using equation 1 (Gamage, 2006).

$$\text{Runoff} = A \times (\text{Rainfall} - B) \times \text{Roof Area} \quad (1)$$

Where,
A = runoff coefficient
B = Loss of rain due to absorption and wetting of the surface. This value is neglected in the calculation.
For the calculation of the catchment area, the horizontal plane area (Roof Area=XY) should be considered as shown in Fig. 1.

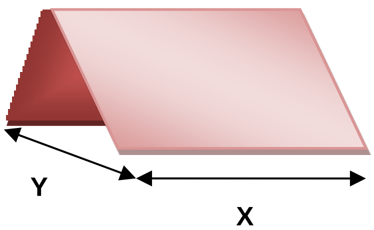


**Fig. 1. Roof dimension**

Runoff coefficient varies with the type of roofing material and it takes into account any loss due to leakage, overflow, evaporation and transportation. Considering different roofing materials, the Runoff coefficient is taken as 0.8 for this study. Table 1 shows the typical values for runoff coefficient for different roofing materials (*RWH Practitioners Guide for Sri Lanka, 2009*).

**Table 1. Runoff coefficients for different roofing materials**

| Roofing material | Runoff coefficient |
|---|---|
| Galvanized iron sheet | > 0.9 |
| Aluminium sheets | 0.8-0.9 |
| Flat Cement roof | 0.6-0.7 |
| Organic( e.g. thatched) | 0.2 |
| Tiles | 0.6-0.9 |
| Asbestos | 0.8 |

## 2.3 Probability of Success

When calculating the probability of success, it is assumed that initially, the tank is full incapacity, rainwater removed in the first flush is negligible and the demand does not change with seasonal variation.

**Table 2. Number of successive months for the year 1951**

| Month | Rainfall (mm) | Flow to reservoir ($m^3$) | Reservoir Deficit ($m^3$) | Success |
|---|---|---|---|---|
| January | 137.0 | -207.6[1] | 200.0 | 0 |
| February | 25.0 | -330.0 | 200.0 | 0 |
| March | 158.0 | -223.6 | 200.0 | 0 |
| April | 165.0 | -218.0 | 200.0 | 0 |
| May | 559.0 | 97.2 | 0 | 1 |
| June | 238.0 | 40.4 | 0 | 1 |
| July | 279.0 | 73.2 | 0 | 1 |
| August | 3.0 | -147.6 | 147.6 | 1 |
| September | 329.0 | -34.4 | 34.4 | 1 |
| October | 196.0 | -27.6 | 27.6 | 1 |
| November | 560.0 | 270.4 | 0 | 1 |
| December | 149.0 | -30.8 | 30.8 | 1 |

A sample calculation of the number of successive months for 1951 at Ratmalana is shown in Table 2. For this sample calculation, the selected tank capacity is 200 $m^3$, roof catchment area 1000 $m^2$ and the monthly water demand is 150 $m^3$.

The selection of success (1) is based on when reservoir deficit is less than tank capacity and failure (0) is assigned when reservoir deficit ≥ tank capacity.

[1]Calculation continues from December 1950 (-167.2 $m^3$)

According to Table 2, the total number of successive months in 1951 is 08.

The sample calculation for January 1951 (Table 2) is as follows:
Using equation (1), Total runoff = 0.8*0.137*1000 = 109.6 $m^3$
Flow to reservoir = 109.6 – 150.0 – 167.2 = -207.6 $m^3$
Reservoir deficit = 200.0 $m^3$ (Flow from reservoir > 200 $m^3$)
Hence failure is assigned (reservoir deficit ≥ tank capacity).

The calculation is continued to obtain the number of successive months from 1950 to 2014 in both Colombo & Ratmalana areas. The probability of success of the RWH system from 1950 to 2014 is obtained as follows:

$$\text{Probability of success} = \frac{\sum \text{Number of successive months}}{\sum \text{Total number of months considered}}$$

The total number of successive months for 150 $m^3$ demand with a roof area of 1000 $m^2$ and a tank capacity of 200 $m^3$ is 605, whereas the total number of months considered is 780. Thus, the relevant probability of success is 0.78 (=605/780). Also, the probability of success was calculated for six different tank capacities (75, 100, 125, 150, 175 and 200 $m^3$) of rainwater, with the catchment area varying from 300 $m^2$ to 1200 $m^2$ for six water demands considering the selected 65-year period. Accordingly, the probability vs demand curves was plotted for both locations.

## 3 RESULTS AND DISCUSSION

From the calculations of the probability of success for different roof areas and different tank capacities, the following results were obtained for Colombo and Ratmalana.

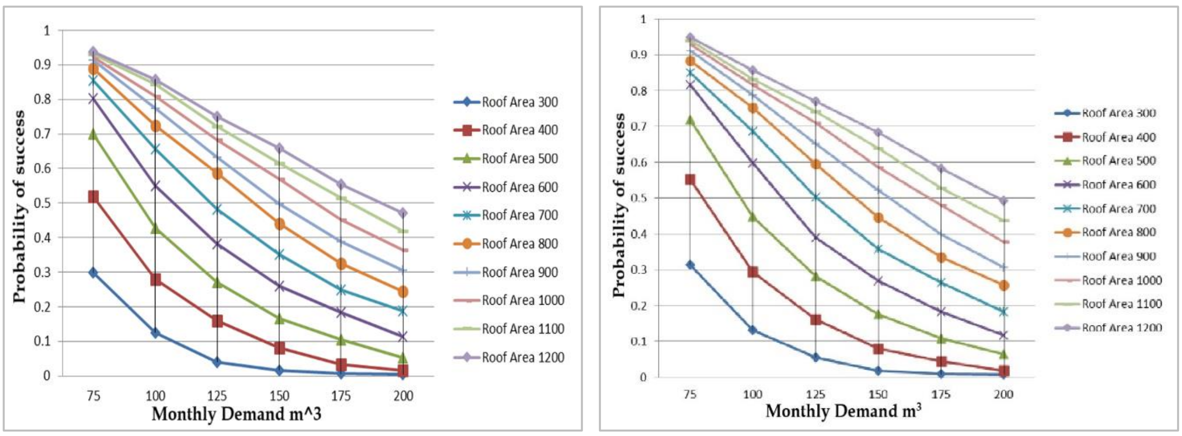


**Fig. 2. Probability vs Demand curve for 75 m³ tank capacity at Colombo (Left) & Ratmalana (Right)**

The results of Probability vs. Demand curves for Colombo and Ratmalana rainfall region for tank capacities of 75 $m^3$, 150 $m^3$ and 200 $m^3$ are shown in Fig. 2, 3 and 4 respectively.

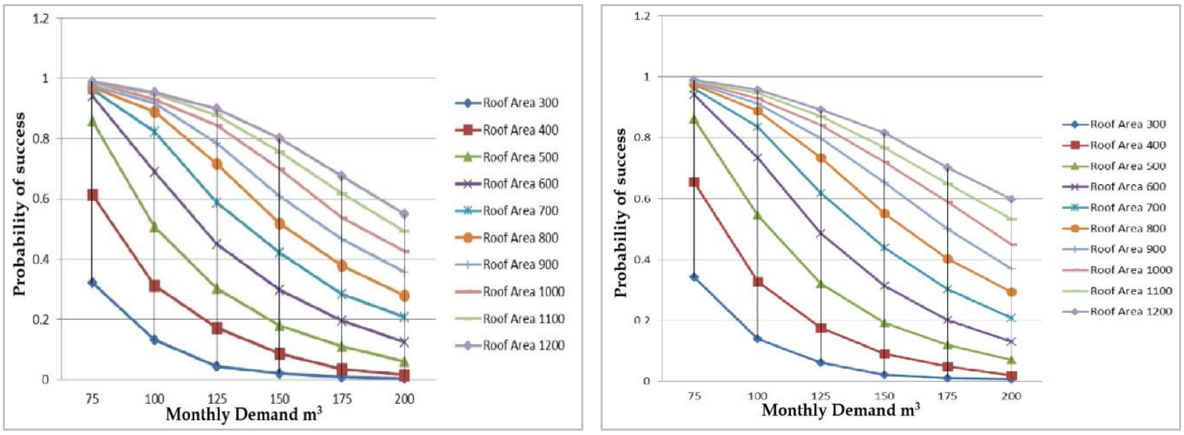


**Fig. 3. Probability vs Demand curve for 150 $m^3$ tank capacity at Colombo (Left) & Ratmalana (Right)**

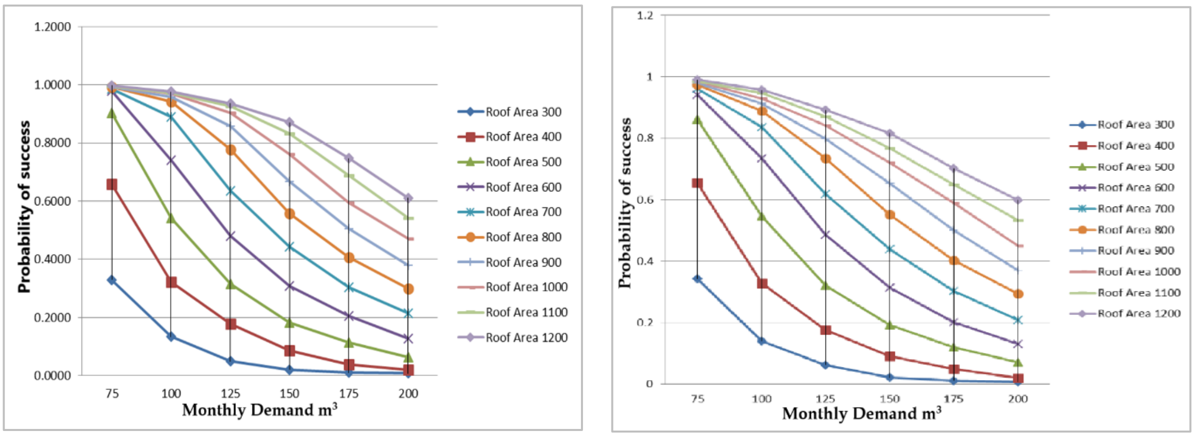


**Fig. 4. Probability vs Demand curve for 200 $m^3$ tank capacity at Colombo (Left) & Ratmalana (Right)**

In many instances, the success of the RWH was calculated using mean annual rainfall data and it gives a much higher probability of success than the actual situation as shown in Fig. 5. When comparing Fig. 4 (Right) and 5, it is seen that the probability of success using monthly data is 0.78 whereas probability rises to 0.98 when using the mean annual rainfall. Thus, it can be argued that the selection of mean annual rainfall data for the calculation can be misleading in RWH. Therefore, when the tank capacities are sufficiently large, monthly rainfall data are used for the calculations and it gives more realistic results.

The analysis is limited for the tanks with large capacities and hence the effect of daily rainfall data will not significant. Because of the change in rainfall pattern and intensity due to global warming in the recent past, it is necessary to keep abreast of calculation.

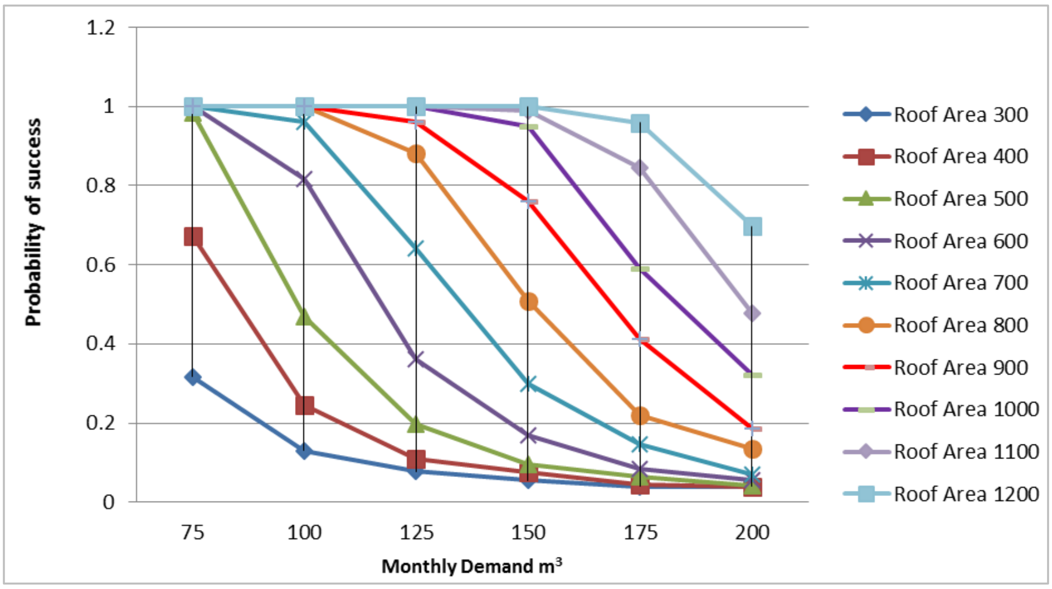


**Fig. 5. Probability vs Demand curve for 200 m³ tank capacity at Ratmalana considering Mean Annual Rainfall**

## 4 CONCLUSION

The results of the study conclude that most of the industrial buildings in Colombo and Ratmalana areas, have large roof areas greater than 800 m² and monthly water consumption (non-potable) is around 125 m³. There is a higher possibility of practising RWH and the probability of meeting the demand is as high as 60% even for the tank capacities of 75m³ in both Colombo and Ratmalana regions. Variation of the probability of success is shown in Table 3. Table 3 and figures 2 to 4 serve as a guideline to find the probability of success for the given monthly demand and roof area.

**Table 3. Guideline to find the Probability of practising Success**

| **Colombo** | | | | **Ratmalana** | | | |
|---|---|---|---|---|---|---|---|
| **Tank Capacity (m³)** | **Monthly Demand (m³)** | **Roof Area (m²)** | **Probability** | **Tank Capacity (m³)** | **Monthly Demand (m³)** | **Roof Area (m²)** | **Probability** |
| 75 | ≤ 125 | ≥ 800 | ≥ 60 % | 75 | ≤ 125 | ≥ 800 | ≥ 60 % |
| 100 | ≤ 125 | ≥ 800 | ≥ 62% | 100 | ≤ 125 | ≥ 800 | ≥ 65 % |
| 125 | ≤ 125 | ≥ 800 | ≥ 68 % | 125 | ≤ 125 | ≥ 800 | ≥ 70 % |
| 150 | ≤ 125 | ≥ 800 | ≥ 72 % | 150 | ≤ 125 | ≥ 800 | ≥ 74 % |
| 175 | ≤ 125 | ≥ 800 | ≥ 75 % | 175 | ≤ 125 | ≥ 800 | ≥ 77 % |
| 200 | ≤ 125 | ≥ 800 | ≥ 77 % | 200 | ≤ 125 | ≥ 800 | ≥ 80 % |

The practice of RWH is universal and can be applied in different situations depending on the needs. However, it does not state that RWH can be used in every location. When the demand is very high especially in large buildings in urban areas, RWH can use to partially fulfil the demand with a higher probability of success. Therefore, the potable water used for other purposes can be saved by capturing rainwater in urban areas.

## 5 ACKNOWLEDGEMENTS

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# Will Pineapple (*Ananas comosus L. Merr.)* be a successful crop with global warming- induced temperature and water stress in Sri Lanka?

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**Abstract -** *Global warming is taking place rapidly mainly due to anthropogenic and natural activities and will have adverse effects on plant growth and development of crop plants depending on the atmospheric temperature and soil moisture level. When the temperature exceeds the optimum and also when there is a water stress, plants respond negatively showing a sharp decline in growth and development which would ultimately affect the yield. In vitro propagation is a widely used vegetative propagation technique to obtain clones of true-to-type daughter plants. This mass scale propagation is used around the world and also in Sri Lanka using different explants, since it produces daughter plants with beneficial characteristics such as high yield and early fruiting.This study intends to investigate the impact of simulated temperature stress and water stress reflecting global warming on in vitro propagated pineapple plants. It is presumed that this research would help in planning in the cultivation of pineapple to obtain a substantial yield. This study was conducted in two locations in the Open University of Sri Lanka premises viz. in a polytunnel at an elevated temperature of 35 $^{o}$C and in a plant house under the ambient temperature. In vitro propagated pineapple plants obtained through ratoon suckers were used for this study. In each location there were two sets of plants maintained under two water regimes. One set was maintained under 100% soil moisture content while the other set was maintained at 50% soil moisture content. The plants were watered daily to their respective water capacities and maintained in completely randomized design. All the experiments were repeated twice to justify, the replication of temperature effect by the poly tunnel. The mean values of the vegetative, yield and quality parameters were taken for statistical analysis.According to the results, shoot initiation and proliferation of pineapple was successful on MS medium fortified with 2.5 and 4.0 mg/l BA respectively using ratoon suckers. Rooting of the proliferated shoots was carried out using MS medium with 1.0 mg/l IAA.The vegetative growth of pineapple was successful even under stressful conditions. The fruit diameter was high under both temperature stress and water stress condition. The fruit weight was also satisfactory under both temperature stress and water stress. The firmness of flesh was low under stressful conditions, which could be considered as a favorable characteristic from the consumers' point of view. The pH values of fruits on exposure to stress were less acidic compared to the pH of the fruits under no stress condition which would be a positive character from the consumers' point of view. It will also help to have good post-harvest quality due to less microbial activity. The total soluble solids were low on exposure to stress but it was not significantly different from other treatments. Fruits with large diameter, soft flesh and which are less acidic under both temperature stress and water stress prove that even under the simulated global warming conditions pineapple yield and quality would not be affected. Therefore $C_4$/CAM plants have more positive effects towards global warming due to their physiological advantage.*

***Key words:*** *Pineapple, Temperature stress, Water Stress, Yield*

## 1 INTRODUCTION

The temperature increment due to global warming is a major problem faced by the world today. According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2014), the cause of this is mainly the anthropogenic emission of various greenhouse gasses such as carbon dioxide, methane and nitrous oxide, which are emitted at an increasing rate with the economic and population growth of the world since the pre-industrial era.

Sri Lanka would also face consequences of this temperature increment. As reported by Chandrapala and Fernando (1995), there was an increase in temperature in Colombo by 0.0164 $^{o}$C year during the period of 1961 to 1990. It was predicted by General Circulation Model (HadCM3) that the annual average global temperature would increase. During May to September, the south west monsoonal period, the annual air temperature across Sri Lanka is predicted to be increased by 1.6 $^{o}$C ($A_2$ scenario) and by 1.2 $^{o}$C ($B_2$ scenario). Further, it is predicted that north east monsoon rainfall also would decrease in the coming years (De Silva *et al*., 2007).

Sri Lanka isexperiencing these effects even now, because temperature related extreme indices have risen over most parts of the country and annual average rain fall has been decreasing at a rate of about 7 mm per year, for the last 57 years (Ranasinghe *et al*., 2014).The increase in temperature and the decrease in rainfall would affect growth and development of plants. Plants would be subjected to temperature as well as water stress due to increase in evapotranspiration. The agricultural activities which involve plant growth and development would heavily be affected by climate.

Chapin *et al*., (1987) reported that temperature and soil moisture are important factors which determine the growth and productivity of plants. De Silva (2006) has predicted that increase in temperature will lead to increase in soil moisture deficit and additional irrigation water would need to satisfy the evapotranspiration. Dishani and De Silva (2013) also reported that the rate of plant growth and development depends on the surrounding temperature of the plant and each plant species has a specific temperature range represented by minimum, maximum and optimum temperatures. When the temperature exceeds the optimum level required for biological processes, the plants would respond negatively, especially showing a steep decline in the growth and yield (Cynthia and Hillel, 1995). According to Pastori and Foyer (2002) an increase in one degree above normal would lead to a significant reduction in growth and yield of a plant.

In this study, pineapple was selected because pineapple is the second most important fruit crop worldwide, after banana, contributing to over 20% of the production of tropical fruits (Coveca 2002). Pineapple (*Ananascomosus*L. Merr.), belongs to the family Bromiliaceae. is a plant found mainly in tropical and subtropical regions of the world. The fruit is a composite fruit and the ripened fruit of this plant is very popular among people as a dessert and syrups extracted from the fruit can be used as a juice or in wine production. In animal food, leaves can be used in three forms: fresh, dried and in silage (Coppens and Leal 2003).The fruit residue after extracting syrup is used as a cattle feed or fertilizer. The use of byproducts of pineapple culture in feed production, canning and juice extraction has been encouraged. Pineapple may offer additional advantages, such as its relevance as fiber source. Leaves are important in obtaining fiber which are used to weave cloth and in paper industry.Pineapple fiber has numerous qualities, such as its texture, its length (up to 60cm), high water and dye holding capacity, high whiteness, brightness, resistance to salt and tension strength (Argan *et al*, 2009).

In addition, *Ananas* sp. has medicinal properties as well. The ripe fruit has germicidal, laxative and invigorative properties since it contains the enzyme bromelain (Tochi *et al.* 2008). Bromelain has been produced for use as a meat tenderizer and as a component of pharmaceuticals. Due to the presence of this enzyme, pineapple is an appetizer. This fruit is also used in treating cardiovascular disorders. Unripe fruit can cause abortions. Further, pineapple is exported to other countries and Sri Lanka earns foreign exchange.There are two commercial varieties in Sri Lanka, i.e., Kew and Mauritius, out of which Mauritius is preferred by farmers and consumers. However, Kew variety has a better export market as a fruit which is used for obtaining syrup and in the jam industry.

## 1.1 Impact of Climate Change on Tissue Cultured Plants

A major problem that both large scale commercial production of pineapple and the expansion of the existing small farms face is the difficulty in obtaining uniform planting material in large quantity due to the low rate of multiplication by conventional methods and the lack of high quality propagules. Pineapple propagation is performed asexually, using shoots from different parts of the plant, such as bulbs, crowns and axillary buds. Recent advances in plant biotechnology methods applied to pineapple crops enhanced their potential application, both for basic studies and for direct application in agriculture (Read, 2007; Aragón *et al*. 2009; 2010).

*In vitro* propagated plants are usually produced by obtaining explants from selected healthy mother plants, having desirable characteristics such as ability to withstand stress, producing high yield and disease resistance. Further, they would inherit these beneficial characteristics from their parent plants, and would be expected to be affected to a lesser extent by the stress. Furthermore, with proper manipulation, a clone of thousands of true- to- type plants could be obtained through micropropagation. With the selection of disease-free mother plants and proper selection of explants, daughter plants which are also disease-free would be resulted.

In addition, seasonality would have no or minimum effect on the growth of the plants, when grown under growth room conditions. However, once the plants are acclimatized and transferred to the field, seasonality would have an impact on the growth and development of the plants. Cost of production is the only drawback of *in vitro* propagation. However, this could be minimized by producing a clone with a large number of plants and adopting a low cost application of this technique to reduce the cost of a micropropagule, without compromising the quality.

## 1.2 CAM Photosynthesis in Pineapple

Crassulacean Acid Metabolism (CAM) is a photosynthetic pathway identified in pineapple plants. Although the designation of CAM derives from the *Crassulaceae* family, the *Ananascomosus*is belonging to family *Bromeliaceae is* the CAM species with the highest commercial value. CAM photosynthesis appears to have originated as a means to scavenge respiratory $CO_2$ under conditions where the carbon balance is restricted, in environments where water availability becomes temporarily or seasonally constrained, such as deserts or rock outcrops. CAM metabolism causes major changes to leaf structure, succulence being the most obvious innovation as it facilitates the capture of night-time $CO_2$ released by respiration (Guralnick *et al*. 2001). Plants with CAM metabolism have a complex balance of $C_3$, $C_4$ and CAM photosynthetic pathways are well characterized but there are still a few metabolic details not well understood (Willert *et al.* 2005). The interpretation of the $C_3$/CAM transition as a complex interaction between environment and metabolism, in opposition to a basic molecular interpretation of the circadian cycle linked to carbon metabolism are still elements to be clarified on pineapple plants.

This research carried out to study the effect of global warming on *in vitro* propagated plants is very important, since no research of this kind has been carried out in Sri Lanka or worldwide up to now. Furthermore, a research on impact of global warming on the plants selected pineapple has not been conducted so far. Therefore, this research would be vital to those who are involved in the field of tissue culture as well as cultivation of pineapple. To date, there are no published data which would allow the prediction of growth and yield reductions of pineapple crop as a result of varying levels of water stress and temperature stress. So far, most studies of plant cold stress at the molecular level have focused on $C_3$ and $C_4$ plants, while research on CAM plants has remained scarce. This study will aid in understanding the temperature stress response in pineapple and other CAM plants.

This study focuses on the adaptive measures developed by plants for increased temperature and decreased rainfall or increase in soil moisture deficit due to global warming. Therefore, temperature stress is induced in temperature regulated polytunnel and water stress is induced by the amount of water applied (i.e: field capacity level and 50% of the field capacity level of soil moisture) and the effect of temperature and water stress on growth and yield parameters were measured. The main aim of the research project was to study the impact of induced temperature and water stress on vegetative and reproductive characteristics of the plants, developed through tissue culture technology, using Pineapple *Ananas comosus as* the model plant.

## 2 METHODOLOGY

### 2.1 *In vitro* propagation

The glassware required for preparation of media, sterilization and inoculation of the explants were washed with the commercial liquid detergent and running tap water and allowed to dry in a dryer. The glassware was then sterilized in a hot air oven at 180 $^{o}$C for two hours. The metal equipment such as scalpels and pair of forceps was washed with the commercial liquid detergent and running tap water. These were then wrapped in aluminium foil and sterilized in a hot air oven at 180 $^{o}$C for two hours. After each use during inoculation, the metal tools were dipped in 70% ethyl alcohol and flamed. The bench and the inner walls of the laminar flow cabinet were cleaned with 70% ethyl alcohol before and after use (Nagahawatte *et al.*, 2014).

Modified Murashige and Skoog's medium, (MS medium; Murashige and Skoog, 1962) was used as the basal medium. Different growth regulator combinations were incorporated into this medium depending on the requirement. In addition, Bacteriological agar and sucrose were also incorporated into each medium as a gelling agent and a carbon source respectively.

Different types of media necessary for shoot initiation, proliferation, sub culturing and rooting were prepared accordingly and the pH of the media was adjusted to 5.8±0.1 with the use of 0.1 N NaOH or 0.1 N HCl. 25 ml of the medium was dispensed into sterilized jam bottles, covered with previously autoclaved polypropylene and secured with rubber bands. The bottles containing media were autoclaved at 121ºC temperature and 1.05 kg/cm$^2$ for 15min. One month old ratoon suckers from mother plants were selected as the explants. The mother plants were brought from CIC Agri Farm Pelwehera, Dambulla and grown in the home garden(Nagahawatte *et al*., 2014).

The suckers were washed thoroughly with water to remove dust particles, and some leaves in the outer whorls of the plants were removed. The height of structures was reduced by cutting the stem and the leaves, leaving only two to three leaves. These were then washed thoroughly in running tap water by immersing in a beaker containing water and a few drops of the detergent Teepol. They were surface sterilized by immersing in a 50% commercial bleach solution (5.2% Sodium Hypochlorite) for 10 minutes, shaking occasionally, under the laminar flow hood. This was followed by rinsing three times in sterilized distilled water (Nagahawatte *et al.,* 2014).

The inoculum was made into a structure of 1.5 cm x 1.5 cm x 2.5 cm under the laminar flow cabinet and inoculated into a MS basal medium incorporated with 2.5 mg/l BA for shoot initiation of pineapple (Figure 1). The cultures were incubated under 16-h photoperiod at 25ºC with light intensity of 3000-4000 lux, in a culture room (Nagahawatte *et al*., 2014).

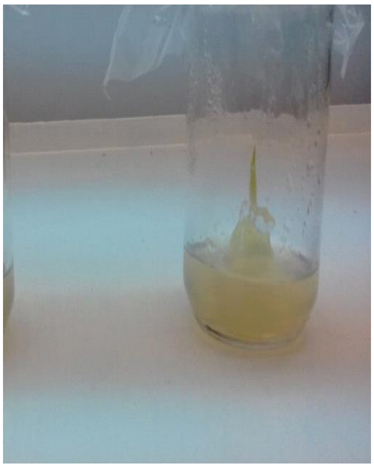

**Fig.1.Inoculation of the Explant of Pineapple (Shoot Meristem of a Ratoon Sucker)**

Initiated shoots were separated into individual shoots and inoculated into MS basal medium with 4.0 mg/l BA and incubated under conditions similar to initiation (Nagahawatte *et al*., 2014).Shoots were transferred to MS basal medium incorporated with 1.0 mg/l IAA and maintained for five weeks to obtain roots. Char coal was added to the medium to enhance rooting.

The plantlets were washed with tap water to remove traces of agar, separated into individual plantlets and potted in pots containing soil. These plants were maintained in a plant house at ambient temperature and watered daily for acclimatization. The acclimatized, *in vitro* propagated pineapple plants were potted, one plant each in pots having a diameter of 0.5 m, in a potting medium of top soil, coir dust and compost in 1:1:1 ratio. All the pots were filled with this mixture in equal amounts.

## 2.2 Temperature Regulated Poly Tunnel as Experimental Unit

The poly tunnel was constructed in the Open University premises, Nawala, in which the maximum daily temperature was maintained at 35 ºC. The poly tunnel was constructed in the direction of North-South to prevent the effect of mutual shading. The floor area of the tunnel was approximately 6.7 x 3.3 $m^2$ and the top was semi-circular elongated in shape (Figure 2). The basic structure was constructed with galvanized iron (GI) pipes and covered with UV treated polythene having the gauge of 120 microns. There was a manually operated door to access tunnel. The top of the tunnel has a semi-circular roof which has an opening enabling air circulation to maintain near natural conditions of relative humidity and $CO_2$ concentration. The above conditions satisfied simulation of high temperature inside the tunnel. However, in order to prevent the temperature from rising above the set temperature of 35 $^oC$, there were two exhaust fans and a thermostat installed. When the internal temperature increased above the set temperature, the automation of fans would bring the temperature down to 35 $^oC$.

(a) (b)

**Fig. 2. (a)The External and (b) Internal View of the Polytunnel in which the Plants were maintained at a Maximum Temperature of 35 $^oC$**

The variation of temperature inside the polytunnel and the ambient temperature outside over a period of 24 hours was measured (Fig. 3). The temperature at night falls below the maximum temperature set for that particular poly tunnel to represent the diurnal variation. However, the temperature maintained inside the poly tunnel was always higher than the ambient temperature; therefore temperature stress was enforced on the plants during day time while there was photosynthetic activity.

## 2.3 Experimental Conditions

All the pots were maintained in a poly tunnel at a maximum daily temperature of 35 ºC using a thermostat and two exhaust fans. The pots containing pineapple plants were individually divided into two equal groups. Two water regimes were imposed on the two sets of plants. They were, watered to 100% field capacity level and 50% of the field capacity level, imposing a water stress. Soil moisture measurements were made using tensio- meters planted in the pots regularly. The plants were maintained in a completely randomized design. The plants of pineapple were manured and maintained except for water management, according to the recommendation of the CIC Agri Farm.

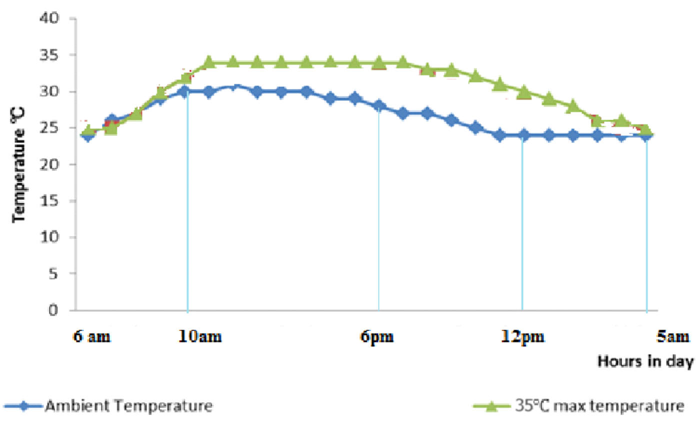


**Fig. 3. Temperature Variation Inside and Outside the Polytunnel**

The four treatments are as follows:
$T_1$- temperature stress, no water stress (in the poly tunnel at maximum temperature of 35 °C and watered to 100% soil moisture level)
$T_2$- temperature stress, water stress (in the poly tunnel at maximum temperature of 35 °C and watered to 50% soil moisture level)
$T_3$-no temperature stress, no water stress (in the plant house at ambient temperature and watered to 100% soil moisture level- control)
$T_4$ – no temperature stress, water stress (in the plant house at ambient temperature and watered to 50% soil moisture level).

## 2.4 Measurement of Parameters

### *2.4.1 Growth parameters*

Immediately after the plants were transferred to each location, and at four week time intervals, vegetative growth parameters such as mean height of plants, mean number of functional leaves, mean length of leaves of pineapple were measured. These measurements were recorded in all four treatments of pineapple plants.

### *2.4.2Yield Parameters of Pineapple*

The time taken for flower initiation and the time taken for fruit ripening were recorded for each pineapple plant. When the fruits have ripened, they were picked and the weights with and without the crowns were recorded using a digital balance. The lengths with and without the crowns were measured using a meter ruler. The diameter of fruits at the widest point of each fruit was recorded using a Vernier caliper.

### *2.4.3 Quality Parameters of Pineapple*

- Fruit Firmness

The firmness of the flesh of the fruits was measured using a Penetrometer. The mean value of three readings was recorded as the fruit firmness measurement.

- pH of the Fruit Juice

The quality parameters of pineapple fruit were evaluated by extracting the juice of the fruit using a mechanical blender. The pH of the juice was assessed using a bench pH meter- (Hanna pH 211 Micro Processor). The mean value of three measurements was expressed as the pH value of each fruit.

- Total Soluble Solids

The total soluble solids of the fruit juice extracted were measured using a digital UV-refractometer. The mean value of three readings was expressed as the Brix value. When the measurements were taken, equal number of drops of the extracted juice was placed on the refractometer prism plate and the readings were noted. After each reading, the prism plate was rinsed with distilled water and wiped with a soft tissue.

### 2.5Experimental Design and Data Analysis

All the experiments were carried out on the experimental design of completely randomized design (CRD). Due to the death of the plants during acclimatization, the number of replicates in pineapple had to be limited to three. ANOVA and hypothesis testing were carried out to compare the means of the parameters related to growth using SAS University software (University version). All the analyses were carried out at least in duplicate and in randomized order with the mean values for each treatment used three replicates to reduce random error.

## 3 RESULTS AND DISCUSSION

### 3.1 *In vitro* Propagation of Pineapple

One month after inoculation, the shoot initiation took place on the explant of pineapple (Figure 4).When the initiated shoots were transferred into a MS basal medium with 4.0 mg/l BA, in approximately 1 ½ months, 6-8 shoots/explant were developed from the sub-cultured shoots.

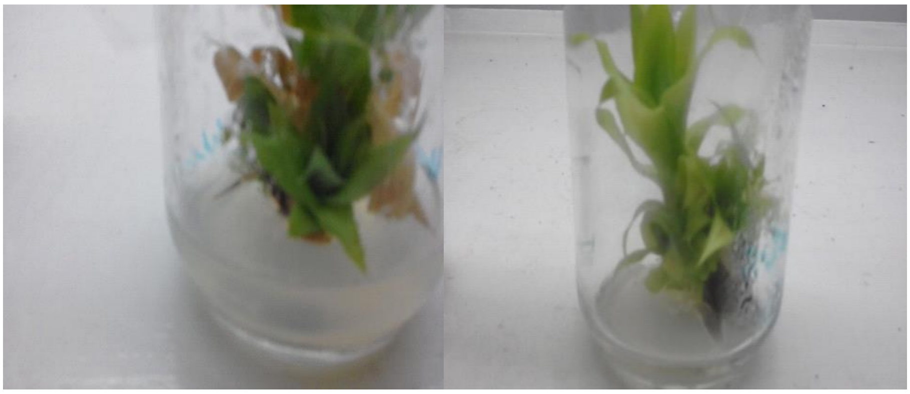

**Fig.4. (a) Shoot Initiation (b) Shoot Proliferation**

When the proliferated shoots were separated and transferred to the rooting medium viz,. MS basal medium incorporated with 1.0 mg/l IAA and charcoal, rooting of shoots took place in approximately 1 ½ months (Figure 5).

The process of acclimatization was successful. The process of acclimatization took approximately 1 ½ months. The plants were transferred to the poly tunnel and the plant house, after the acclimatization process, for the treatments to be imposed.


**Fig. 5. (a)Rooting of Pineapple Shoots (b).Pineapple plants after Acclimatization**

## 3.2 Growth Parameters

### *3.2.1 Height*

The plant height has shown an increasing trend pattern from week 0 to week 80. The highest plant height was shown in plants under the treatment of temperature stress and water stress. The plants exhibiting the lowest plant height varied over the weeks.

According to Figure 6 which shows the plant height after 80 weeks, highest plant height was shown in plants which were under temperature stress and water stress. This was significantly higher than when compared with the other treatments. The lowest plant height was shown in plants of the treatment with no temperature stress but with water stress. However, there was no significant difference among heights of the plants of the other three treatments viz., temperature stress with no water stress, no temperature and no water stress and no temperature stress but with water stress. Further, there was no interaction effect of both the stresses on the height of plant according to the ANOVA.

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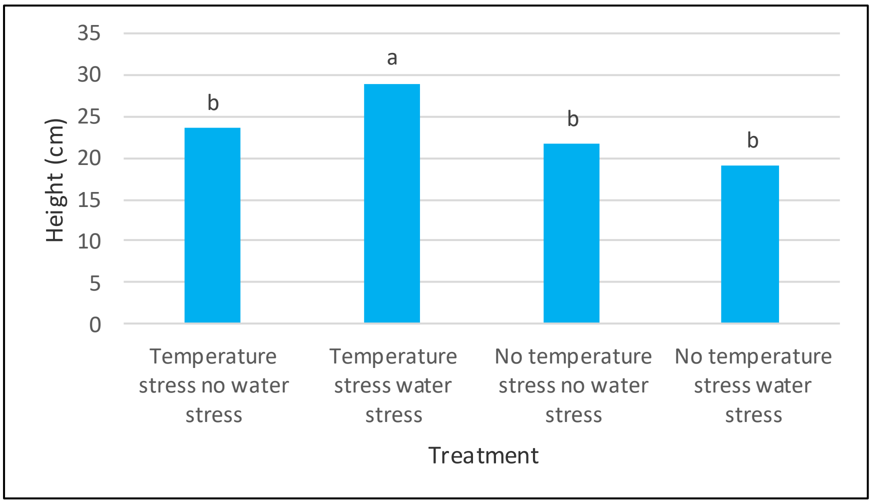


**Fig. 6. Plant Height, after 80 Weeks**

Pineapple being a plant with crassulacean acid metabolism (CAM) that facilitates the uptake of carbon dioxide at night, improves its water-use efficiency under dry conditions. The succulent leaves collect and store water in the leaf axils, where it is absorbed by surrounding tissue or by aerial roots (Aragon *et al*, 2012). Due to these physiological and morphological features, the vegetative growth of pineapple is less affected by water stress and they prefer arid conditions. This may be the reason why the plants in temperature stress and water stress showed significantly higher plant height.

### *3.2.2 Leaf Length*

The leaf length has shown an increasing trend pattern from week 0 to week 80. The highest leaf length was shown in the plants under the treatment of temperature stress but with no water stress. The lowest leaf length was shown in the plants under the treatment of temperature stress and water stress.

According to Figure 7 which shows the leaf length at week 80, the highest leaf length was shown in plants in the treatment of no temperature stress and no water stress and it was not significantly different from all other treatments. The lowest leaf length was shown in plants in the treatment with temperature and water stress and it was also not significantly different from all other treatments. It is a typical feature of bromeliads to be less affected by stresses usually, as they grow well in arid conditions. This may be the reason for not having any significant difference between treatments. It shows that there is no impact of water stress and temperature stress on leaf length of pineapple. According to the ANOVA, both factors such as temperature and water have not significantly influenced the variation of the leaf length and therefore the interaction effect was not significant.

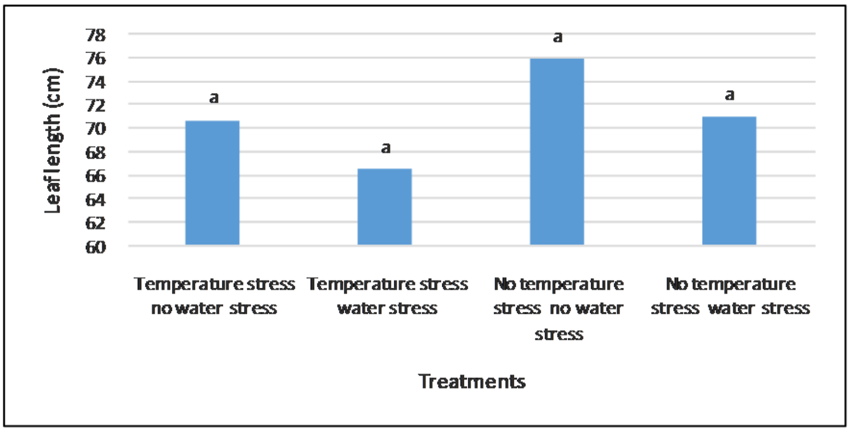


**Fig. 7. Leaf Length after 80 Weeks**

In agreement with previous results obtained in the same experimental system (Aragón et al. 2012), succulence, normally associated to leaf anatomy of CAM plants of different families (Madison, 1977), was also verified. Mesophyll tight cells with highly enlarged vacuoles contribute not only to water but also to malic acid storage (Winter and Smith, 1996).

### *3.2.3. Number of Leaves*

Number of leaves has shown an increasing trend pattern up to the period of 64 weeks and then it has shown a decreasing trend pattern. The highest number of leaves was shown in the plants under the treatment of temperature and water stress. The lowest number of leaves was shown in the treatment of no temperature stress and no water stress.

According to Figure 8, the highest number of leaves at week 80 was shown in the treatment with temperature stress and water stress and it was significantly different from other treatments. The lowest number of leaves was shown in the treatment with no temperature and no water stress. However, this treatment was not significantly different from the treatment of no temperature stress but with water stress. As it is shown by Figure 7 the temperature and water stress have not exerted a negative impact on the number of leaves. According to the ANOVA both factors, temperature stress and water stress have not significantly influenced the number of leaves. Furthermore interaction effect was not significant.

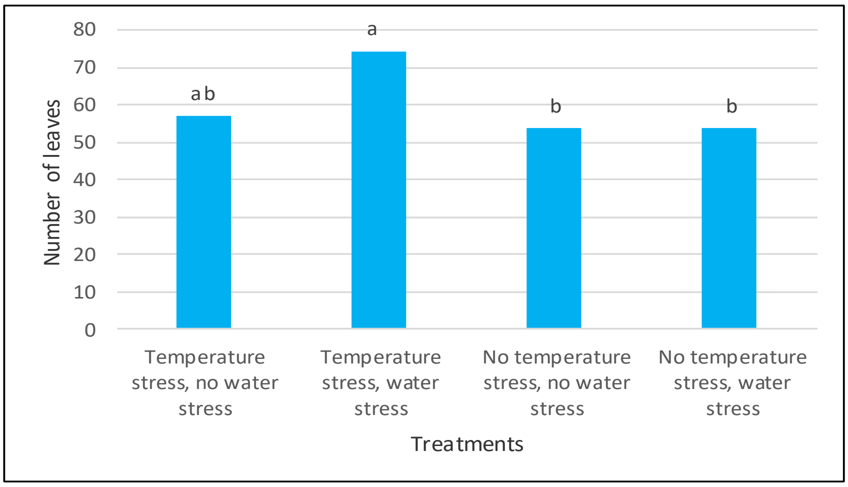


**Fig. 8. Number of Leaves from Week 0 to Week 80**

Pineapple being a plant exhibiting crassulacean acid metabolism and also having the ability to collect and store water in the rosette like leaf arrangement, and with the special features like the water-storing phytotelmata, the plant is able to adapt to water and heat stress (Lüttge, 2004). CAM physiological and biochemical features are deeply associated to leaf anatomy. In opposition to the majority of non- CAM plants, the anatomy of adult pineapple leaves is characterized by the presence of aerating canals, fiber strands, water storage tissue and hypodermis as described in adult pineapple plants as reported by D´Eeckenbrugge and Leal (2003) and more recently, by Pérez *et al.*( 2012) in new pineapple somaclonal variants. Anatomy of *invitro* and *exvitro* pineapple leaves has also been compared (Barboza *et al*. 2006). Leaf anatomy of in vitro propagated pineapple plants also shows canals, fibers, an aquifer parenchyma, a chlorenchyma and hypodermic tissue, mostly maintained during the initial *exvitro* stages. However, the leaf anatomy of CAM plants has a high degree of plasticity in response to the environmental conditions

## 3.3 Yield Parameters

### *3.3.1 Fruit Diameter*

Figure 9 indicated that the diameter of the fruit was maximum when the plants were under water stress and temperature stress. However, the diameter of the fruit was lowest in no temperature and no water stress which is significantly different from other treatments except the treatment with temperature stress but no water stress. High diameter observed with pineapple fruits seemed to indicate a gain of flesh. It would mean that fruits contain more juice, when fruits were grown under temperature and/ or water stress. It shows that pineapple prefer stressful condition due to its specialized physiological processes. When CAM plants are under stress, they produce large cells with water storage ability as a heat dissipation strategy which induces large diameter fruits than the fruits of plants growing under no stress conditions (Espírito and Pugialli, 1998). The large vacuoles of the cells of those tissues are also associated to malic acid storage, an aspect described in a number of CAM species.

According to the ANOVA both factors water stress and temperature stress and also the interaction effect have not significantly influenced on the diameter of the fruit. Therefore, there was no interaction effect.

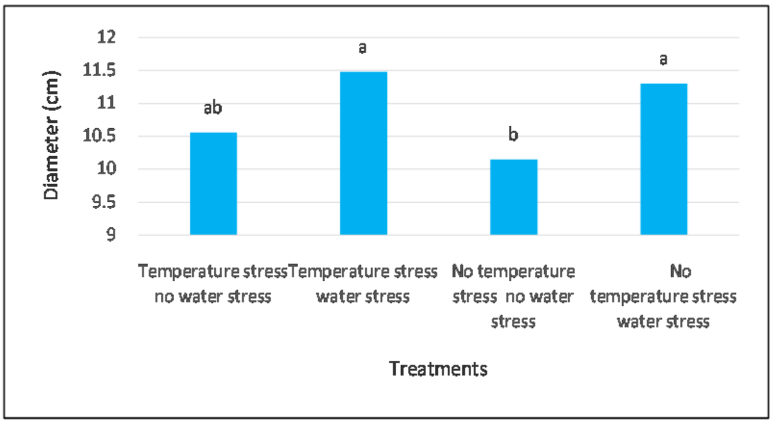


**Fig. 9. Effect of Temperature Stress and Water Stress on Diameter of Pineapple fruit**

### *3.3.2 Length of Fruits without Crown*

According to Figure 10, the treatment with temperature stress and water stress has shown the highest length of fruit without crown which is significantly different from the length of fruit without crown in no temperature stress and no water stress. But the length of fruit without crown in temperature and water stress treatment is not significantly different from temperature stress and no water stress and no temperature stress with water stress. In the interest of the consumer what is important is the length of fruit not that of the crown. According to the ANOVA both factors such as water and temperature have not created any significant difference and also interaction effect has not imposed any significant influence on the length of fruit without crown. Therefore, there was no interaction effect.

Therefore, it can be inferred that the temperature and the water stress which was imposed on the pineapple plants have a positive impact on the length of the fruits. These finding of fruits with larger diameter and higher length than the fruits under no stress conditions agree with the finding of Espírito and Pugialli (1998). This study showed that pineapple would successfully cope up with global warming induced temperature stress and water stress.

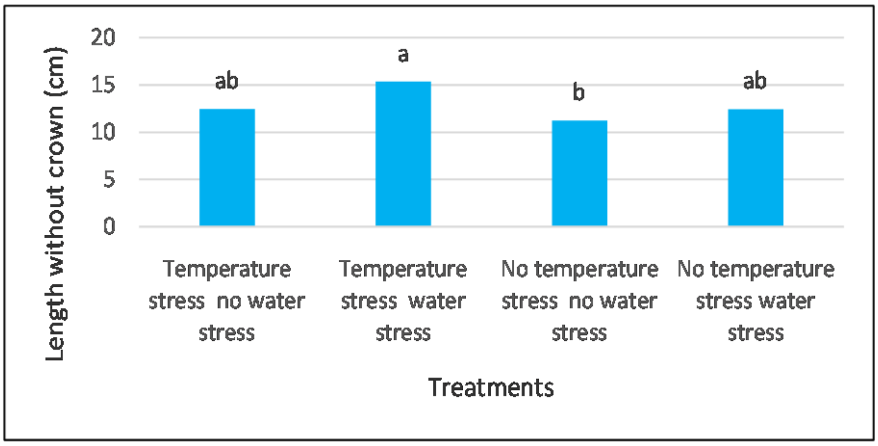


**Fig.10. Effect of Temperature Stress and Water Stress on Length of fruit without Crown**

### *3.3.3 Weight of Fruit without Crown*

According to Figure 11, treatment with temperature stress and no water stress has shown the highest value for weight without crown. However, it was not significantly different from all other treatments. The treatment with no temperature and no water stress has shown the lowest weight without crown but it was not significantly different from all other treatments. This shows that temperature and /or water stress have not imposed any negative impact on weight of fruit without crown. Because they yield successfully, even in stressful situations they contribute to the world market.

According to the ANOVA, both factors water stress and temperature stress have not significantly influenced on the variation of the weight of fruit without crown. Also interaction effect has not created any significant difference on the weight without crown. Therefore, there was no interaction effect as the interaction effect was not significant.

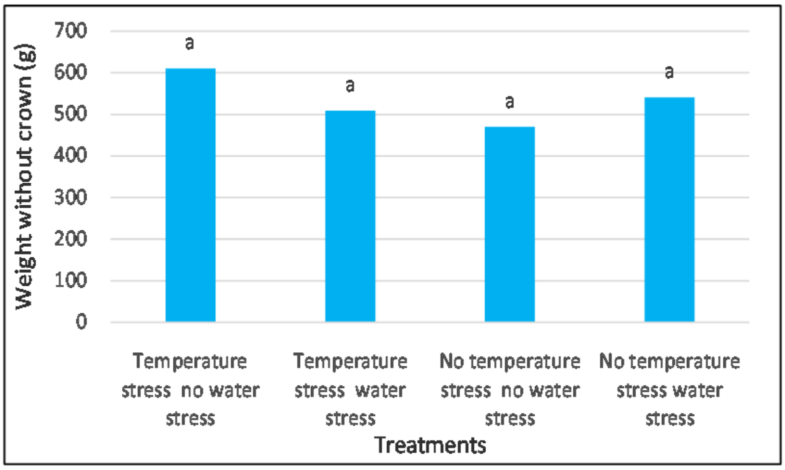


**Fig.11.Effect of Temperature Stress and Water Stress on Weight of Fruit without Crown**

Pineapple has unique anatomical and physiological modifications which enable the plant tosurvive periods of water stress. Under drought conditions, the plants are as hardy as cactus. For these and other reasons, the pineapple is one of the few crop plants that can be classified as a true xerophyte (Aragon *et al* 2012). In areas where water is limiting, the effects of water stress on the growth and yield of pineapple are of particular interest.

## 3.4 Quality Parameters of Pineapple

### *3.4.1 Firmness of the Flesh*

According to Figure 12, the treatment with temperature stress and water stress has shown the lowest firmness of the flesh but it was not significantly different from all other treatments. The highest firmness of the flesh was shown in the treatment with temperature stress and with no water stress and it was also not significantly different from all other treatments. According to the ANOVA, temperature stress and water stress have not contributed to a significant influence for the firmness of the flesh. And also there was no interaction effect, because interaction effect was not significant.

This indicated that fruit is soft when the plant is under temperature stress and water stress. When firmness of flesh is low or when fruit is soft, it is preferred over the hard flesh fruits. Firmness of fruit is determined by the cell wall structure and cuticle properties (Chaib*et.al.*,2007). When the fruit is ripening there is cell wall degradation and remodelling of cell wall which causes softening of the flesh of the fruits (Matas*et.al*, 2009). When CAM plants are under stress, they produce large cells with water storage ability as a heat dissipation strategy (Espírito and Pugialli, 1998). When the pineapple fruits are exposed to high pre-harvest temperature a disorder with similarities to water core which is flesh translucence in pineapple occurs, where the symptoms are water soaking and increased porosity (Paull and Chen, 2000). Relatively high fruit temperatures early in the season may induce some tolerance to heat during later fruit growth; the disorder appears to be associated with heat stress in these later stages. This also causes the flesh of the pineapple fruits to be soft (Paull and Chen, 2000).

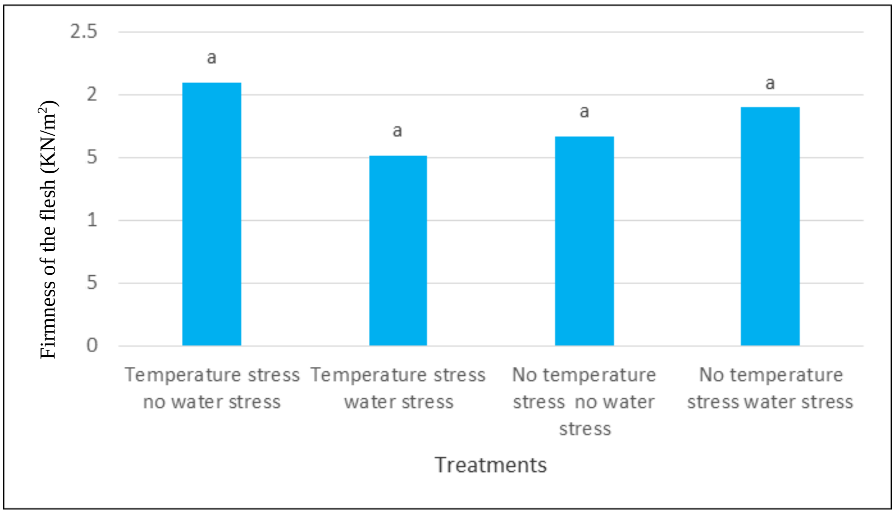


**Fig. 12. Effect of Temperature Stress and Water Stress on Firmness of the Flesh**

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### *3.4.2 pH of the Fruit*

According to Figure 13, the treatment with temperature stress and no water stress has shown the highest pH value and it was significantly different from all other treatments. The treatment with no temperature and no water stress has shown the lowest pH value (3.1-3.2) and it was also significantly different from all other treatments. This shows that when the plants are under stress, they produce fruits having comparatively higher pH (3.7-4.3) compared to the fruits in no temperature stress and no water stress (3.1). Microorganisms have minimum and an optimum pH requirement for their growth. The excellent storing qualities of fruits are related to their respective pH, such as fruits with low pH value are usually not really spoiled by bacteria. According to the ANOVA, temperature stress was the only factor that contributed significantly on the pH. The other factor water stress has not contributed significantly on the pH. However, the interaction effect was significant, therefore, there was an interaction effect.

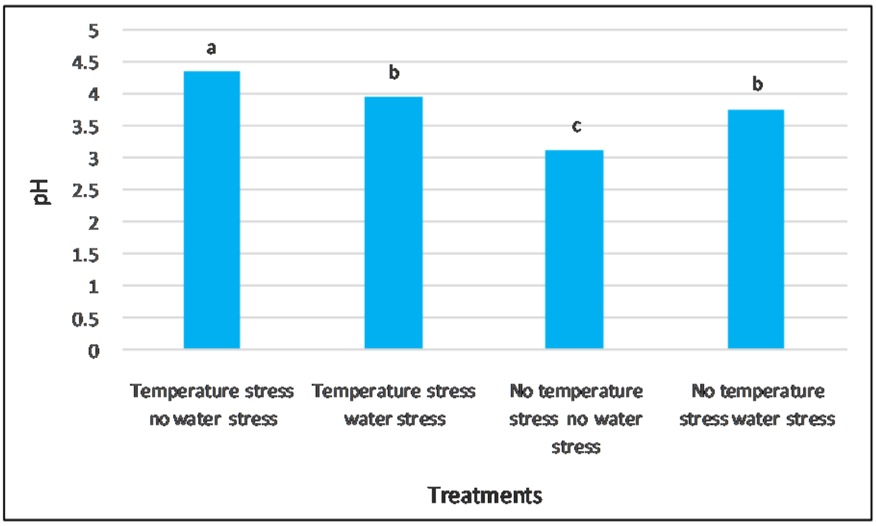


**Fig.13.Effect of Temperature Stress and Water Stress on pH of the Pineapple Fruit**

According to Andersen and Wilkins (1989) and Hummel *et al*, (2010) water stress increases the accumulation of organic acids in the leaves and xylem fluid which leads to import of organic acids to the fruit resulting in low pH. However, as reported by Esteban *et al*. (1999), des Gachons*et al*. (2005), and Thakur and Singh, (2012) there is a positive relationship between water supply and organic acid content in ripe fruits indicating a lower pH under no water stress condition.The daily variations of mesophyll pH in CAM plants usually follow the trend of values decreasing in the dark period due to the accumulation of malic acid and increasing in the light period when malic acid released from the vacuole is decarboxylated by cytoplasmic malic enzyme (Antony *et al*. 2008). In fact, it is possible to establish a direct relationship between the low pH values in the dark in vitro and ex vitro CAM induced plants and the high malic acid concentrations measured (Aragón *et al*. 2012).

### *3.4.3 Total Soluble Solids*

According to Figure 14, the treatment with no temperature stress and no water stress has shown the highest value for TSS and it was significantly different from treatment with temperature stress and water stress but not significantly different from fruits from the treatments of temperature stress with no water stress and no temperature stress with water stress.

The treatment with temperature stress and water stress showed the lowest value for TSS. The total soluble solid is an indication of the amount of sugars present in the fruit. However, May (1993) has observed that low water stress resulted in products with best soluble solids in tomatoes. According to the ANOVA, both factors the water stress and temperature stress have not imposed any significant effect. Also interaction effect has not contributed any significant influence on the total soluble solids. Therefore, there was no interaction effect.

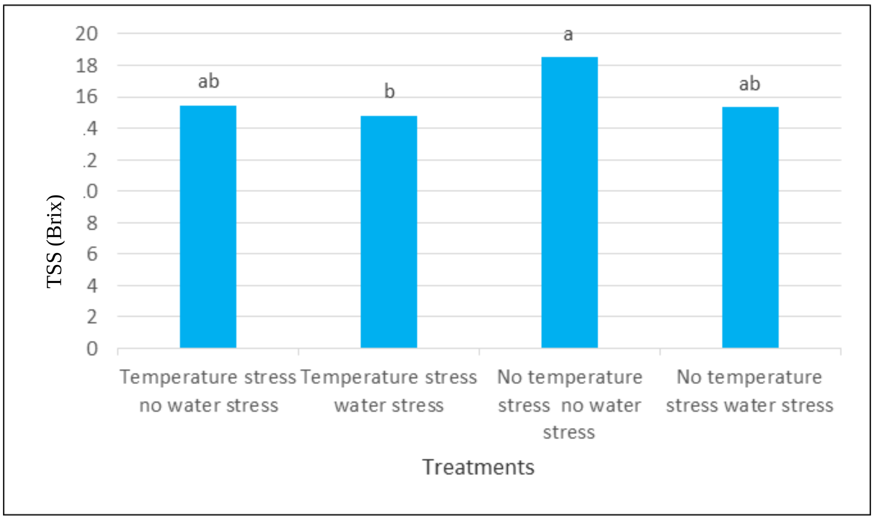


**Fig. 14. Effect of Temperature Stress and Water Stress on Total Soluble Solids of Fruit**

## 4 CONCLUSIONS AND RECOMMENDATIONS

The results obtained for pineapple propose that the vegetative growth was not affected much due to temperature stress and water stress imposed, reflecting global warming. The vegetative growth parameters such as plant height, number of leaves and leaf length also have not been affected significantly by the temperature stress and the water stress imposed. This suggests that the vegetative growth of *in vitro* propagated pineapple variety Kew would be less affected by the predicted global warming.

As pineapple is a plant exhibiting heat dissipation strategies, the diameter of pineapple fruit was significantly high under both temperature stress and water stress. It shows that temperature stress and water stress have a positive impact on the diameter and size of the fruit. The length of fruit without the crown also has shown a positive results when the temperature stress and water stress were imposed. The weight of fruit without the crown also has not shown a considerably significant reduction due to stresses imposed. Therefore, it can be inferred that yield of pineapple variety 'Kew' would be increased considerably, on exposure to the temperature and water stress due to the predicted climate change.

According to the quality parameters of pineapple, the firmness of the flesh has shown a comparatively low value, when the plants were under stress, therefore the flesh is soft which could be preferred by the consumers. Hence, it is evident from these results that the plant would produce fruits that would be preferred by the consumers, when it is under temperature and water stress. When the plants were under stress, the pineapple fruits that they produced showed a acidic pH (3.7- 4.3) which is one of the good post-harvest qualities as there will be less spoilage by bacteria. The total soluble solids of fruits showed a slight decline when the plants were under stress but that is not much different from the fruits produced without any stress.

The finding of this study indicates the pineapple will be a successful crop even if there is temperature and water stress due to global warming. Therefore, farmers are encouraged to cultivate pineapple even under temperature and water stress conditions to increase the yield without crop failures as experienced in other crops.

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# Acoustic Based Defective Glass-Ware Detector

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**Abstract** – *Glass-ware play a vital role in industry and household. There are many defects that can develop in a glass container during the manufacturing process. It is important to detect defective containers to deliver a quality product.*

*A methodology is proposed to overcome costly systems available in industry for detection of defective glass containers. This investigation is through frequency spectrum analysis of non-defective containers and defective containers which is implemented in MATLAB software. Acoustic features are extracted from recorded soundtracks and compared with the non-defective templates available in a database. The frequency spectrum is obtained using the Fast Fourier Transform (FFT) and the features are extracted using Cross-Correlation and Mel Frequency Cepstrum Coefficients (MFCC) to identify the defective containers from non-defective containers. The comparison process involves the use of the Euclidean distance which measures the percentage of dissimilar bits out of the number of comparisons made.*

*The proposed system includes a striking device to excite vibrations on the glass container and the sound signal thus generated is detected by a microphone sensor and amplified. The amplified signal is passed through a band pass filter to obtain a narrow signal envelop as it facilitates the process of comparison of defective signals with a non-defective signal.*

***Keywords****: Cross-Correlation, FFT, Feature Extraction, MATLAB, MFCC*

## 1 INTRODUCTION

Glass-ware plays a vital role in industry and household. Glass containers are essential in many areas such as food industry, drink manufactures and medical packaging. It is important that containers normally in the form of bottles must be damage-free. The packages which contain perishable food or drink items must be airtight as the presence of air can cause bacterial spoilage and other health concerns. In the medical stream non-defective glass containers are essential as any leakage will cause health issues to the patients as well as the operators. The Fig. 1 shows an example image of a defective glass container.

**Fig. 1. Defective Container (Dented Body)**

There are many defects that can develop in a container during the manufacturing process such as cracks, air bubbles, freaks etc. (Anon, 1967). So, it is important to detect defective containers to deliver a quality product. Glass ware defects due to faults in the manufacturing process, packaging and delivering, cause difficulties to the consumer.

In most of the production lines detection of defective containers is done by human operators. Manual inspection process is slow, time consuming and prone to error. In recent years, image analysis techniques have been increasingly used in industry for surface inspection, where small defects that appear as local anomalies in material surfaces are detected (Mohan and Poobal, 2017). But these systems are expensive.

An automated and cost-effective detection method is essential to deliver a quality product in the glass-ware industry.

## 2 LITERATURE REVIEW

### 2.1 Manufacturing Process

Glass is super cooled liquid that can create marvellous objects. Silica is the main raw material, which is taken from sand filtered to eliminate $CaCO_3$, $MgCO_3$, and $Na_2CO_3$. To form different kinds of glass containers, raw materials are melted and passed through various metallic moulds to obtain different glass-container designs. Fig. 2 shows the manufacturing process of glass containers.

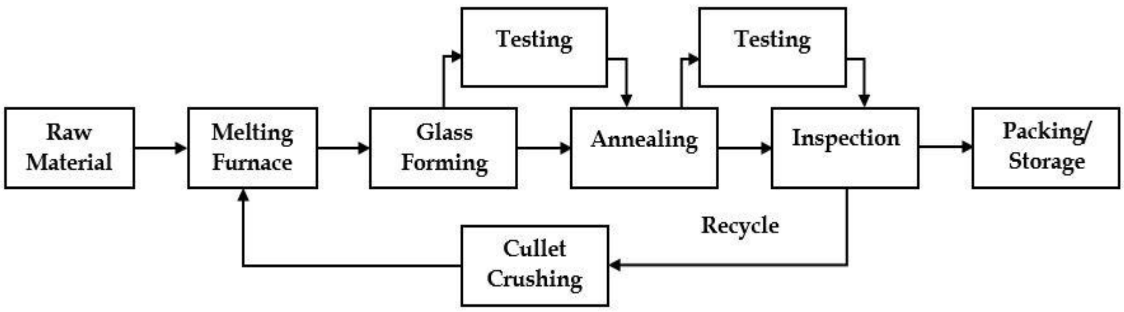


**Fig. 2. Glass Container Manufacturing Process**

## 2.2 Types of Glass Container Defects

Defects are named under parts of a container (Anon, 1967).

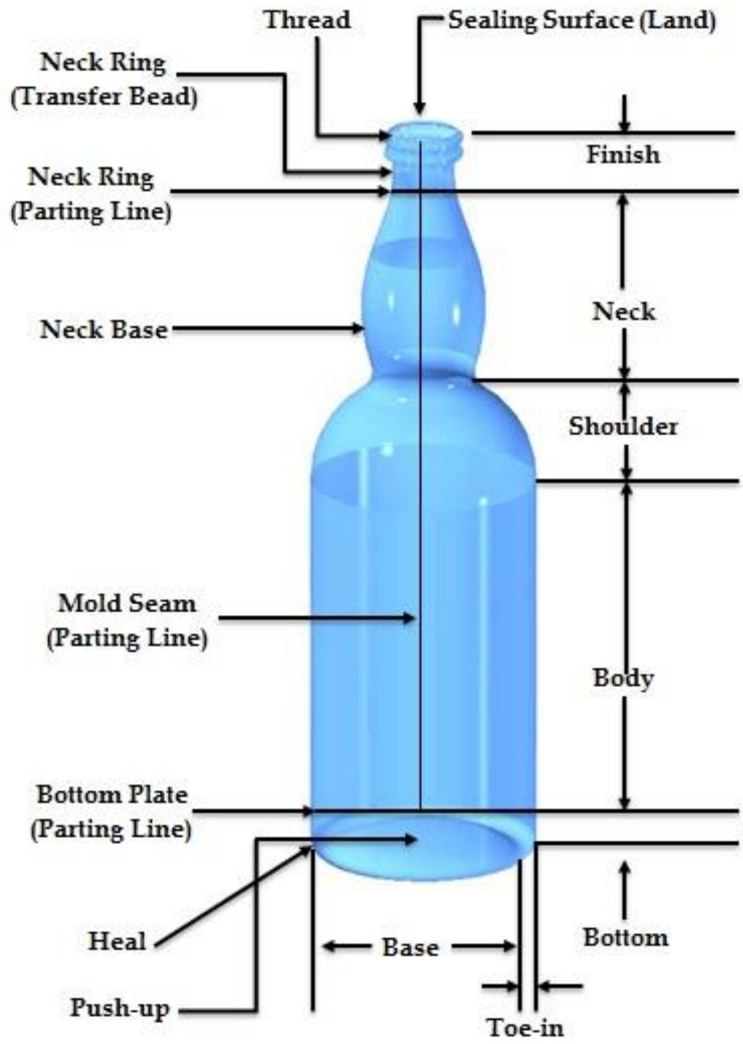


**Fig. 3. Parts of a Glass Container**

The various types of defects that can be present in the glass are (Anon, 1967): Checks: Consists of miniature and slight crack which does not leakage but it certainly weakness the body wall. Non-glass inclusions: Glass defects due to dirt, adhering to any unsustainable particles or due to enormous oil parks. Marks: Depict the spot or any stray marks in the glass which diminishes the quality of glass. The body of the glass becomes thinner and weaker.

Some of the glass container defects are summarised in the Table 1.

**Table 1 Glass Container Defects**

| Critical Defects | Body Defects | Finish Defects | Neck Defects | Bottom Defects | Shoulder Defects |
|---|---|---|---|---|---|
| Freaks | Stringy Glass | Offset | Seam on Neck | Flanged Bottom | Shoulder Check |
| Spikes | Bulged Sides | Off Gauge | Dirty Neck | Wedge Bottom | Sunken Shoulder |
| Checked and Split Finish | Hot or Panel Check | Bulged and Chipped | Bent Neck | Heavy Rocker | Thin Shoulder |
| Crizzeled Finish | Pressure and Letter Checks | Over Pressed | Ling Neck | Baffle Marks | |
| Checks under Finish | Blow Mold Seam | Corkage Check | Hollow Neck | Swung Baffle | |
| Unfilled Finish | Bird Cage | Neck Ring Seam | Pinched Neck | Wedge Bottom | |
| Chocked Neck or Bore | Cold Molds | Bent or Crooked | Danny Neck | Thin Bottom | |
| Bottom Check Thin Ware | Wash Modes | Tear Under Finish | | | |
| Stuck Glass Particles | Sunken Sides | Dirty or Rough | | | |

## 2.3 Existing Systems

### 2.3.1 Machine Vision Based Defect Detection

For the inspection of a glass container, image processing is the latest technique used today. By scanning an image of a glass container and compare it with existing image templates in database and then find defective container and reject them (Mohan and Poobal, 2017, Nishu & Agrawal, S., 2011).

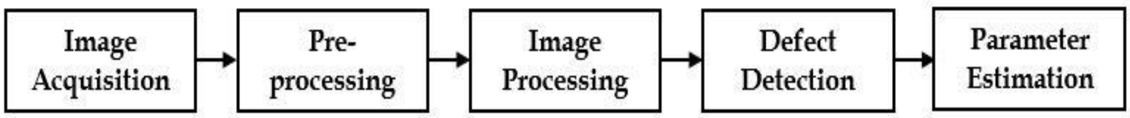


**Fig.4. The Architecture of Image Processing Based Crack Detection**

The processing difficulty of the crack detection completely depends on the size of the image. Recent digital cameras have the image resolution beyond 10 megapixels. This increase in resolution enables the acquisition of detailed images of concrete surfaces. By using the trendy cameras of commercial purpose, a wide range of a concrete surface can be acquired in a single shot. For inexpensive applications, a wide range image can be used for the practical crack detection (Mohan and Poobal, 2017; Ma *et al*, 2002). This system is expensive and for accurate inspection container is scanned by changing its orientation like body check, bottom check, finish check etc. But some defects are inspected through manual examination which cannot catch by image processing.

#### 2.3.2 Photo-Electric Crack Detector for Glass Bottles

This system is introduced apparatus for photo-electrically detecting cracks or flaws in the bottoms, necks, or lips of glass bottles while being rotated and traversed in single line through a test path, storing the effect of a signal resulting from the presence of such a defect, and utilizing said stored effect to cause ejection of defective bottles after they pass beyond the test area (Powers, 1971).

### 2.4 Acoustic Based Systems

According to the direction of this system development is considered the acoustic behavior of a container. There are many systems implemented all over the world based on acoustic characteristics such as acoustic accident detection system, car accident detection and notification, engine fault diagnosis using acoustic signals, leak detection in gas pipeline by acoustic and, detection of diesel engine injector faults, etc. (Atti *et al*, 2007). The following systems developed to detect some other glass container defects.

#### 2.4.1 Plastic Coated Bottle Testing

According to this system it tests plastic coat of the bottle by its sound characteristics and reject those defective. Bottle is struck by an impact mechanism. The sound of impact is detected, and the sound decay characteristics are utilized to determine whether the bottle is solid and acceptable or whether it is cracked or broken and thereby rejected (Hartman, 1975). This system developed to check only coated bottle but can be used to detect empty glass container.

#### 2.4.2 Method and Apparatus for Analyzing the Fill Characteristics of a Packaging Container

This system is considered about filling characteristics defects. It introduced a method for analyzing the internal pressure of a closed container includes inducing vibration in a surface of the container, detecting sound resulting from the vibration; deriving information representing the detecting sound; and predetermining whether this information corresponds to a predetermined spectral frequency condition and a predetermined spectral amplitude condition (Rodriguez, 1998). This idea can be used to detect defects which are developed during the manufacturing of glass container.

## 3 METHODOLOGY

In this work, a methodology is proposed to detect defective bottles or containers based on its acoustic behaviour. After taking the sound signals of bottles, signal processing and analysis techniques are applied to isolate the differences in frequency responses of non-defective glass containers and defective glass containers.

It is approached through frequency spectrum analysis of non-defective containers and defective containers. Acoustic features are extracted from the recorded soundtracks and compared with the non-defective templates available in the database. Therefore, frequency spectrum is obtained by using Fast Fourier Transformation (FFT) technique and features are extracted using Cross-Correlation and Mel Frequency Cepstrum Coefficients (MFCC) methods to isolate the defective containers from non-defective containers.

Implementation of the system includes a striking device used to excite vibration on the glass container and the sound signal is directed by a microphone sensor and amplified. The amplified signal is then passed through a band-pass filter to obtain a narrow signal envelope as it facilitates the process of comparison of defective signals with non-defective signals. Then the defective container is rejected. The block diagram of the system is given in Fig. 5.

**3.1 Cause Vibration**

Glass container must vibrate to obtain its sound emission and the vibration strength should be same for whole experiment. Therefore, a tap is given to the center of the body of glass container by a striking device which is designed using a solenoid because the push-pull mechanism of a solenoid can be used to tap the glass container (vibration) and then frequency levels of each container can be obtained.

**3.2 Amplifier**

The signal outcome of a glass container due to the vibration is detected by a microphone sensor which is situated on top of the bottle lip and amplified it to obtain a larger signal as it facilitates the work of signal processing. The frequency response lied between 5.5 kHz – 7.5 kHz. Common-Emitter Amplifier is designed as amplifier circuitry using 2N3904 NPN transistor.

**3.3 Bandpass Filter**

The frequency spectrums of glass containers obtained using MATLAB and it is lied between 5.5 kHz and 7.5 Hz. Therefore, wide band pass filter is designed as the filter circuitry.

**3.4 Decision Making Unit**

Spectrums of each signal must analyze to identify differences of sound signals of glass containers. Therefore, decision making unit involves two feature extraction methods which are used in signal processing. The two methods are Mel Frequency Cepstrum Coefficients (MFCC) and Cross-Correlation which is implemented in MATLAB environment. Features extracted for all non-defective sound samples in the database and for a given glass container. Extracted features are matched using a mathematical function called Euclidian Distance to make the final decision whether a given glass container is defective or not.

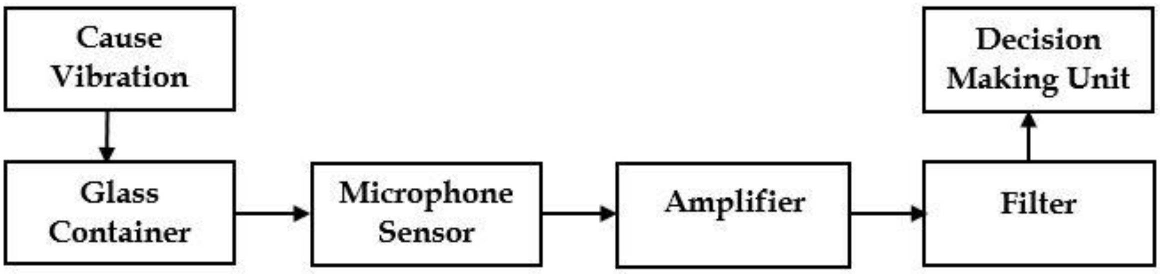


**Fig.5. Block Diagram of the System**

# 4 THEORY

## 4.1 Fast Fourier Transformation (FFT)

Frequency spectrum of sound signals are obtained by applying the mathematical process of Fast Fourier Transformation (FFT) which converts the amplitude data into frequency data. For any given time-window of a sound recording, FFT calculates the frequency components of the signal and their relative amplitudes produce a frequency spectrum (French, 1983).

## 4.2 Feature Extraction

A database contained 10 sound samples of non-defective containers and decision is made by comparing each spectrum of sound samples in database with a given sound sample of a glass container. Fig. 6 shows signals of two non-defective sound sample and Fig. 7 shows a signal of a defective sound sample.

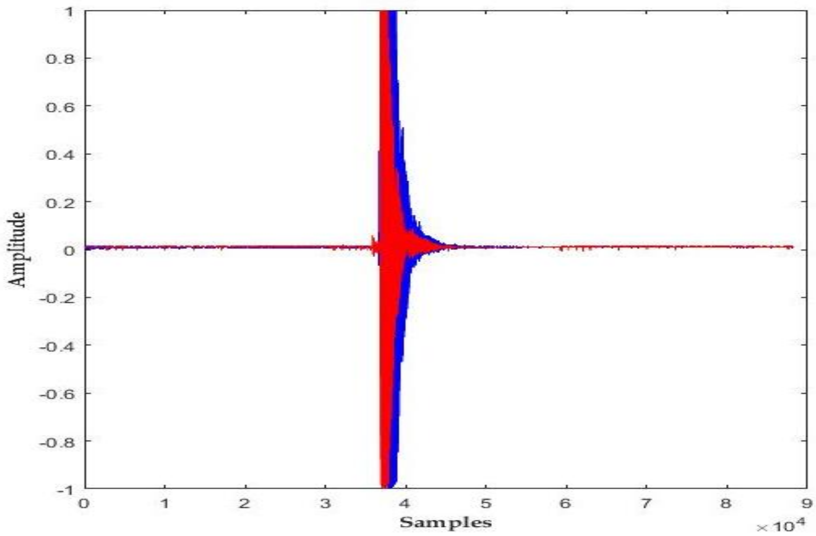


**Fig. 6. Sound Samples of two Non-Defective Glass Containers**

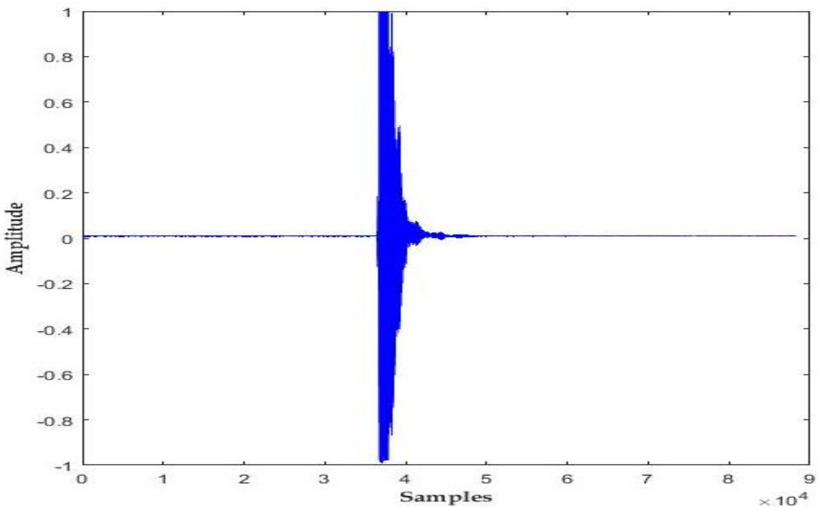


**Fig. 7. Sound Sample of a Defective Glass Container**

To analyse and identify differences between glass containers, spectrums are obtained of each signal and processed in MATLAB environment using two audio feature extraction methods called Cross-correlation and Mel Frequency Cepstrum Coefficients (MFCC) (MathWorks Inc, 2004). Fig. 8 and Fig. 9 represent spectrums of two non-defective glass containers and a spectrum of a defective glass container respectively.

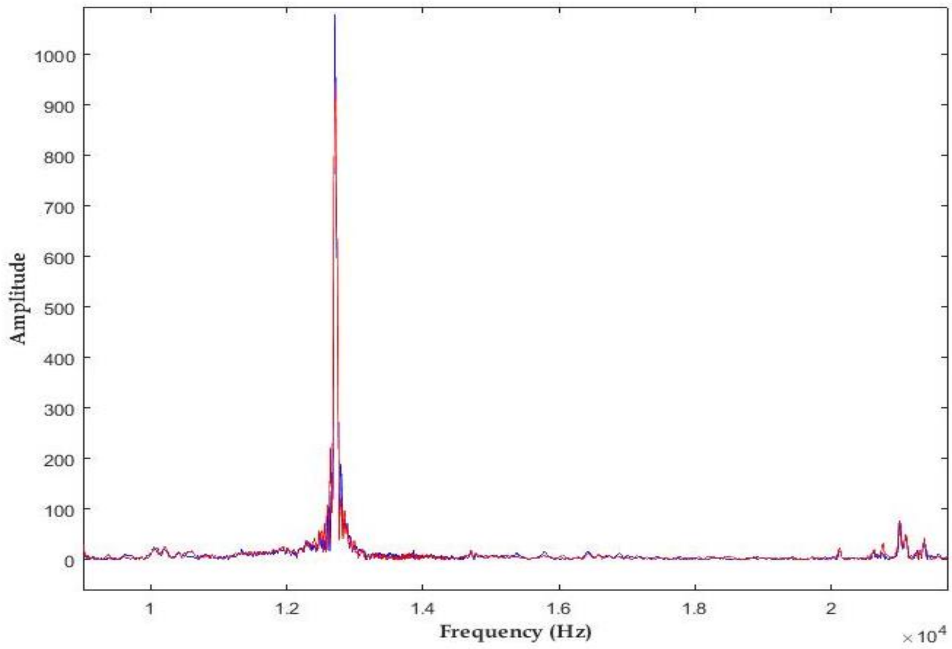


**Fig. 8. Spectrums of two Non-Defective Glass Containers**

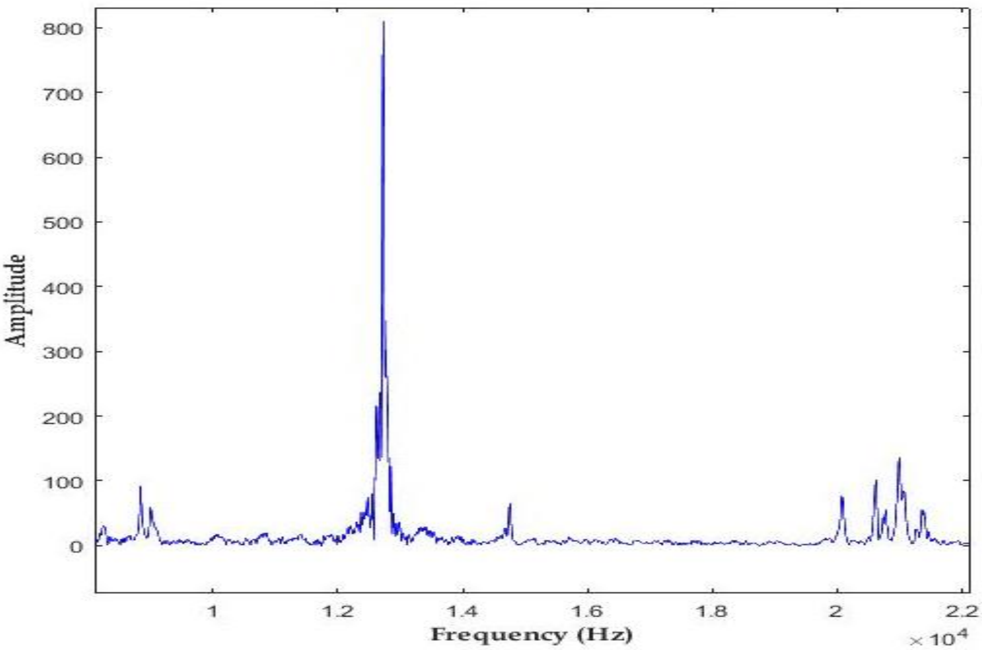


**Fig. 9. Spectrum of a Defective Glass Container**

In feature extraction, each audio signal segment into a relevant small number of parameters or features which describes each segment in such a characteristic way that other similar segments can be grouped together by comparing their features.

#### 4.2.1 Cross-Correlation

Correlation function gives similarity study between signals (Atti *et al*, 2007).

#### 4.2.2 Mel-Frequency Cepstrum Coefficients (MFCC)

MFCC are coefficients that represent audio. They are derived from a type of cepstral representation of the audio clip (a "spectrum-of-a-spectrum"). The difference between the cepstrum and the Mel-frequency cepstrum is that in the MFC, the frequency bands are positioned logarithmically (on the Mel scale) which approximates the human auditory system's response more closely than the linearly spaced frequency bands obtained directly from the FFT (Fast Fourier Transformation) or DCT (Discrete Cosine Transform). This can allow for better data processing (Bala *et al*, 2010). Fig. 6 explains the process of MFCC test.

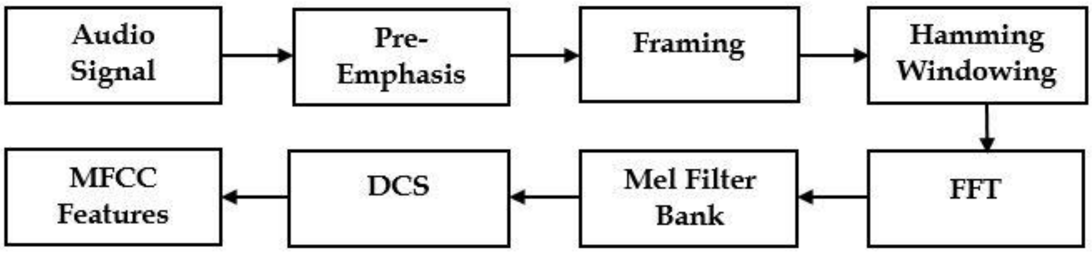


**Fig. 10. Flow Diagram of MFCC Process**

Pre-emphasis filter is used to balance the frequency spectrum by amplifying high frequencies (Bala *et al*, 2010). It is difficult to do Fourier transformation across the signal because frequencies in a signal change over time. To avoid this, frequencies in a signal are kept stationary over a very short period which is called "frame" and do Fourier transform over this frame (Bala *et al*, 2010). Then each frame is multiplied with hamming window. Fast Fourier Transform (FFT) is applied to each frame which transforms signal to frequency domain. Thus, the spectrum for each frame is obtained. It still contains lot of information not required for feature matching stage. The feature matching algorithm cannot discern the difference between two closely spaced frequencies (Hasan *at al*, 2004). Therefore, take clumps of spectral bins and sum them up to get an idea of how much energy exists in various frequency regions. This can be performed by multiplying each frame with Triangular MEL Filter banks (Hasan *at al*, 2004).

The result of the conversion is called Mel Frequency Cepstrum Coefficient. The set of coefficients is called acoustic vectors. Therefore, each input utterance is transformed into a sequence of acoustic vectors.

### 4.3 Feature Matching

#### 4.3.1 Euclidean Distance

The comparison process involves the use of a Euclidean distance to evaluate the result of MFCC test. The Euclidean distance measures the percentage of dissimilar bits out of the number of comparisons made (Black, 2004). Ideally, when input a sound wave of a non-defective glass container, nearly its entire features match and when input a sound wave of a defective- glass container, which does not fully match, and the system will reject the defective container.

### 4.3.2 FAR and FRR

The final matching decision is taken based on matching score and acceptance rates. The performance of the system is evaluated using two parameters called False Acceptance Rate (FAR) and False Reject Rate (FRR) (Hasan *et al* 2004).

FAR is calculated as [FP/ (TN + FP)] * 100 %
FRR is calculated as [FN/ (TP + FN)] * 100 %
Where,
FP is the False Positive i.e. incorrectly identified.
TP is the True Positive i.e. correctly identified.
TN is the True Negative i.e. correctly rejected.
FN is the False Negative i.e. incorrectly rejected.

## 5 COMPARISON

The evaluation in this work is done using 125ml Alpha (A) bottle which is shown in the Fig. 11.

**Fig. 2. 125ml Alpha (A) Bottle**

Frequency spectrums of sound signals of containers lie between 5.5 kHz and 7.5 kHz. According to the observations, spectrums of non-defective containers quite similar while defective containers give different spectrums.

In Fig. 12, spectrums of 10 sound samples non-defective glass containers represent in blue colour and red colour represents a spectrum of a defective glass container.

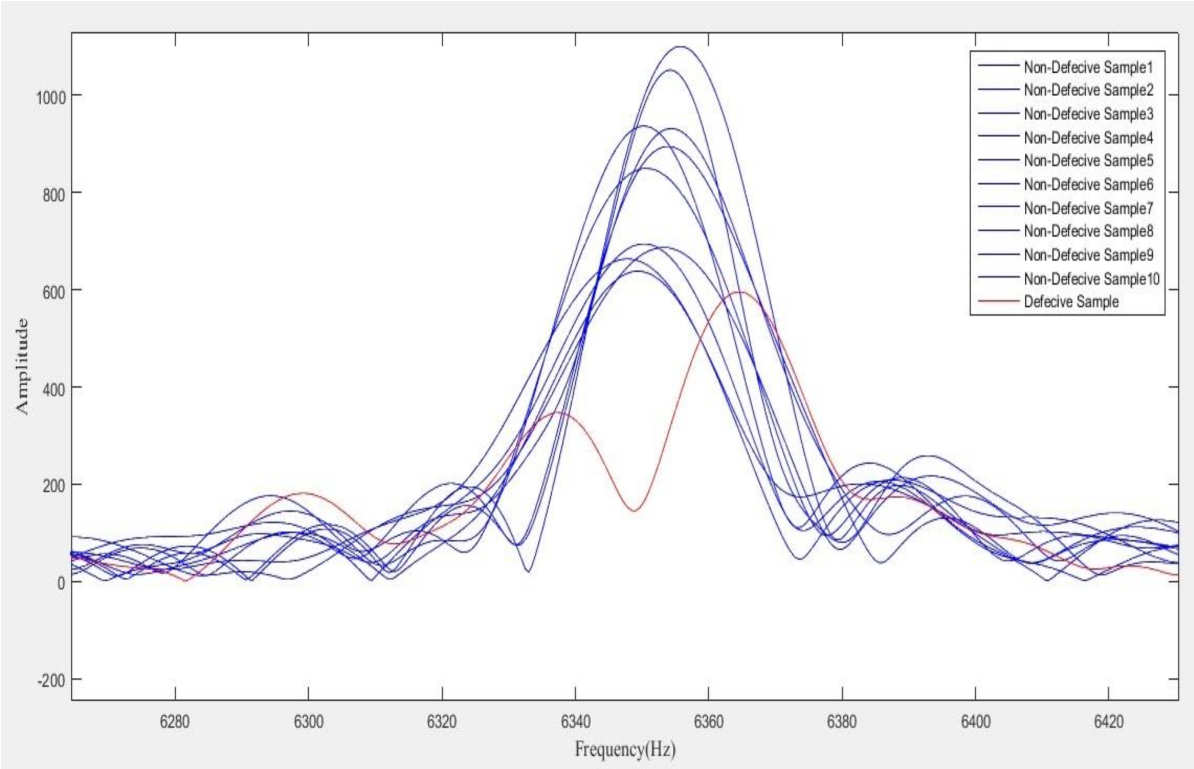


**Fig. 12. Comparison of Frequency Spectrums of Non-Defective Glass Containers vs Defective Glass Containers**

Each test used for feature extraction and matching gives a vector table. After doing several tests each vector table evaluated to find a value that can predict a threshold level which can use to direct the comparison process. The database is created including 10 audio samples of non-defective glass containers which were recorded for 2 seconds. For the real time testing, audio signal recording time for a given glass container is stationary to 2 seconds. In the testing process, test file is overlapped with the template files in the database and their features are compared. The analysis concludes whether the container is damage-free or otherwise.

## 6 RESULTS

### 6.1 Cross-Correlation Test

According to the evaluation of the vector tables received for cross-correlation test a threshold value is identified as 600. Therefore, in the design it checks whether the maximum values obtained in the vector tables during the cross-correlation test, exceeds the threshold value.

If a processed audio wave for a given glass container exceeds the threshold value, then it gives the result as the container is not defective. If that value lies below the threshold value, the container is identified as a defective one. Following Table 2 shows the results for three tests which are applied cross-correlation test.

**Table 2 Results for Cross-correlation Test**

| Database | Defective Container1 | Defective Container2 | Non-Defective Container |
|---|---|---|---|
| **Sample 01** | 447.120 | 367.913 | 1147.097 |
| **Sample 02** | 434.258 | 366.530 | 1030.859 |
| **Sample 03** | 535.043 | 351.768 | 511.014 |
| **Sample 04** | 357.698 | 321.715 | 712.359 |
| **Sample 05** | 511.716 | 376.805 | 1142.853 |
| **Sample 06** | 375.490 | 342.189 | 767.511 |
| **Sample 07** | 434.338 | 372.178 | 1016.184 |
| **Sample 08** | 442.189 | 340.933 | 891.427 |
| **Sample 09** | 490.659 | 399.687 | 969.486 |
| **Sample 10** | 458.603 | 372.689 | 1016.389 |

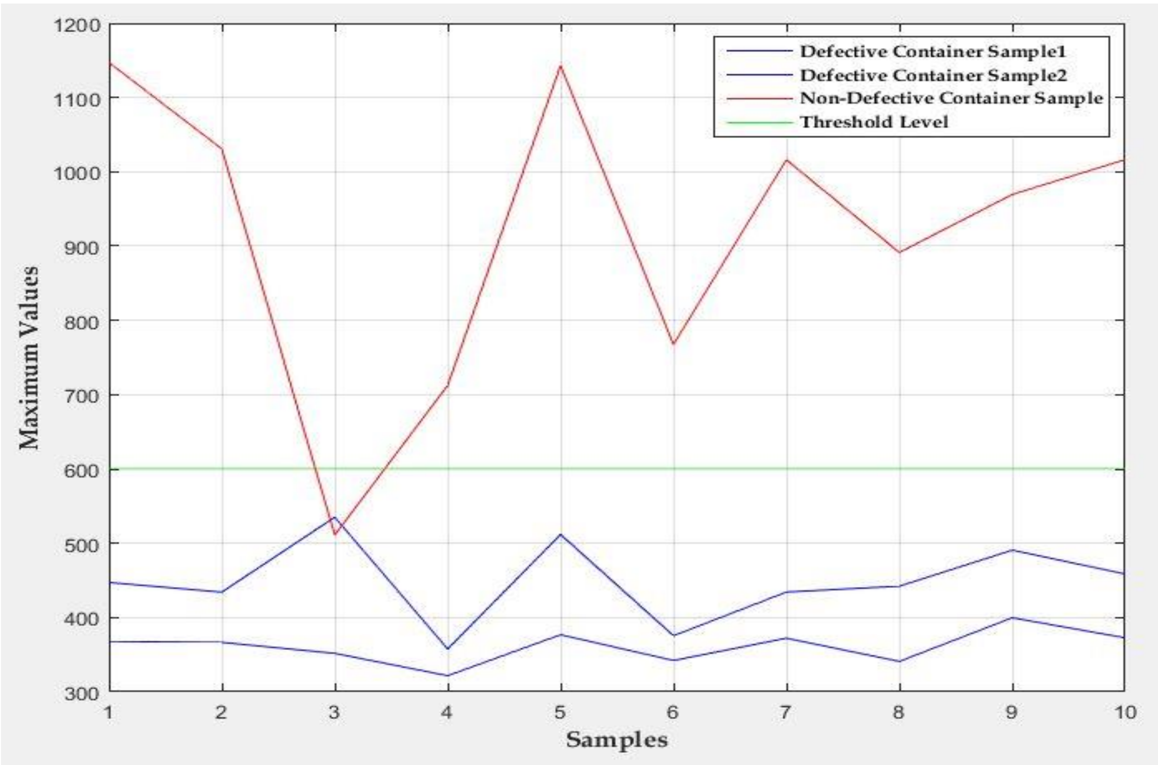


**Fig. 13. Cross-correlation Result of Three Tests**

Green line in the Fig. 13 represents the threshold level which is concluded for the prediction of container status. The result of a test which is lie below the threshold value (i.e. 600), is identified as a defective container.

### 6.2 MFCC Test

In the MFCC test it calculates 13 MFCC coefficients of each audio sample. To apply MFCC method following parameters should be defined according to the type of the container.

**Table 3 Parameter Values for MFCC Test**

| Parameter | Value |
|---|---|
| **Analysis Frame Duration** | 25ms |
| **Analysis Frame Shift** | 10ms |
| **Pre-emphasis Coefficient** | 0.97 |
| **Centre Frequency of Lowest Mel-filter** | 5000Hz |
| **Centre Frequency of Highest Mel-filter** | 7000Hz |
| **No. of Mel bands** | 40 |
| **Sampling Frequency** | 44100Hz |
| **No. of Cepestral Coefficients** | 13 |

Euclidean distance between test audio sample and samples in database is calculated to direct the comparison process. It gives distance vectors of 13x13 matrixes for each comparison. The $13^{th}$ column of each distance vector gives the variation for distances. Therefore, each vector table evaluated to obtain a threshold value. According to the evaluation of vector tables a threshold value is identified as 860. This is the maximum possible distance value for a non-defective container can acquire. Following Table 4 and Fig. 15 shows the test results of three tests with same glass containers used for cross correlation test given above.

**Table 4 Results for MFCC Test**

| Database | Defective Container1 | Defective Contaner2 | Non-Defective Container |
|---|---|---|---|
| **Sample 01** | 829.202 | 822.740 | 909.947 |
| **Sample 02** | 838.892 | 831.818 | 918.037 |
| **Sample 03** | 815.817 | 810.244 | 889.153 |
| **Sample 04** | 835.219 | 828.556 | 912.36 |
| **Sample 05** | 848.772 | 842.516 | 926.526 |
| **Sample 06** | 815.817 | 810.244 | 889.153 |
| **Sample 07** | 846.629 | 840.071 | 925.312 |
| **Sample 08** | 829.137 | 822.744 | 904.835 |
| **Sample 09** | 832.081 | 825.059 | 913.496 |
| **Sample 10** | 842.095 | 835.531 | 922.505 |

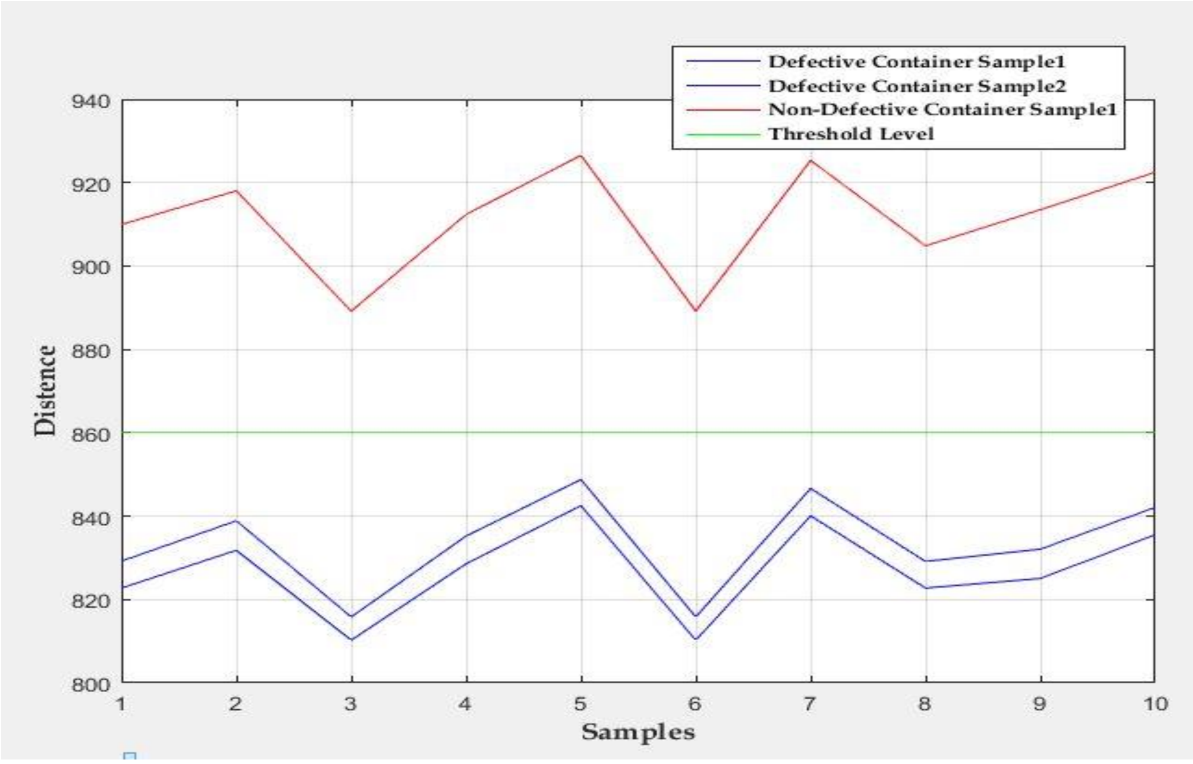


**Fig. 14. MFCC Result for three Tests**

In the Fig. 14 the threshold level represents by the green line (i.e. 860). If the maximum value of a distance vector exceeds the threshold value, the test sample is identified as defective container.

### 6.3 FAR and FRR

The final prediction is done by comparing both test results and obtained the FAR is around10%, and FRR is around 18%. The FAR and FRR test results of 60 tests are given in the Table 5.

**Table 5 Test Results of FAR and FRR**

| Test | FAR % | FRR % |
|---|---|---|
| **1 - 10** | 9 | 16 |
| **11 - 20** | 7 | 18 |
| **21 - 30** | 10 | 16 |
| **31 - 40** | 6 | 15 |
| **41 - 50** | 11 | 11 |
| **51 - 60** | 8 | 18 |

## 7 CONCLUSIONS

This investigation is approached through frequency spectrum analysis of non-defective glass containers and defective glass containers. By vibrating a glass container its' sound outcome is recorded to extract acoustic features which is then compared with non-defective sound templates available in the database. Therefore, frequency spectrum is obtained by using Fast Fourier Transform (FFT) technique and features are extracted using Cross-Correlation and Mel Frequency Cepstrum Coefficients (MFCC) methods to isolate the defective containers from non-defective containers. The comparison process involves the use of a Euclidean distance which measures the percentage of dissimilar bits out of the number of comparisons made. The final prediction is done by comparing both test results and obtained the FAR is around 10%, and FRR is around 18%. We expect that the extracted features can uniquely represent the status of the container.

Recently, machine vision based (image processing) defect detection systems are most popular in the industry. But we have identified advantages and disadvantages of those systems by comparing them with this proposed system.

**Table 6 Comparison with Existing Systems**

| Feature | Existing Systems | Proposed System |
|---|---|---|
| **Cost** | High | Low |
| **Portability** | Low | High |
| **Set-up Area** | High | Medium |
| **Maintenance** | High | Low |
| **Reliability** | Medium | Medium |
| **Operating** | High | Medium |
| **Accuracy (False Acceptance Rate - FAR)** | Low | Medium |
| **Accuracy (False Rejection Rate - FRR)** | Medium | Medium |

This work is concluded through strong defects such as chocked bore, offset seal, wavy body, dented body, etc. For further arrangements we hope to develop this methodology to detect all kind of defects.

## ACKNOWLEDGEMENT

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# Groundwater Responses to Artificial Recharge of Rainwater in Kilinochchi District in Sri Lanka

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**Abstract** – *Groundwater is one of Sri Lanka's most precious natural resources. A large number of people depend on it for their sustenance with no expense to the State. When compared with surface water, groundwater is a hidden resource, which is more reliable and also less subject to the type of year-round variation as in the case with surface streams and rivers. However in Kilinochchi area the groundwater quality has deteriorated over the years due to various reasons. Further the water level in the well decreases and dries up during dry season. Since over 80% of the population depends on groundwater for domestic and irrigation purposes. This important to increase the water levels in the well and improve the quality. Rainwater harvesting is an age old technology to harvest rainwater from roof and store for domestic and other purposes. In this study rainwater harvested from the roof is diverted to the well to increase the well water level using two methods called direct method and overflow method. In direct method the harvested rainwater from the roof is diverted to the nearby well for artificial recharging. In overflow method the rainwater harvested from the roof is stored in tank and the overflow from the tank is diverted to the well. In total 11 wells were selected and artificial recharging was done either by direct or overflow method. Water levels were monitored in the wells as well as rainwater harvesting tanks. Further water quality parameters such as pH, EC and Total Dissolved Salts were measured in both well water and rainwater. According to the study results groundwater recharge is higher in wells in Madduvil Nadu GTMS, Periyakulam IyanarVidyalayam and Punnaineeravi GTMS because these wells were artificially recharged by direct method. Therefore direct method of artificial recharging using rainwater is effective in drought prone areas. Average recharge varies from 196mm to 301mm per year. Groundwater quality analysis showed that pH, EC and TDS were within the safe limit of 6.5-8.5, 1500 µS/cm and 500mg/L in Madduvil Nadu GTMS, Periyakulam IyanarVidyalayam and Punnaineeravi GTMS wells respectively. Other wells were not suitable for drinking purposes due to higher EC and TDS values. Rainwater harvesting tank water quality in all 11 well sites were within the safe limit. Therefore artificial recharging using rainwater does not pose any threat for well water quality. Therefore communities in this study site are advised use rainwater harvesting to increase the water levels in the wells and also to improve the well water quality.*

***Key words**: Groundwater, rainwater, quality, recharge*

## 1 INTRODUCTION

Water is an essential and most important resource to sustain life humans. It forms 50 to 60% of body weight and plays an active role in all the vital processes of our body. Approximately 25% of the world's population has no access to clean and safe drinking water (Amarasinghe,*et al.*, 1999). Even though freshwater is available in most parts of the world, many of these water sources contaminated by natural means or through human activity. With the population boom and industry expansion, the demand for potable water is ever increasing, and freshwater supplies are being contaminated and scarce (Amarasinghe,*et al*., 1999). A satisfactory supply must be available to all humans and other lives on earth. Improving access to safe drinking-water can result in tangible benefits to health. Water plays a vital role in the development of communities since a reliable supply of water is an essential prerequisite for the establishment of a permanent community.

Unfortunately, the liquid, gas and solid wastes from such a community have a considerable potential for water pollution. Water shortage and water pollution cause four million deaths per year around the world; this means one person dies every eight seconds. The majority of the victims are infants under five years of age from Africa and the developing countries of Asia (Asian Development Bank, 2011).

Almost 80% of the rural populations in Sri Lanka rely on groundwater for their domestic needs because of its excellent natural quality and sustained availability throughout the year (Panapokke and Perera, 2005). Main towns in the dry zone of Sri Lanka such as Jaffna, Mullaitivu, Kilinochchi, Polonnaruwa, Anuradhapura, Batticaloa, Mannar, Puttalam, Vavuniya depend almost 90 % on the groundwater supply (Panabokke and Perera, 2005).The composition of groundwater naturally reflects the underlying geology, the residence time in the rock, the previous composition of the groundwater and in some instances, the flow path. Due to the slower movement of groundwater as compared to that of surface water, the composition of the groundwater shows a negligible variation with time for a given aquifer (Lerner et al 1990).

During monsoon/post-monsoon (*Maha* season) groundwater levels near to the ground surface as the recharge to the aquifer takes place during *Maha* season. During dry season (*Yala* season) groundwater level goes down due to abstraction, evapotranspiration and other losses such as seepage and percolation (De Silva and Rushton, 2007). Further it is aggravated when discharge rates are greater than there recharge rates. Seasonal fluctuation of groundwater is significantly correlated with precipitation, as is found that recharge into the groundwater system is considered entirely to be from rainfall infiltration and percolation (De Silva and Rushton, 2007).

Water quality refers to the physico-chemical and biological quality parameters of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or domestic purposes. Water quality is important because it directly affects the health of the people, animals and plants that drink or utilize the water for their survival. When water quality is compromised, its usage puts users at risk of developing health complications. Water quality standards are put in a place to ensure the efficient use of water for the designated purpose. Water quality analysis is to measure the required parameters of water following standard methods, to check whether they are in accordance with the standards. The qualities of groundwater resources vary naturally and widely depending on climate, season, and geology of bedrock as well as anthropogenic activities (De Silva and Rushton, 2007). In addition to the natural sources of constituents acquired by water during its interaction with atmosphere and rocks, various human activities such as industrial, sewage and domestic waste disposal, fertilizers, pesticides etc. also contribute to change the natural chemical constituents of water. Therefore, a regular check of its chemical quality is required for assessing its suitability for different purposes and for quantitatively for monitoring any future change. Over pumping of aquifers, discharge of toxic chemicals and contamination of water bodies with substance that promote algae growth are major cause for water quality degradation and also the pollution of the groundwater happens mostly due to percolation of pluvial water and the infiltration of contaminants through the soil under waste disposal sites(Humbarde, *et al*., 2014).

The environmental impact of human activity on the groundwater is considered as one of the major hazards. Rapid Urbanization and increased agricultural activities have resulted in the degradation of the quality of water. Unused fertilizers, pesticides, effluents discharged from industries and sewage water are the main contaminants of the groundwater. The chemical budget of major ions and heavy metals are important in determining the quality of groundwater. Total Dissolved Solids (TDS) values are considered important in determining the usage of water and groundwater with high TDS values are not suitable for both irrigation and drinking purposes (Rajasooriya, 2002).

### 1.1 Justification for the study

Wells in the schools, hospitals and primary health care units of the study area in Kilinochchi were holding less amount of little water during the dry season and some wells get completely dried during dry season. Further, the quality of the groundwater was not good because of the high concentration ofions in groundwater during dry season. The well water columns also showing quality variation due to the density effects, during the wet season the water quality parameters were nearly same at bottom and the surface of the well water but during the dry season, those parameters show significant variation between the bottom and surface of the well water. Bottom quality values were higher than the surface values mainly during dry season when wells hold little water (Saravanan,*et al*., 2014). Adding more water to the well water may improve the water quality. Rainwater is free water received which could be used effectively to artificially add water to these groundwater wells to improve the quantity as well as quality. Due to these reasons the wells in the study area especially schools, hospitals and primary health care units were in need for rainwater harvesting and means to artificially recharge the wells so that they could get more groundwater and better quality water during dry season. This research project was designed to study the groundwater responses to artificial recharge of rainwater in the study area for sustainable groundwater quantity and quality.

## 2 BACKGROUND OF THE STUDY AREA

The Killinochchi area is situated in the dry zones of Northern Sri Lanka on 9.3803° N, 80.3770° Ecoordinates. The total land area is approximately 1205 Km$^2$. The poverty level in this area is as high as 64 %, which is more than double for the national average (Asian Development Bank, 2011). The Killinochchi area, being at the center of the 26 years long devastating civil war (1983–2009), has seen major destruction of its irrigation facilities and water reservoirs. Hence, the poverty in the area can be mainly attributed to the war that resulted in the destruction of most of the infrastructure in the district. As the war displaced residents return to their villages, competition for the already scarce water resource is expected to grow sharply. According to the national census data, the population has quadrupled from 23,625 in 2009 to 112,875 in 2012.

## 2.1 Climate

There are two distinct seasons in the study area call *Maha* (wet) and *Yala*(dry) season. *Maha* is from October to February and receives rainfall from second inter-monsoon and north east monsoon to the northern and eastern regions of Sri Lanka. The average annual rainfall in dry zone is 1,800 mm per year. Most of the rainfall occurs during the *Maha* season, and January is the coolest month. The *Yala* (dry) season varies from May to September receives very less or no rain and May is the hottest month. Although rainfall amount is quite enough for this small area, because of temporal asymmetry and poor water resource management policies, there is water scarcity especially during the dry period (Mikunthan and De Silva, 2009).

## 2.2. Geology

Geology also plays major role in groundwater occurrence in the study area. PanKaj Kumar *et al* (2016) have conducted a detailed study on mapping of groundwater potential zones in Killinochchi area which is used for this study as the basis and their findings are directly used for this study. According to PanKaj Kumar *et al* (2016), the study area is occupied by five major features (Figure 1) as follows:

• Alluvial and lagoonal clay, silt, and sand
Alluvial is the depositional structure formed by running water from all different basins in Killinochchi area. Lagoons are bodies of water on the landward side of barrier islands near the coastal region. Both of these places contain finer sediments with grain size varying from clay to sand and poor sorting order. Area is consideredmoderately well for groundwater exploration.

• Chamockitic biotic gneiss:
Charnockite represents a conformable intrusive igneous rock which with biotite gneiss was subjected to high-grade metamorphism. Charnockite and surrounding gneiss have layer structure composed of melanocratic and leucocratic parts. Mineralogically, melanocratic parts consist of hornblende and biotite in gneiss, and ortho pyroxene addedincharnockite. Leucocratic parts are composed of biotite and colorless minerals in gneiss, while biotite is absent in charnockite.

• Jaffna limestone:
Jaffna limestone is typically a compact, hard, partly crystalline rock formed in the early Miocene age. The limestone is a creamy colored hard compact, indistinctly bedded, and partly crystallized rock. It is massive in parts, but some layers are richly fossiliferous into a honeycombed mass. Easily, soluble limestone gives rise to a number of underground

solution caverns. The limestone is an important aquifer, and, together with thin sand layers, forms an extensive cover providing a source of drinking water and irrigation across the area.

• Red earth, red, and brown sand:
They are the sand stone with the mineral composition of quartz and/or feldspar. In the study area, it is of red and brown colored. These rock formations usually allow easy percolation of water and other fluids and are porous enough to store large quantities, making them valuable aquifer.

• Undifferentiated Vijayan gneiss with trend lines:
They are mainly granitic rocks composed of garnet and feldspar with very low porosity. They are considered as poor aquifers zones.

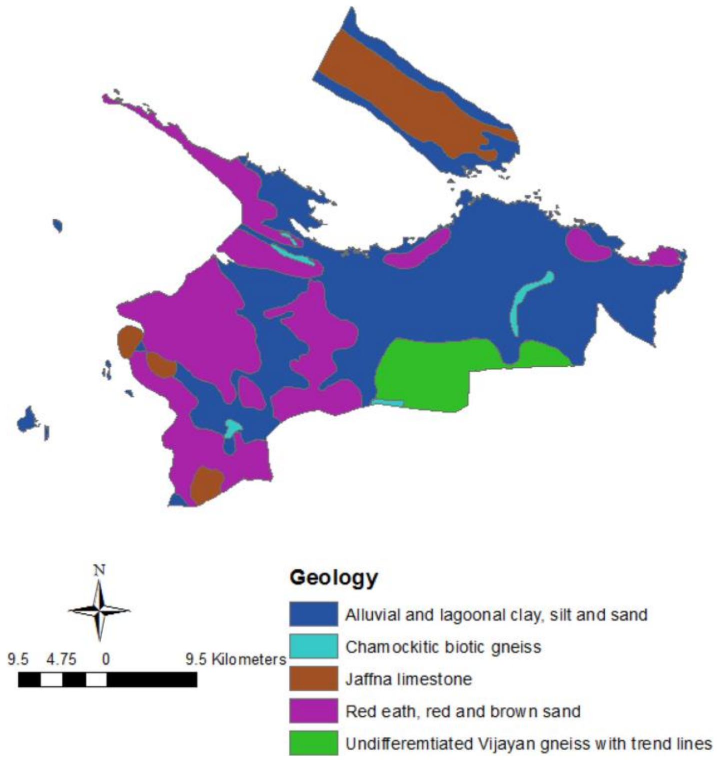


**Fig. 1. Geology of the Kilinochchi area** (Source Kumar, *et al.*, 2016)

## 2.3. Soil type

Soil is an important factor for delineating the groundwater potential zones. The climate, physiography and geology characterize soil and play an important role in groundwater recharge and runoff. The water holding capacity of the area depends upon the soil types and their permeability. According to the analysis of the soil type by PankajKumar *et al.* (2016) the study area is predominantly covered by four main soil types, namely, soil classes Immature brown loams (dry zone); reddish brown earths; regosolic alluvial soil; and solodised solonetz and solonchaks (Figure 2). According to their influence on groundwater occurrence, regosolic alluvial soil is considered as very good, whereas reddish brown earths are being considered as moderately better than other soil types.

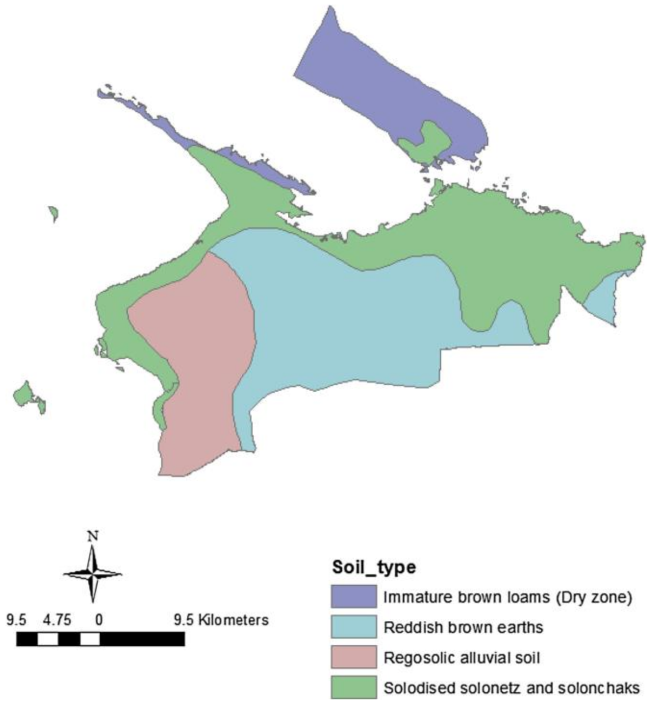


**Fig. 2.Soil type of the Kilinochchi area** (Source: PankajKumar,*et al.*, 2016).

## 2.4. Groundwater potential zones

According to Pankaj Kumar *et al.* (2016) soil is an important factor for delineating the groundwater potential zones. The climate, physiography, and geology characterize soil and play an important role in groundwater recharge and runoff. The water holding capacity of the area depends upon the soil types and their permeability. The analysis of the soil type reveals that the study area is predominantly covered by four main soil types, namely, soil classes Immature brown loams (dry zone); reddish brown earths; regosolic alluvial soil; and solodised solonetz and solonchaks (Figure 3). According to their influence on groundwater occurrence, regosolic alluvial soil is considered as very good, whereas reddish brown earths are being considered as moderately better than other soil types (Pankaj Kumar,*et al*., 2016).

According to Pankaj Kumar *et al.* (2016), the groundwater potential zonation was prepared by overlaying cumulative weight assigned to all the five thematic layers, viz., geomorphology, geology, slope, soil, and land-use/land-cover maps, using the weighted overlay methods in spatial analysis tool of Arc GIS 10.2. Through the weighted overlay analysis process, knowledge-based ranking and weightage of different class for each thematic layer has been given based on their contribution toward groundwater potentiality/development. Based on calculation, groundwater potential index (GWPI) for the study area ranges from 0.06 to 0.30 with a standard deviation of 0.04. Then, natural-break classification scheme using Jenk's optimization method was applied for mapping

(Jenks, 1967). The GWPI was grouped into four classes: good, moderate, poor, and very poor. All the thematic layers were converted into raster format and overlaid in Arc/Info; and the resultant composite coverage was classified into four groundwater potential zones, such as good (5.3 % of the area), moderate (61.9 % of the area), poor (26.6 % of the area), and very poor (6.2 % of area) (Figure 3). The maximum area (61.9 % of the total area) is characterized by moderate groundwater potential zone.

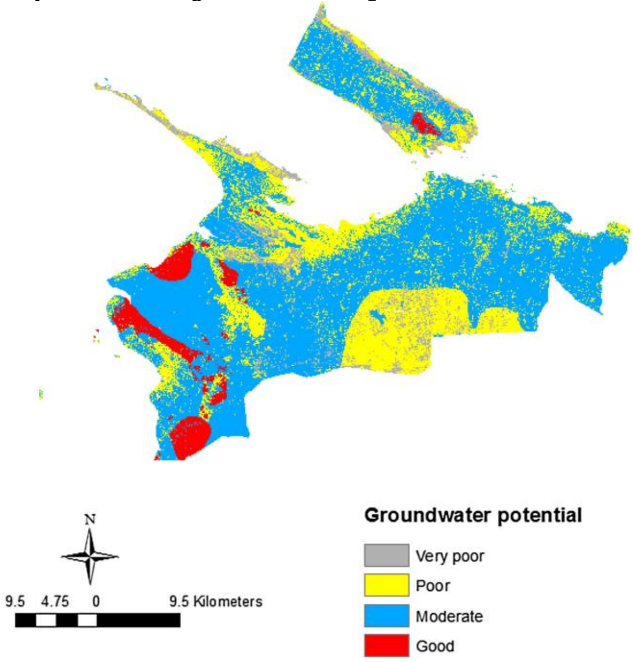


**Fig. 3. Groundwater Potential of the Kilinochchi area**
Source: Pankaj Kumar *et al.*, (2016)

Further PankajKumar *et al*. (2016) found that the excellent groundwater potential zone is concentrated in the south–western and north–western regions of the study area due to its almost flat terrain nature like alluvial plains with the distribution of limestone and dense forest land with high infiltration ability.

## 2.5. Groundwater Quality

Mahagamage *et al.* (2017) reported that the rural population in the Kilinochchi District area depends mostly on groundwater sources as the area does not get treated water. Majority of the population in the district are farmers. Mahagamage *et al.* (2017) conducted the study to determine the ground water quality along with pathogenic contamination status of groundwater in Kilinochchi area. In this study thirty wells were sampled in April 2017 and water temperatures, Dissolved Oxygen (DO), pH, conductivity, Total Dissolved Solids (TDS), salinity were measured at the site itself using standard meters. N-NO3-, N-NO2-, N-NH3, Total Phosphate (TP), Chemical Oxygen Demand (COD) and total hardness were measured by the standard spectrophotometric and titrimetric methods. Total coliform and fecal coliform count were obtained from membrane filtration methods. *Salmonalla* sp. and *Shigella* sp. were identified using WHO standard methods. The ground water pH varied between 4.30 to 8.40 whereas DO was between 1.13 mg/l to 9.18 mg/l. Water TDS, salinity and conductivity ranged between 38 to 5569 mg/l, 27to 3978 mg/l, 60 to 8840µs/cm respectively. It was found that most of the wells exceeded the values given by Sri Lankan Standard Institution (SLSI) for drinking water standard.N-NO3-, N-NO2-, N-NH3 concentration ranged between <1.00 to17.56 mg/l, <1.00 to 2.50 µg/l and <1.00 to 21.51 µg/l respectively.TP, COD and total hardness ranged between 47.67 to 191.42 µg/l,12.81 to 420.90 mg/l and 62.0 to 796 mg/l. Almost all ground water samples exceeded SLSI drinking water standard for COD (10 mg/L). Thirty seven percent of samples exceeded SLSI drinking water standard for total hardness (250 mg/l) as well. Sixty percent of samples were contaminated with total coliform whereas 47%of samples were contaminated with fecal coliform bacteria. Interestingly 37% of samples were positive for *Salmonalla*sp. and one groundwater source was contaminated with *Shigella* sp. The result of the present study revealed that 50% of ground water sources were not within the SLSI drinking water quality standards. Microbial contamination with *Salmonalla* sp. shows that continuous monitoring is essential to safeguard ground water consumers and take action accordingly. Therefore, Mahagamage*et al.* (2017) recommended prior treatment is a must before consumption of groundwater for drinking purposes.

## 3 METHODOLOGY

In total eleven wells in schools and primary medical care units (PMCU) were selected randomly for this study in order to improve the groundwater quantity through artificial recharge using rainwater and quality of water (Figure 4). All these wells were categorized in four groups based on the well depth (Table 1). Shallow wells are in less than 4m depth, Medium depth wells are in 4m-5.5 m depth and deep wells are in 5.5 m to 7m depth (Mikunthan and De Silva, 2009). Deepest well is having the depth of more than 7m. The maximum depth of the well in the study area is 10.4 m and the minimum depth is 4m. All the wells are in 2-3m diameter except one with less than 2 m diameter.

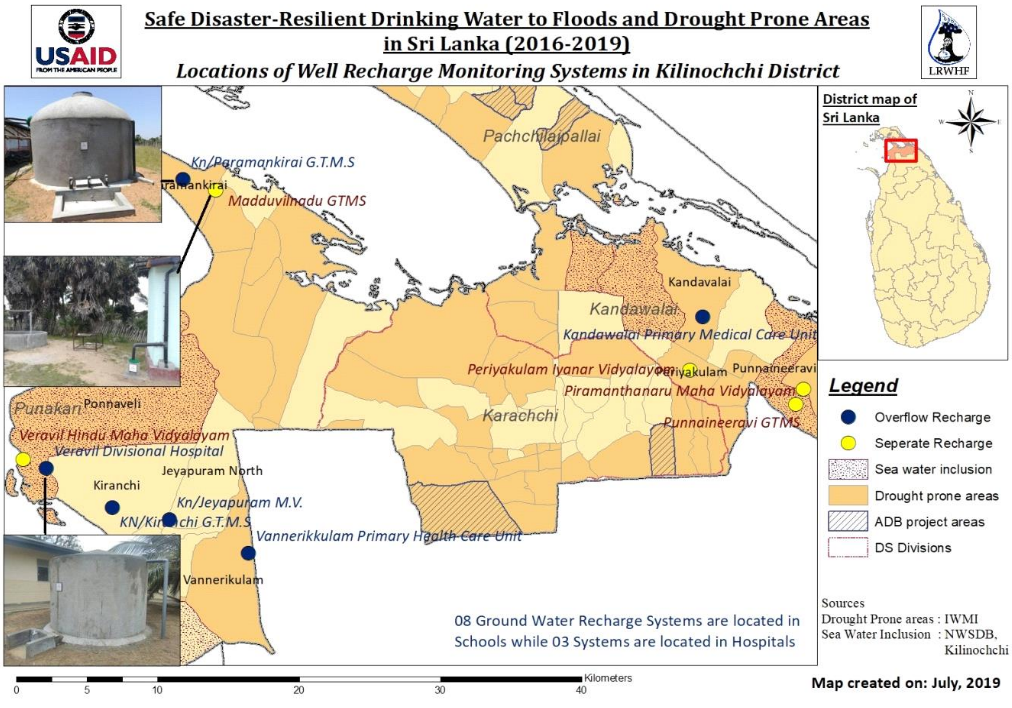


**Fig.4. Sampling locations in the Kilinochchi area**

Pankaj Kumar et al (2016)'s study finding in the Kilinochchi area is used as the base for this study as there is no need to redo the same process. Geology of the wells also varies in nature. According to Pankaj Kumar *et al*. (2016) geology demarcation of six wells are in Red earth, red and brown sand which usually allow easy percolation of water and other fluids and are porous enough to store large quantities, making them valuable aquifers. However, according to Pankaj Kumar *et al*. (2016) these wells are located in moderate groundwater potential zone. Other 5 wells are located in Alluvial and lagoonal clay, silt, and sand these wells also classified as moderate groundwater potential by Pankaj Kumar *et al*. (2016). Table 2 shows the location of the well and possible aquifer type and groundwater potential zone. As these wells are in moderate groundwater potential zone, these wells are mostly dried during dry season or hold less water in the bottom of the well making its unavailable for domestic or other uses. Because of the above reasons these wells were selected for this artificial recharging by rainwater harvesting project.

There were two methods of artificially recharging the wells. When the wells are near to the House/Building rainwater harvested from the roof is directly diverted to the wells. This is called "direct recharging method". When wells located far away from the roof the rainwater from the roof is collected into the rainwater harvesting tank and the over flow of the rainwater harvesting tank was diverted to the well. This is called "Overflow recharge method". These methods were selected based on the location of well and rainwater harvesting tank and rainwater capturing roof (De Silva and Ariyananda, 2020).

**Table 1 Well details in the study area**

| Well Name | DSD/GND | Well No | Well Depth (m) | Well Diameter (m) |
|---|---|---|---|---|
| ***Shallow Wells > 4m depth*** | | | | |
| Madduvill Nadu GTMS | Poonakari | 1 | 4.1 | 2.36 |
| Paramankirai GTMS | Poonakari | 2 | 4 | 2.03 |
| Kallaru Tamil Vidyalayam | Kandawallai | 4 | 4.06 | |
| ***Medium Depth Wells 4m-5.5m depth*** | | | | |
| PeriyakulamIyanarVidiyalayam | Karachchi | 3 | 5.2 | 1.3 |
| Kandawallai PMCU | Kandawallai | 6 | 4.52 | 3.07 |
| Veravil Divisional Hospital | Poonakari | 10 | 5.1 | 3.05 |
| Veravil Hindu MahaVidyalayam | Poonakari | 11 | 5.1 | 2.6 |
| ***Deep Wells 5.5m-7m*** | | | | |
| Vannerikkulam PMCU | Karachchi | 7 | 5.7 | 2.14 |
| Piramanthanaru M.V. | Kandawallai | 8 | 5.95 | 2 |
| Punnaineeravi GTMS | Kandawallai | 5 | 6.2 | 2.14 |
| ***Deepest Well >7m*** | | | | |
| Jeyapuram M.V. | Poonakari | 9 | 10.4 | 2.64 |

**Table 2. Geological information and artificial recharging methods of selected wells**

| Well Name | DSD/GND | Well No | Aquifer type | Artificial recharging method |
|---|---|---|---|---|
| Madduvill Nadu GTMS | Poonakari | 1 | Red earth, red and brown sand | Direct |
| Paramankirai GTMS | Poonakari | 2 | Red earth, red and brown sand | Overflow |
| PeriyakulamIyanarVidiyalayam | Karachchi | 3 | Alluvial Lagoonal Clay, sand | Direct |
| Kallaru Tamil Vidyalayam | Kandawallai | 4 | Alluvial Lagoonal Clay, sand | Overflow |
| Punnaineeravi GTMS | Kandawallai | 5 | Alluvial Lagoonal Clay, sand | Direct |
| Kandawallai PMCU | Kandawallai | 6 | Alluvial Lagoonal Clay, sand | Overflow |
| Vannerikkulam PMCU | Karachchi | 7 | Red earth, red and Brown sand | Overflow |
| Piramanthanaru M.V. | Kandawallai | 8 | Alluvial Lagoonal Clay, sand | Direct |
| Jeyapuram M.V. | Poonakari | 9 | Red earth, red and brown sand | Overflow |
| Veravil Divisional Hospital | Poonakari | 10 | Red earth, red and brown sand | Over flow but no water |
| Veravil Hindu Maha Vidyalayam | Poonakari | 11 | Red earth, red and brown sand | Overflow but no recharge |

Well water levels below ground level (m) and water level in the rainwater harvesting tanks were monitored from May 2017 to May 2019 on weekly basis. Further well and rainwater harvesting tank water quality was also measured in weekly basis. Measured quality parameters were pH, Electrical Conductivity (μS/cm) and Total Dissolved Solids (mg/L).

# 4 RESULTS AND DISCUSSION

## 4.1 Artificial groundwater recharge

### *4.1.1. Effect of Method of artificial recharge on shallow well water level*

Paramkirai GTMS and Madduvill Nadu GTMS wells are located in red earth, red brown sand areas. Both the wells were artificially recharged by rainwater. But the Madduvil Nadu GTMS was rechargedby direct method from 15/11/2017 to 31/5/2019 (one and half year) (Figure 5). Paramankirai GTMS well was artificially recharged by the overflow method from 15/11/2017 to 31/05/2019 (Figure 6). Therefore, the total amount of water applied for artificially recharging the well in Madduvil Nadu GTMS is higher than that of the Paramankirai GTMS. As the result the well water level increased almost near to the ground surface (0.3mbgl) at Madduvil Nadu GTMS facilitating the availability of groundwater during the dry season.

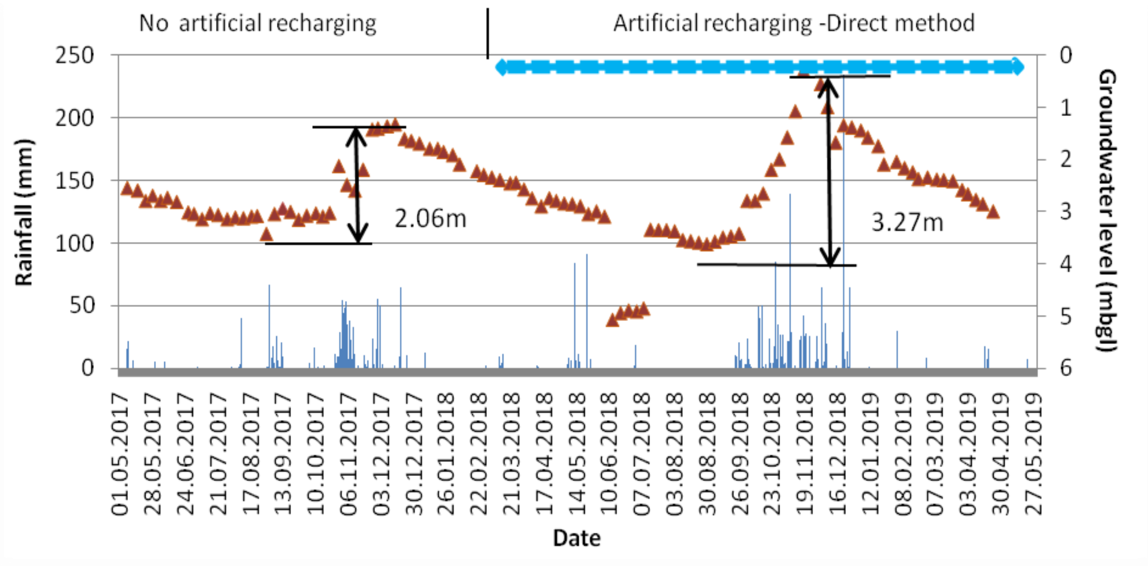


**Fig. 5. Rainfall pattern and groundwater levels variation of in Madduvil Nadu GTMS well due to direct method of artificial recharging.**

The groundwater level rise observed in well water level in Madduvil Nadu GTMS due to direct recharge was 3.27m in the year 2018 and it was 1.21m higher than the non recharging year of 2017. Whereas the groundwater level rise observed in the well water level in Paramankirai GTMS was 2.76m during 2018 and it was 0.56m higher than the non recharging year of 2017 (Figure 6). However, the rainfall received during May 2017 to April 2018 was only 1067.5 mm, whereas the rainfall received during May 2018 to April 2019 was 1744.3 mm. Even though there was higher rainfall in 2018, the wells showed difference in groundwater level rise based on the method of artificial recharging. It proves that the direct recharge (rainwater harvested in the roof to well) method was effective to have better recharge. It showed the artificial recharge by direct method is better than overflow method to achieve increase the well water level inthe drought prone areas in Kilinochchi.

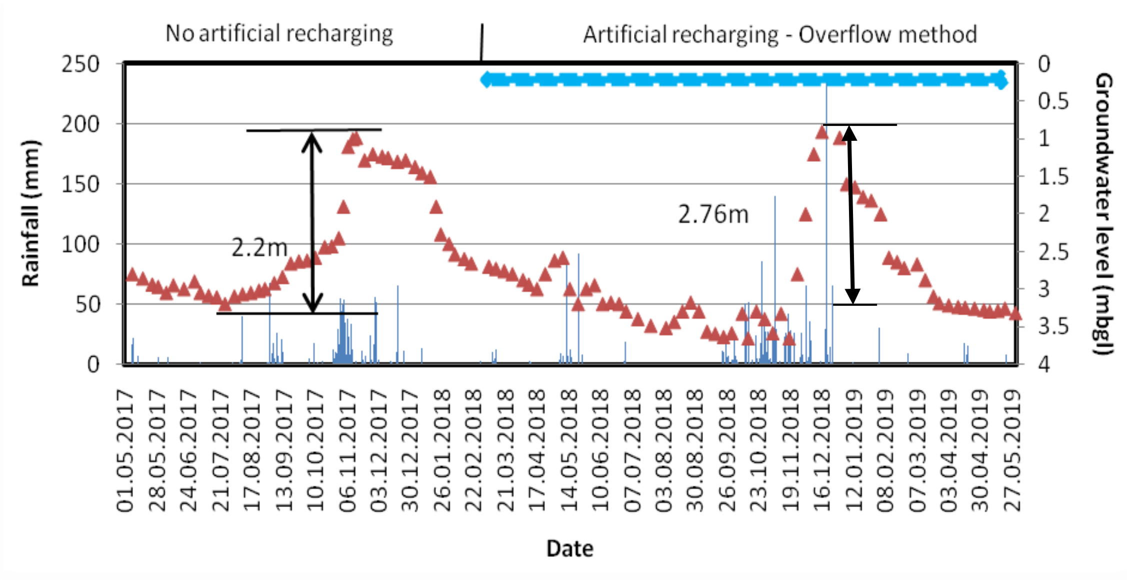


**Fig. 6. Rainfall pattern and groundwater level variation in Paramankirai GTMS due to overflow method of artificial recharge**

### *4.1.2 Effect of Method of artificial recharge on Medium Depth well water level*

Both wells in Periyakulam Iyanar Vidiyalayam and Kandawallai PMCU are located in Alluvial and lagoonal clay, silt, and sand in medium depth in (4.0-5.5m). PeriyakulumIyanarVidyalam well was recharged by direct method from 18/11/2017 to 31/5/2019 (Figure 7). But Kandawalai PMCU was artificially recharged by overflow method from 22/12/2017 to 31/5 /2019.In both wells there was an increment in recharge when artificially recharged the wells by rainwater. Due to artificial recharge in both wells the well water level was maintained near to the ground level (<1mbgl) during dry season.

According to the groundwater level rise calculation PeriyakulamIyanarVidyalayam has higher groundwater level rise (4.33m) compared to Kandawalai PMCU well where the groundwater level rise was only 3.41m. It shows that the artificial recharging by direct method is more efficient method than the overflow method. It may be due to the fact that in the overflow methodthe quantity of rain water was not adequate to increase the well water level.

Both Veravil divisional Hospital and Veravil Hindu M.V wells are located in Red earth, red, and brown sand. Both these wells are medium depth (4.0-5.5m). However these wells were not successfully artificially recharge by overflow method during study period. Therefore groundwater level rise observed in the well for Veravil Divisional Hospital and Veravil Hindu M.V was 3.0 m and 3.2 m respectively.

However, the rainfall received during May 2017 to April 2018 was only 1067.5 mm. whereas the rainfall received during May 2018 to April 2019 was 1744.3 mm. Even though there was higher rainfall in 2018, the wells showed difference in groundwater recharge based on the method of artificial recharging. Wells in Veravil Divisional Hospital and Veravil Hindu M.V showed the lowest recharge because there was no artificial recharge to these two wells. Among the two methods of artificial recharging wells rainwater direct method was the effective method to have better recharge. Therefore artificial recharge by direct method is better than overflow method to achieve higher recharge in drought prone areas in Kilinochchi.

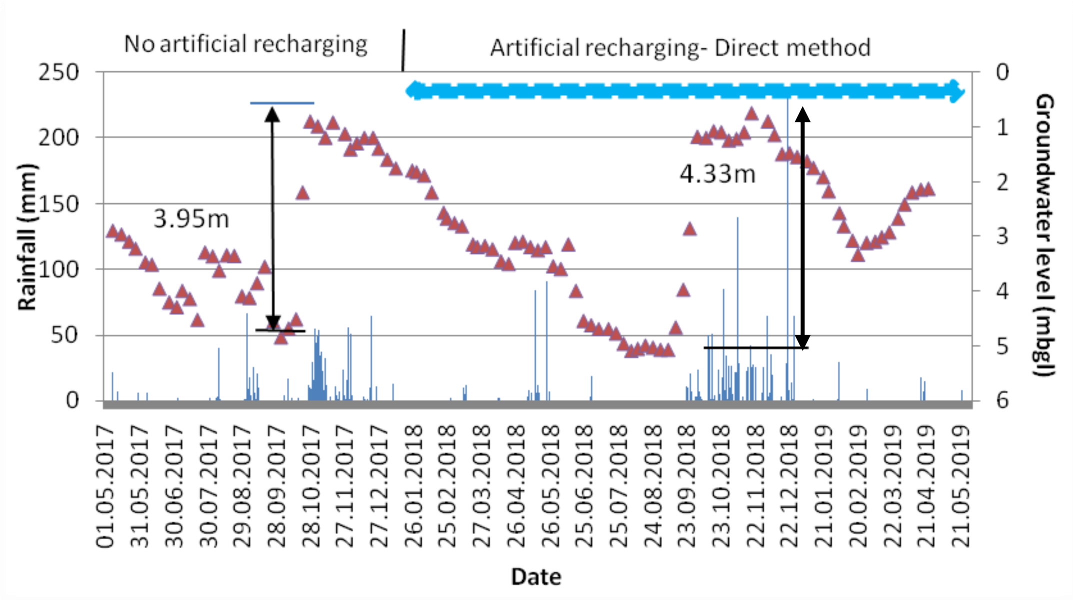


**Fig. 7. Rainfall pattern and groundwater level variation in PeriyakulumIyanarVidyalayam due to direct method of artificial recharge**

### *4.1.3. Effect of Method of artificial recharge on Deeper Depth well water level*

Wells in Punnaineeravi GTMS, Piramanthanaru M.V and Vannerikkulam PMCU are in deep wells category having the well depth of 5.5m -7m depth (Table 1). Punnaineravi GTMS well and Piramanthanaru M.V were in Alluvial lagoonal Clay and sand, whereas Vannerikulam PMCU well is located in Red Earth red Brown sand. However both these aquifers were classified as moderate potential for groundwater. When considered the artificial recharging method, Punnainveeravi GTMS and Piramanthanaru M.V well were artificially recharged by direct method whereas Vannerikulam PMCU well was artificially recharged by overflow method. Even though the rainfall received during May 2017 to April 2018 was only 1067.5 mm and rainfall received during May 2018 to April 2019 was 1744.3 mm, method of artificial recharging played a major role in well water table rise during the year 2018. Accordingly Punnainveeravi GTMS well showed 5.02 m rise in groundwater level (Figure 8) whereas Vannerikulam PMCU well showed only 4.92 m. It showed that that the direct method is effective than the overflow method of artificial recharging in drought prone areas in Kilinochchi.

### *4.1.4. Effect of Method of artificial recharge on deepest well water level*

Well in Jeyapuram M.V is the deepest well with 10.4m depth and this well is located in Red earth, red and brown sand. This well was artificially recharged with overflow of rainwater harvesting tank and from 19/05/2018 to 31/05/2019. However, there was only a 2.84 m rise in groundwater level (Figure 9). This may be due to the reason that artificial recharging is not effective in deepest well of 10m depth.

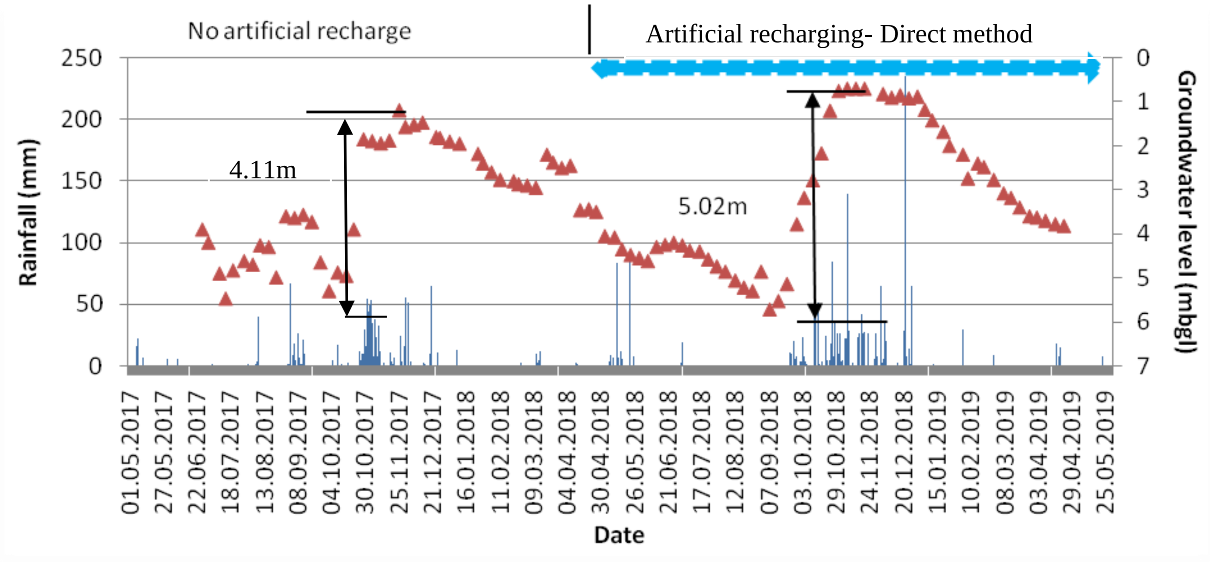


**Fig. 8 : Rainfall pattern and groundwater level variation in Punnaineeravi GTMS due to direct method of artificial recharge.**

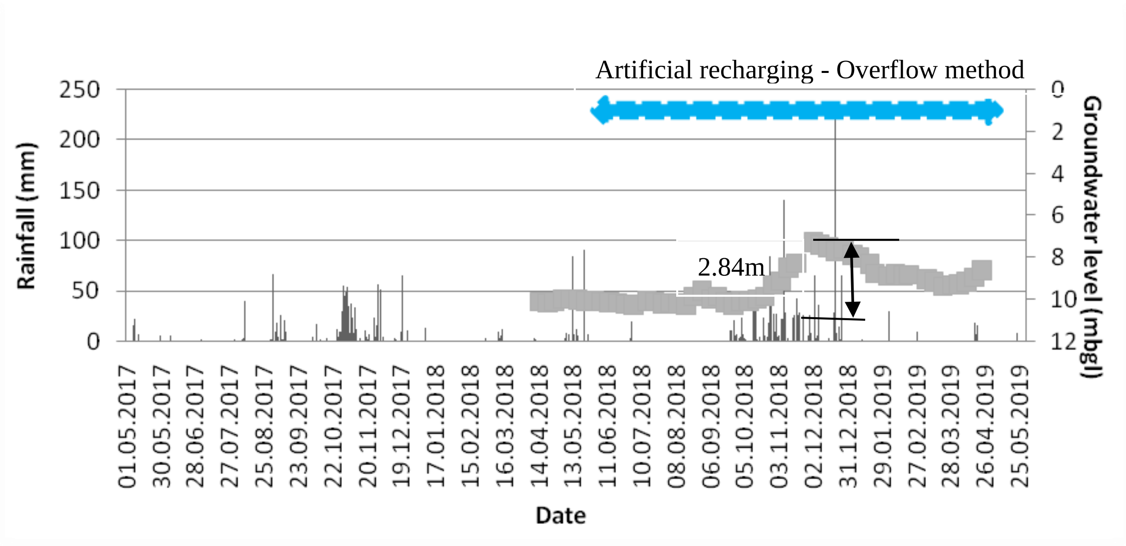


**Fig.9: Rainfall pattern and groundwater level variation in Jeyapuram M.V due to overflow method of artificial recharge**

Table 3 shows the recharge took place in each location during the year 2017 and 2018. Year 2017 was before artificial recharging by rainwater and 2018 was after the artificial recharging by rainwater harvesting either by direct or overflow method. Recharge during 2018 was higher than that in 2017 mainly due to the impact of artificial recharging. Even within 2018, direct method of artificial recharging contributed to the higher recharge than the overflow method of artificial recharging. It may be due to the fact that direct recharge contributes higher volume of rainwater whereas the overflow takes place only when the tank is full and when there is overflow. Therefore overflow recharging contributed to the limited volume of rainwater for artificial recharging. To calculate the recharge, water table rise in the groundwater level and the specific yield of the aquifer based on the literature (De Silva and Rushton, 2007; Mikunthan and De Silva 2012, Mikunthan and De Silva 2009; Kumar, et al., 2016) was used.

**Table 3.Recharge in groundwater wells from artificial recharging by direct method or Overflow method**

| Well Name | DSD/GND | Well No | Recharge 2017 (mm) | Recharge 2018 (mm) |
|---|---|---|---|---|
| Madduvill Nadu GTMS* | Poonakari | 1 | 124 | 196 |
| Paramankirai GTMS** | Poonakari | 2 | 132 | 166 |
| PeriyakulamIyanarVidiyalayam* | Karachchi | 3 | 237 | 260 |
| Punnaineeravi GTMS* | Kandawallai | 5 | - | 301 |
| Kandawallai PMCU** | Kandawallai | 6 | - | 205 |
| Vannerikkulam PMCU** | Karachchi | 7 | - | 295 |
| Jeyapuram M.V.** | Poonakari | 9 | - | 170 |
| Veravil Divisional Hospital | Poonakari | 10 | - | 180 |
| Veravil Hindu MahaVidyalayam | Poonakari | 11 | - | 192 |

*Direct Method **Overflow method

## 4.2 Water quality

### *4.2.1 Well water Quality*

- *pH*

pH is one of the important water quality parameters that describes groundwater quality, since pH largely controls the amount of chemicals form of organic and inorganic compounds in groundwater (Mahagamage *et al*., 2016). pH of the well water is within the safe limit for drinking water is 6.5 to 8.5 (SLSI, 2016) in deepest well (Jeyapuram M.V) except during no rainfall period during January to May 2019. Among the deep wells Punnaineeravi GTMS and Vannerikulum PMCU wells were recordedpH within 6.5 to 8.5. But Piramanthanaaru well was having higher pH of 8.5 during rainless period from March to September 2018 and March to May 2019. However pH didn't exceed 10 in these wells. Among the medium depth wells, PeriyakulamIyanarVidyalam, Vervil Hindu M.V and Veravil DH well water were within the safe limit of pH 6.5-8.5. But Kandawallai PMCU well water was above the safe limit of 8.5 during rain less period. However the pH was below 10 in all wells. Among shallow depth wells Kallar Tamil Vidyalam well water was measured pH less than 6.5, which is unsuitable to drinking purposes. Other wells in Madduvil Nadu GTMS and Paramankirai GTMS well water was below pH 10 and most of time the pH is within the safe limit for drinking water (Figure 10).

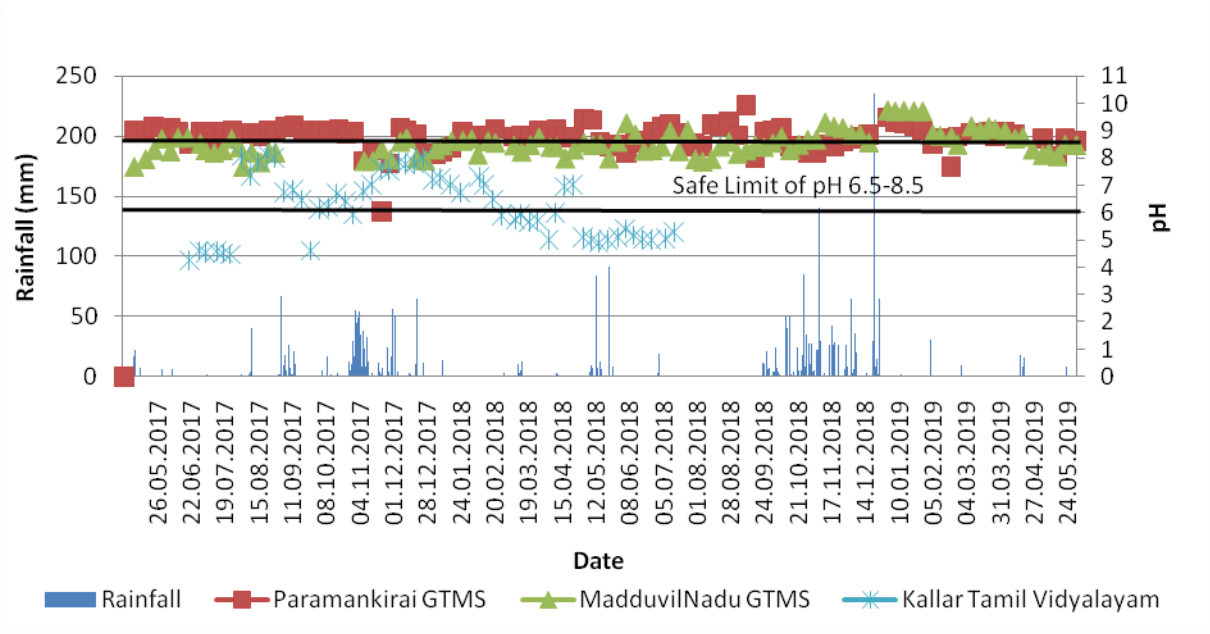


**Fig.10. Temporal variation of pH of shallow depth well water in the study area**

- *Electrical Conductivity(µS/cm)*

EC comprises the inorganic salts and organic matter that are dissolved in water(Mahagamage*et al.*,2019).Electrical conductivity of the deepest well water was above safe limit of 1500 µS/cm, higher as 2250 µS/cm during dry period from March to October 2018 and below the safe limit during October 2018 to May 2019 after *Maha* season rains. This is due to the dilution of well water during rainy season (Mikunthan and De Silva, 2008). Among deep wells electrical conductivity of Pirmanthanaaru MV well water is below the safe limit throughout the study period. However,Vannerikulam and Punnaineeravi GTMS well water were always above the safe limit (Figure 11). Electrical conductivity of Vannerikulam PMCU well water was almost 9500µS/cm during the study period and electrical conductivity of Punnaineeravi GTMS well water reached 4000µS/cm making this well water unsuitable for domestic purposes. This may be due to the higher ion concentration in deep well water.

Among the medium depth wells, electrical conductivity of PeriyakulamIyanarVidyalayam well water was below the safe limit of 1500µS/cm during the study period. Electrical conductivity of Kandawallai PMCU well water was above the safe limit (up to 2500µS/cm during the study period except for a short period during December 2018 to February 2019 due to dilution after *Maha* season rains. Electrical conductivity of Veravil Hindu M.V well water was above the safe limit throughout the study period and it was nearly 6500µS/cm and this well water is unsuitable for domestic purposes.

Among the shallow depth wells electrical conductivity of Maduvil Nadu GTMS well water was below the safe limit of 1500µS/cm throughout the study period (Figure 11). Electrical conductivity of Kallar Tamil Vidyalam well water quality was below the safe limit from September 2017 to May 2018 but during the other period the electrical conductivity was above the safe limit of about 3500µS/cm which makes the well water unsuitable for domestic purposes.

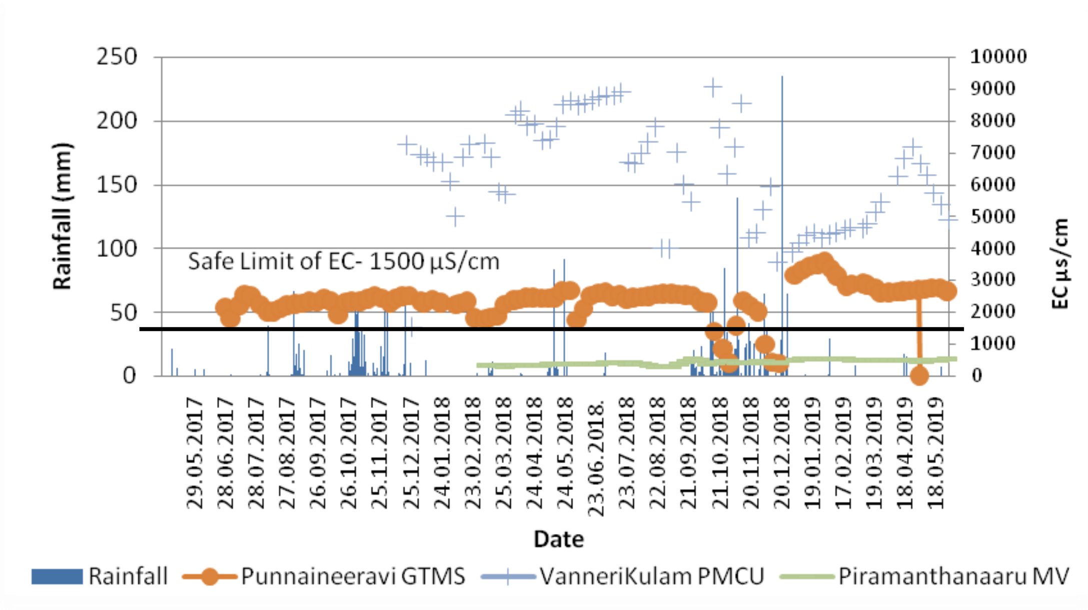


**Fig. 11. Temporal variation of electrical conductivity (µS/cm) in deep wells water in the study area**

- *Total Dissolved Solids (mg/L)*

Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water (SLSI, 2016). Acceptable safe limit of TDS is 500mg/L (SLSI, 2016). Among the wells in the study area only PeriyakulamIyanarVidyalam (Figure 12), Maduvil Nadu GTMS and Piramanthanaaru MV wells are having Total Dissolved Solids less than 500mg/L which is the safe limit. All the others wells water is having higher TDS values above 500mg/L. Deepest well in Jeyapuram MV is having TDS value of about 1120mg/L except during the rainy season from October 2018 to April 2019. During rainy season the TDS value is within the safe limit of 500mg/L. TDS value of the well water in Paramankirai GTMS, was above the safe limit. Lowest and highest TDS value obtained in Paramankirai GTMS during the study period was 1170mg/L (September 2019) and 6490mg/L (November 2019) which makes the well unsuitable for domestic purposes. TDS value of the well water is Kanadawallai PMCU was above the safe limit of 500mg/L and the lowest and highest TDS values obtained was 538 mg/L (Dec 2018) and 1386 mg/L (August 2018) respectively. TDS values decreased during *Maha* season rains in December due to dilution of the well water due to recharge. TDS value of the well water in Veravil DH was well above the safe limit of 500mg/L. The lowest and highest TDS observed in Veravil DH well water was 2781mg/L (January 2019) and 8856mg/L (March 2019) respectively which makes this well water unsuitable for drinking purposes. TDS in Vannarikulam PMCU well water was well above the safe limit of 500mg/L throughout the study period. The lowest and highest TDS values in Vannarikulam PMCU were 1770 mg/L and 7730mg/L respectively. TDS value of well water in Veravil Hindu M.V was above the safe limit throughout the study period and the lowest and highest TDS values observed in Veravil Hindu M.V well were 1113mg/L and 2918mg/L respectively. TDS value of the well water in Punnaineerai GTMS was above the safe limit of 500mg/L throughout the study period except in December 2018 TDS value came down to 200mg/L only for a short period due to *Maha* season rains and dilution of water in the well. The lowest and highest TDS values observed in this well was 200 mg/L and 1714mg/L respectively. It showed only three wells namely PeriyakulamIyanarVidyalam, Maduvil Nadu GTMS and Piramanthanaaru MV in the study area are having TDS value below 500mg/L of safe limit throughout the study period and suitable for drinking purposes. It may be these wells have higher recharge which dilutes the concentration of ions in the well water.

These harmful minerals accumulate because the body cannot excrete or utilize them. In most instances, TDS in your drinking water will not present a health problem but it's important to note, should TDS levels exceed 500mg/L, the drinking water can be considered unfit for human consumption (SLSI, 2016). It is recommended that people with kidney problem should drink pure water having TDS level below 100 mg/L for better recovery. There are ways to remove TDS through Reverse Osmosis (R.O.) Reverse Osmosis removes TDS by forcing the water, under pressure, through a synthetic membrane; distillation (Mahagamage, et al., 2016). The process involves boiling water to produce water vapor and deionisation (DI). But RO water doesn't have many of the essential nutrients you need for your health. Higher TDS value in about 70% of the study area is a concern as most of the rural communities suffer from Chronis Kidney Disease(Mahagamage, et al., 2016).

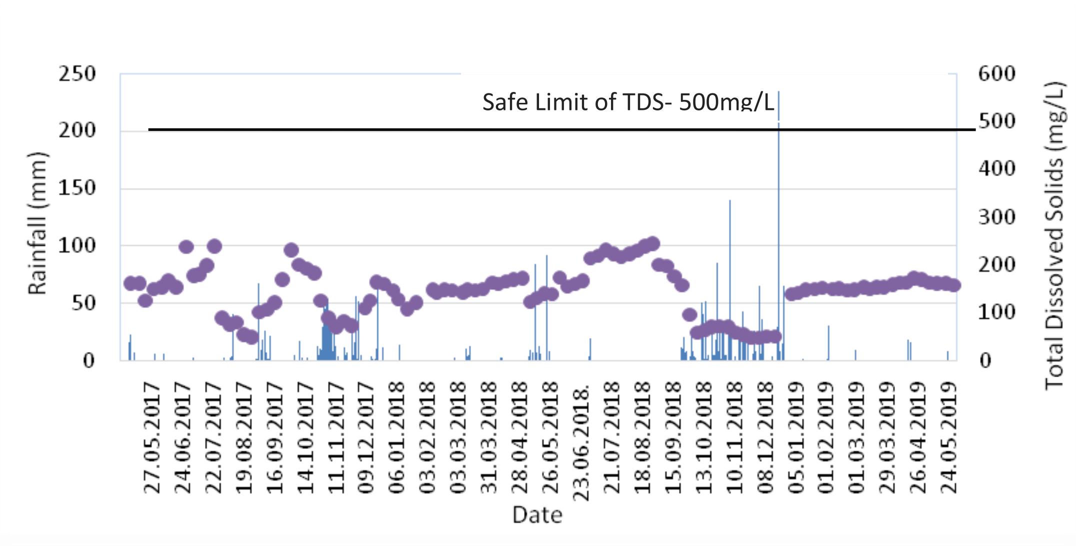


**Fig.12. Temporal variation of Total Dissolved Solids (mg/L) in PeriyakulamIyanarVidyalayam well.**

#### *4.2.2. Rainwater Harvesting Tank water quality*

- *pH*

The pH of pure water is 7. In general, water with a pH lower than 7 is considered acidic, and with a pH greater than 7 is considered basic. The normal range for pH in surface watersystems is 6.5 to 8.5, and the pH range for groundwater systems is between 6 and

8.5. In the study area pH of all the rainwater harvesting tank water in all locations were above the safe limit of 6.5-8.5 (Figure 13). According to Weidman,*et al.,* (2016) the higher pH or alkaline water can help slow the aging process, regulate your body's pH level by neutralizing the acid in the body, increases energy levels, extra hydrating than other water and prevent chronic diseases like cancer because alkaline water is suggested as containing antioxidants to extensively hydrate and filter out free radicals in your body. Normal drinking water generally has a neutral pHof 7. Alkaline water typically has a pH of 8 or 9.When you have kidney disease, it's more difficult for your kidneys to remove acid from your blood. Because of that, a high-alkaline diet, one that is low in acidic foods, may help people with kidney disease to balance their pH levels (Weidman *et al.* 2016).Further the reason for high pH levels in the Rain water Tank is due to cement dissolving of the Ferro cement tank when they are newly constructed. It will be reduced with time when the tank is used continuously. Therefore the pH in the Rainwater Harvesting Tank water quality is not a serious matter.

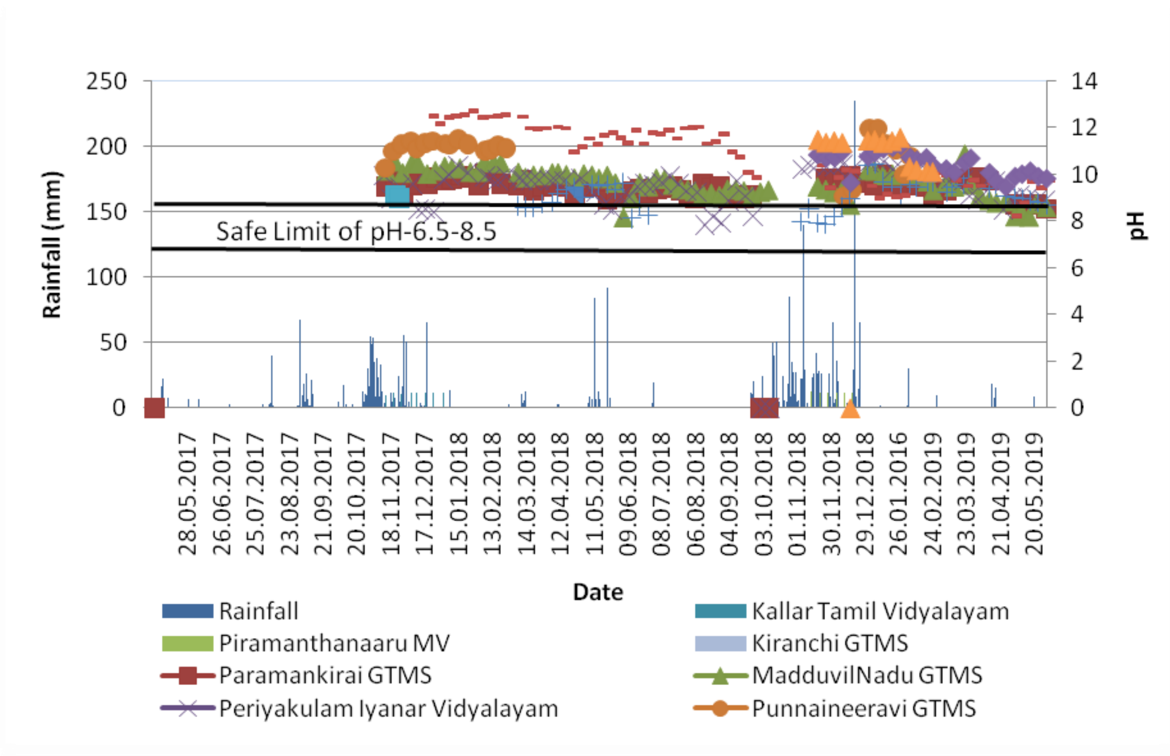


**Fig. 13. Temporal variation of pH in water in the rainwater harvested tank**

- *Electrical Conductivity (µS/cm)*

An electrical current result from the motion of electrically charged particles in response to forces that act on them from an applied electric field. Within most solid materials a current arise from the flow of electrons, which is called electronic conduction. In all conductors, semiconductors, and many insulated materials only electronic conduction exists, and the electrical conductivity is strongly dependent on the number of electrons available to participate to the conduction process. Most metals are extremely good conductors of electricity, because of the large number of free electrons that can be excited in an empty and available energy state (Meride and Ayenew 2016).

Electrical conductivity in all the rainwater harvesting tank water in all locations was within the safe limit of 1500 µS/cm (Figure 14). Therefore, the rainwater harvesting tank water quality is better than the well water quality of the study area. Some locations have higher EC values, and it may be due to cement dissolving of the Ferro cement tank when they are newly constructed.

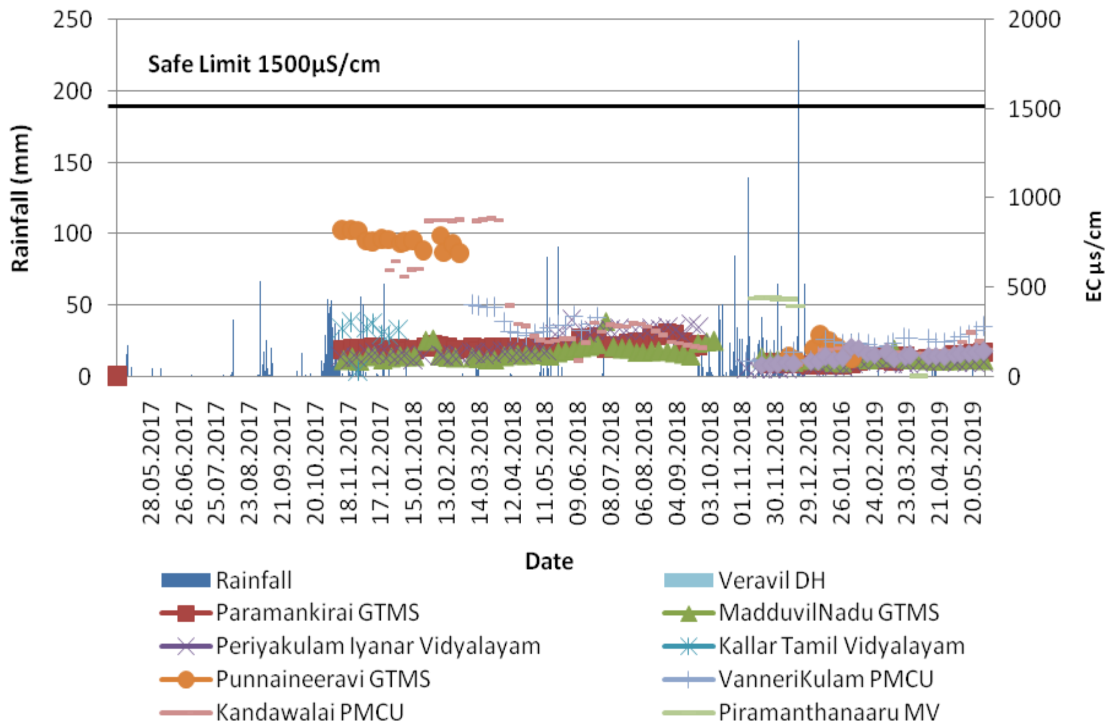


**Fig. 14. Temporal variation of Electrical Conductivity in rainwater harvesting tank water**

- *Total Dissolved Solids (mg/L)*

Total dissolved solids (TDS) is a measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized, or micro-granular (colloidal sol) suspended form (Meride and Ayenew, 2016). Generally, the operational definition is that the solids must be small enough to survive filtration through a filter with 2-micrometer (nominal size, or smaller) pores. Total dissolved solids are normally discussed only for freshwater systems, as salinity includes some of the ions constituting the definition of TDS. Although TDS is not generally considered a primary pollutant, it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants (Meride and Ayenew, 2016). The United States has established a secondary water quality standard of 500 mg/L to provide for palatability of drinking water. According to the results obtained in the TDS of Rainwater Harvesting tank water in all locations are within the safe limit (Figure 15). It shows that the Rainwater harvested water is in better quality than the groundwater well water quality in the study area. Some locations have higher TDS values, and it may be due to cement dissolving of the Ferro cement tank when they are newly constructed.

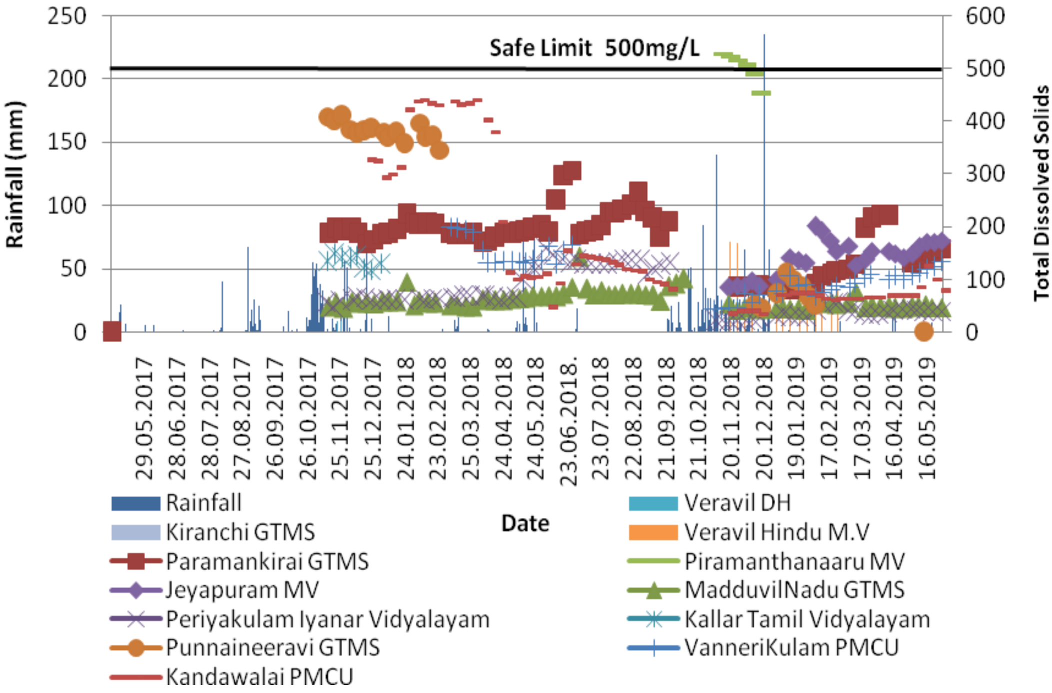


**Fig. 15. Temporal variation of Total Soluble Solids *(mg/L)* in rainwater harvesting tank water**

## 5 CONCLUSIONS AND RECOMMENDATIONS

This study proves that rainwater harvesting and using the rainwater harvested during wet season to recharge the groundwater wells is an appropriate methodology to keep the well water levels high during dry period. If the rainwater is not harvested, most of the water would have lost as runoff and not contributed to groundwater recharge effectively.

This study used two method of rainwater harvesting to recharge the groundwater wells. First method is to divert the water harvested on the roof straight to the groundwater wells (Direct method). Second method is to store the rainwater harvested in roof to the Rainwater Harvesting tank and the overflow of the rainwater from the rainwater harvesting tank is diverted to the groundwater wells for artificial recharging (Overflow method). According to the study results groundwater recharge is higher in wells in Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Punnaineeravi GTMS which were artificially recharged by direct method. Therefore direct method of artificial recharging using rainwater is effective in drought prone areas. Average recharge varies from 196mm to 301mm per year.

Groundwater quality analysis showed that pH of the well water was within the safe limit of 6-8.5 for drinking water; only in Madduvil Nadu GTMS, PeriyakulamIyanar

Vidyalayam and Punnaineeravi GTMS wells. Electrical conductivity in well water was within the safe limit of 1500 µS/cm only in wells in Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Piramanthanaaru M.V. TDS was within the safe limits of 500mg/L in wells of Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Piramanthanaaru M.V. Groundwater sourcesin Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Punnaineeravi GTMS are having higher recharge compared to the other wells , therefore, the well water quality is improved due to the dilution process.

Rainwater harvesting tank water quality in all study locations were within the safe limit of 1500 µS/cm of electrical conductivity and 500mg/L total soluble solids. But pH was in higher side of 9-10 even though the safe limit is 6.5-8.5. Therefore, rainwater harvested water quality is superior to the groundwater quality in the study area. Therefore, artificial
recharging using rainwater harvested water is not posing any threats to groundwater quality. Artificial recharging of groundwater wells by harvested rainwater is improving the water quality of the groundwater.

Therefore this study results recommends the following:
- Introduce rainwater harvesting tank in all households in the Kiliniochchi area.
- Use the rainwater harvested water drinking purposes as the groundwater quality is inferior to the harvested rainwater.
- Introduce direct method of artificial recharge the groundwater using harvested rainwater from the roof as much as possible.

## 6 ACKNOWLEDGEMENTS

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# Effect of Seed Inoculation of *Rhizobium leguminosarum on* Growth and Yield responses of Cowpea *Vigna unguiculata* (L.) Walp Under rain-fed Conditions

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***Abstract*** *– Legume is an important source of protein in the developed world and the main food in the developing world. Despite as a human diet legume can improv soil fertility through biological nitrogen fixation. .Thus, it reduces the nitrogen fertilizer requirement of legume and makes the legume-based cropping systems sustainable. Therefore, the impact of rhizobia inoculated seeds on overall growth and yield performances of Cowpea required to be evaluated to popularize the seed inoculations among farmers. A field experiment was conducted to investigate the response of cowpea to seed inoculated rhizobia, organic manure and recommended inorganic fertilizer. Waruni a local cowpea variety was used for this study as it is widely cultivated in Sri Lanka. Randomized complete block design with five replicates was used for the study. Seed inoculated rhizobia increased the number of nodules and nodules dry weight per plant, 100 seed weight, number of pods per plant, yield, hydration coefficient and cookability. Control treatment added with 100 kg/ha TSP only showed significant increase in total defects and non-soakers. Moisture content did not show a statistically significant difference among the treatments. The study indicated that the effect of seed inoculated rhizobia, organic manure and inorganic fertilizer on nodulation, yield and seed physical properties on cowpea. The study indicated that the Cowpea responded to inoculation in seeds containing Rhizobium showing positive interactions for most of the growth, yield, nodulation and seed physical properties and was more pronounced for yield and seed physical parameters.*

***Keywords****: Rhizobia inoculated seeds, Cowpea, growth, yield*

## 1 INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp] is one of the major grain legumes grown to acquire the protein requirement of humans. As per the researches done in the past, the protein content of cowpea leaves ranges from 27 to 43% and protein concentration of the dry grain range from 21 to 33% (Ahenkora et al, 1998; Ddamulira et al., 2015; Abudulai et al., 2016). In Sri Lanka generally Cowpea is supplied with the inorganic fertilizer mixture recommended by the Department of Agriculture. Commercial or synthetic fertilizers are tremendously increased in their price. Also, certain toxic compounds of synthetic fertilizers not only remain for a longer time in the soil but also enter into our food chain. Thus, the use of microbial fertilizers is a function in many ways to benefits the ecosystem. All the legumes are in symbiotic $N_2$ fixation which can compensate for missing soil nitrogen (N) by saving costly mineral N fertilizer (Guimarães et al, 2012). The farmers do not know or consider the ability of the root nodulation and fixing nitrogen by the

Cowpea. As per the Pule-Meulenberg et al, in 2010, Cowpea was shown to establish symbioses with several species and genera of the rhizobia. However, limited information is available on the performance of cowpea with inoculant strains in soils containing indigenous rhizobia population. It reduces environmental problems and enhances the productivity of the crop. Further, the benefits of microbial inoculation may be achieved when microbial cells are used along with compost (Gadalla et al. 2010). Therefore, enhancing the rhizobia nodulation in legumes would be beneficial to overcome the current problem of heavy use of fertilizers up to a certain level. Several studies are required to find the extent of inoculants used by the Rhizobia naturally present in soil and to access the requirement of inoculation to enhance the Nitrogen fixation.

Until recently, inoculation was not practiced for Cowpea assuming that the abundantly present indigenous *Bradyrhizobium* spp. in tropical soils effectively nodulate cowpea under natural environmental conditions (Singleton et al, 1992; Kimiti and Odee, 2010). However, recent studies have shown that cowpea responds to inoculation (Soares et al, 2006; Zilli et al, 2009; Almeida et al, 2010; Costa et al, 2011; Ferreira et al, 2013; Onduru et al, 2008; Nyoki and Ndakidemi, 2013, 2014). In these studies, the application of Bradyrhizobia inoculants improved nodulation, shoot dry matter as well as grain yield. Almeida et al, (2010), applied three inoculant strains separately which has increased cowpea grain yield by 29–50% compared with the non-inoculated control with no Nitrogen fertilization. In the trials by both Onduru et al, (2008) and Nyoki and Ndakidemi, (2013), inoculation increased nodulation, shoot dry weight, grain yields, and other growth variables.

Furthermore, as per some researchers' application of inoculants together with Phosphorus increased dry matter and grain yields more than applying inoculant or Phosphorus alone suggesting that cowpea growth and yield are limited by Phosphorus deficiency. The phosphorus is an essential nutrient for nodulation. The importance of Phosphorus in nodulation and grain yield of cowpea is well documented by several researchers (Bationo et al, 2002; Carsky and Toukourou, 2005; Jemo et al, 2006; Singh et al, 2011; Ayodele and Oso, 2014; Abaidoo et al, 2016). However, limited information is available on the performance of cowpea with inoculant strains and Phosphorus fertilization in soils containing indigenous rhizobia population. The present study was aimed to evaluate the overall performances of cowpea from germination to the consumption of seeds by establishing ***Rhizobium leguminosarum*** inoculated seeds under rainfed conditions. Organic manure as well as the application of recommended inorganic fertilizers at the recommended growth stages were also considered as treatments to conclude the outcomes with a comparative analysis.

## 2. METHODOLOGY

### 2.1 Site Description

A field study was conducted at the model farm of the Department of Agricultural and Plantation Engineering (DAPE), the Open University of Sri Lanka at Nawala, Nugegoda (6° 55' 37.4844'' N, 79° 51' 40.4784'' E, 3.1 m.a.s.l.) from July to December 2011. The selected field was abandoned for more than five years without any crop. As per the European Digital Archive of Soil Maps (EuDASM**)** the predominant soil type in the area is Red Yellow Podzolic soils with Soft and Hard Laterite (Panagos et al, 2011). The average annual temperature is 30 $^{0}$C and the average annual precipitation is 2000 mm.

## 2.2 Analyzing the composition of soil and composted cattle manure

Composite soil samples from ten random locations in the field and composted cattle manure were analyzed for chemical composition and availability of microbes one week before start the experiment.

Composite soil samples were prepared by mixing ten random soil samples collected up to a depth of 20 cm using a soil auger. The pH was determined using a high impedance voltmeter on 1:2 soil–water suspension. Total organic carbon was determined by Walkley–Black method. Nitrogen was determined by Kjeldahl method (Black, 1965). Perchloric and nitric acid digestion was employed for Phosphorous and Potassium analysis (Jakson, 1958). As an initial study, 10 g of finely ground composted cattle manure dissolved in 100 ml of water was also analyzed for the pH, Phosphorous, Potassium, Nitrogen and total organic carbon by following the same methods above.

## 2.3 Experimental procedure and treatments

The experiment lied as a Randomized Complete Block Design with four treatments with four replications. The treatment combinations are given in table 02. To minimize the effect of phosphorous, 100 kg/ha phosphorous in the form of TSP was applied evenly to cover all replicates including control.

**Table 01: Treatment combinations**

| Treatments | Fertilizer type and quantities |
|---|---|
| T1 | Inorganic Fertilizer mixture (35 kg/ha of nitrogen, and 100 kg/ha TSP) |
| T2 | Organic fertilizer (8 kg/ ha and 100 kg/ha TSP) |
| T3 | Seed Inoculated Rhizobium (100 grams inoculants used for 10 kg seeds and 100 kg/ha TSP) |
| T4 | Control (100 kg/ha TSP only) |

## 2.4 Preparing inoculum for field application

Commercial pure culture of *Rhizobium leguminosarum (*Sri Bio-Tech Commercial Industries, Mawathagama, Padukka) was maintained at 32 $^{0}$C by subculturing on Yeast Mannitol Agar. *Rhizobium leguminosarum* inoculum was prepared by adding a loop full of bacteria into the Yeast Mannitol Broth - YMB followed by employing ten steps, 10-fold ($10^{-1}$ to $10^{-10}$) serial dilution in the estimation of the total number of rhizobia in the soil samples, respectively, using a saline solution (0.89% NaCl) as the diluent. The concentration of the inoculating broth selected was 2 x 109 c.f.u/ml.

Seed inoculation was performed by weighing 20 g of seeds in plastic bags and adding 2 ml of water and 0.04 g sugar solution as a sticker and 200 ml of the prepared broth. The seeds and sugar solution were mixed thoroughly and 1 kg of Telcom powder was added for formulating (according to the manufacturers' recommendation), mixed thoroughly until all the seeds were completely covered with an inoculant. The inoculant was applied to supply approximately 106 rhizobia cells per seed. The seeds were treated in the field immediately before planting.

## 2.5 Land preparation, Field planting and crop management

Plots of 3.0 m × 5.0 m consisted of two rows with a spacing of 50 cm and 20 cm between and within rows respectively. Land preparation was accomplished by ploughing followed by two harrowing. Two to three seeds were placed in a hole to a 2 cm depth. To minimize contamination, the non-inoculated plots were planted first. Weed controlling was carried out whenever necessary. The plant was thinned to one plant per hill after emergence. The plants were grown under rainfed conditions.

## 2.6 Parameters Measured and Data Analysis

Seed germination percentage was analyzed on the third day after seeding. Shoot length was recorded and the number of leaves per plant counted at weekly intervals. At the end of the seventh week of field planting, three plants were selected randomly from each plot and washed the roots after removing the soil carefully. The nodules were picked from the roots and their numbers were recorded. Later, the dry weight of shoots as well as roots were determined by oven drying at 70 $^0$C for 48 hours. The dry weight of the separated nodules was also determined by oven drying at the same temperature and time, practiced above. Number of flowers per plant was counted at four days intervals of each plant separately. Number of pods per plant were calculated by harvesting mature pods when they becoming yellow, nine weeks after planting from each plant. Number of seeds per pod was calculated by manually counting seeds of the cleaned pods from each plant separately. 100 seed weight was calculated by manually counting the number of pure seeds from randomly selected plants from each plot and by weighing to take the average value of replicates. Finally, the yield per plant was calculated in grams in each plant. Physical properties of cowpea seeds were determined. Seed moisture content (weight/weight) was determined using Low Constant Temperature Oven Method. Cookability test was conducted by weighing twenty grams of seeds followed by soaking in 200 ml of tap water for 16 hours then boiling at 110 $^0$C for 30 minutes and by reweighing the cooked seeds. Non soakers were calculated by randomly selecting 100 seeds from each plant and by soaking in tap water by adding four times upper to the level of seeds for 16 hours followed by sorting and weighing the non-soaker seeds in each sample. Hydration coefficient percentage was calculated by dividing the weight of soaked seeds by initial weight. The total defects percentage was calculated by adding percentage of other defects to the non soaker seed percentage. Total other defects were calculated by dividing the weight of seeds having all other defects such as broken or physically damaged, failure to reach maturity and or being very small in size by the initial weight.

Data analysis was performed using SAS version 9.4 (SAS Institute, 2012). The Analysis of Variance (ANOVA) was carried out to test the significant ($p<0.05$) variation among treatments. Duncan's Multiple Range Test (DNMRT) was used to compare mean differences among treatments.

# 3.0 RESULTS AND DISCUSSION

The results of the composite soil sample and composted cattle manure analysis are given in table 01. The composted cattle manure has relatively high low total nitrogen and potassium content. Phosphorus and total organic carbon were low in both, soils of the experimented field as well as organic manure.

**Table 02: Chemical properties and available *Rhizobium leguminosarum* population of the Composite Soil sample (0–20 cm depth) and composted cattle manure**

| Location | pH (1:2 $H_2O$) | Total org. C (%) | Total N (%) | P (mg $kg^{-1}$) | K (mg $kg^{-1}$) | *Rhizobium leguminosarum* number (cells $g^{-1}$ soil) |
|---|---|---|---|---|---|---|
| Soil | 6.4 | 66 | 1.08 | 6.5 | 1.6 | $1.07 \times 10^3$ |
| Composted cattle manure | 7.2 | 12.6 | 10 | 3 | 6 | - |

Results of all treatments on seed germination and growth of cowpea are presented in table 03. Average seed germination was high in all treatments and the control had the lowest numerical value while showing significantly difference value with all other treatments (84) Inorganic fertilizer added treatment resulted with highest numerical mean value (98) while showing statistically significant. Control treatment was added with 100 kg/ha TSP only. Therefore, the seed germination was supported by the existing nutrients in the field only. These results are in line with the findings of (Kala et al, 2011), who reported that seed inoculated with rhizobium showed induced germination percentage than untreated seeds.

**Table 03: Seed germination percentage, mean values of plant growth parameters, LSD and CV of Cowpea grown under different fertilizers**

| Treatment | Germination % | Plant Height (cm) | Number of Leaves /Plant | Shoot dry weight (g) | Root dry weight (g) |
|---|---|---|---|---|---|
| Inorganic fertilizer | 98A | 22.86BC | 24.34A | 61.80A | 4.38A |
| Composted cattle manure | 94A | 23.30A | 25.58A | 70.22A | 4.62A |
| Seed inoculated Rhizobium | 96BA | 23.10AB | 26.21A | 73.42A | 5.12A |
| Control | 84B | 21.86C | 24.83A | 59.00A | 3.84A |
| LSD | 1.24 | 1.17 | 2.97 | 6.25 | 0.64 |
| CV (%) | 9.67 | 7.55 | 8.55 | 20.58 | 31.94 |

**Note**: Means with the same letters along the columns are not significantly different at $p>0.05$. Means are the average of the five replicates.

Composted cattle manure showed the significantly different plant height (23.30) when compared with other treatments which had lowest in control (21.86). However, number of leaves per plant, shoot as well as root dry weight did not show significant variation ($P<0.05$) among treatments. These results are in contrast to the findings of Patra and Bhattacharya in 1998, who reported that the cowpea plants produced from inoculated seeds exhibited significantly greater root and shoot length when compared to un-inoculated control cowpea plants. Cattle manure contains most of the important micro and macronutrients for the growth of Cowpea, however, essential nutrient supply is limited in other treatments.

**Table 04: Linear correlation analysis between plant height, number of leaves per plant, germination percentage, shoot dry weight and root dry weight**

| | Plant Height | No. of leaves | Shoot dry weight | Root dry weight | Yield per ha |
|---|---|---|---|---|---|
| Plant Height | - | -0.18ns | -0.03ns | 0.19ns | 0.3ns |
| No. of leaves | - | - | 0.51* | 0.64** | 0.25ns |
| Shoot dry weight | - | - | - | 0.48* | 0.22ns |
| Root dry weight | - | - | - | - | 0.32ns |
| Yield per ha | - | - | - | - | - |

*** Significant at P=0.0001 *Significant at P=0.05 ** Significant at P=0.01 ns non-significant at P=0.05

Correlation analysis was performed to evaluate the strength of relationship between the plant height, the number of leaves per plant, shoot dry weight, and root dry weight and yield per hectare (Table 4). Plant height showed a non-significant negative correlation with the number of leaves per plant and shoot dry weight while root dry weight and germination percentage showed a non-significant positive correlation with plant height. The number of leaves showed significant ($p<0.05$) positive correlation with shoot dry weight and moderately significant ($p<0.01$) positive correlation with root dry weight. Further, shoot dry weight showed a significant ($p<0.05$) positive correlation with root dry weight. Yield per hectare was non-significant with other parameters and however, it showed a positive correlation with other parameters.

**Table 05: Mean valuses of nodule formation, LSD and CV of Cowpea grown under different fertilizers**

| Treatment | Nodule number | Nodule dry weight (mg) |
|---|---|---|
| Inorganic fertilizer | 2.39BA | 0.017A |
| Composted cattle manure | 2.19B | 0.033B |
| Seed inoculated Rhizobium | 4.78A | 0.056A |
| Control | 1.79B | 0.010c |
| LSD | 2.57 | 0.023 |
| CV (%) | 66.79 | 57.52 |

Note: Means with the same letters along the columns are not significantly different at $p>0.05$. Means are the average of the five replicates.

Table 05 explaining the relationship between the mean nodule formation of Cowpea among different treatments. Seeds inoculated with Rhizobium showed significant difference on the number of nodule formation (4.78) and non significant in nodule dry weight (0.056). The similar records were resulted with the researches done by Hungria et al, 2000 and Mostasso et al, 2002 by having increased number of nodules due to seed inoculated Rhizobia in the field-grown common bean in Brazil. Further, composted cattle manure as well as inorganic fertilizer showed non significant difference in nodule number (2.19), (2.39) and nodule dry weight (0.033), (0.017) respectively when compared to the control. In both parameters control showed the lowest numerical value as well as non significant difference in both nodule number (1.79) and nodule dry weight (0.010). Nodule dry weight did not show significance difference among all the treatments. Moreover, the present experiment was recorded considerable higher response to the seeds inoculated with Rhizobium by resulting large number of nodules per plant in comparison to uninoculated treatments specially in a field with no cropping history of Cowpea.

**Table 06: Mean yield components, LSD and CV of Cowpea grown under different fertilizers**

| | No. of flowers/plant | No. of pods/ plant | Seeds/pod | 100 seed weight (g) |
|---|---|---|---|---|
| Inorganic fertilizer | 10.94 BA | 10.28A | 10.42 BA | 9.9B |
| Composted cattle manure | 9.97B | 8.79A | 9.45B | 9.3B |
| Seed inoculated Rhizobium | 12.93A | 10.11A | 11.13A | 12.2A |
| Control | 8.93B | 8.48A | 9.67BA | 8.9B |
| LSD | 2.77 | 3.007 | 1.67 | 1.26 |
| CV (%) | 18.77 | 23.17 | 11.91 | 9.10 |

Note: Means with the same letters along the columns are not significantly different at p>0.05. Means are the average of the five replicates.

Table 06 explain the mean yield components of the all three treatments and the control. Treatments with seed inoculated Rhizobium showed statistically significant increase in total number of flowers (12.93), seeds per pod (11.13) and 100 seed weight (12.2) when compared to the other treatments whereas Composted cattle manure had non-significant difference among number of flowers (9.97), seeds per pod (9.45) and 100 seed weight (9.3) whereas the same in Inorganic fertilizer having non-significant difference in total number of flowers (10.94), seeds per pod (10.42) and 100 seed weight (9.9). Further, control which had the lowest numerical numbers and non significant difference in total number of flowers (8.93), seeds per pod (9.67) and 100 seed weight (8.9). High vegetative growth owing to the availability of nitrogen in soil so as the end of the vegetative stage nitrogen availability was reduced in the soil. The plants were used the nitrogen for their growth.

The effect of different group of fertilizer application on pods per plant was non-significant for all treatments including control. Inorganic fertilizer treated plant had higher mean (10.28) value than the other treatments. These results were similar with the findings of Otieno et al, (2007) who reported total numbers of pods were not significantly increased in the legume species with the added nitrogen. Further, the same results were experienced by Kyei-Boahen et al., in 2017 by having non-significant difference among the treated plants with Fertilizer treated plant had higher number of pods per plant compared to Rhizobia, manure and the control.

Rhizobia inoculated as well as other fertilizer applied treatments resulted significantly higher grain yield relative to the control (Figure 1). Highest weight, 1678.3 kg/ha was produced by seed inoculated treatment and lowest mean weight, 1243.4 kg/ha observed in control treatment. Control treatment and composted cattle manure added treatment showed statistically similar result.

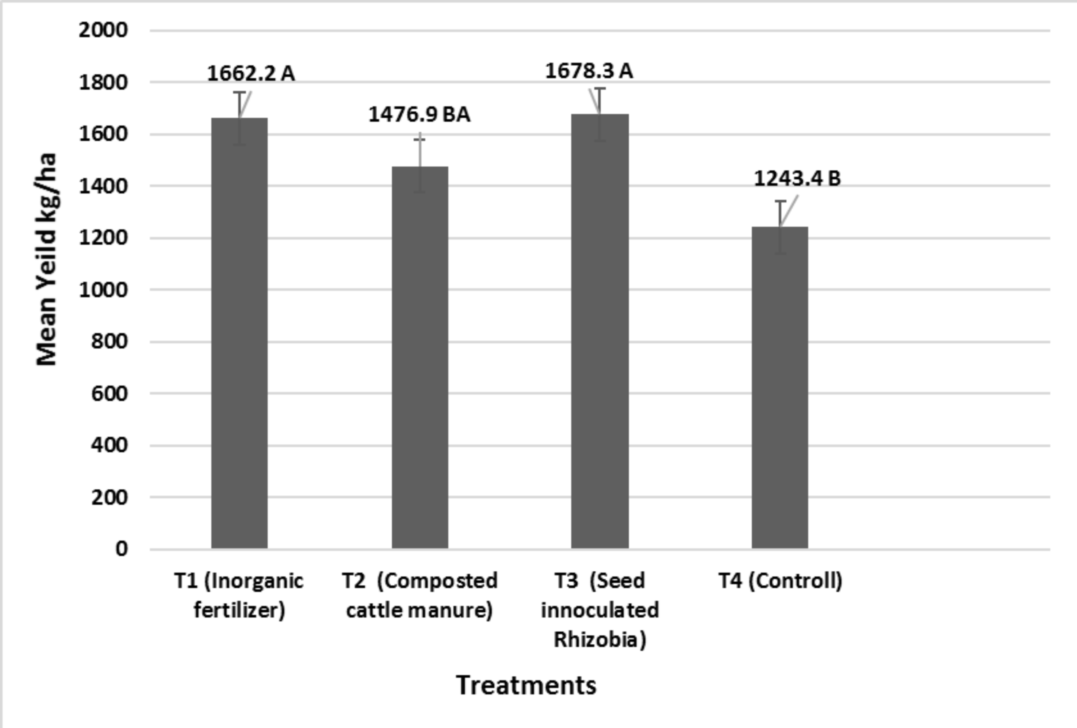


**Figure 01: Mean yield of cowpea under different fertilizers**

**Table 07: Mean values of Seed Physical Properties, LSD and CV of Cowpea grown under different fertilizers**

| | Seed moisture % | Cookability | Non soakers | Hydration coefficient | Total defects |
|---|---|---|---|---|---|
| Inorganic fertilizer | $0.05^{A}$ | $127.7^{B}$ | $5.1^{BA}$ | $110.7^{BA}$ | $9.2^{BA}$ |
| Composted cattle manure | $0.03^{A}$ | $123.3^{B}$ | $3.8^{BC}$ | $96.8^{B}$ | $7.1^{B}$ |
| Seed inoculated Rhizobium | $0.20^{A}$ | $138.3^{A}$ | $1.7^{C}$ | $125.6^{A}$ | $3.2^{B}$ |
| Control | $0.23^{A}$ | $121.3^{B}$ | $6.5^{A}$ | $100.2^{B}$ | $11.2^{A}$ |
| *LSD* | 0.42 | 8.46 | 2.41 | 15.43 | 3.84 |
| *CV (%)* | 230.53 | 4.81 | 40.94 | 10.34 | 36.30 |

**Note:** *Means with the same letters along the columns are not significantly different at p>0.05 Means are the average of the five replicates.*

Table 07 explaining the mean values of seed physical properties which is one of the most important parameter of consumable seeds. As per the results seeds inoculated with Rhizobium did not affect the moisture content of cowpea. Maximum mean value (0.21) was observed in control treatment and lowest mean value (0.03) was obsered in composted cattle manure treated experiments. Similar result were obtained in Faba bean by Elesheikh and Mohamedzein in 1998 and Fenugreek seeds by Abdelgani et. al. In 1999 as well as in ground nut seeds by Elsheikh and Ahamed, in 2000. However, few reports showed a significant increase in the moisture content of the seeds of inoculated plants (Elsheikh and Elzidany, 1997; Elsheikh and Ahamed, in 2000). Generally, the moisture content is affected by cultivar and the relative humidity of surrounding atmosphere at harvesting and storage. The cook ability of cowpea seed was significantly increased by inoculation with Rhizobia. Maximum cookability value (138.3) was in seed inoculated with Rhizobium. Lowest mean vales (121.3) was in control and the Inorganic Composted cattle manure as well as the control had statistically similar results. Similar results have been reported by Elsheikh and Elzidany in 1997 through a research done with groundnut in Sudan. Cookability is known to be affected by soaking time, type of water, time of cooking environmental factor, location and time of harvesting (Salih and Elmubarak, 1986, Elmubarark et al, 1988). The effect of different group of fertilizers on non-soaker percentage was significantly increased (6.5) in control teratment were are added with phosphorus only while lowest mean value (1.7) showed by the treastments innoculated with Rhizobium. The hydration coefficient whcih is a valuable attribute for both consumers and producers since it is a good indicator of seed quality because it plays a major role in defining the ability of the seed to absorb water and hence, become ready for the cooking process. Hydration coefficient of cowpea seeds were significantly diffrence in seed inoculated Rhizobium (126.6) relative to control (100.2). Low hydration coefficient indicates that's the seeds are not significantly capable of imbibing water when soaked (Elmubarak et al, 1998). Total defect range between 3.2 to 11.2% in different treatment shown in table number 7. The total defects followed a similar trend to that of the non-soakers' percentage. Control showed higher significant difference (11.2) than composted cattle manure (7.1) and seed inoculated Rhizobium (3.2).

**Table 08**: **Linear Correlation Coefficients of Seed Moisture Content, Cookability, Non-Soakers, Hydration coefficient and Total defects**

| | Seed Moisture content % | Cookability % | Non-soakers % | Hydration coefficient % | Total defects % |
|---|---|---|---|---|---|
| Moisture content | - | $0.31^{ns}$ | $0.32^{ns}$ | $0.10^{ns}$ | $0.09^{ns}$ |
| Cookability | - | - | $-0.36^{ns}$ | $0.77^{***}$ | $0.46^{*}$ |
| Non-soakers | - | - | - | $-0.52^{*}$ | $0.92^{***}$ |
| Hydration coefficient | - | - | - | - | $-0.57^{**}$ |
| Total defects | - | - | - | - | - |

**** Significant at P=0.0001 *Significant at P=0.05 ** Significant at P=0.01 $^{ns}$ non-significant at P=0.05*

Table 08 explain the correlation analysis among treatments applied for seed physical properties evaluation. Positive correlation was observed, for all treatments, between the non-soakers, hydration coefficient and cookability. The seed moisture content was non-significant with other seed physical properties. Cookability showed non-significant negative correlation with non-soaker seeds. The hydration coefficient showed a highly significant (p<0.0001) positive correlation with total defects. The hydration coefficient showed a significant positive correlation with cookability. Cookability showed a significant positive correlation with non-soaker seeds and nonsmoker seeds showed a highly significant (p<0.0001) positive correlation with total defects. The hydration coefficient showed a moderately significant (p<0.01) negative correlation with total defects.

## 4.0 CONCLUSION

Cowpea responded to inoculation in seeds containing Rhizobium showing positive interactions for most of the growth, yield, nodulation and seed physical properties and was more pronounced for yield and seed physical parameters. The study has demonstrated that using seed inoculant can enhance food security through increased grain yield and nutritional quality of many smallholder farmers in Sri Lanka. Furthermore, this management practice can contribute to the sustainability of the production system by replacing the inorganic fertilizer at least up to some level due to the reason of receiving higher yield from seed inoculated treatments. Farmers would benefit economically from using inoculant due to its low cost. Moreover, rhizobium inoculation is environmentally friendly application.

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