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The Journal of Applied Research on Science and Technology (JARST) aims to disseminate and share knowledge and ideas in the form of high-quality articles to academia, professionals, industrialists, and an important forum for exchanging knowledge between researchers, academics, faculty members and students both national and international, which will bring benefits in building academic cooperation and network that will lead to sustainable use of research. The articles that will be published in this journal must not be ever presented and published or in the evaluation processes in any other journals. Any piracy occurred will be only under the responsibility of the authors. The journal will not be responsible for such consequences.

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The scope of the journal includes the following areas of research: General Engineering, General Materials Science, General Agricultural and Biological Sciences, General Computer Science, and General Mathematics with particular emphasis on issues that deepen in the basic and applied research. The JARST includes full length original, novel research articles and review articles. Accepted articles are immediately available online and are freely accessible without any restrictions or any other obligations to researchers and scholarly people globally.

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The Editor-in-Chief will see whether the topic and theme of the article are appropriate and congruent with the stipulated objectives and format of the Journal. Plagiarism and benefits relating to theory and business contribution will also be investigated. The submitted paper may be returned to the author for preliminary revising or, if the aforesaid criteria are not met, rejected.

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The Journal of Applied Research on Science and Technology (JARST) will be 3 issues/year, as follows:

1st issue: January - April
2nd issue: May - August
3rd issue: September - December

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Editorial Note

The Journal of Applied Research on Science and Technology (JARST) is an academic journal prepared by Institute of Research and Development, Rajamangala University of Technology Thanyaburi (RMUTT). The JARST aims to disseminate and share knowledge and ideas in the form of high-quality articles related General Engineering, General Materials Science, General Agricultural and Biological Sciences, General Computer Science, and General Mathematics to researchers, academics, faculty members and students both national and international.

This journal published eight research articles and one review article. Each of the research articles presented interesting concepts such as Preparation of nylon 6/PLA blend nanofibers by needleless electrospinning, Drowsiness detection using Raspberry Pi for EVs and smart cars, Simulation of flood protection using Hec Ras Modeling: A case study of the Lam Phra Phloeng river basin, Fermentation of bamboo shoots using mature coconut water and its stability during storage at different conditions, Combining vehicle routing and bin packing problem for vehicle routing planning: A case study of a chemical factory, All solutions of the Diophantine equation 1/x+1/y+1/z=u/(u+2), Mobile random text-based voice authentication for older adults: A pilot study and Strategic environmental assessment of Thai river basins: Incorporating climate change considerations. Therefore, this journal is a channel disseminating the knowledge areas of physical sciences and life sciences which related persons could apply it for further benefits.

Lastly, the editorial team would like to considerably thank you for supporting and pushing forward this journal to occur and well accomplish. We are hopeful of your good cooperation and continuing support in the future.

Editorial Team

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Preparation of nylon 6/PLA blend nanofibers by needleless electrospinning

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ABSTRACT

The nylon 6/PLA blend nanofibers have been prepared for the first time by needleless electrospinning. The formic acid (FA) was found to be the co-solvent with dichloromethane (DCM) at a ratio of 3:1 for dissolving nylon 6/PLA blend. The nylon 6/PLA blend solutions in various ratios of PLA (8, 10, and 12 wt%) were studied to prepare nanofiber at the applied voltage range of 25 kV to 30 kV. The morphology images of the fibers were shown by scanning electron microscope (SEM). It was found that the average diameter of the nylon 6/PLA blend fibers became smaller as the applied voltage increased from 25 kV to 30 kV and as the PLA content increased from 8 to 12 wt%. The morphology of the fibers became finer with increasing the PLA content. The morphology of the nylon 6:PLA (20:10) nanofibers presented a smooth surface without the formation of beads with an average diameter of 157 nm at the applied voltage of 25 kV. The high PLA content (12 wt%) at a low applied voltage (25 kV) exhibited the bead formation. In contrast, the bead was formed at the medium PLA concentration (10 wt%) at the applied voltage of 30 kV. Therefore, the high PLA content (12 wt%) at a high applied voltage (30 kV) presented a ribbon-like nanofiber of nylon 6/PLA without bead formation. The particle size distribution obtained from SEM images of the nylon 6/PLA nanofiber was narrow at low PLA contents and became broader at higher PLA concentrations.

Keywords: Nylon 6/PLA blend, Needleless electrospinning, Nanofibers, Nanoweb

INTRODUCTION

A nonwoven web or nanoweb is a sheet or mat of fibers connected by physical entanglements or adhesion between individual fibers without knitting or stitching [1]. Several methods can be used to produce nonwoven or nanoweb, for instance, electrospinning, wet spinning, and molding. Electrospinning (ES) is the most common method used in the fabrication of nanofibers and has found uses in both scientific research work and industrial applications. Furthermore, electrospinning is an effective method as it is a versatile, low-cost, and easy method of producing nanoweb membranes [2, 3]. In recent years, some progress has been made to increase the production rate of ES by exploiting multi-needle spinnerets. However, multi-needle spinnerets also present challenges and do not resolve the problem of needle clogging [4]. For this reason, needleless electrospinning (NLES) systems have been developed to increase nanofiber production rates and overcome the needle-associated challenges of the conventional ES process [5].

Poly(lactic acid) or polylactide (PLA) is a biodegradable, bioabsorbable, and biocompatible thermoplastic aliphatic polyester with good thermal performance. These characteristics, including non-toxicity for humans, make it an ideal material for bioengineering applications. However, the mechanical performance of PLA depends on its shape, molecular weight, and process. For example, the mechanical properties of nanowebs from needleless electrospinning techniques depend on the thickness [6]. Therefore, some researchers were using other polymers to improve the mechanical performance of the nanoweb. Jia Xu et al. [6], study the chitosan/PLA blend micro/nanofibers by electrospinning. It was noticed that the average diameter of the chitosan/PLA blend fibers became larger, and the morphology of the fibers became finer

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with the increase in the content of PLA. Nylon-6 is a versatile material because easily spun (electrospinning) and can dissolve in polar and nonpolar solvents [7]. Nylon 6 nanofiber membranes have been widely used as aerosol filtration media and filters because they can produce uniform fibers and have good mechanical properties, low density, and high porosity [8].

Therefore, in this study, the nylon 6/PLA blend micro/nanofibers have been prepared for the first time by needleless electrospinning. Formic acid (FA) was found to be the co-solvent for electrospinning. The nanoweb morphology was studied using a scanning electron microscope (SEM).

MATERIALS AND METHODS

Materials

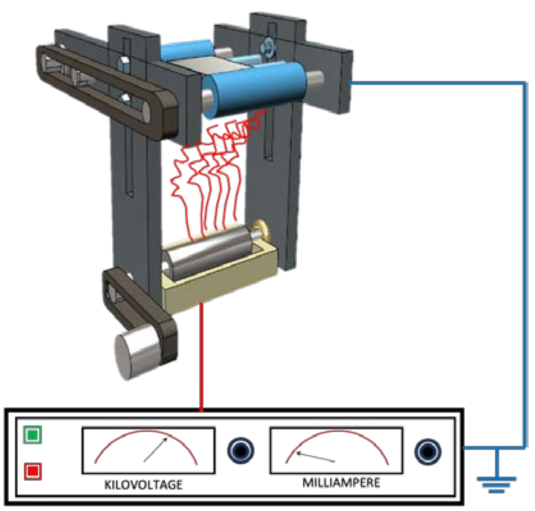
Poly(lactic acid) (PLA, $\bar{M}_w$ of 55.4 kg/mol [9], Ingeo™ Biopolymer 3251D, NatureWorks LLC), nylon 6 (UBE 1013NW8, $\bar{M}_n$ of 13.0 kg/mol [10] Chemicals Asia), dichloromethane (DCM, 99.5%, QRëC™), formic acid (FA, 90%, KemAus™), span bond (75 grams) were used as received.

Table 1 The experimental details of the preparation of the nylon 6:PLA solution.

Sample name	Nylon 6 (wt%)	PLA (wt% of nylon)
Nylon 6:PLA (20:8)	20	8
Nylon 6:PLA (20:10)	20	10
Nylon 6:PLA (20:12)	20	12

Preparation of nylon 6:PLA solution

8.0 g of nylon 6 and difference wt% of poly(lactic acid) (8, 10 and 12 wt%) polymer were dissolved in a 20 cm^3 solution of dichloromethane and formic acid at a ratio (1:3) with a magnetic stirrer at 50 °C for 2 h. The experimental details are shown in Table 1.



Schematic 1 Needleless electrospinning apparatus.

Needleless Electrospinning

The polymer solution was poured into the polymer bath. High voltage was supplied by attaching a clip to the bath. The collector was wrapped with a layer of 75 grams of span bond sheet. The collector-to-bath distance was fixed at 8 cm, as seen in Schematic 1. The electrospinning voltage was applied at 25 and 30 kV. The temperature was 25 °C.

Characterization

The morphology of the nanowebs was observed using a scanning electron microscope (SEM) model SEM-JSM-5410LV from Jeol, Japan. The nanoweb was cut in 9 mm diameter. The substrate was removed and placed on an SEM stub. All the samples were coated with palladium prior to use. The nanowebs diameter was measured with ImageJ software version 1.53e with Java 1.8.0_172.

RESULTS AND DISCUSSION

The effect of the polymer concentration on the nylon 6:PLA nanofibers.

The nylon 6:PLA nanofibers with different PLA ratios were produced by the electrospinning technique. The nylon 6:PLA was dissolved using DCM:FA 3:1. Figure 1 demonstrated SEM images of the nanofiber with the polymer ratios of nylon6:PLA (20:8, 20:10, and 20:12) and their size distribution at the applied voltage 25 kV. It was found that the nanofibers of nylon 6 blended with PLA at the concentration 20:10 presented the uniform fiber size and shape length across the whole region of the spinning area after the electrospinning process, as seen in Figure 1c. In addition, the average diameter of nanofiber nylon 6:PLA (20:10) was 157 nm, which showed a smooth morphology surface without forming beads, as seen in Figure 1d. In contrast, the nylon 6:PLA (20:8) demonstrated the nonuniformity of the nanofibers across the whole spun area, as presented in Figure 1a. Figure 1b presented the average particle size distribution of nylon 6:PLA (20:8), which was 193 nm and broader than the others. However, the bead formation was found at a high concentration of nylon 6:PLA (20:12), as displayed in Figure 1e. Therefore, the average diameter distribution of the nanofibers decreased with increasing the PLA concentration. The viscosity of the polymer blend solution increased by raising the PLA concentration [11]. The Taylor cone is generally generated and stabilized through the strong interactions between polymer molecules in the solution, resulting in the Taylor cone being stretched into a fine jet. However, increasing the PLA concentration caused

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the instability of the Taylor cone [12], resulting in bead formation and a decrease in fiber diameter [11].

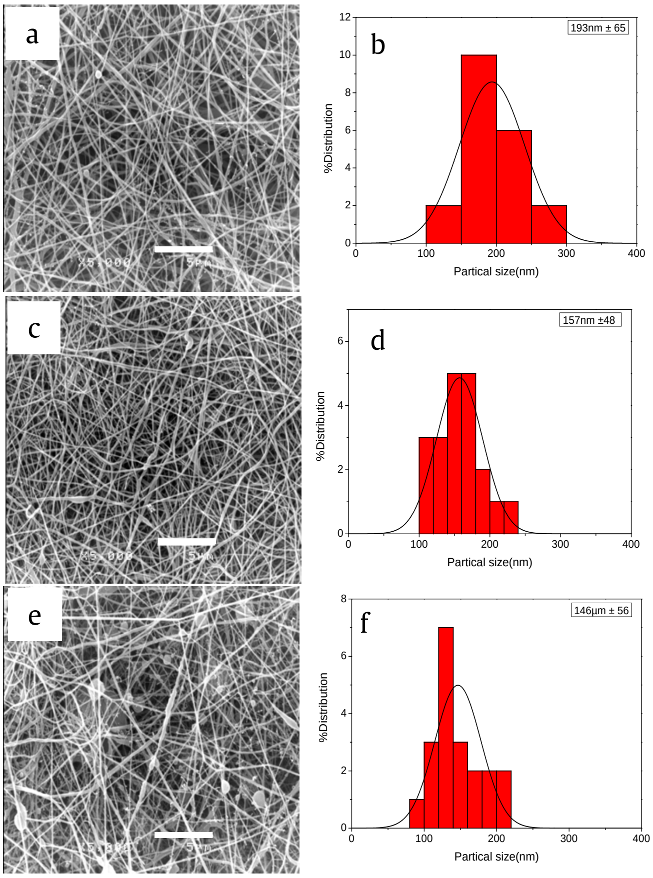

Figure 1 The SEM images of electrospinning nanofiber and their size distribution of (a-b) nylon 6:PLA (20:8) (c-d) nylon 6:PLA, (20:10) (e-f) nylon 6:PLA (20:12) using the solvent ratio DCM:FA (1:3) at the applied voltage 25 kV. The scale bar was 5 μm.

The effect of applied voltage on the nylon 6:PLA nanofibers.

The morphology of nylon 6:PLA with different concentrations of PLA to nylon (20:8, 20:10, and 20:12) and their size distribution at 30 kV were displayed in Figure 2. It was found that the diameter of the nylon 6:PLA (20:8) nanofibers decreased from 193 nm to 143 nm with increasing the applied voltage from 25 kV to 30 kV, as seen in Figures 1a and 2a, respectively. Higher voltage can provide stronger driving forces, facilitate jet formation, promote solution jet elongation, and reduce fiber diameter [13]. However, the diameter of the nylon 6:PLA (20:12) nanofibers was increased from 146 nm to 285 nm when the applied voltage was increased from 25 kV to 30 kV, respectively, as seen in Figure 1e and 2e, respectively. Moreover, the morphology of this nylon 6:PLA (20:12) nanofibers was a ribbon-like shape. A few beats occurred for nylon 6:PLA (20:10) at 30 kV. Therefore, the diameter of nylon 6:PLA (20:10) at 30 kV decreased with the increase in bead formation. The bead was created with increased polymer blend concentration due to the nonlinear interaction of polymer components, resulting in a changing viscosity [11].

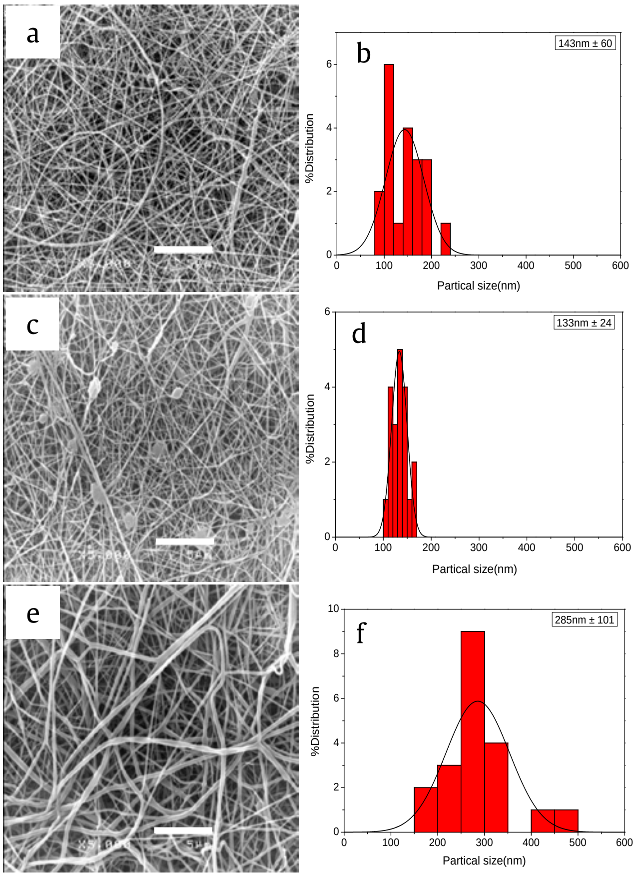

Figure 2 The electrospinning nanofiber mat of (a-b) nylon 6:PLA (20:8) wt% (c-d) nylon 6:PLA, (20:10) wt% (e-f) nylon 6:PLA (20:12) using the solvent ratio DCM:FA (1:3) at the applied voltage 30 kV. The scale bar was 5 μm.

CONCLUSIONS

The nylon/PLA blend micro/nanofibers have been successfully prepared by needleless electrospinning. The mixture of formic acid (FA) and dichloromethane (DCM) at a ratio (1:3) was used as the solvent for electrospinning. The morphology of the fibers was shown by scanning electron microscope (SEM). To study the effect of the polymer concentration of nylon 6:PLA, the conditions of the mixtures are as follows; 20:8, 20:10, and 20:12 at 25 kV. It was found that nanofibers of nylon 6 blended with PLA at the concentration 20:10 presented uniform fiber size and shape length across the whole region of the spinning area after the electrospinning process. The average diameter of nanofibers was 160 nm. Therefore, the diameter of the nanofibers decreased with increasing the PLA concentration. The high concentration of PLA increased the bead formation. The effect of applied voltage on the nylon 6:PLA nanofibers was also studied. It was found that the diameter of the

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nylon 6:PLA nanofibers decreased when increasing the applied voltage from 25 kV to 30 kV, respectively.

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Drowsiness detection using Raspberry Pi for EVs and smart cars

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ABSTRACT

Drowsiness detection is highly significant in assuring the safety and effectiveness of intelligent automobiles and electric vehicles (EVs). It used to be that managing driver fatigue was only a question of comfort for contemporary transportation systems. However, with the rapid improvements that have been made in automotive technology and the growing prevalence of autonomous features, this need has developed into a fundamental requirement. Sleepiness detection systems perform the role of watchful co-pilots by continually monitoring the driver's behavior and sounding alerts or taking other appropriate actions when indicators of tiredness are identified. They are an effective strategy to limit the dangerous practice of sleepy driving, which is responsible for many motor vehicle accidents. These accidents are caused by a combination of factors, including fatigue, distraction, and inattention. In the current investigation, a Raspberry Pi is a real-time monitoring system to determine drowsiness. The dataset had one thousand unique images, each depicting a different feature of a real-world driving event. These images have been organized into the following four categories: open eyes (250 images), closed eyes (250 images), open mouth (250 images), and closed mouth (250 images). During this investigation, the experimental circumstances were looked at during daylight and the evening hours. For the system to function correctly, it relies on the Eye Aspect Ratio (EAR) algorithm and the facial landmarks method. The recommended strategy showed a higher degree of accuracy when put into practice. However, the study found that false negative blinks were noticed due to noise that could not be repaired within the collected signal. In the future, we want to concentrate our research efforts on determining whether or not the recommended technique is effective in a broader variety of contexts.

Keywords: Drowsiness detection, Eye aspect ratio, Facial landmarks technique

INTRODUCTION

The automotive industry is now experiencing a rapid transformation, characterized by the emergence of electric cars and intelligent autos as the frontrunners in this significant change. The increasing incorporation of connection, autonomy, and advanced technology in automobiles has led to a redefined and broader understanding of safety. One crucial aspect of promoting vehicle safety is recognizing and mitigating drowsy driving, a hazardous condition that presents a significant danger to the overall security of roadways. Drowsiness detection systems have emerged as a pivotal component in enhancing road safety, particularly in the context of electric vehicles and intelligent autos. Drowsy driving is a pervasive occurrence that has significant consequences, including not just fatal accidents but also economic repercussions and emotional distress for those immediately affected and their families. Integration of tiredness detection systems in these vehicles is optional and imperative, driven by various compelling causes. Sleepiness detection systems serve as vigilant co-pilots, continually monitoring driver behavior and promptly notifying or executing corrective actions when signs of drowsiness are detected. Specific advanced iterations of these systems have the potential to provide partial or complete autonomous control, hence potentially reducing the likelihood of accidents. In addition, the implementation of tiredness detection systems plays a significant role in enhancing the overall driving experience in electric cars (EVs) and intelligent autos. Extended journeys, often associated with electric vehicles, may potentially lead to fatigue, making drivers susceptible to tiredness. These technologies contribute to the overall comfort and enjoyment of the trip by motivating drivers to take regular breaks, efficiently managing their fatigue levels, and optimizing vehicle settings to ensure heightened levels of alertness are maintained.

Moreover, according to J. Singh, individuals who engage in prolonged driving activities exhibit a deterioration in their overall physical well-being. As a result of this occurrence, drivers commonly encounter feelings of fatigue and are frequently on the verge of

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experiencing exhaustion. This mechanism gives rise to the manifestation of microsleep, a term that describes tiny periods of somnolence ranging from a fraction of a second to a maximum duration of 30 seconds. During these episodes, people cannot react to environmental stimuli and undergo a transient state of unconsciousness. As a result, road accidents have become a widespread occurrence globally. This research aims to provide a system for efficiently alerting drivers experiencing weariness while operating a vehicle. The present study tried to address the issue by devising a specialized module tailored for detecting ocular fatigue. A unique system for face region recognition has been devised using a collection of 68 crucial features.

Consequently, these facial regions are crucial for evaluating the driver's state. The degree of accuracy attained was 92.5%. Furthermore, it has been noted that a considerable proportion of persons perish each year due to deadly traffic collisions that transpire on a global scale. Significantly, drowsy driving has emerged as a key contributing cause to these incidents and resultant deaths. The predominant factor contributing to significant accidents often arises from driver weariness and instances of microsleep encountered during vehicle operation. However, it is feasible to identify early signs of fatigue before the onset of a disastrous event. As a result, the ongoing exploration of driver tiredness detection and its associated symptoms continues to be a topic of academic interest. The predominant methods used in the identification of drowsiness mainly depend on behavioral cues, while some techniques may be intrusive and could distract drivers.

Moreover, specific methodologies need the use of expensive sensor technologies. Therefore, this research introduces and executes the creation of a lightweight, real-time system for detecting driver's tiredness via an Android application. The system employs image processing algorithms to acquire and analyze motion pictures, emphasizing identifying the driver's facial features in every frame. The system can detect and determine certain places on the face, often referred to as facial landmarks. Subsequently, these prominent points are used to compute two metrics: the Eye Aspect Ratio (EAR) and the Eye Closure Ratio (ECR). The measures used in this study assess the degree of fatigue a driver shows using an adaptive thresholding methodology. Machine learning techniques have been used to evaluate the efficacy of the proposed approach. The empirical results suggest that the model being examined demonstrates a degree of precision of 84% when using the random forest classifier.

It is accepted that any system that tracks the physiological features and the vehicle behavior tends to be more dependable as acquiring the physical signals is relatively more accessible and reliable regarding the results it generates. However, what marks a drawback to an otherwise very effective system is the number of signals and the difficulty in processing them, thus making the system all the more complex and complicated. Another fact that cannot be undermined is the bulky size that defeats the importance of compactness for ease of installation in the vehicle. Another classification of the weariness of the vehicle operator detection system is determined by observation using the image processing technique. The point to be reiterated here is that it does not use sensors to trace the driver's signals but tries to estimate fatigue by capturing the data about the blinking of the eye. Research in this area has repeatedly affirmed that the driver's fatigue starts with its effect on his eyes and mouth. Thus, the non-intrusive systems for fatigue detection take into account the features of the face using a computer vision approach. The facial Analysis technique is commonly used for real-time applications such as airport security checks, electronic gadgets for authentication, legal issues, and surveillance systems.

Our research framework investigates the EAR algorithm and the facial landmarks technique on the Raspberry Pi to evaluate whether they can operate in real-time. The examination will be conducted both during the day and night. In addition, the dataset included a total of one thousand unique images. These photographs are utilized in the process of configuring and updating the system.

MATERIALS AND METHODS

The experiment was carried out and proved that monitoring the pupil based on the appearance of the eye gave positive results, given that there were no obstructions to the eyes and that the eyes were in an open state. In addition, it has been shown that using a filter that performs subtraction in real time may effectively alleviate problems caused by lighting. Despite this, the problem of visual organ obstruction remains a continuing worry. In the realm of eye tracking, it has been shown that the combination of appearance-based approaches with active infrared illumination has a synergistic influence, leveraging the unique benefits of each methodology. However, there were still limitations due to boundaries, visual aids, and the general illumination in the area. According to the findings of the research, these systems have the potential to provide input images of an exceptionally high standard and integrate some distinct methods that are complimentary in order to precisely identify the pupil, making the most of their respective advantages while minimizing their drawbacks.

Eye detection is a method used in computer vision that focuses mainly on the localization and identification of areas within an image that correspond to the eyes. Eye detection is often used in facial recognition software. The present work makes use of a few different stages that follow one another in order to improve the identification of ocular traits.

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1. The initial stage in eye detection is often identifying the facial region within the given picture or video frame. This may take place either manually or automatically. As was noted previously, face recognition algorithms are utilized to identify the approximate location of a face, which acts as an initial point of reference for subsequent eye detection. In other words, a face's eyes are detected after the approximate position of the face has been determined.

2. The step of recognizing the face, which is the first step in extracting the region of interest (ROI), is followed by isolating a smaller area inside the facial region that is anticipated to include the eyes. The region of interest, also called the designated area on occasion, serves as the input for the subsequent algorithms used in the eye recognition process.

3. It is common practice to do preprocessing to improve the Region of Interest (ROI) quality and make reliable eye identification more straightforward. Scaling, converting to grayscale, changing contrast, and reducing noise are typical examples of preprocessing methods used in image analysis.

4. Various methods and procedures are used to identify and localize the ocular structures in a certain region of interest (ROI). The algorithms may be divided into two primary groups: traditional computer vision approaches and more modern methodologies based on either machine learning or deep learning. Each of these categories has its subcategories.

5. After the eyes have been found, the next step in eye localization is determining the precise location of each eye within a designated region of interest (ROI). Either the development of bounding boxes or other visual representations around the eyes or the calculation of exact eye coordinates may be part of the technique.

The structure of the experiment can be set up as shown in Figure 1-2.

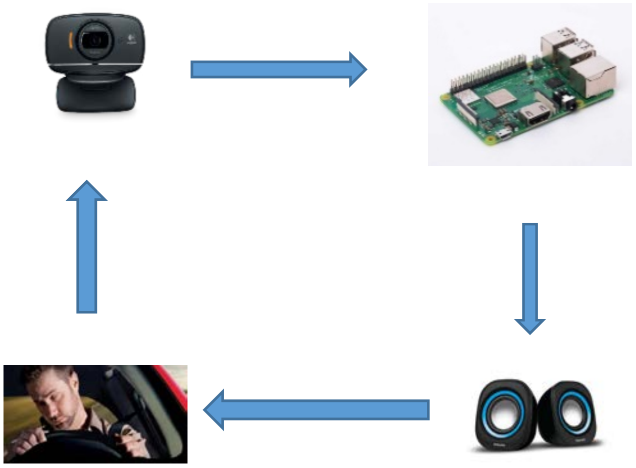

Figure 1 The proposed structure installed.

The suggested methodology may be executed following the specified approach, as followed.

1. The camera monitors the driver's facial expressions to assess if the driver has shown signs of tiredness during the vehicle's operation.

2. The Raspberry Pi's processing component calculates the camera input it receives. The occurrence often known as "drowsy driving" pertains to situations when a person operating a motor vehicle exhibits signs suggesting the onset of drowsiness.

3. The auditory indication functions as a cautionary alert for the motorist. When healthcare practitioners see the emergence of indications related to the abuse of opiates and the resulting repercussions, they often refer to this phenomenon as "the opiate crisis".

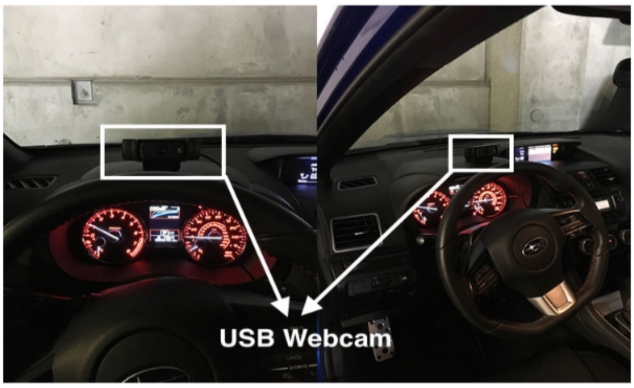

Figure 2 Camera installed.

The sample code used in the image processing process is shown in Figure 3. The hardware and software are installed and operated according to the process diagram shown in Figure 4.

After collecting a dataset of one thousand images that each showed a different aspect of a real-life driving situation, images were separated into the following categories: open eyes (250 images), closed eyes (250 images), open mouth (250 images), and closed mouth (250 images). In addition, the technology now under consideration has been tested in a nighttime environment. The next part contains detailed information on all the outcomes discussed before.

The proposed methodology effectively accomplishes precise and efficient eye blink detection via the Eye Aspect Ratio (EAR) algorithm and the facial landmarks technique. The user's text lacks sufficient information to be rewritten academically. The essential elements and procedural stages of the EAR algorithm are followed.

1. The first stage of the EAR algorithm involves the identification of distinct facial landmarks that play a crucial role in the computation of the eye-aspect ratio. The landmarks above are often situated at the outermost points of the ocular area and along the upper and lower peripheries of said region. A frequently used option for this purpose involves using the library, renowned for its proficiency in identifying facial landmarks.

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```
sudo apt-get update
sudo apt-get install python3-opencv
```

```
import cv2

# Initialize the camera
cap = cv2.VideoCapture(0)

# Load the pre-trained eye cascade classifier
eye_cascade = cv2.CascadeClassifier('haarcascade_eye.xml')

while True:
    ret, frame = cap.read()

    # Convert the frame to grayscale
    gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)

    # Detect eyes in the frame
    eyes = eye_cascade.detectMultiScale(gray, scaleFactor=1.1, minNeighbors

    for (ex, ey, ew, eh) in eyes:
        cv2.rectangle(frame, (ex, ey), (ex + ew, ey + eh), (0, 255, 0), 2)

    cv2.imshow('Eye Detection', frame)

    if cv2.waitKey(1) & 0xFF == ord('q'):
        break

cap.release()
cv2.destroyAllWindows()
```

Figure 3 Example of code that connected camera and Raspberry Pi.

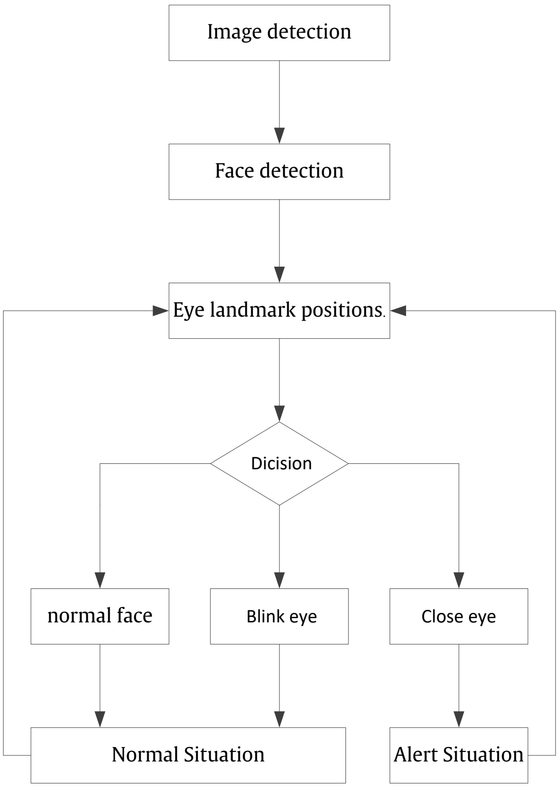

Figure 4 Diagram of the proposed system.

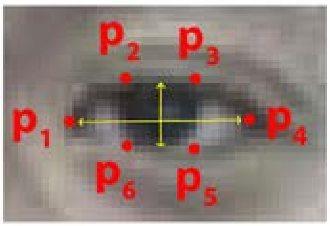

Figure 5 Eye landmark positions.

2. Calculating the effective area ratio (EAR) involves using the coordinates of specific facial landmarks. The measurement is determined by the horizontal separation between the two groups of prominent features located at the upper and lower regions and the vertical separation between the features positioned at the corners of the eyes. The equation representing the Effective Annual Rate (EAR) is as follows:

$$EAR = \frac{||P_2 - P_6|| + ||P_3 - P_5||}{2||P_1 - P_4||} \quad (1)$$

3. The thresholding process entails using a pre-established threshold to identify whether the eye is open or closed based on the calculated EAR. When the EAR lowers to a certain threshold, it indicates the closing of the eye, suggesting the presence of either

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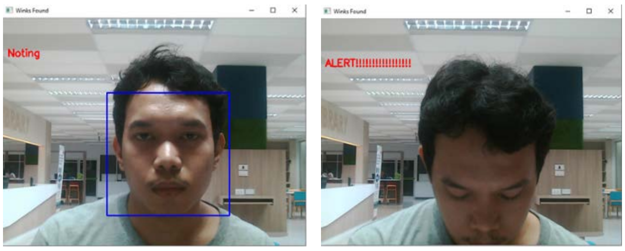
a blink or a state of drowsiness.

4. The proposed approach involves continuous monitoring of the EAR for a specified duration in order to identify instances of blinking. When the system detects a quick and substantial change in EAR values, particularly suggesting a blink, it triggers a blink event or alerts the system appropriately. The criteria used for blink detection, such as the rate of EAR change, might vary depending on the specific situation or objective.

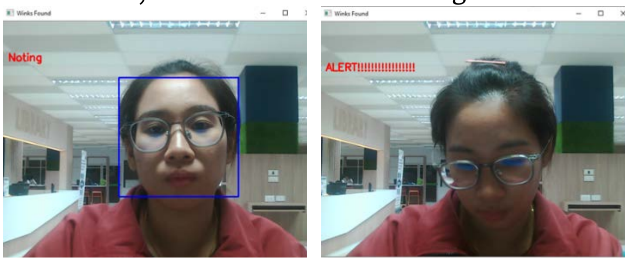
RESULTS AND DISCUSSION

The findings of the experiments that were conducted to determine whether or not weariness was present using a Raspberry Pi are shown in Figures 6 through 10. The principal experiment, which uses face detection, may be shown in Figure 6. This experiment is carried out in both daylight and nighttime settings. The gadget delivers acceptable performance in both regular and abnormal operating environments. The apparatus has the capability of determining whether or not the face is inclined in a downward position.

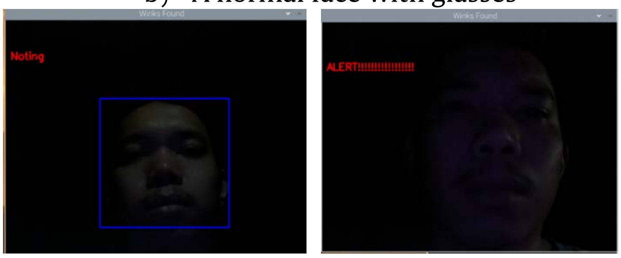
An experiment to detect the blinking of the eye is shown in Figure 7. It has come to our attention that the suggested system has the potential to function very effectively. In addition, Figure 8 displays the length of the blink, which varies from subject to subject since the amplitude represents the degree to which one's eyes are open. It comes to around 0.3 EAR in total.



a) A normal face without glasses

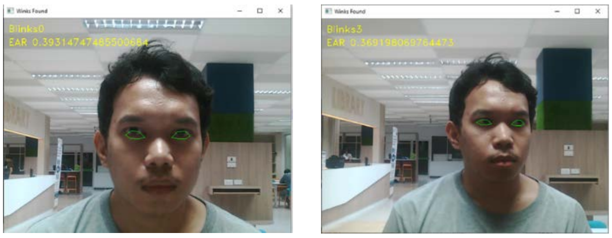


b) A normal face with glasses

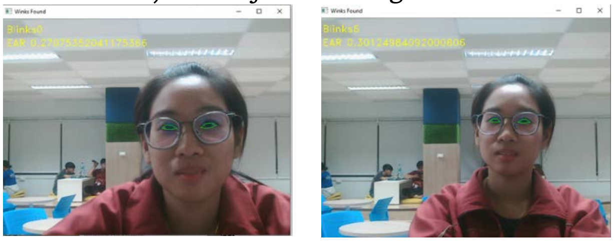


c) A normal face without glasses at nighttime

Figure 6 Face detection.



a) Blink eye without glasses



b) Blink eye with glasses

c) Blink eye without glasses in the nighttime

Figure 7 Blink eye detection.

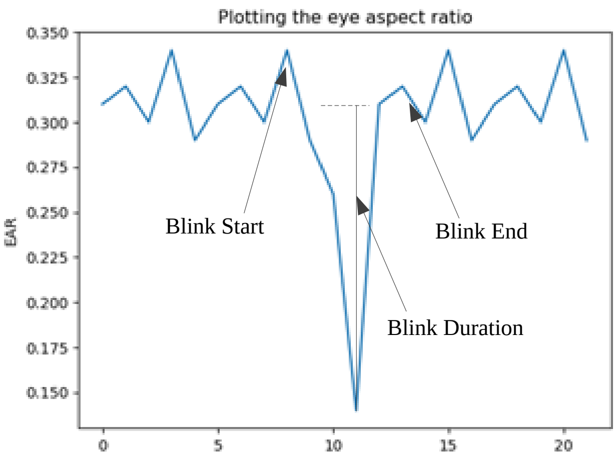


Figure 8 Blink eye illustration.

Figure 9 demonstrates that the approach effectively identifies squint eye problems, especially in conditions with limited light. The temporal extent of the syndrome known as squint eye is shown in Figure 10, which may be found here. The graph that illustrates the EAR demonstrates behavior that is analogous to the quick motion of an eye blink, although it persists for longer.

The proposed approach consistently generates correct outcomes via comprehensive assessment and testing, effectively detecting and alerting a fatigued motorist with a 96% success rate, regardless of the time of day. The accuracy is determined by analyzing 1000 photos, which were categorized into four groups: open eyes (250 images), closed eyes (250 images), open mouth (250 images), and closed mouth (250 images).

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However, other research findings may be compared to this proposed technique. In their study, M. Miranda et al. [10] suggested that the Internet of Things allows car owners to monitor driver fatigue effectively during work. The suggested technique employs the surveillance of eyelid movements to identify driver weariness. The technology sporadically notifies fatigued drivers. The online application expeditiously sends the report to the car owner. Testing demonstrated that the program warned driver experiencing sleepiness in 95% of cases. The research undertaken by Ashlin Deepa, R. N., et al. [11] focuses on the identification of tiredness and alcohol consumption by the use of an MQ3 sensor specifically built for alcohol detection. The car slows down when the driver's breath emits the scent of alcohol. The sensors are connected to the Arduino UNO. When experiencing weariness, the use of alcohol causes the LED to light up and the buzzer to activate. These conditions alter the car's speed. This system works on the Arduino UNO platform. Furthermore, G. Jung [12] introduces a prototype Internet of Things (IoT) system that improves the detection of sleepiness and alertness to avoid driving when fatigued. Sleepiness-detection technology included in wristbands monitors the driver's pulse rate and oxygen saturation levels. The stimulation persists until the RCS verifies the reinstatement of driver vigilance. In practical terms, the suggested system can detect driver weariness and reduce occurrences of driving while fatigued.

a) Squint eye without glasses

b) Squint eye with glasses

c) Squint eye without glasses in the nighttime

Figure 9 Squint eyes.

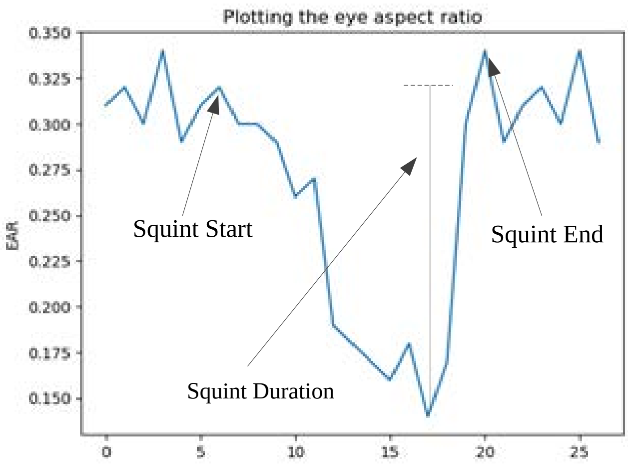

Figure 10 Squint eye illustration.

CONCLUSIONS

There has been an increasing academic focus on advancing and using eye blink detection algorithms for various purposes, such as identifying driver fatigue and evaluating cognitive workload. This article offers an overview of notable methodologies for eye blink detection and proposes an automated technique for identifying eye blinks via a face tracker. The implementation of this approach involves using a Raspberry Pi as a real-time system. The proposed approaches were subjected to rigorous experimental testing and qualitative assessment using datasets that included nighttime circumstances. The proposed approach consistently produces precise results via thorough evaluation and experimentation, efficiently identifying and notifying a drowsy driver with a success rate of 96%, irrespective of the time of day. The recommended technique exhibited a higher degree of precision. However, the study found the occurrence of false negative blinks due to the existence of unfixable noise in the collected signal. The observed auditory disturbance was ascribed to deliberate eye blinks, which tend to display an extended length.

Furthermore, the participants' use of spectacles with a high refractive index led to an amplified occurrence of light reflection, hence exacerbating the noise level. Finally, it was determined that the distance of the subjects from the camera had a role in the occurrence of this noise. In order to investigate the dynamics of eye movement, data was collected on the duration, frequency, and intensity of eye blinks. In future research, we aim to evaluate the proposed technique's effectiveness across more contexts. Furthermore, we want to conduct further analyses using other digital filters or their combination to attenuate signal interference efficiently. Also, we will conduct tests on the system under various weather situations, road kinds, and driving scenarios in order to assess its resilience and dependability.

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Simulation of flood protection using Hec Ras modeling: A case study of the Lam Phra Phloeng river basin

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ABSTRACT

The Lam Phra Phloeng reservoir, positioned within the Lam Phra Phloeng river basin and situated in Nakhon Ratchasimi province, assumes a substantial role in the realm of regional water management. During severe storms in the reservoir's upper region, excess water flows downstream, occasionally resulting in devastating floods in Pak Thongchai district, as witnessed in 2010 and 2020. Both flooding events have resulted in significant economic, social, and livelihood disruptions to the local population in the affected areas. This study pursues two primary objectives: firstly, to assess the extent of flood-prone areas across various return periods (2, 5, 10, 25, 50, 100, and 500 years); secondly, to employ Hec Ras modeling for an in-depth analysis of strategies aimed at flood prevention and mitigation within the Lam Phra Phloeng river basin. The Hec Ras modeling incorporates both 1D and 2D flow simulations. The findings reveal that the flood-prone areas, corresponding to the specified return periods, occupy 0.20%, 1.10%, 1.60%, 2.08%, 2.39%, 2.66%, and 3.17% of the total area in the Lam Phra Phloeng river basin, respectively. To safeguard against flooding and minimize its impact, a multifaceted approach is recommended, encompassing the construction of water barrier flaps, augmentation of water transmission and drainage capacity, implementation of flood alarm systems along the Lam Phra Phloeng river, installation of runoff stations, and the establishment of a comprehensive database system for flood and drought prevention. Among these measures, constructing water barrier flaps and enhancing water transmission and drainage capabilities stand out as effective strategies to protect the Lam Phra Phloeng river basin from flooding.

Keywords: Flood area, HEC RAS model, Flood protection, Structure measurement, non-structure measurement

INTRODUCTION

In 2010 and 2020, the Lam Phra Phloeng River basin experienced severe flooding, causing significant distress and harm to the local population. The primary cause of these floods can be heavy rainfall in the upstream and downstream areas of the reservoir, resulting in a substantial volume of water accumulating within the Lam Phra Phloeng reservoir, ultimately leading to overflow. These events resulted in widespread flooding, particularly affecting the Pak Thongchai district. Therefore, identifying flood-prone areas is paramount and warrants thorough evaluation [1, 2]. This information is crucial for the development of flood prevention and mitigation policies.

Generally, flood management strategies encompass two critical approaches: structural measures and non-structural measures [3, 4]. Both strategies have been widely adopted, not only in Thailand but also internationally, with their implementation varying based on the suitability for each specific region. Non-structural measures are often used in conjunction with structural measures to ensure a sustainable approach to flood prevention and management. These efforts aim to address and mitigate the challenges posed by flooding, safeguard the well-being of affected communities, and promote long-term resilience in flood management practices [5-11].

Structural measurements pertain to quantifying and assessing physical infrastructure intended to mitigate the repercussions of flooding. These entities encompass levees, dams, floodgates, and stormwater drainage systems. The meticulous measurement and evaluation of structural components are imperative to ascertain their efficacy during inundation events. This entails the continuous surveillance of water levels, structural integrity, and the operational capacity of flood control apparatus. Pervasive technological advancements, notably remote sensing, real-time monitoring, and Geographic Information Systems (GIS) have substantially augmented the precision and temporal relevance of structural measurements. These advancements facilitate informed decision-making by authorities during flood occurrences [12].

Conversely, non-structural measurements encompass the assessment of flood-relevant variables

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that are not directly associated with tangible infrastructure. These metrics predominantly encompass meteorological and hydrological data, such as precipitation patterns, river discharge rates, and soil moisture content. The comprehension of non-structural measurements holds pivotal significance in forecasting flood events, tracking their progression, prognosticating potential ramifications, and managing water. Contemporary tools, including weather radar, river gauging systems, and numerical weather models, have ushered in a paradigm shift in non-structural measurements, affording heightened precision in forecasting and early warning capabilities. These, in turn, are indispensable for the execution of timely evacuations and formulation of emergency response strategies [13].

Structural and non-structural measurements exhibit an intricate interplay, each complementing the other in a mutually reinforcing manner. The veracious non-structural data, such as precipitation forecasts and river discharge metrics, underpin decisions concerning the operational facets of structural elements like dams and floodgates. Simultaneously, structural measurements, encompassing the monitoring of levee conditions and embankment integrity, offer valuable feedback regarding their efficiency in attenuating flooding. Consequently, an integrated approach synthesizing structural and non-structural measurements constitutes an indispensable facet of comprehensive flood management. This confluence permits optimizing flood control systems while ensuring the populace remains well-informed and secure. The measurement and assessment of flooding comprise the dual facets of structural and non-structural measurements. Structural measurements are centered on the appraisal of tangible infrastructure intended for flood mitigation, while non-structural measurements are rooted in monitoring meteorological and hydrological variables. These two symbiotic methodological paradigms provide invaluable insights for flood monitoring, prediction, and emergency response. A holistic grasp of both structural and non-structural measurements is imperative for effective flood management and the amelioration of disaster risk in flood-prone regions within the purview of academic inquiry [14-15].

The objectives of this study are twofold: (1) to assess flood-prone areas at runoff various return periods of 2, 5, 10, 25, 50, 100, and 500 years, and (2) to analyze strategies for flood prevention and damage reduction in the Lam Phra Phloeng river basin using the Hec Ras modeling approach. This study employs the Hec Ras modeling method to simulate one-dimensional and two-dimensional flow conditions. Furthermore, the model can effectively depict areas at risk of flooding due to water volume exceeding the riverbank's capacity.

Study area: Lam Phra Phloeng river basin

The Lam Phra Phloeng river basin is entirely located in the Nakhon Ratchasima province and features a significant water reservoir, namely the Lam Phra Phloeng Reservoir. This reservoir, which serves as a dam on the Lam Phra Phloeng river, is a tributary of the Mun river, situated in the Takob sub-district, Pak Thongchai District, Nakhon Ratchasima province. The basin encompasses a total area of 807 square kilometers and is primarily designed for water retention purposes, with a normal retention level of 263 meters above sea level and a minimum retention level of 240 meters above sea level. This river basin covers 40 sub-districts in 7 districts, which are Wang Nam Khiew, Khon Buri, Pak Thong Chai, Chok Chai, Pak Chong, Sung Nein and Mueang districts presented in Figure 1. The reservoir has a storage capacity of approximately 106.30 million cubic meters. It is vital to provide water assistance for agricultural cultivation within the project area, covering 75,524 rai during the rainy season and 40,000 rai during the dry season. Additionally, it supplies water for the municipal water supply in Pak Thongchai district, Chok Chai district, and numerous rural communities, as well as for agricultural purposes outside the irrigation project area through natural water channels on an intermittent basis.

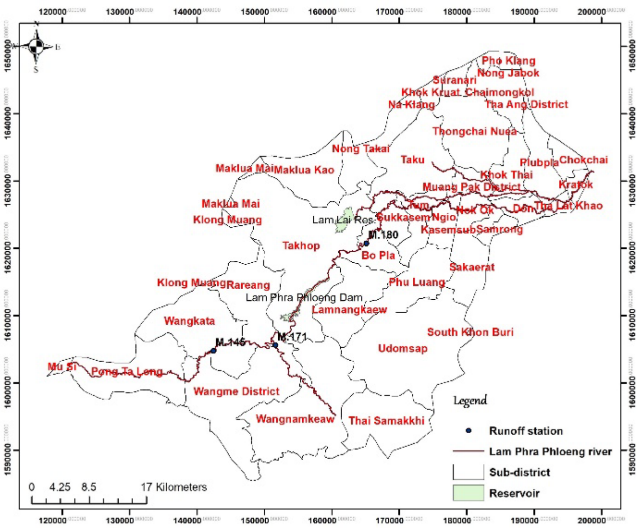

Figure 1 The sub-district in the Lam Phra Phloeng river basin.

This study utilizes land use data for the Lam Phra Phloeng river basin obtained through aerial and satellite imagery from the Department of Land Development. The study categorizes land use into five major types as follows:

1. The agricultural land primarily serves for the cultivation of rice, orchards, and a diverse range of crops, including mangoes, longan, jackfruit, papaya, lychee, guava, corn, sugarcane, various legumes, sesame, watermelon, chili, and others. This land category encompasses an expanse of 839,753.35 rai, representing 58.16% of the total area within the Lam Phra Phloeng river basin.

2. The forested land category encompasses a variety of forest types, including disturbed forests,

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primary forests, bamboo forests, mixed deciduous forests, and dense orchards, and spans across an area of 484,333.81 rai, representing 33.55% of the entire basin's land area.

3. Within the category of grasslands and suitable forests, formed because of human activities like shifting cultivation and road construction, notable plant species found in these areas include Napier grass, cogon grass, and Indian goosegrass. This land classification encompasses 39,156.14 rai, representing 2.71% of the total land area within the basin.

4. The classification of residential and industrial areas within the basin includes small to medium-sized communities, designated villages, religious institutions, educational establishments, government offices, and industrial complexes. This land category spans 63,988.53 rai, accounting for 4.43% of the total area within the Lam Phra Phloeng river basin.

5. The classification of water bodies within the region encompasses various natural water reservoirs, canals, and, notably, significant river confluences. This category extends over an area of 16,518.17 rai, representing 1.14% of the entire basin's geographical extent.

MATERIALS AND METHODS

The process conducted to facilitate flood area assessment using the Hec Ras modeling system consists of three primary phases: data collection, model setup, and model calibration and validation. Data collection involves acquiring relevant data and information necessary for the modeling process. Model setup pertains to configuring the modeling system, which includes defining parameters, establishing boundary conditions, and addressing other critical factors. Model calibration and validation encompass the adjustment and verification of the model to ensure its accuracy and reliability in replicating real scenarios. Following this, the calibrated and validated model is deployed to assess flood-prone areas across runoff various return periods, namely 2, 5, 10, 25, 50, 100, and 500 years. These stages collectively form the basis for a comprehensive and detailed analysis of flood-prone areas within the specified return periods. The specific intricacies of each phase are outlined as follows:

1. Data Collection

Hec Ras modeling employs five distinct methods for data collection, which are outlined as follows:

1.1 Data on the physical characteristics of the river basin area are employed to define the physical attributes of the river basin. These include information on river networks longitudinal river cross-sectional profiles along the entire Lam Phra Phloeng river, from its source to its confluence with the Mun river. Digital elevation maps (DEM) and river cross-sectional data are also collected. The river cross-sectional data is gathered from measurements at the river gauge stations of the Royal Irrigation Department and through additional survey efforts within this study, totaling 32 cross-sectional profiles.

1.2 Hydrological data comprise daily water flow measurements, utilizing data from various water gauge stations within the river basin of the Royal Irrigation Department. This includes the relationship between flow rates and water levels at these gauge stations. Data from station M.180 for the years 2008-2017 is used for the modeling. In cases where data is missing for some periods, the Hec Ras model is employed to generate data for those missing time intervals.

1.3 Data pertaining to the physical attributes of flood control structures holds significant importance in the context of river flow dynamics, as these attributes influence water flow patterns and volume regulation. Accurate information regarding the placement and dimensions of flood control structures positioned within river systems serves as essential input data for modeling processes, striving to replicate flow conditions with utmost fidelity to real scenarios.

1.4 In the domain of multi-purpose water issues and their management, problem data is pivotal in delineating the modeling parameters, particularly in regions susceptible to diverse water-related challenges. Conversely, management data serves to ascertain the constituent elements of the model, encompassing extant water management infrastructures.

1.5 Land use data is used to determine Manning's roughness coefficients and the coefficients for flood control structures in rivers. This data is essential for defining the boundaries and details in modeling, prioritizing flood-prone areas, and studying flood area management strategies.

2. Model Setup

The model setup process involves several steps to create the hydrological model of the study area.

2.1 Establish the river network of the Lam Phra Phloeng river by defining the relevant river network boundaries within the study area, from the Lam Phra Phloeng Dam to the confluence with the Mun river.

2.2 Specify boundary water conditions for the model, dividing them into inlet conditions at the upstream boundary and outlet conditions at the downstream boundary. These inlet conditions should include the flow rate discharged from the Lam Phra Phloeng Dam. The depth of flow is assumed to be constant.

2.3 Incorporate physical data, such as river cross-sectional profiles obtained from estimates based on surveyed cross-sectional data and ground elevation data for flood-prone areas. The river cross-sectional profiles are derived from data collected by the Royal Irrigation Department and the project's surveys.

2.4 The Hec Ras model is utilized to compute steady and unsteady flow conditions over time, represented by the following equations [16-19]:

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$$Y_2+Z_2+\frac{a_2V_2^2}{2g} = Y_1+Z_1+\frac{a_1V_1^2}{2g}+h_e \quad (1)$$

where Y is depth at the considered cross-section, Z is the elevation of the riverbed at the considered cross-section, V is average water flow velocity, a is the weight coefficient of velocity, g is gravitational acceleration and h_e is energy loss resulting from resistive forces due to compression and expansion of the cross-section.

$$h_e = L\bar{S}_f + C\left|\frac{a_2V_2^2}{2g} - \frac{a_1V_1^2}{2g}\right| \quad (2)$$

where L is the weight of the flow within the considered range, $\bar{S}_f$ is the slope of the frictional resistance force between two cross-sections and C = Coefficient of loss due to expansion or contraction of the flow path. The variable "L" can be calculated using Equation (3).

$$L = \frac{L_{lob}\bar{Q}_{lob}+L_{ch}\bar{Q}_{ch}+L_{rob}\bar{Q}_{rob}}{\bar{Q}_{lob}+\bar{Q}_{ch}+\bar{Q}_{rob}} \quad (3)$$

where L_{lob}, L_{ch}, and L_{rob} are the lengths of the cross-sectional areas defined for flooding on the left, the main river, and the right, respectively. $\bar{Q}_{lob}$, $\bar{Q}_{ch}$, and $\bar{Q}_{rob}$ represent the flow rates of the specified cross-sectional lengths for flooding on the left in the main river and on the right, respectively.

The Saint-Venant equations, which result from the combination of the continuity equation with the momentum conservation equation, are as follows:

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g(S_0 - S_f) = 0 \quad (4)$$

3. Model Calibration and Validation

The calibration and validation phases are fundamental and integral components in the refinement and improvement of the modeling process, serving as the bedrock for reliable and accurate simulations [20]. The dataset utilized for calibration and validation includes crucial parameters such as water levels, flow rates, and flood extent. Ensuring this input data's quality, accuracy, and spatial authenticity is a fundamental requirement for achieving dependable results within the Hec Ras modeling framework. The calibration process employed in this study is distinguished by its comprehensive methodology, which involves the integration of both graphical and numerical metrics for assessing model performance. The evaluation of simulated and observed hydrographs involves a rigorous graphical analysis, while the numerical performance evaluation is based on the overall water balance error [21]. This error is determined by quantifying the disparity between the average simulated and observed discharge, measuring the model's accuracy and dependability [22].

Model calibration was conducted after creating the model and importing data into the Hec Ras model. During the calibration process, the focus was on the flow rate data from station M.180, specifically for the year 2551. Adjustments were made to Manning's roughness coefficient (Manning's n) to ensure the model's realism and accuracy. The calibration results yielded a correlation coefficient (R^2) of 0.869, representing 86.90% and a Nash-Sutcliffe Efficiency (NSE) index of 0.816, indicating an accuracy of 81.60% [23-25].

To further evaluate the model's performance, model validation was performed using flow rate data from station M.180 for the year 2554. The validation results showed a high correlation coefficient (R^2) of 0.995, signifying 99.50% accuracy, and a Nash-Sutcliffe Efficiency (NSE) index of 0.993, indicating an efficiency of 99.30%. It's important to note that this study conducted a calibration and validation comparison for a limited two-year period due to complete data availability. These outcomes demonstrate R^2 values exceeding 0.5, indicative of a commendable level of agreement, further underscoring the fidelity of the model [26].

Table 1 The result of the confusion matrix.

GISTDA data (Reference data)	Hec-Ras Model		Row total
	Flood	Non-Flood	
Flood	3,451,600	1,929,600	5,381,200
Non-Flood	2,327,600	85,278,000	87,605,600
Column Total	5,779,200	87,207,600	92,986,800

The extent of flooding derived from the model was compared to the extent from a floodplain map that was generated using satellite imagery by the Geo-Informatics and Space Technology Development Agency (GISTDA). It was observed that the maximum flood extent determined by the model covered an area of 144.48 square kilometers. This was overlaid with the floodplain map from the year 2553 (B.E.) provided by GISTDA, which covered an area of 134.52 square kilometers. The model's accuracy was assessed using a confusion matrix [27], and the results are presented in Table 1. Statistical accuracy comparison using the confusion matrix revealed that the overlap accuracy between the flood extent obtained from the model and the GISTDA floodplain map was 95.40%.

Finally, the calibrated and validated model is deployed to assess flood-prone areas across runoff various return periods, namely 2, 5, 10, 25, 50, 100,

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and 500 years. This study calculated water levels and flooded areas under current conditions for return periods of 2, 5, 10, 25, 50, 100, and 500 years to predict the impacts of flooding. Various water data from hydrological analysis were used to create water level graphs for each return period. The maximum flow rate data measured annually at station M.180 from 2002 to 2018 was utilized for the Gumbel distribution method to calculate the recurrence intervals. This method was developed by the Lower Northeaster Region Hydrological Irrigation Center, Royal Irrigation Department, as Table 2. shows that the flow rate at the 2-year return period is 61.40 m^3/s, which is smaller than the flow rate at the 5-year return period by almost three times. Additionally, as we move from the 5-year return period to the 10, 25, 50, 100, and 500-year return periods, the flow rate increases by 100 m^3/s or 0.2-0.4 times. This observation indicates that the Lam Phra Phloeng river basin does not experience an immediate and drastic increase in water volume; instead, it gradually increases over time.

Table 2 The runoff/flow rate of return periods 2, 5, 10, 25, 50, 100, and 500 years.

Return period	Flow rate (m^3/s)
2	61.40
5	178.90
10	256.80
25	355.10
50	428.10
100	500.0
500	667.8

RESULTS AND DISCUSSION

The investigation outcomes involving flood simulations at different return periods employing the Hec Ras model, as well as flood event simulations post-implementation of barrier flaps and river dredging, are presented hereinafter.

1. The study of flood risk areas in various return periods in the Lam Phra Phloeng watershed reveals important insights. Figures 2 through 8 illustrate the calculated flood areas without additional flood protection structures in the current conditions, utilizing the flow rates at various return periods of 2, 5, 10, 25, 50, 100, and 500 years. The Gumbel distribution frequency analysis is employed to predict the probability of flood impact on specific areas. These flood areas result from the flow rates within the river system, leading to overflow and inundation of different areas. It's important to note that the model does not consider rainfall quantities within the watershed but focuses on the flow rates entering the watershed or flowing into the river/canal, as shown in Table 3.

Table 3 shows the extent of areas impacted by flooding in different return periods. Most flood-affected areas are in Pak Thong Chai district, with some parts of Chok Chai district also experiencing flooding. These flooded areas are closely situated along the Lam Phra Phloeng river. The Lam Phra Phloeng river overflow contributes to these areas' inundation. The findings of this study are consistent and aligned with the results of the floodplain study using the MIKE FLOOD model in the same area [28].

The flooded area in the 2-year return period is only 4.62 km^2, occurring along the river's natural course. However, with the increased water volume corresponding to the 5-year return period, the flooded area expands significantly to 5.5 times that of the 2-year return period. When examining Table 2, it is evident that the inflow into the river at the 5-year return period is 2.9 times that of the inflow at the 2-year return period. This observation indicates that an increase in water volume from the 2-year return period to the 5-year return period has a substantial impact on the occurrence of flooding.

2. Flood Prevention Plan using Structural measurement and non-structural measurement.

2. 1 Construction of water barrier flaps

In the context of mitigating flood impacts due to river overflow within the Lam Phra Phloeng river Basin, it is recommended that water barrier flaps be constructed. To make these plans actionable, detailed surveys of the affected areas should be conducted to design the barrier flaps effectively. In this investigation, initial evaluations of the locations and elevations of these flood control structures were considered, as detailed in Table 4. The study findings suggest that it is advisable to establish flood control structures along the river. Subsequently, the inundated areas post-construction of these flood control structures are delineated in Table 3 and Figure 9 to Figure 15, considering various return periods. The areas benefiting from the construction of these water barriers are as follows:

- For return period 2-yr: Tha Lad Khao sub-district, Phlapphla sub-district, Chok Chai district, Mueang Pak sub-district, Takhoo sub-district, Sam Rong sub-district, Pak Thong Chai district.
- For return period 5-yr: Phlapphla sub-district, Chok Chai district, Mueang Pak sub-district, Takhoo sub-district, Sam Rong sub-district, Pak Thong Chai district.
- For return period 10-yr: Phlapphla sub-district, Chok Chai district, Mueang Pak sub-district, Takhoo sub-district, Sam Rong sub-district, Pak Thong Chai district.
- For the return period 25-yr to 500-yr, the study area's affected flood extent is similar in both scenarios, with or without the water barriers. However, the magnitude of the affected area is reduced due to the presence of the water barriers.

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Table 3 shows that the construction of water barrier flaps significantly reduces the flooded area from the 2-year return period to the 100-year return period, with a reduction of over 40%. However, for the 500-year return period, considered an extreme and unlikely scenario, there is only a marginal 2% reduction in the flooded area. This minimal reduction is due to the high volume and topography of the Lam Phra Phloeng river, which cannot adequately accommodate the excess water. Therefore, the construction of water barrier flaps is paramount for flood prevention and damage reduction and should be given top priority.

2.2 Increasing Water Conveyance and Drainage Capacity

As the collective water drainage capacity of the Lam Phra Phloeng river can handle a 100-yr return period flood [29], it is imperative to augment the river's capacity at sections where it falls short of the 100-yr return period to ensure it can handle such floods. The details of these improvements are presented in Table 5.

Table 5 shows that the Lam Phra Phloeng river has segments where river dredging is necessary, a total 5 segments. Dredging these river segments allows for increased water conveyance. However, in segments km 20+535 and 79+861, the flow rate increases by only 5-7% due to the topographical conditions that limit dredging in more expansive areas. For segments km 84+757, 89+653, and 90+034, dredging results in a significant increase in flow rate of over 32%.

Table 3 Comparison of flood impact in cases with and without water barricades in the Lam Phra Phloeng river.

Return Period	Current Conditions		Water Barricades Conditions	
	Flood area (km²)	No. of sub-district	Flood area (km²)	No. of sub-district
2	4.62	14	1.88	9
5	25.53	16	15.09	12
10	37.28	16	18.85	12
25	48.42	16	38.51	15
50	55.63	16	50.94	16
100	61.83	16	48.07	16
500	75.10	17	73.74	17

Table 4 Positions and Heights of Water barrier flap in the Lam Phra Phloeng river.

Station (km.)	Barrier flap (m)		Station (km.)	Barrier flap (m)		Station (km.)	Barrier flap (m)	
	Left	Right		Left	Right		Left	Right
98+607.34	-	-	65+434.97	0.73	-	33+914	0.72	0.72
96+027.43	-	-	64+045.18	1.34	-	31+423.49	0.19	0.58
94+086.22	-	-	61+841.17	1.62	0.9	30+032.92	-	0.18
91+716.34	-	-	59+206.14	0.48	0.82	28+128.04	-	0.86
89+894.2	-	-	57+258.74	0.76	1.22	26+000	1.39	1.38
88+081.13	-	-	55+922.32	1.86	2.12	23+411.6	1.01	0.98
84+874.48	-	4.56	54+000	2.82	2.69	22+000	1.21	1.01
83+578.36	-	2.83	51+767.07	3.15	3.07	20+000	1.36	1.89
81+107.22	3.89	3.53	50+763.81	0.88	0.89	17+844.62	1.18	0.53
79+830.1	3.55	3.61	48+410.13	1.55	1.9	16+444.98	0.58	0.62
78+379.25	2.66	2.38	46+253.15	1.06	0.92	14+000	0.19	0.27
75+900.99	-	-	43+737.25	2.21	0.77	12+000	1.72	1.62
73+940.95	2.39	-	41+834.26	2.02	1.1	9+930.664	0.84	3.59
72+677.6	1.43	-	40+000	2.06	1.18	7+306.1	1.12	2.08
70+063.51	0.99	-	38+064.14	3.1	1.42	5+789.655	0.77	0.62
68+707.44	1.37	-	36+000	0.45	0.45	4+000	0.95	0.91
						1+588.808	0.41	0.28

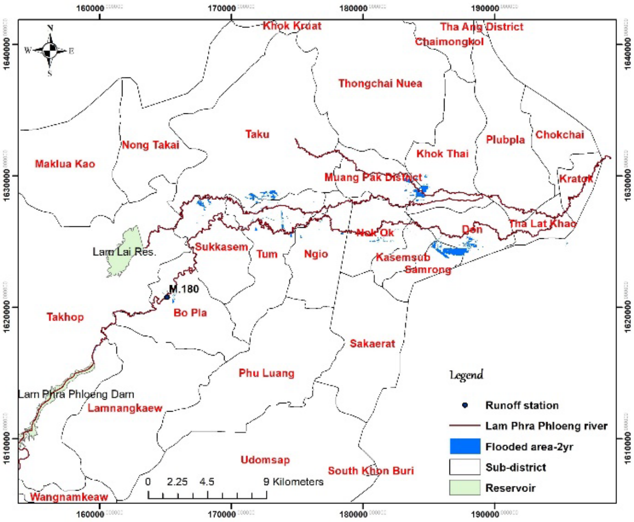

Figure 2 Flooded area in return period 2-yr.

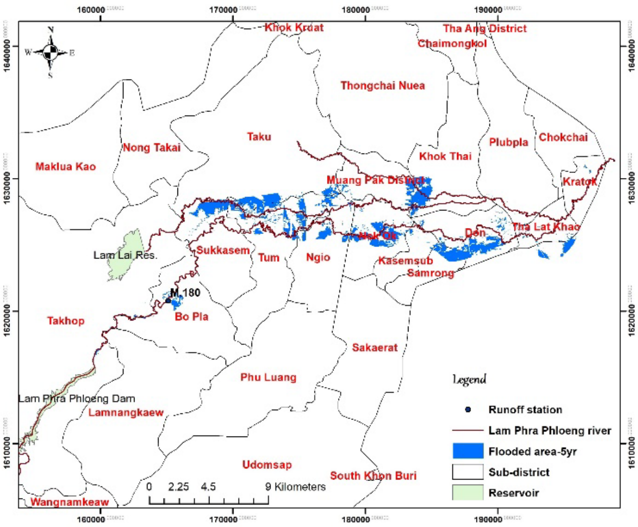

Figure 3 Flooded area in return period 5-yr.

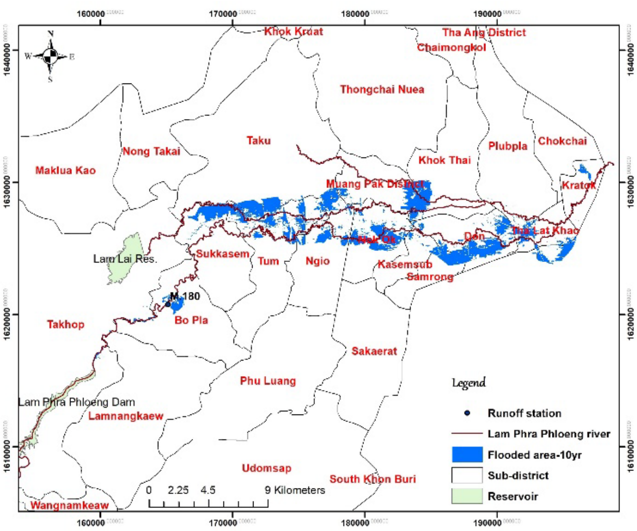

Figure 4 Flooded area in return period 10-yr.

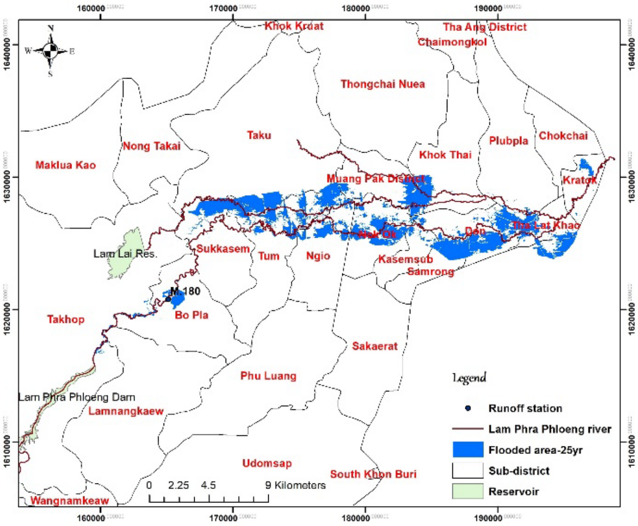

Figure 5 Flooded area in return period 25-yr.

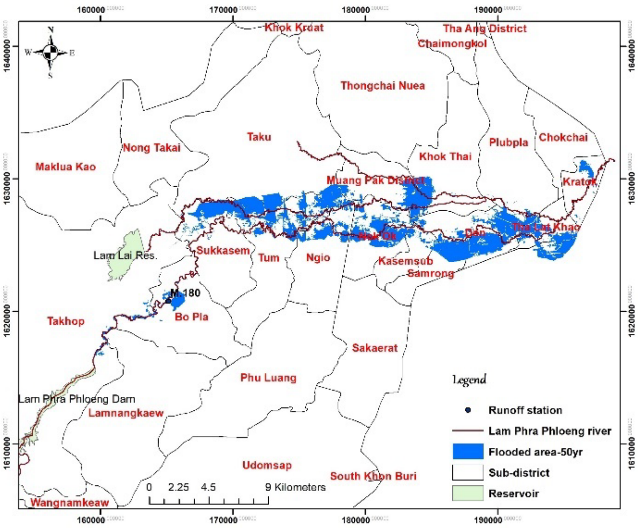

Figure 6 Flooded area in return period 50-yr.

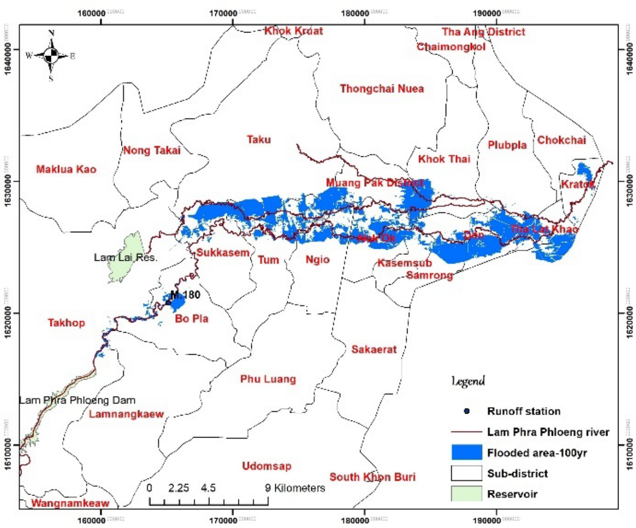

Figure 7 Flooded area in return period 100-yr.

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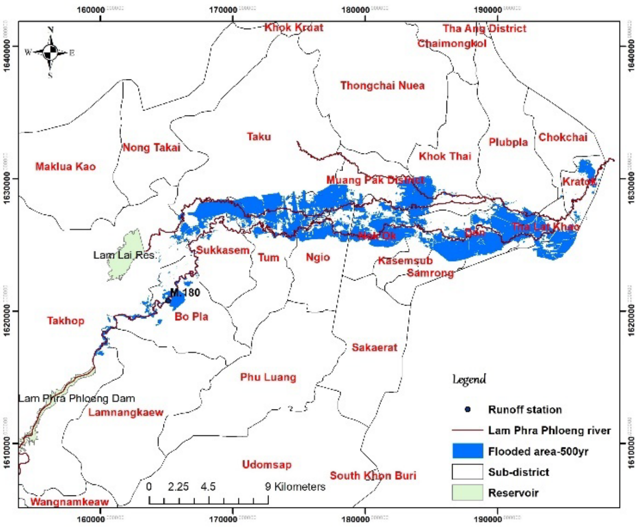

Figure 8 Flooded area in return period 500-yr.

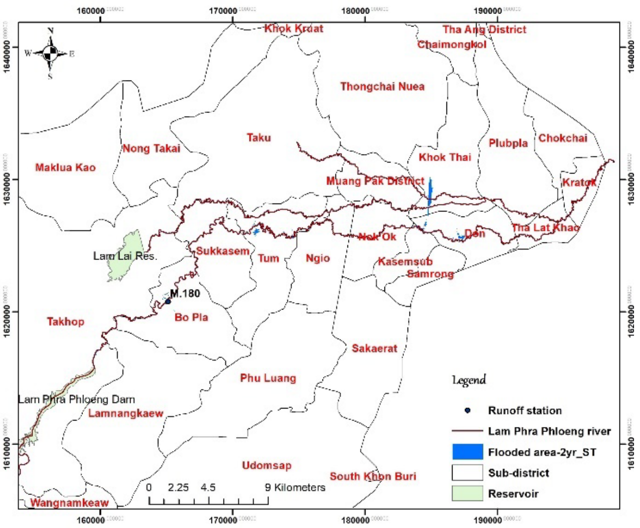

Figure 9 Flooded area in return period 2-yr with water barrier flaps.

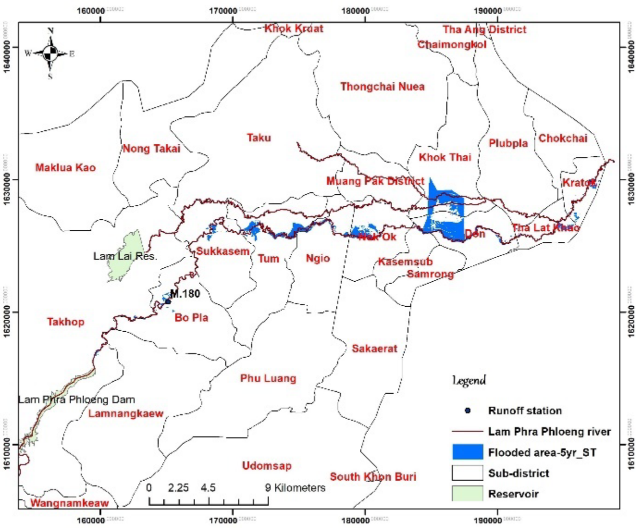

Figure 10 Flooded area in return period 5-yr with water barrier flaps.

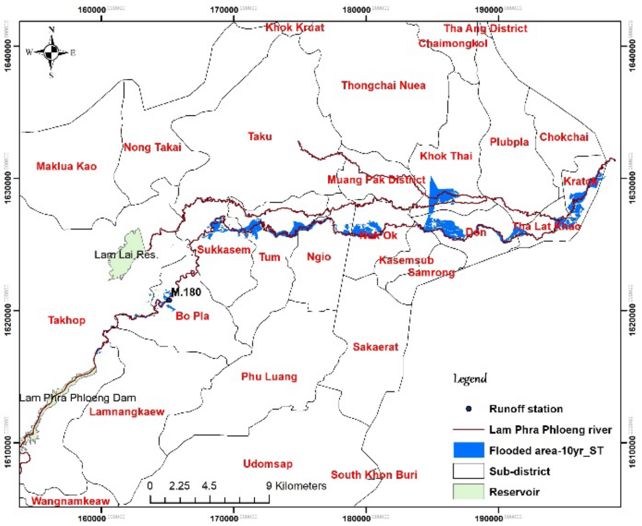

Figure 11 Flooded area in return period 10-yr with water barrier flaps.

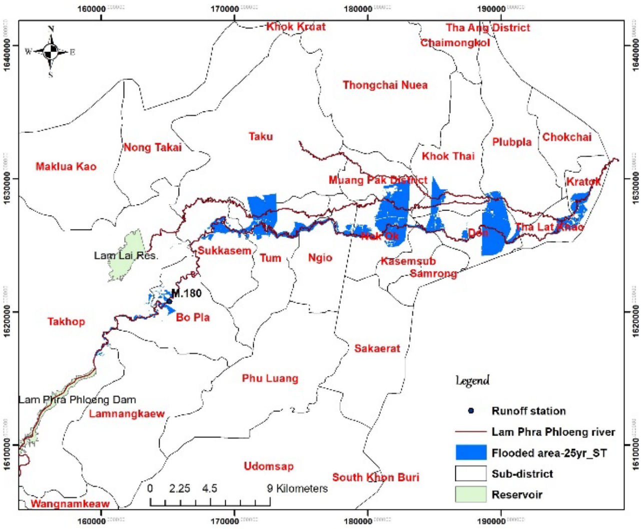

Figure 12 Flooded area in return period 25-yr with water barrier flaps.

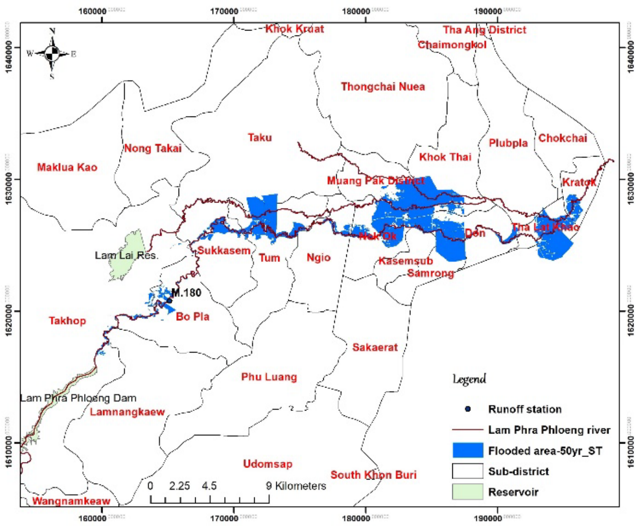

Figure 13 Flooded area in return period 50-yr with water barrier flaps.

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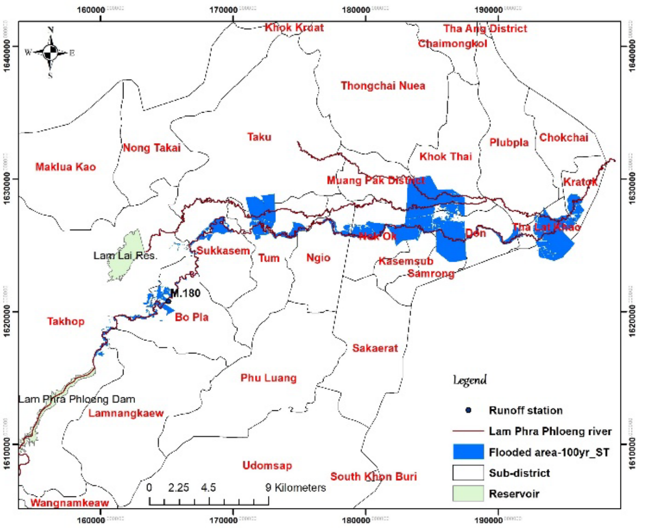

Figure 14 Flooded area in return period 100-yr with water barrier flaps.

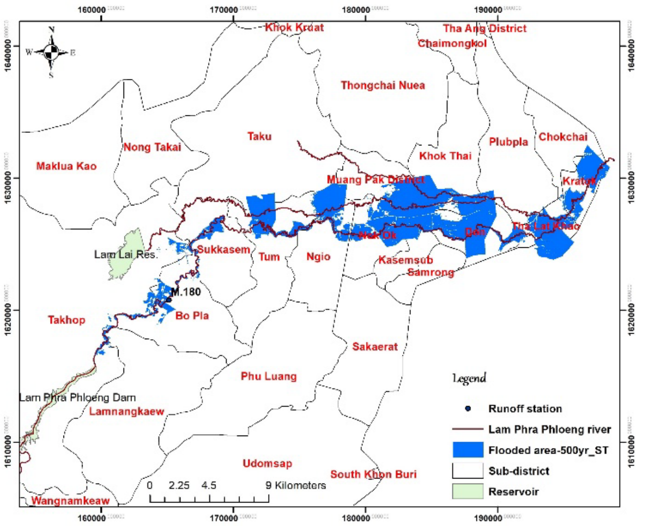

Figure 15 Flooded area in return period 500-yr with water barrier flaps.

Table 5 Positions for enhancing the potential of the Lam Phra Phloeng river in Pak Thongchai.

Km.	Coordinate		Location	Drainage Capacity (m^3/s)	
	UTM_N	UTM_E	Sub-district	Current	New
20+535	1625589.05	190231.50	Don	147.68	157.90
79+861	1622272.95	165919.48	Bo Pla Tong	412.68	434.73
84+757	1620773.17	165105.37	Bo Pla Tong	170.95	379.16
89+653	1619553.17	162908.27	Takhop	163.17	309.15
90+034	1619420.16	162632.48	Bo Pla Tong	497.11	656.18

Table 6 Surveillance flow rate for flooding.

Km.	UTM-N	UTM-E	Sub-district	Surveillance flow rate (m^3/s)
98+615	1615794.38	159864.06	Takhop	61.40
64+246	1626038.14	170494.48	Sukkasem	61.31
50+016	1626300.66	175841.20	Tum	56.07
43+438	1625923.28	178150.24	Ngio	61.40
33+328	1626345.08	183438.04	Nok Ok	54.85

2.3 Studying of river alarm system.

Implementing an alarm system in areas vulnerable to flooding can significantly reduce flood-related damages. In the Lam Phra Phloeng river Basin, the flood risk starts to materialize at the 2-yr return period or when water levels rise significantly either at the Lam Phra Phloeng Dam or in the vicinity of Tak Kho sub-district, Pak Thong Chai district, reaching 61.40 m^3/s. Relevant authorities should inform the residents of affected communities as well as those living near riverbanks and floodplain areas. These guidelines are presented in Table 6.

Table 6 shows that the Lam Phra Phloeng river has a total of 5 flood warning station locations. The average flow rate for flood warnings is 59 m^3/s. This study has identified the UTM-N and UTM-E coordinates for these station locations, enabling their utilization in determining the installation points for flood warning stations.

2.4 Additional location of runoff station

Due to the insufficient number of runoff stations and the missing data in some areas, increasing the quantity of these runoff stations and emphasizing the efficient and continuous collection of data is paramount. Also, these additional runoff stations can be applied to flood monitoring stations. Following the successful calibration and validation of the model, data collected from water level monitoring stations were incorporated into the model. Trial and error methods were applied to determine the suitable distances between these

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stations. The distances to install runoff stations along the river were identified as follows:

- Kilometer 0+530 in Krathok sub-district, Chok Chai district, which serves as the point where water from Lam Phra Phloeng river flows into the Mun river.
- Kilometer 30+166 in Don sub-district, Pak Thong Chai district.
- Kilometer 60+077 in Tum sub-district, Pak Thong Chai district.
- Kilometer 98+615 in Tak Kho sub-district, Pak Thong Chai district.

These runoff stations should be automated and equipped with data lockers to ensure systematic data collection and data continuity.

To effectively mitigate and minimize the repercussions of flooding in the Lam Phra Phloeng river Basin, it is imperative to implement a combination of structural and non-structural measures, as recommended by the research findings. Additionally, a heightened emphasis on enhancing the water network infrastructure and the establishment of a robust, comprehensive database system in the foreseeable future will play a pivotal role in proactively averting and alleviating flood-related damages within the Lam Phra Phloeng river basin. The water network, connecting primary rivers, tributaries, and reservoirs, will redirect surplus water to storage areas for regions facing water shortages. Furthermore, it is essential to consider flood mitigation measures that focus on minimizing flood-related destruction and storing excessive water during the rainy season for later use during dry periods.

Regarding the database system for flood and drought prevention, developing a comprehensive database system is paramount. This database should encompass various data types, including records of water levels, rainfall data, data from rain gauge stations, water level monitoring stations, meteorological information, land use data, elevation contours, river discharge capacities, reservoir storage volumes, flood-prone areas, areas with recurrent floods, and drought-prone regions, in addition to telemetry systems. These data should be made available in diverse formats, such as Geographic Information Systems (GIS), tabular representations, and textual descriptions. Furthermore, easy accessibility to this information must be ensured for all relevant agencies, with data updates conducted regularly, based on different update frequencies, ranging from hourly to yearly contingent upon the nature of the data.

CONCLUSIONS

In conclusion, this study has illuminated critical insights into assessing flood-prone areas within the Lam Phra Phloeng river Basin, offering valuable information for water management and disaster preparedness. The major findings of this research are as follows:

Firstly, the analysis of various return periods, spanning from 2 to 500 years, has revealed the extent of flood-prone areas within the Lam Phra Phloeng river Basin. These flood-vulnerable regions encompass 0.20%, 1.10%, 1.60%, 2.08%, 2.39%, 2.66%, and 3.17% of the total basin area, respectively. Predominantly, these areas encompass the majority of Pak Thong Chai District and extend into some parts of Chok Chai District.

Secondly, it has been established that the Lam Phra Phloeng river Basin experiences flood events primarily in its downstream agricultural lands. Notably, flooding occurs when the flow rate reaches 61.4 cubic meters per second at the river's starting point, corresponding to a 2-yr return period. It is essential to underline that flood-prone areas at this return period are relatively limited and do not significantly damage the Lam Phra Phloeng river Basin. However, the flood-prone areas at a 5- yr return period, with a water flow rate of 178.9 m^3/s, witness considerable expansion, signifying a critical range for flood monitoring.

Thirdly, it is imperative to implement strategic measures to mitigate the impact of flooding in the Lam Phra Phloeng river Basin. These measures should encompass the construction of water barriers and the augmentation of water transmission and drainage capacities. These initial projects hold the potential to considerably diminish the severity of flood events and reduce the ensuing damage to the basin. These insights form the foundation for informed decision-making and proactive flood management in the Lam Phra Phloeng river Basin.

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Fermentation of bamboo shoots using mature coconut water and its stability during storage at different conditions

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ABSTRACT

Fermented-bamboo-shoots are a common raw ingredient used in several Thai local dishes. However, contamination of harmful and undesirable microorganisms in the fermented bamboo shoots has been reported due to improper and long fermentation processes. Mature coconut water (MCW) could shorten the bamboo shoot fermentation process and improve the product quality. This study aimed to develop fermented bamboo shoots using mature coconut water and determine their stability during storage in different conditions. Bamboo shoots from Prachinburi province were mixed with 25 g/kg of Kosher salt and fermented with MCW to obtain fermented bamboo shoots with coconut water (FBSC) at room temperature. Traditional fermented bamboo shoots (TFBS), prepared using 100 g/kg of Kosher salt, were used as a control. After fermentation, the samples were packed in polypropylene (PP) or polyethylene terephthalate (PET) bags and stored at different temperatures for 60 days. The number of bacteria, pH, and total acidity (TA) were determined during fermentation and storage, as well as the color changes of the shoots. The results indicated that in the fermentation process, MCM with low salt concentration could effectively increase the number of lactic acid bacteria (LAB) greater than the traditional method. The number of LAB in FBSC was 9.78±0.43 CFU/mL of LAB, while TFBS had 8.08±0.02 log CFU/mL. Lower pH was significantly found in FBSC (3.89±0.01) than in TFBS (4.00±0.01), while TA of FBSC was significantly higher than that of TFBS, which were 11.25±0.01 g/L and 6.00±0.01 g/L, respectively. During storage, it was found that fermentation methods, types of packaging, and storage temperatures significantly affect the shoot colors but not pH and TA. PET bags could better delay the browning reaction of the fermented shoots than PP bags. The higher storage temperatures were, the faster color changes were observed. This study indicated that MCW could be used as fermentation media for bamboo shoots.

Keywords: Bamboo shoots, Coconut water, Fermentation, Stability

INTRODUCTION

Dendrocalamus asper, called in Thai Phai Tong, is one of the important bamboo species found in Thailand, especially in Prachinburi Province. They are commonly used for their edible shoots as they are sweet and have a unique taste. In addition, it was reported that the shoots contain certain nutritional values, including protein, carbohydrate, and fiber. They also have a good profile of minerals, consisting of potassium, calcium, manganese, and zinc [1, 2]. Since the shoots are very perishable and have a limited shelf life, They are generally preserved by boiling, drying, or fermenting [3, 4]. Fermentation of bamboo shoots is the most popular method to preserve the shoots as it is simple, requires less labor, and low cost. The fermented bamboo shoots could be prepared by peeling them and then slicing them into small, thin pieces. The thin pieces are then washed and mixed with salt, and kept in closed containers for at least 30 days before being ready to eat [4-6]. However, several reports mentioned the negative feedback of fermented bamboo shoots. Due to the long fermentation period, the fermented shoots could be contaminated with undesirable microorganisms such as *Escherichia coli*, *Staphylococcus aureus*, or *Clostridium botulinum* during fermentation and storage [7].

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Mature coconut water (MCW) is a waste product from the coconut milk industry. In Thailand, MCW might produce nata de coco, while some are discharged directly into the drain in large quantities, roughly 200,000 tons/year [8]. MCW comprises several types of sugar, such as mainly sucrose, sorbitol, glucose, and fructose, followed by minor sugars, including galactose, xylose, and mannose [9]. It was used as a rich, nutritious media for lactic acid bacteria fermentation [8, 10] reported that MCM was used as media for probiotic *Lactobacillus plantarum* DW12. Fermentation of the probiotic in MCW showed a sharp increase of cell density from 7.01 log CFU/mL to 8.34 log CFU/mL after 24 h of incubation and a significant increase of the total acidity with a significant drop of pH from 6.00 to 3.37. Similarly, it could effectively grow *Lactobacillus casei* Shirota from 7.4 x 10^8 CFU/mL to 2.5 x 10^9 CUF/mL after 12 h of fermentation [11]. These indicated that MCM could be used as a medium to shorten the fermentation time and reduce contamination risks. This study aimed to investigate the effects of MCW as a media on bamboo shoot quality during fermentation and storage.

MATERIALS AND METHODS

Preparation of mature coconut water (MCW)

Freshly mature coconut water (MCW) was purchased from the Uthong market in Pathum Thani province, Thailand. It was pasteurized at 100 °C for 30 min to reduce the risk of microbial contamination before use. MCW was measured for pH, total acidity, total sugars, total soluble solids using an abbe refractometer (Master refractometer, ATAGO, Japan), and total reducing sugars [12].

Bamboo shoot fermentation

Fresh bamboo shoots from Prachinburi Province were peeled, sliced, and soaked in tap water for 1 h to remove cyanogen [13]. The shoots were mixed with 25 g/kg of Kosher salt, less than the traditional method of 75%. The shoot was left at room temperature for 30 minutes before being squeezed and packed in a plastic bucket. The pasteurized MCW was added until it covered the shoots. The buckets were then tightly closed with a cover. The samples, named FBSC, were incubated at room temperature until the pH was below 4.6. Traditional fermented bamboo shoots (TFBS) were used as a control.

TFBS was prepared by following a traditional fermentation method from a local enterprise located in Prachinburi Province. Fresh bamboo shoots from Prachinburi Province, Thailand, were peeled, sliced, and soaked in tap water containing 10 g/kg of Kosher salt overnight. The bamboo shoots were then squeezed before mixed with 100 g/kg of Kosher salt and left for 30 min. After that, they were squeezed, packed in a plastic bucket, and added to drinking water until it covered the shoots for fermentation. The buckets were then tightly closed with a cover. TFBS were incubated at room temperature until the pH was below 4.6.

During fermentation, both FBSC and TFBS were taken to determine pH by using a digital pH meter (pH 700, Eutech), total acidity. By titration, the number of total lactic acid bacteria (LAB) is determined by a pour plate method in Lactobacillus de Man, Rogosa, and Sharpe (MRS) agar.

Stability of bamboo shoots during storage

After fermentation, TFBS and FBSC (40 g) were packed in polypropylene (PP) or polyethylene terephthalate (PET) bags. Twenty-five mL of saline water (4.85% NaCl) was then added to the bags before being sealed. The samples in bags were then pasteurized in boiling water for 30 min and left at room temperature overnight. The samples were then stored at 4 °C, room temperature (25±3 °C), and 35 °C for 60 days. During storage, the shoots were measured for their colors (CIE Lab scale), pH, total acidity, and the number of bacteria, yeast, mold, and *E. coli*.

Determinations

1. Total sugar, total reducing sugar, and total acidity

Total sugars were determined colorimetrically using the phenol sulphuric acid and expressed as percentage sugar [14]. The absorbance was measured at 490 nm and expressed as glucose concentration (mg/mL). Similarly, the reducing sugars were determined colorimetrically using 3, 5-dinitro salicylic acid (DNS) reagent. The absorbance was measured at 540 nm and expressed as glucose concentration (mg/mL) [14]. Total acidity (TA) was determined by the titration [15]. Three mL of samples were titrated with 0.1 N NaOH solution until their pH reached 8.2. Titratable acidity was calculated by following eq. 1 and expressed as g/L of lactic acid.

$$\text{Total acidity (g/L)} = (V_o \times N \times MW)/(V_s) \qquad (1)$$

where V_o was the volume of 0.1 N NaOH, N was the Normality of NaOH, MW was the Molecular Mass of lactic acid (90.08 g/mol), and V_s was the volume of the sample.

2. Color

The color of fermented bamboo shoot samples was measured using a colorimeter (WR-10QC, FRU, China) and reported in CIELAB color scales L*, a*, and b* values [16].

Total color difference (TCD) was also calculated by following eq 2.

$$\text{TCD} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \qquad (2)$$

where L* is the degree of lightness to darkness, a* is the degree of redness to greenness, and b* is the degree of yellowness to blueness.

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Microbial determination

The microbial determination for fermented bamboo shoots was carried out. 25 g fermented bamboo shoots were blended in 225 mL of phosphate-buffered saline (PBS), an isotonic buffer solution used for bacterial cell dilution, by a stomacher (Bagmixer 400, Interscience, France) for 60 s [17]. Appropriate dilutions from samples were made using sterile PBS water (9 mL). The samples were placed on 3M petrifilm aerobic count plates to determine total plate counts and 3M petrifilm *E. coli* count plates, while pour plated method was performed using MRS agar to measure for total lactic acid bacteria and yeast and mold by using potato dextrose agar by a pour plate method. The samples were then incubated at 35 °C for 48 h. The experiment was performed in triplicate, and the average number of colony-forming units per gram (CFU/g).

Statistic analysis

Each experiment was conducted three times. The influences of the various parameters were assessed by one-way analysis of variance (ANOVA) and the Duncan test for mean comparison. Differences were considered significant at a confidence level superior to 95%. The SPSS statistical program version 16.0 was used for the analyses.

RESULTS AND DISCUSSION

Mature coconut water (MCW)

MCW used in this study had 5 °Brix of total soluble solids, while pH and TA were 5.59±0.10 g/L and 1.17±0.21 g/L, respectively. It also consisted of 26.07±0.13 g/L of total sugar and 23.54±0.15 g/L of reducing sugar. These were important factors affecting the growth of bacteria. It was reported that MCW showed higher TSS (6.15±0.21 °Brix) than immature coconut water (IMCW) and overly-mature coconut water (OMCW), which were 5.60±0.14 and 4.85±0.17 °Brix, respectively [18]. The pH and TA of coconut water depended on fruit maturity. The pH of coconut water increased with fruit maturity. Tan et al. (2014) revealed that the pH of coconut water obtained from coconuts IMCW, MCW, and OMC were recorded at 4.78±0.13, 5.34±0.12, and 5.71±0.10, respectively [18]. Malic acid is the dominant organic acid in coconut water. In contrast with pH, coconut water's TA It was reported that TA of IMCW was 0.89 g/L, which was more significant than followed by those of MCW (0.76 g/L) and OMCW (0.61 g/L) [18]. The TSS and pH of the MCW could be useful in judging consumers' acceptance and spoilage potential. TSS value could indicate the sweetness of the coconut water, while pH of coconut water could affect its flavor, consistency, and shelf life [19]. In order to ensure quality control, it was suggested that MCW should have pH values between 5.3 and 5.8 and Total soluble solids (TSS) values between 3.9 and 5.5 °Brix [20]. These could affect the taste and flavor that consumers accept [19, 20].

Sugars are the main fraction of soluble solids in coconut water. Coconut water contains sucrose, sorbitol, glucose, and fructose, followed by minor sugars, including galactose, xylose, and mannose [21]. These changes in the sugar contents in coconut water could be due to the formation of sucrose at the expense of fructose and glucose. Researchers reported that during maturity, non-reducing sugar contents (sucrose) increased but decreased in reducing sugars (fructose and glucose) [22, 23]. MCW contained both reducing and non-reducing sugars. According to Rethinam and Krishnakumar (2022) [24], in the early stages of maturity, the sugars present were almost entirely reducing sugars, particularly glucose and fructose (>75%) [24], but in the latter stages, the non-reducing sugar (sucrose) content increased. Similarly, it was found that the MCW of malayan yellow dwarf yielded the highest sucrose (2.49 ± 0.11 g/100 mL), while young malayan yellow dwarf showed the lowest of that 0.54 ± 0.11 g/100 mL) [25]. Thus, the composition and physicochemical properties of coconut water vary with maturity of the coconut fruit. Moreover, it was revealed that coconut water could be fermented by *Lactobacillus plantarum*, *Bacillus clausii*, or *Saccharomyces boulardii* to develop symbiotic drink [26].

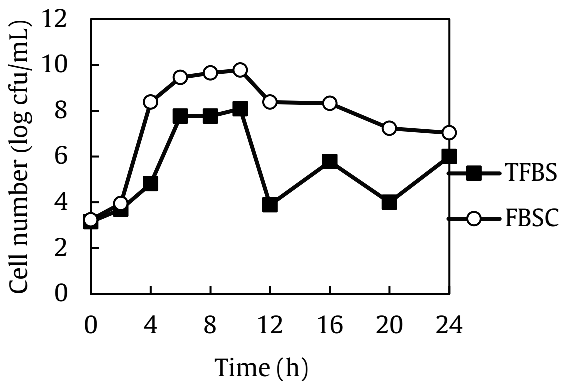

Figure 1 Total lactic acid bacteria of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) during storage at room temperature for 24 h.

Microbiology of fermented bamboo shoots

The number of LAB produced in the FBSC was significantly higher than in TFBS (Figure 1). After 24 h fermentation, the number of LAB of TFBS was increased from 3.15±0.21 log CFU/mL to 8.08±0.02 log CFU/mL, while FBSC had 9.78±0.43 log CFU/mL. These could be attributed to chemical compositions in MCW. It was revealed that MCW were composed of sugars, vitamins, amino acids and minerals. All of them were nutrient sources for microbial growth such as *Lactobacillus plantarum*, *Bacillus clausii*, or *Saccharomyces boulardii* [8, 26]. Moreover, pH of MCM was also suitable for

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bacterial growth. It was reported that lactobacilli could grow in a ranging pH between 4.5 and 6.5, while the optimal pH was between 5.5 and 6.2 [27, 28].

Bamboo shoots could be fermented by a mixture of LAB such as *Lactobacillus plantarum*, *Lactobacillus brevis*, *Lactobacillus curvatus*, *Lactobacillus delbrueckii*, *Leuconostoc citreum*, *Leuconostoc fallax*, *Leuconostoc lactis*, *Leuconostoc mesenteroides*, *Streptococcus lactis*, and *Pediococcus pentosaceus* [29]. In addition, salt concentrations also affected the number and diversity of the microorganisms during fermentation. Our results showed that FBSC, which contained 25 g/kg of salt, had a significantly greater number of microbes than TFBS, in which 100 g/kg of salt was used. Guan et al. (2022) [30] reported that salinity was a crucial factor shaping the variation in microbial community composition. Jing-Fang Shen et al. (2023) [31] found that the higher the salt concentration, the lower the microbes produced. Too high salt concentrations could reduce acid production, causing lactic acid bacteria to be less able to convert sugar, while promoting yeast growth [32]. This could indicate that the dual effects of MCM and low salt concentrations probably shorten fermentation time and reduce the risk of contamination.

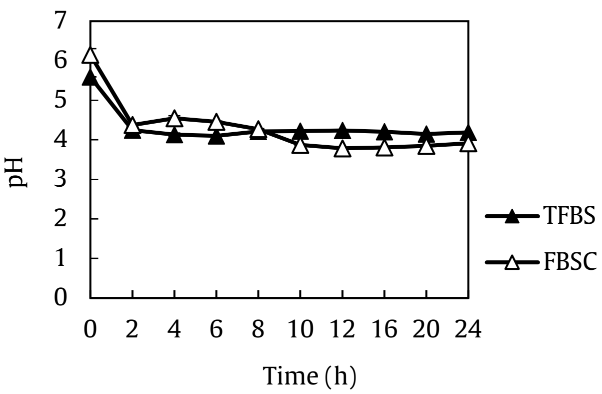

Figure 2 The pH of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) during fermentation at room temperature for 24 h.

During fermentation, dynamic changes in the physicochemical properties, including pH (Figure 2) and titratable acidity (g/L) (Figure 3) were observed. The pH value is an important parameter for fermentation. The decrease of pH and the increase of TA were mainly due to sugar consumption and the formation of organic acids, naturally occurring by lactic acid bacteria [31].

The pH of TFBS declined gradually from 6.00±0.00 to 4.00±0.01, while that of FBSC decreased from 6.15±0.16 to 3.89±0.01 after fermentation for 24 h. In contrast, titratable acidity (g/L) of TFBS and FBSC increased steadily from 2.00±0.07 g/L to 6.00±0.01 g/L and 5.85±0.21 g/L to 11.25±0.21 g/L, respectively. Bamboo shoots contain high amounts of carbohydrates, mainly polysaccharides, oligosaccharides, and monosaccharides. During the fermentation, LAB decomposed and utilized carbohydrates in bamboo shoots to produce organic acids, resulting in flavor formation. With the accumulation of organic acids, pH and TA were changed [33].

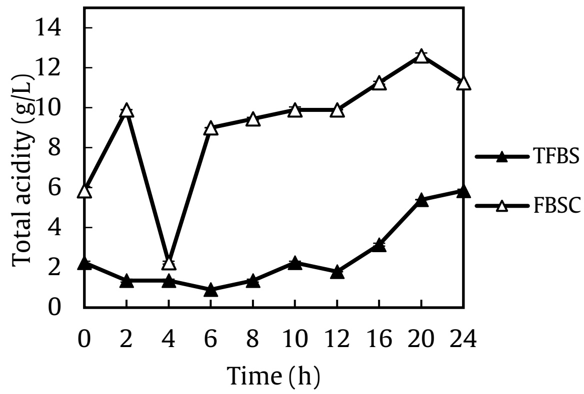

Figure 3 The total acidity of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) during fermentation at room temperature for 24 h.

Stability of fermented bamboo shoots during storage

1. Colors

Color changes of TEBS and FBSC stored in different conditions were observed. At day 0, the *L**, the lightness, of all samples was not significantly different, as shown in Figure 4. They were ranked between 56.3-63.4. At 4 °C after 60-day storage, it was found that types of packaging bags influenced the bamboo shoot colors.

FBSC and TFBS in PET (FBSC-PET and TFBS-PET) were lighter than those packed in PP. L* of TFBS-PET (61.63±1.00) was significantly higher than FBSC-PET (57.83±1.69), followed by TFBS-PP (56.57±0.25) and FBSC-PP (54.63±0.59) (Figure 4a). Similar results were shown in the samples stored at room temperature (RT). PET could protect the samples better than PP. The highest lightness was found in TFBS-PET, which was 63.03±0.64 and significantly different when compared with FBSC-PET (60.47±1.53), followed by FBSC-PP (59.37±1.57) and TFBS-PP (56.63±0.58) (Figure 4b). At 35 °C, L* of TFBS and FBSC were not significantly different, although different types of plastic bags were used. L* of FBSC-PET, TFBS-PET, and FBSC-PP were 55.33±0.93, 56.13±1.05 and 56.70±0.56, respectively. L* of TFBS-PP (58.53±0.21) was significantly greater than others but not significantly different when compared with FBSC-PP (Figure 4c).

The a* could indicate a darker brown color of the bamboo shoots. The greater a* was shown, the redder the samples would be observed. The results showed that the samples' redness increased with the storage temperature. After storage for 30 days at 4 °C, the a* of FBSC-PP (8.03±0.74) was significantly higher than TFBS-PP (5.93±0.87), while FBSC-PET (4.10±0.96) and TFBS-PET (3.70±0.17) were not significantly different (Figure 5a).

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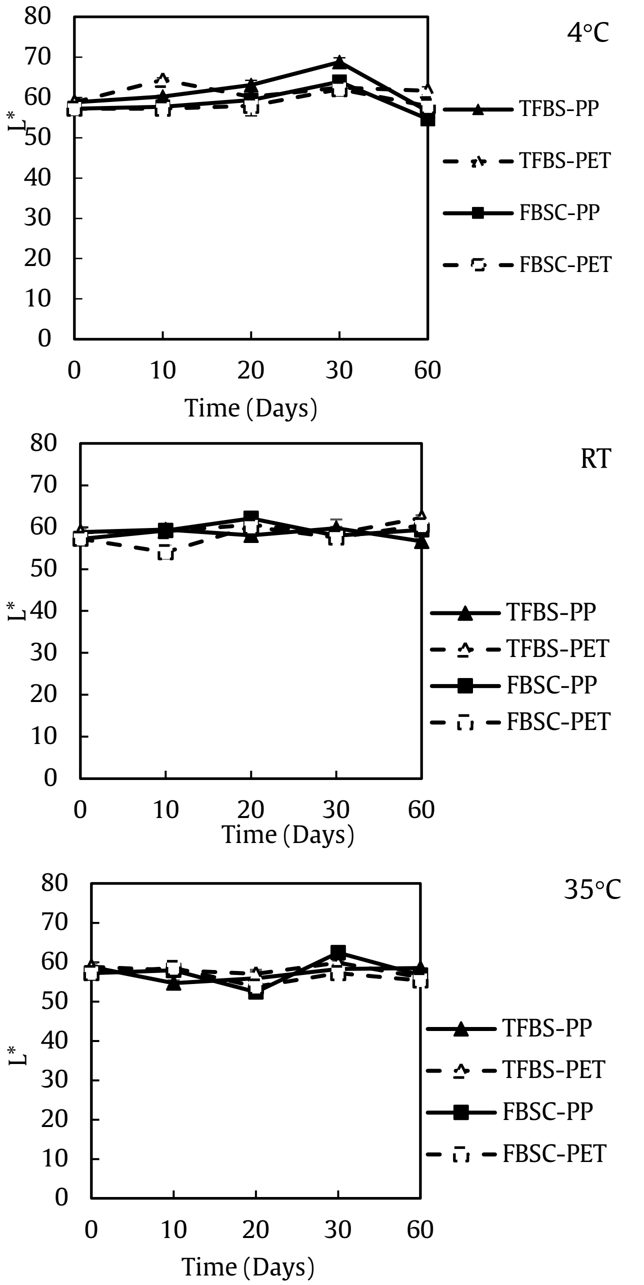

Figure 4 The color of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) in polypropylene (PP) or polyethylene terephthalate (PET) during storage at 4 °C (4a) RT (4b) and 35°C (4c) for 60 days.

The a* of the samples stored at room temperature (RT) or 35 °C increased more noticeably than that at 4 °C. At RT after 60 days of storage at RT, a* of FBSC-PP (5.37±0.49) and FBSC-PET (5.53±0.49) were significantly lower than that of TFBS-PET (7.43±0.25) and TFBS-PP (8.03±0.40) (Figure 5b). Similarly, a* of the sample stored at 35 °C, regardless of packaging types, FBSC was significantly less red than TFBS. The highest a* was observed in TFBS-PP (9.73±0.15), followed by TFBS-PET (6.13±0.06), FBSC-PET (3.63±0.15) and FBSC-PP (3.27±0.31) (Figure 5c).

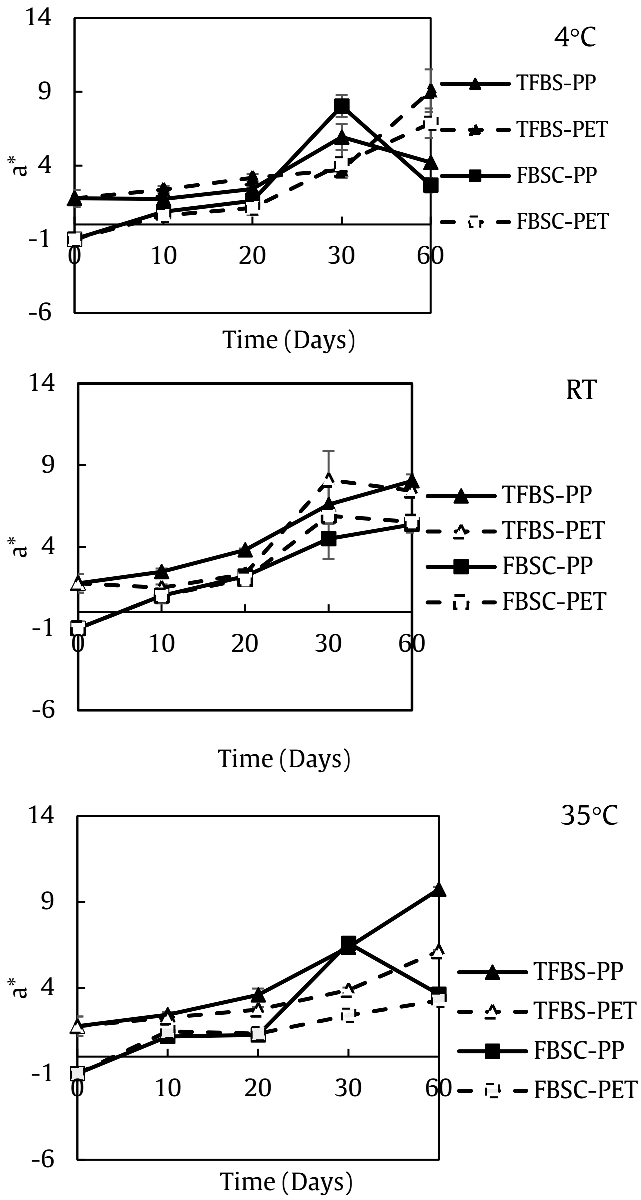

Figure 5 The greenness (a*) of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) in polypropylene (PP) or polyethylene terephthalate (PET) during storage at 4 °C (5a) RT (5b) and 35°C (5c) for 60 days.

The b* indicates yellow color. The greater b* was, the more yellowish the sample would be. The results were reported that after storage for 60 days at 4 °C, b* of all samples increased; TFBS-PET (6.13±0.06) was higher than FBSC-PP (3.27±0.31), but they were not significantly different. However, they were significantly greater than FBSC-PP (11.63±1.02) and TFBS-PET (11.93 ±0.93) (Figure 6a). When the storage temperatures were elevated, b* of all samples significantly increased (Figure 6b and 6c). Evidently, at 35 C, b* were ranked between 16.57-21.4. TFBS-PP (21.40±0.30) and FBSC-PP (20.93±0.78) had higher yellowish than FBSC-PET (18.83±0.67) significantly, followed by TFBS-PET (16.57±0.49).

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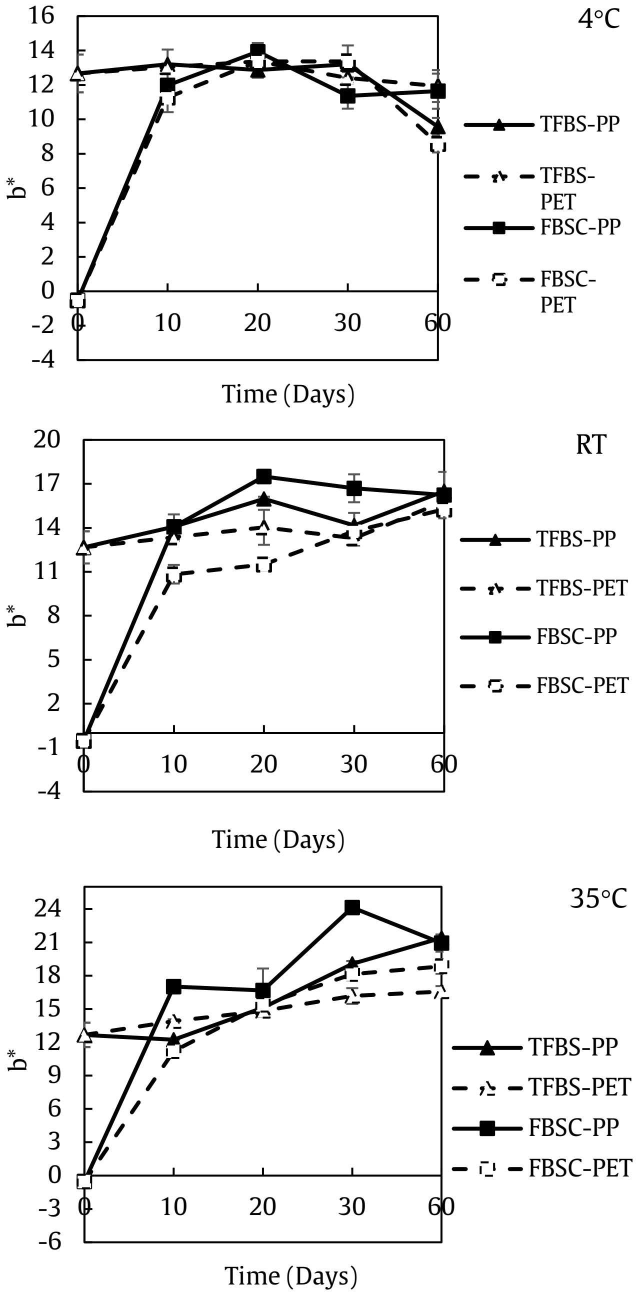

Figure 6 The color b* of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) in polypropylene (PP) or polyethylene terephthalate (PET) during storage at 4 °C (6a) RT (6b) and 35°C (6c) for 60 days.

TCD is an index of color change during storage. The color change greater than 2 is visible [34]. According to our study, several factors affected the color changes of the fermented bamboo shoots during storage, including fermentation methods, types of packaging, and storage temperatures. After storage for 60 days, the results showed that fermentation with MCM had higher changes than the traditional methods. Regardless of storage temperature and packaging types, TFBS showed less TCD than FBSC. Noticeably, TFBS-PET (7.54±1.23) and TEBS-PP (7.78±0.58) were significantly lower than FBSC-PET (17.43±0.18) and FBSC-PP (18.16±1.58) when they were stored at RT. Similarly, at 35 °C, FBSC-PET (20.03±0.67) and FBSC-PP (21.91±0.77) were significantly higher than TFBS-PET (6.81±1.43) and TFBS-PP (11.86±1.05) (Figure 7).

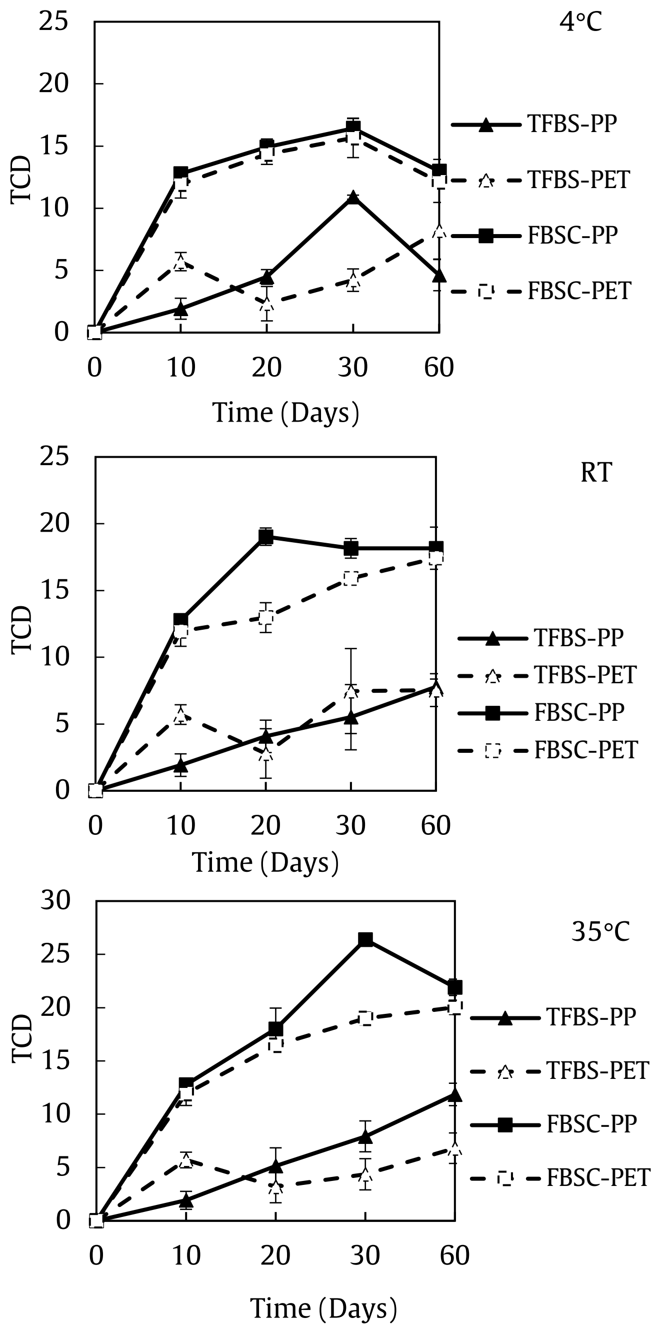

Figure 7 Total color difference of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) in polypropylene (PP) or polyethylene terephthalate (PET) during storage at 4 °C, room temperature (28 °C), 35 °C, for 60 days.

This would contribute to the anti-browning activity of salt [35]. It was reported that salts could delay the browning reaction. Their efficiency was different depending upon their chemical compositions. Anti-browning activity of salts was greatest when

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sodium, potassium, or calcium ions bind with chloride or phosphate, followed by sulfate and nitrate. Tissue extracted from chloride- and fluoride-treated slices showed polyphenol oxidase (PPO) activity, the same as that of control (non-treated slices). However, the PPO activity dropped when the slices were added to NaF and NaCl solutions. The level of polyphenols in treated slices was NaF > NaCl > control [36].

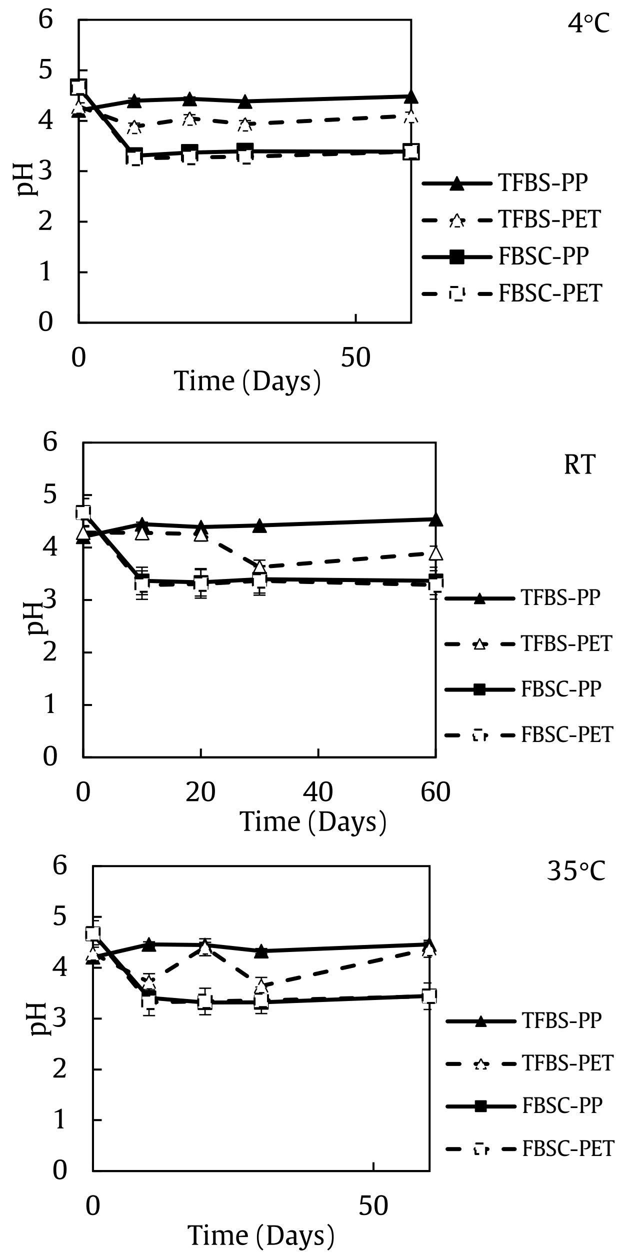

Figure 8 pH changes of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) in polypropylene (PP) or polyethylene terephthalate (PET) during storage at 4 ºC (A), room temperature (B), 35 ºC (C) for 60 days.

In addition, chemical reactions during fermentation, including non-enzymatic browning, enzymatic browning, and maillard reaction, could cause the color change in bamboo shoot. As bamboo shoot cells contain lutein and chlorophyll, they are generally yellowish green. These pigments could be degraded by acids produced during fermentation process. Moreover, the bamboo shoots could undergo maillard reaction, resulting in browning, and loss of original color [37, 38]. Ngadze et al. (2018) [39] reported that blanching bamboo shoots at 100°C for 10 min could inactivate endogenous enzymes, causing the shoots to become lighter. Moreover, the increase in temperature affected the total color difference and b*. The shoots turned darker yellow at a higher temperature due to color degradation and non-enzymatic browning reaction [40, 41].

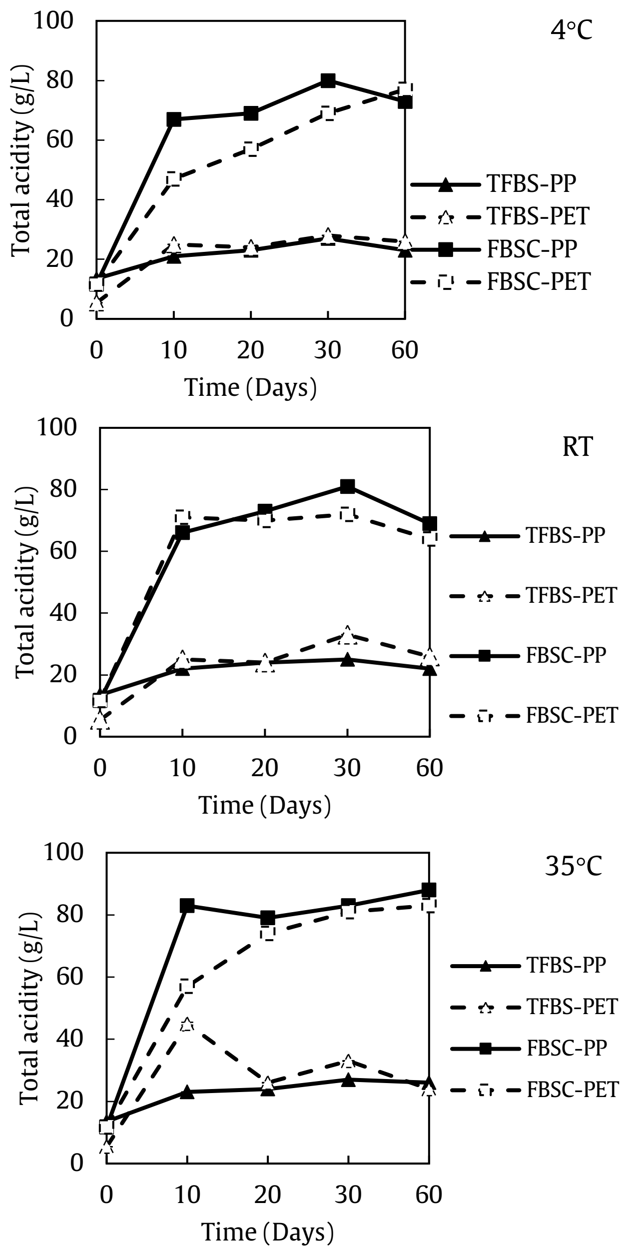

Figure 9 Total acidity of traditional fermented bamboo shoots (TFBS) and fermented bamboo shoots with coconut water (FBSC) in polypropylene (PP) or polyethylene terephthalate (PET) during storage at 4 ºC, room temperature, 35 ºC for 60 days.

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According to the results, PET bags could delay the color changes of the fermented bamboo shoots during storage. Package materials can limit gas and water vapor or moisture penetration, affecting rates of oxidation and browning reactions [42, 43]. It was found that PET showed better barrier properties in prolonging the shelf-life of shelled bamboo shoots than PE and PVC, when they were stored at room temperature and 10 °C [44]. PET jars were reported to have greater ability to retain the quality of cookies supplemented with 6% and 8% bamboo shoot powder and dietary fiber than LDPE pouches when stored at ambient conditions for 90 days [45]. On the contrary, PP has a moderate barrier to moisture, gases and odors, compared to PET [46]. Types of packaging could influence the translucence and colors of samples. It was found that only PP packages failed to protect litchi fruit from browning reactions during storage at room temperature for 5 days [47].

pH and total acidity

The changes in pH of TFBS and FBSC during storage at different conditions are shown in Figure 8. The pH of FBSC and TFBS on day 0 was 4.67±0.01 and 4.29±0.05, respectively. After storage for 60 days at 4 °C, pH of all samples decreased (Figure 8a), however, they were not significantly different. At RT, pH ranged between 3.29±0.04 (FBSC-PET) and 4.54±0.02 (TFBS-PP) shown in Figure 8b. At 35 °C, the maximum pH value was found in TFBS-PP, which was 4.46±0.01and the lowest pH was 3.44±0.05 belonging to FBSC-PET (Figure 8c).

During storage, TA was significantly increased (Figure 9). Regardless of fermentation methods, non-significant differences were found between PP and PET bags. Niazmand et al. (2021) observed that titratable acidity contents of barberries packaged in different films increased by 38% after storage for six months [48].

Microorganisms

During storage, TFBS and FBSC were measured for microorganism analysis. The results showed that all samples had a total plate count of bacteria, coliforms, yeast, and mold less than 30 CFU/g. Storage conditions have an important effect on the quality of fermented foods through the activity of various microbes. Several studies showed the quality characteristics of fermented bamboo shot products during storage.

Pasteurization processes used in the industry do kill microorganisms in foods; they only target pertinent pathogens and lower levels of spoilage organisms that may grow during storage and distribution [49]. Cho and Song (2021) inactivated microorganisms in Korean vegetables "doenjang" by conventional heat treatments. Less than 10^1 CFU/g in doenjang were reduced when the product was heated at 75 - 85 °C for 60 min. The inactivation effect was partially improved when the heating temperature was 105 °C for 20 min. Mold, yeast, and vegetative cells with weak heat resistance could be inactivated at 100–105°C [50]. Similarly, it was reported that one-log reduction of vegetative bacteria, such as *E. coli* and *Salmonella* spp could be achieved by heating samples at 70 °C for 1 min. 90% of *Aeromonas hydrophila* and yeast could be killed within a few seconds at 60 °C [51].

CONCLUSIONS

Mature coconut water could improve the fermentation process of bamboo shoots. The number of lactic acid bacteria was higher than the traditional method. During storage, fermentation methods, types of packaging, and storage temperatures significantly affect the shoot colors but not pH and TA. Mature coconut water had no positive effects on the color of the fermented shoot. PET bags could better delay the browning reaction of the fermented shoots than PP bags. This study indicated that MCW had the potential to be used as a low-cost fermentation media for bamboo shoots, which could help shorten the fermentation time and reduce risks of contamination for traditional fermentation.

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Combining vehicle routing and bin packing problem for vehicle routing planning: A case study of a chemical factory

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ABSTRACT

In the logistics distribution process, effective transportation management is required to ensure quality and timely delivery. In addition, transportation must be more economical and faster. The case study company is a chemical plant, an industrial company that produces products for hygiene and cleaning. The delivery manager plans the transportation routes based only on her experience because no decision-making aids are available. In addition, the manager considers the shipping order from first to last when arranging the products on the transportation vehicles. The goods for the final delivery location are placed at the back and bottom of the delivery truck. This cannot guarantee that the transportation routes set by the manager are suitable. Therefore, this study aims to plan delivery routes, arrange items in trucks, and reduce transportation costs for a case study of a chemical factory by using vehicle route problems and container filling problems. Then, the program is developed in Python using the Saving Algorithm, the 3D First Fit Decreasing Algorithm, and the 3D Best Fit Algorithm. The results show that the program method can reduce the use of transportation vehicles from 19 to 14, which is 26.32%; reduce the total distance from 5,499.8 kilometers to 3,406.92 kilometers, which is 38.05%; reduce the wages of transportation vehicles from 36,666 to 24,993 baht, which is 31.84%; can increase the average total weight per vehicle from 961.22 to 1,319.71 kilograms, which is 37.30%; and increase the average space utilization per vehicle from 37.93% to 51.47%, which is 13.54%. This method can reduce costs and increase efficiency for the company. Finally, the developed program also supports inexperienced operations managers in making decisions when planning transportation routes and loading goods, Thereby saving working time.

Keywords: Vehicle routing problem, Bin packing problem, Saving algorithm, 3D first fit algorithm, 3D best fit algorithm

INTRODUCTION

In the logistics distribution process, effective delivery management is required to ensure high-quality and timely delivery. In recent decades, operations research and mathematical programming techniques have been developed to optimize the delivery of goods and services in distribution systems [1]. The optimization challenge posed by many transportation issues requires customized algorithms to be easily solved by computer analytics [2].

The case study company is a Chemical Factory, an industrial company that produces hygiene and cleaning products. The warehouse delivers 200-300 orders per day. For this reason, the company needs many vehicles every day. The company rents trucks from third-party service providers and charges a daily fixed fee per vehicle. However, the manager will consider the transportation route as follows: (1) Bangkok and the surrounding areas are divided into districts. (2) Provincial areas are separated by zip code. The distance and appropriateness will be considered as well. The manager will take the order of shipping from first to last into consideration while arranging products onto transport vehicles. The final delivery location's goods will be put at the back and bottom of the delivery truck. Since all order information is completed by 4.30 p.m., the manager begins routing daily at 4:30 p.m. and finishes at around 6:00 p.m. Please note that the employee gets off work at 5:30 p.m. The delivery manager arranges the transportation routes based only on her experience because there are no decision-making tools accessible. This cannot guarantee that the

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transportation routes the manager decided are the most suitable and use the fewest vehicles. Thus, transportation costs can be decreased by planning effective routes for transportation.

The vehicle routing problem, one of the most studied topics in operational research, arises from the fact that the distribution of products is influenced by a variety of factors, including those arising from the needs of transportation companies, customers, and the external environment [3]. The Bin Packing Problem (BPP) is about arranging a set of products that all have a positive length and packing the products into as few bins as possible. Furthermore, the total length of the products in a bin must not exceed the allocated capacity of the bin [4].

This study deals with the problem of vehicle routing in combination with the problem of storage space occupancy. The combination of these two problems could help the company reduce costs more successfully. Accordingly, this study aims to plan delivery routes, arrange items in trucks, and reduce transportation costs for a case study of a chemical plant by using a VRP and storage space problem program. Thanks to a route-planning program, the company will be able to work more effortlessly. It also allows the company to maintain and grow its market share and have a direct impact on customer satisfaction. Sustainability and environmental aspects can also be affected.

The remainder of this article is organized as follows: A literature review on VRP and bin packing is given in Section 2. The problem statement and assumptions are described in Section 3. Then, we investigate the solution methods in Section 4. Section 5 shows the results and discussion. Finally, Section 6 draws a conclusion and gives recommendations for future work.

MATERIALS AND METHODS

Literature reviews

1. Vehicle routing problem

In the last sixty years, vehicle routing problems (VRP) have been studied extensively and in rapid succession [5]. The Vehicle Routing Problem as a mathematical programming model was developed by [6]. The Vehicle Routing Problem is an extension of the Traveling Salesman Problem (TSP). The VRP is both an NP-hard problem and a combinatorial optimization problem. The number of studies in this field is increasing rapidly, which leads to extending the VRP to several variants to make it a real-world problem. Researchers have tried to develop precise approaches, heuristics, and metaheuristics to solve the problem [7].

Many researchers and industry practitioners have developed vehicle routing for managing logistics operations and have modeled these logistics challenges. An improved metaheuristic moth-flame algorithm is used for electric vehicle routing. Battery capacity and visits to charging stations are taken into account [8]. A supply chain design strategy for organ transplants and a mathematical model were proposed by [9]. The described mathematical model aims to establish a link between the different implementations of the chain to ensure that people's irregular demands are met and the overall cost is minimized. A novel version of VRPD extends the traditional truck-drone delivery problem to a two-echelon network, taking into account a number of real-world constraints, such as consumer deadlines and drone energy capacity [10]. Routing problems with multiple vehicles have a maximum capacity constraint and no time constraint. They found that the TABU search proved to be better than other algorithms in terms of meeting the objective of cost minimization [11]. After reviewing various research papers, it can be concluded that although metaheuristics can be successfully used in VRP, there are still many areas that need further research [12]. One possibility is to develop algorithms that can be better adapted to changes in the operational environment. This has also been demonstrated in various studies conducted on specific VRP models that exist in different real-life situations.

2. Bin packing problem

The Bin Packing Problem (BPP) has been extensively studied by both computer scientists and operations researchers. It is well known that the bin packing problem is NP-hard and can be solved using a variety of techniques that have been proposed by many researchers. The First Fit Decreasing and the Best Fit algorithms were the two primary heuristic algorithms for bin packing used by the system. They were preferred over other heuristic algorithms because they run faster and provide results that are significantly closer to the optimal solution than those of most other heuristic algorithms.

References [13] aim to pack all items to be delivered onto the pallets, reflecting a three-dimensional bin-packing problem of the size of a single bin. They proposed a 3D BPP model that needs to be applied to load all pallets of corresponding customers into each vehicle, with a different objective function: maximizing volume utilization. The problem of packing variable-size containers with time windows is introduced and studied [14], a real problem in the logistics industry. The objective is to choose the most favorable containers to pack each item when there are a number of items with different quantities and time windows and several types of containers with different sizes and costs. A novel problem arises when setting up a last-mile parcel delivery service in a city and considering different transportation companies (TC) [15]. They show how this problem can be represented as a brand new packing problem, the Generalized Bin Packing Problem with Bin-Dependent Item Profits (GBPPI), where

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the TCs are the bins and the items are the parcels to be delivered. The space-saving heuristic for determining the optimal match between the next item to be loaded and the loading position is practical [16]. The subproblem of the vehicle routing problem is solved by the variable neighborhood search (VNS) algorithm, while the subproblem of the bin packing problem is solved by the stochastic gradient homology (SSH) algorithms.

Regarding research gaps, there are many studies that combine these two problems [17-19]. In this study, the sparse algorithm is used to calculate the routing. Then the 3D best fit algorithm and the 3D first fit decreasing algorithm are run to arrange the items.

Problem description and assumptions

To support decision making in the planning of transportation routes and the loading of goods for inexperienced operators and to save working time. In this study, a program is also developed in Python using the Saving Algorithm to solve transportation route problems and the 3D First Fit Decreasing Algorithm and 3D Best Fit Algorithm to solve product packaging problems. While the 3D First Fit and 3D Best Fit algorithms are not guaranteed to provide the optimal solution, their simplicity and efficiency make them a practical choice for many real-world applications.

1. The savings algorithm

Since 1964, the savings algorithm has been proposed as an approach to increasing computational speed. In addition, numerous extensions of the basic VRP have been investigated using improvements to the sparsity algorithm [20]. The sparsity algorithm of Clarke and Wright (CW) is the most commonly used heuristic for solving the Capacitated Vehicle Routing Problem (CVRP). These extensions take into account constraints such as route length and vehicle capacity. The classical savings algorithm first calculates the cost savings value for each pair of customers as follows:

$$S_{i,j} = D_{1,i} + D_{j,1} - D_{i,j} \tag{1}$$

where $D_{1,i}$ is the traveling distance between depot 1 and customer i.

$D_{j,1}$ is the traveling distance between customer j and depot 1.

$D_{i,j}$ is the traveling distance between customer i and customer j.

All savings values $S_{i,j}$ are sorted in descending order. Starting with the top entry in the list. Then any two customers, i and j, in any value from the list are combined to form the cost savings link, provided that the total demand is less than or equal to the capacity of the vehicle. The process is repeated to process the next value in the list until no feasible connection is possible. Ultimately, the vehicle routes are created by adding customers, i and j to the connection. However, if a customer is unassigned, it is assigned a route that starts at the depot, goes to the unassigned customer, and ends back at the depot [21].

2. 3D best fit algorithm

Decide on a packing direction, each bin has three directions in which to pack, a width direction (or x), a height direction (or y) and a depth direction (or z). Pack one bin at a time. First, we select a pivot point, which is a point in a specific 3D bin that will be attempted to be packed; it is represented by an (x, y, z) coordinate. The lower left corner of the item will be placed at the pivot. The lower left corner of the item will be placed at the pivot. If the item cannot be packed at the pivot position, then it is rotated until it can be packed at the pivot point or until we have tried all 6 possible rotation types. After trying to pack the remaining items, we proceed to pack another item and add the unpacked item to a list of items that will be packed if the item cannot be packed at the pivot point even after rotation. In an empty bin, (0,0,0) is always the initial pivot point [22, 23].

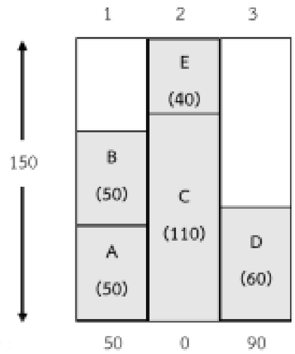

Figure 1 Best-fit Algorithm.

3. 3D first fit decreasing

To pack an object, you must first decide the packing direction. The longest side of the container corresponds to the packing direction. Then rotate each item so that the longest side of that item is the side that corresponds to the packing direction, i.e., if we pack by width, then the longest side of the item should be the width of the item. For example, if the packing direction is by width and the current height of the item is longer than its width, then you should rotate the item. If the article does not fit into the container after the rotation (s) have been carried out (i.e., one or more dimensions of the article exceed the corresponding dimension of the container), then we rotate the article until the second longest side of this article is the side that corresponds to the packing direction. If the item does not fit into the container after the rotation(s), we rotate the item until the third longest side of this item is the side that corresponds to the packing direction. Next, we sort the items in decreasing order by width, height, or depth, depending on the packing direction [22, 23].

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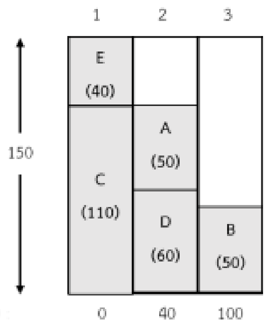

Figure 2 First-fit Decreasing Algorithm.

Solution methods

1. Program

In the program development, the Python code from Github with the username ishelo is used for the route planning of vehicles. The savings algorithm is used to calculate the routing.

On the other hand, the Python code from a Github account with the username Shiu Ruei-Chang is used. We use the package py3dbp, which implements the 3D best-fit algorithm and the 3D first-fit decreasing algorithm for the bin packing problem.

2. Conditions

The delivery vehicles are a pickup truck with a cabin and 4 wheels that can transport heavy water. The payload is 2,700 kilograms. The size of the container is used as a standard for the installation of fixed cabinets. For a pickup with a single-cab cabin, the proportions inside the container are 2.37 meters long, 1.73 meters wide, and 1.25 meters high.

Limitation of the packaging volume: The total volume of all packaged products must not exceed the volume of the pickup. The program defines tolerances for the filling volume in order to avoid filling incidents with insufficient product or product packaging.

Since the packaged products are chemical products that cannot be rotated vertically as indicated, we also do not indicate that they can be rotated in the direction of the y-axis. Also, after packing, arrange bulky items according to the delivery order.

RESULTS AND DISCUSSION

The shipping information for each of the 54 locations will be considered once the routing and packaging planning program is completed. The results are as follows:

1. Vehicle route planning by the delivery manager

In this case, the delivery manager will use his expertise to plan the vehicle route. Table 1 shows that the lowest total load per vehicle is 106.80 kilograms, and the highest is 2,735 kilograms. The lowest total distance per vehicle is 77.80 kilograms, and the highest is 946 kilometers. The lowest utilization per vehicle is 14.12 percent, the highest is 78.26 percent, and the average is 37.93 percent.

Table 1 Vehicle Route Planning by the delivery manager.

No. Vehicle	Route	Weight (Kg)	Total Distance (Km)	Cost (Baht)	Area utilization rate (%)
1	0>14>53>16>29>41>28>27>7>30>0	608	300	1,950	30.58
2	0>3>0	316.17	200	1,650	34.09
3	0>51>26>4>20>42>39>21>10>13>49 >22>12>0	1,350.09	374	2,172	60.32
4	0>6>47>0	1,060	166	1,548	28.72
5	0>5>0	1,000	319	2,007	26.93
6	0>44>0	2,700	196	1,638	61.72
7	0>33>0	181.2	241	1,773	17.70
8	0>50>54>24>0	173.6	77.8	1,500	15.03
9	0>52>23>0	2,735	152	1,506	78.26
10	0>40>37>15>31>35>0	909.5	318	2,004	61.95
11	0>11>25>32>0	167	348	2,094	14.12
12	0>46>0	1,200	324	2,022	26.93
13	0>45>48>0	1,550	218	1,704	40.77
14	0>2>0	202.3	230	1,740	35.41
15	0>8>0	1,200	946	3,888	35.84
16	0>36>38>19>0	106.8	278	1,884	17.73
17	0>17>43>9>18>0	1,200.5	248	1,794	64.78
18	0>34>1>0	403	240	1,770	42.82
19	0>46>0	1,200	324	2,022	26.93

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2. Vehicle route planning by program

In this case, the program takes both the VDP and the bin packing problems into account when planning the vehicle routes. The results of the transport route planning show that the lowest total load per vehicle is 423 kilograms and the highest is 2,700 kilograms. The lowest total distance per vehicle is 128.79 kilometers, and the highest is 794.26 kilometers. The lowest land utilization rate per vehicle is 38.77 percent, and the highest is 68.70 percent, with an average of 51.47 percent, as shown in Table 2.

Table 2 Vehicle Route Planning by Program.

No. Vehicle	Route	Weight (Kg)	Total Distance (Km)	Cost (Baht)	Area utilization rate (%)
1	0>18>0	945	202.40	1,658	59.82
2	0>44>0	2,700	159.83	1,530	61.72
3	0>46>0	2,400	268.66	1,856	53.85
4	0>52>0	2,400	128.79	1,500	68.70
5	0>27>2>33>0	423	208.00	1,675	53.83
6	0>16>53>29>1>43>9>34>0	523	207.02	1,672	54.06
7	0>41>30>35>40>7>32>0	582	215.38	1,697	53.40
8	0>5>14>28>0	1,165	270.33	1,862	38.77
9	0>45>48>0	1,550	152.10	1,507	40.77
10	0>47>17>19>38>37>36>15>31>11>25>0	1,415	300.38	1,952	53.94
11	0>3>23>0	651	166.21	1,549	43.65
12	0>39>26>42>20>13>21>10>4>12>22>0	964	159.00	1,528	43.38
13	0>6>49>51>24>0	1,435	174.57	1,574	45.25
14	0>54>8>50>0	1,323	794.26	3,433	49.50

Table 3 Comparison results.

No.	Planning by		Difference Percentage
	Delivery manager	Program	
Number of transport vehicles used	19	14	26.32
Average total weight (Kg)	961.22	1,319.71	37.30
Total distance (Km)	5,499.8	3,406.92	38.05
Shipping cost (Baht)	36,666	24,993	31.83
Area utilization rate (%)	37.93	51.47	13.54

3. Arrange products by routing

From a total of 14 vehicle routes, the program has arranged the positions as shown in Figure 3. It can be seen that some trucks will not have the full amount of products or room for additional products. However, if the researchers add more orders to this vehicle, it will exceed the limits of the truck, be overweight or unable to arrange the products, etc.

4. Comparison results between vehicle route planning by the delivery manager and the program

Table 3 shows that a total of 19 transport vehicles are used by the delivery manager when planning the transport routes. The total distance of the transport is 5,499.8 kilometers. The average load weight per vehicle is 961.22 kilograms. The total cost of the transport vehicles is 36,666 baht, and the average space utilization is 37.93. In contrast, a total of 14 vehicles are used in the program-controlled planning of the transport routes. The total transport distance is 3,406.92 kilometers. The average payload per vehicle is 1,319.71 kilograms. The total cost of the transport vehicles is 24,993 baht, and the average space utilization is 51.47.

In summary, the results show that the program's route plans are to be preferred. Even if it is not the optimal solution, the program can process the answer in a reasonable time and is easy to use for the users. Moreover, the case study company can accept these results and be satisfied with them. The vehicle routing application will simplify the company's operations [25]. In addition, the combination of vehicle route planning and container packing problems will enable a reduction in the number of vehicles, total distance, and transportation costs. It also increases the average total weight and the space utilization rate. Sustainability is also influenced by fewer vehicles and routes, as carbon dioxide emissions are reduced [24].

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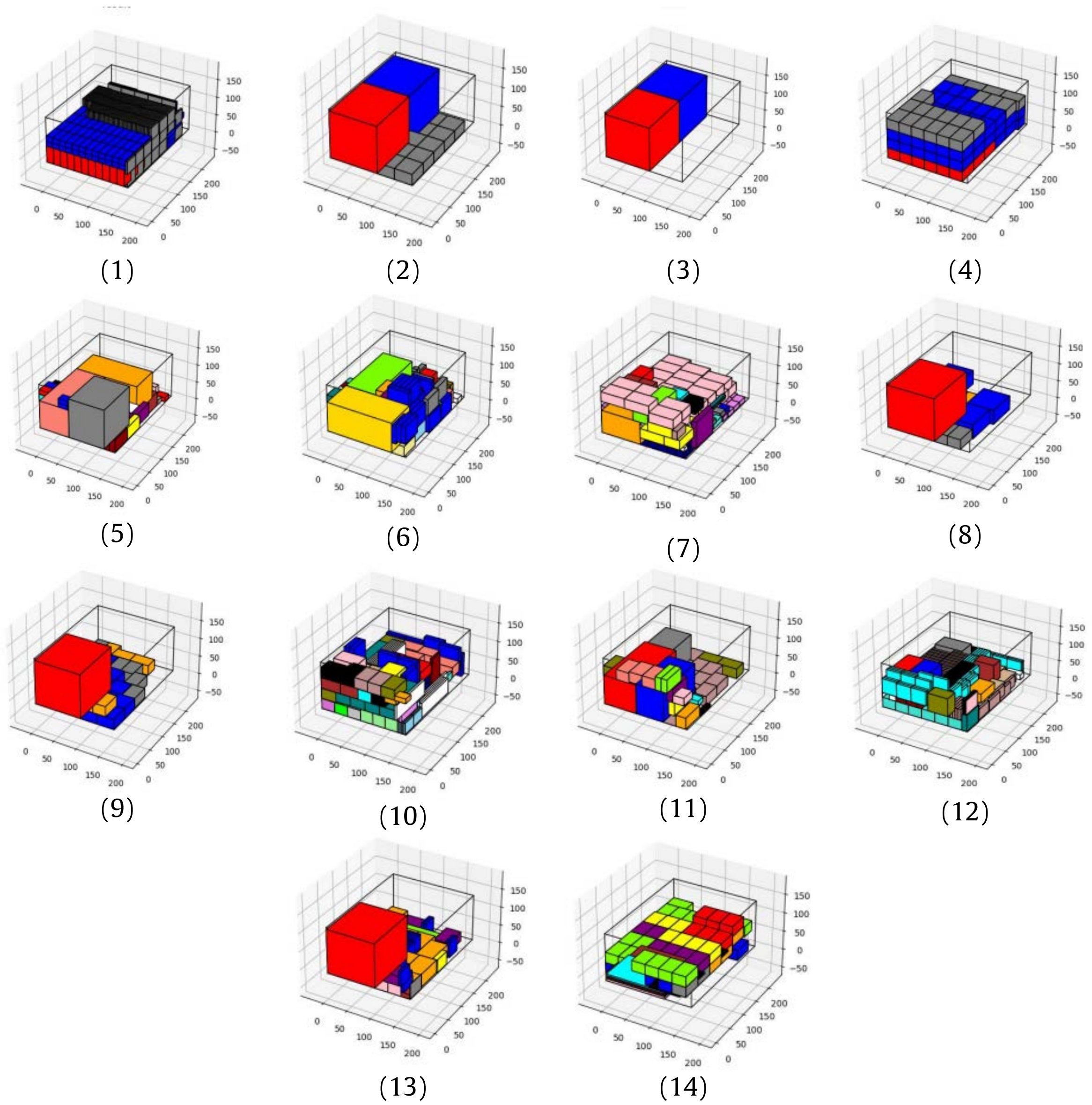

Figure 3 Items on vehicle number 1-14.

CONCLUSIONS

This study is about planning delivery routes, arranging items in trucks, and reducing transportation costs for a case study of a chemical plant using VRP and storage space issues. In this study, a program was also developed in Python using the Spar Algorithm to solve traffic routing problems and the 3D first fit decreasing algorithm and 3D best fit algorithm to solve product packaging problems. Python code provided by users via the Github website was used, with weight and volume constraints added to the routing constraints. Furthermore, since the products to be packaged are chemical products that cannot be rotated vertically as specified, we do not specify that they can be rotated in the y-axis direction. Also, after packing, arrange the bulky items according to the delivery sequence.

The results from the execution of the program are compared with the results of the calculation by the delivery manager. It has been found that the vehicle routes provided by the program can help reduce costs and make operations more efficient. As for the results of the data set, even if the program is not optimal, it can process the answer in a reasonable time and is easy for users to operate. Furthermore, the case study company can accept these results and be satisfied with them. So the results may not be the cheapest, but they are appropriate for the company's work.

In the future, other solutions can be used for product packaging, such as genetic algorithms, local search, etc. Additionally, consider line balancing to ensure equality between shippers/drivers in terms of driving hours or similar amounts of distance traveled.

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All solutions of the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+2}$

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ABSTRACT

In the history of mathematics, many mathematical researchers have investigated the Diophantine equation in the form $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{v}$, where x, y, z, u and v are positive integers. Without loss of generality, we may assume that $x \leq y \leq z$. This Diophantine equation, also known as the Egyptian fraction equation of length 3, is to write the fraction as a sum of three fractions with the numerator being one and the denominators being different positive integers. Examples of research such as, in 2021, Sandor and Atanassov studied and found that the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+1}$ has forty-four positive integer solutions. In this paper, we will study and find the complete positive integer solutions of the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+2}$, by using elementary methods of number theory and computer calculations. In the process, we can see that $1 \leq x \leq 9$. Then, we will consider separately the value of a positive integer x in nine cases. The first case is impossible. For the second and third cases, we will separate to consider the value of y. For the remaining cases, we will separate to consider the value of u. The research results showed that all positive integer solutions of the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+2}$ are eighty-seven positive integer solutions. Moreover, from the steps to find the above positive integer solutions, we expect that it can be used to find the complete positive integer solutions of the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+k}$, where k is a positive integer with $k \geq 3$.

Keywords: Diophantine equation, Positive integer solution, Egyptian fraction equation

INTRODUCTION

A Diophantine equation is an equation, for which only integer solutions are of interest. One of the Diophantine equations that has caught the attention of many researchers is the equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{v}$, where x, y, z, u and v are positive integers with $x \leq y \leq z$. For example, in 2013 Rabago and Tagle [1] found that if $u = 1$ and $v = 2$, then the equation has only ten positive integer solutions. Tadee and Poopra [2] proved that if $u = 1$ and $v = 3$, then the equation has exactly twenty-one positive integer solutions. Meanwhile, Delang [3] showed some conditions of the non-existence of the solutions for the equation, where $u = 4$ and $v > 1$. Later, Kishan, Rani and Agarwal [4] investigated all positive integer solutions of the equation, where $u = 3$ and $v \equiv 1 \pmod 2$. In 2021, Zhao, Lu and Wang [5] studied the equation for some prime number v. In the same year, Banderier et al. [6] gave the bounds to the number of integer solutions to the equation, where u and v are relatively prime. Recently, Sandor and Atanassov [7] proved that if $v = u + 1$, then the equation has forty-four solutions.

In this article, we will show that if $v = u + 2$, then the equation has eighty-seven solutions.

MATERIALS AND METHODS

Let x, y, z and u be positive integers with $x \leq y \leq z$ such that

$$\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+2}. \tag{1}$$

Since $x \leq y \leq z$, we get

$$\frac{1}{z} \leq \frac{1}{y} \leq \frac{1}{x}. \tag{2}$$

From (1) and (2), it implies that $\frac{u}{u+2} \leq \frac{3}{x}$. Then

$$u(x-3) \leq 6. \tag{3}$$

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Since $u \geq 1$, we have $x \leq 9$. We consider the following cases:

Case 1. $\boldsymbol{x} = \mathbf{1}$. Then $\frac{1}{x} + \frac{1}{y} + \frac{1}{z} > 1$. From (1), we obtain $\frac{u}{u+2} > 1$. This is impossible.

Case 2. $\boldsymbol{x} = \mathbf{2}$. From (1), we have

$$\frac{1}{y} + \frac{1}{z} = \frac{u-2}{2u+4}. \quad (4)$$

Thus $u \geq 3$. From (2), it implies that $\frac{u-2}{2u+4} \leq \frac{2}{y}$. Therefore,

$$u(y-4) \leq 2y + 8. \quad (5)$$

Subcase 2.1. $y = 1$. Then $x > y$, a contradiction.

Subcase 2.2. $y = 2$. Then $\frac{1}{x} + \frac{1}{y} + \frac{1}{z} = 1 + \frac{1}{z} > 1$. From (1), we have $\frac{u}{u+2} > 1$, which is impossible.

Subcase 2.3. $y = 3$. From (4), we get $\frac{1}{z} = \frac{u-10}{6u+12}$. Then $z = 6 + \frac{72}{u-10}$. Since z is a positive integer, it implies that $u - 10 = 1, 2, 3, 4, 6, 8, 9, 12, 18, 24, 36$ or 72. Therefore, $u = 11, 12, 13, 14, 16, 18, 19, 22, 28, 34, 46$ or 82.

If $u = 11$, then $z = 78$ and so $(x, y, z, u) = (2, 3, 78, 11)$.
If $u = 12$, then $z = 42$ and so $(x, y, z, u) = (2, 3, 42, 12)$.
If $u = 13$, then $z = 30$ and so $(x, y, z, u) = (2, 3, 30, 13)$.
If $u = 14$, then $z = 24$ and so $(x, y, z, u) = (2, 3, 24, 14)$.
If $u = 16$, then $z = 18$ and so $(x, y, z, u) = (2, 3, 18, 16)$.
If $u = 18$, then $z = 15$ and so $(x, y, z, u) = (2, 3, 15, 18)$.
If $u = 19$, then $z = 14$ and so $(x, y, z, u) = (2, 3, 14, 19)$.
If $u = 22$, then $z = 12$ and so $(x, y, z, u) = (2, 3, 12, 22)$.
If $u = 28$, then $z = 10$ and so $(x, y, z, u) = (2, 3, 10, 28)$.
If $u = 34$, then $z = 9$ and so $(x, y, z, u) = (2, 3, 9, 34)$.
If $u = 46$, then $z = 8$ and so $(x, y, z, u) = (2, 3, 8, 46)$.
If $u = 82$, then $z = 7$ and so $(x, y, z, u) = (2, 3, 7, 82)$.

Subcase 2.4. $y = 4$. From (4), we have $\frac{1}{z} = \frac{u-6}{4u+8}$. Then $z = 4 + \frac{32}{u-6}$. Since z is a positive integer, it implies that $u - 6 = 1, 2, 4, 8, 16$ or 32. Therefore, $u = 7, 8, 10, 14, 22$ or 38.

If $u = 7$, then $z = 36$ and so $(x, y, z, u) = (2, 4, 36, 7)$.
If $u = 8$, then $z = 20$ and so $(x, y, z, u) = (2, 4, 20, 8)$.
If $u = 10$, then $z = 12$ and so $(x, y, z, u) = (2, 4, 12, 10)$.
If $u = 14$, then $z = 8$ and so $(x, y, z, u) = (2, 4, 8, 14)$.
If $u = 22$, then $z = 6$ and so $(x, y, z, u) = (2, 4, 6, 22)$.
If $u = 38$, then $z = 5$ and so $(x, y, z, u) = (2, 4, 5, 38)$.

Subcase 2.5. $y = 5$. From (5), we obtain $u \leq 18$. From (4), it follows that $z = \frac{10u+20}{3u-14}$. Since z is a positive integer, we get $u = 5, 6, 8, 13$ or 18.

If $u = 5$, then $z = 70$ and so $(x, y, z, u) = (2, 5, 70, 5)$.
If $u = 6$, then $z = 20$ and so $(x, y, z, u) = (2, 5, 20, 6)$.
If $u = 8$, then $z = 10$ and so $(x, y, z, u) = (2, 5, 10, 8)$.
If $u = 13$, then $z = 6$ and so $(x, y, z, u) = (2, 5, 6, 13)$.
If $u = 18$, then $z = 5$ and so $(x, y, z, u) = (2, 5, 5, 18)$.

Subcase 2.6. $y = 6$. From (5), we obtain $u \leq 10$. From (4), it follows that $z = \frac{3u+6}{u-4}$. Since z is a positive integer, we get $u = 5, 6, 7$ or 10.

If $u = 5$, then $z = 21$ and so $(x, y, z, u) = (2, 6, 21, 5)$.
If $u = 6$, then $z = 12$ and so $(x, y, z, u) = (2, 6, 12, 6)$.
If $u = 7$, then $z = 9$ and so $(x, y, z, u) = (2, 6, 9, 7)$.
If $u = 10$, then $z = 6$ and so $(x, y, z, u) = (2, 6, 6, 10)$.

Subcase 2.7. $y = 7$. From (5), we have $u \leq 7$. From (4), it follows that $z = \frac{14u+28}{5u-18}$. Since z is a positive integer, we get $u = 4$ or 5.

If $u = 4$, then $z = 42$ and so $(x, y, z, u) = (2, 7, 42, 4)$.
If $u = 5$, then $z = 14$ and so $(x, y, z, u) = (2, 7, 14, 5)$.

Subcase 2.8. $y = 8$. From (5), we have $u \leq 6$. From (4), it follows that $z = \frac{8u+16}{3u-10}$. Since z is a positive integer, we get $u = 4$ or 6.

If $u = 4$, then $z = 24$ and so $(x, y, z, u) = (2, 8, 24, 4)$.
If $u = 6$, then $z = 8$ and so $(x, y, z, u) = (2, 8, 8, 6)$.

Subcase 2.9. $y = 9$. From (5), we have $u \leq 5$. From (4), it follows that $z = \frac{18u+36}{7u-22}$. Since z is a positive integer, we get $u = 4$. Then $z = 18$ and $(x, y, z, u) = (2, 9, 18, 4)$.

Subcase 2.10. $y = 10$. From (5), we have $u \leq 4$. From (4), it follows that $z = \frac{5u+10}{2u-6}$. Since z is a positive integer, we get $u = 4$. Then $z = 15$ and $(x, y, z, u) = (2, 10, 15, 4)$.

Subcase 2.11. $y = 11$. From (5), we have $u \leq 4$. From (4), it follows that $z = \frac{22u+44}{9u-26}$. Since z is a positive integer, we get $u = 3$. Then $z = 110$ and $(x, y, z, u) = (2, 11, 110, 3)$.

Subcase 2.12. $y = 12$. From (5), we have $u \leq 4$. From (4), it follows that $z = \frac{12u+24}{5u-14}$. Since z is a positive integer, we get $u = 3$ or 4.

If $u = 3$, then $z = 60$ and so $(x, y, z, u) = (2, 12, 60, 3)$.
If $u = 4$, then $z = 12$ and so $(x, y, z, u) = (2, 12, 12, 4)$.

Subcase 2.13. $y \geq 13$. Then $\frac{2y+8}{y-4} < 4$. From (5) and (4), we have $u = 3$ and $\frac{1}{y} + \frac{1}{z} = \frac{1}{10}$. Then $z = \frac{10y}{y-10}$. From (2), it follows that $\frac{2}{y} \geq \frac{1}{10}$ or $y \leq 20$. Since z is a positive integer, we get $y = 14, 15$ or 20.

If $y = 14$, then $z = 35$ and so $(x, y, z, u) = (2, 14, 35, 3)$.
If $y = 15$, then $z = 30$ and so $(x, y, z, u) = (2, 15, 30, 3)$.

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If $y = 20$, then $z = 20$ and so $(x, y, z, u) = (2, 20, 20, 3)$.

Case 3. $\boldsymbol{x = 3}$. From (1), we have

$$\frac{1}{y} + \frac{1}{z} = \frac{2u-2}{3u+6}. \tag{6}$$

From (2), it implies that $\frac{2u-2}{3u+6} \le \frac{2}{y}$. Therefore,

$$u(y-3) \le y + 6. \tag{7}$$

Since $x \le y$, we have $3 \le y$.

<u>Subcase 3.1.</u> $y = 3$. From (6), we have $\frac{1}{z} = \frac{u-4}{3u+6}$. Then $z = 3 + \frac{18}{u-4}$. Since z is a positive integer, we get $u - 4 = 1, 2, 3, 6, 9$ or 18. Therefore, $u = 5, 6, 7, 10, 13$ or 22.
If $u = 5$, then $z = 21$ and so $(x, y, z, u) = (3, 3, 21, 5)$.
If $u = 6$, then $z = 12$ and so $(x, y, z, u) = (3, 3, 12, 6)$.
If $u = 7$, then $z = 9$ and so $(x, y, z, u) = (3, 3, 9, 7)$.
If $u = 10$, then $z = 6$ and so $(x, y, z, u) = (3, 3, 6, 10)$.
If $u = 13$, then $z = 5$ and so $(x, y, z, u) = (3, 3, 5, 13)$.
If $u = 22$, then $z = 4$ and so $(x, y, z, u) = (3, 3, 4, 22)$.

<u>Subcase 3.2.</u> $y = 4$. From (7) and (6), we have $u \le 10$ and $z = \frac{12u+24}{5u-14}$, consequently. Since z is a positive integer, we have $u = 3, 4, 6$ or 10.
If $u = 3$, then $z = 60$ and so $(x, y, z, u) = (3, 4, 60, 3)$.
If $u = 4$, then $z = 12$ and so $(x, y, z, u) = (3, 4, 12, 4)$.
If $u = 6$, then $z = 6$ and so $(x, y, z, u) = (3, 4, 6, 6)$.
If $u = 10$, then $z = 4$ and so $(x, y, z, u) = (3, 4, 4, 10)$.

<u>Subcase 3.3.</u> $y = 5$. From (7) and (6), we have $u \le 5$ and $z = \frac{15u+30}{7u-16}$, consequently. Since z is a positive integer, we have $u = 3$. Then $z = 15$ and so $(x, y, z, u) = (3, 5, 15, 3)$.

<u>Subcase 3.4.</u> $y = 6$. From (7) and (6), we have $u \le 4$ and $z = \frac{2u+4}{u-2}$, consequently. Since z is a positive integer, we have $u = 3$ or 4.
If $u = 3$, then $z = 10$ and so $(x, y, z, u) = (3, 6, 10, 3)$.
If $u = 4$, then $z = 6$ and so $(x, y, z, u) = (3, 6, 6, 4)$.

<u>Subcase 3.5.</u> $y = 7$. From (7) and (6), we have $u \le 3$ and $z = \frac{21u+42}{11u-20}$, consequently. Since z is a positive integer, we have $u = 2$. Then $z = 42$ and so $(x, y, z, u) = (3, 7, 42, 2)$.

<u>Subcase 3.6.</u> $y \ge 8$. Then $\frac{y+6}{y-3} < 3$. From (7) and (6), we have $u = 2$ and $\frac{1}{y} + \frac{1}{z} = \frac{1}{6}$. Then $z = \frac{6y}{y-6}$. From (2), it follows that $\frac{2}{y} \ge \frac{1}{6}$ or $y \le 12$. Since z is a positive integer, we get $y = 8, 9, 10$ or 12.
If $y = 8$, then $z = 24$ and so $(x, y, z, u) = (3, 8, 24, 2)$.
If $y = 9$, then $z = 18$ and so $(x, y, z, u) = (3, 9, 18, 2)$.
If $y = 10$, then $z = 15$ and so $(x, y, z, u) = (3, 10, 15, 2)$.
If $y = 12$, then $z = 12$ and so $(x, y, z, u) = (3, 12, 12, 2)$.

Case 4. $\boldsymbol{x = 4}$. From (3) and (1), we have $u \le 6$ and

$$\frac{1}{y} + \frac{1}{z} = \frac{3u-2}{4u+8}. \tag{8}$$

<u>Subcase 4.1.</u> $u = 1$. From (2) and (8), it follows that

$$\frac{2}{y} \ge \frac{1}{y} + \frac{1}{z} = \frac{1}{12}.$$

Then $y \le 24$ and $z = \frac{12y}{y-12}$. Since z is a positive integer, we have $y = 13, 14, 15, 16, 18, 20, 21$ or 24.
If $y = 13$, then $z = 156$ and so $(x, y, z, u) = (4, 13, 156, 1)$.
If $y = 14$, then $z = 84$ and so $(x, y, z, u) = (4, 14, 84, 1)$.
If $y = 15$, then $z = 60$ and so $(x, y, z, u) = (4, 15, 60, 1)$.
If $y = 16$, then $z = 48$ and so $(x, y, z, u) = (4, 16, 48, 1)$.
If $y = 18$, then $z = 36$ and so $(x, y, z, u) = (4, 18, 36, 1)$.
If $y = 20$, then $z = 30$ and so $(x, y, z, u) = (4, 20, 30, 1)$.
If $y = 21$, then $z = 28$ and so $(x, y, z, u) = (4, 21, 28, 1)$.
If $y = 24$, then $z = 24$ and so $(x, y, z, u) = (4, 24, 24, 1)$.

<u>Subcase 4.2.</u> $u = 2$. From (2) and (8), it follows that

$$\frac{2}{y} \ge \frac{1}{y} + \frac{1}{z} = \frac{1}{4}.$$

Then $y \le 8$ and $z = \frac{4y}{y-4}$. Since z is a positive integer, we have $y = 5, 6$ or 8.
If $y = 5$, then $z = 20$ and so $(x, y, z, u) = (4, 5, 20, 2)$.
If $y = 6$, then $z = 12$ and so $(x, y, z, u) = (4, 6, 12, 2)$.
If $y = 8$, then $z = 8$ and so $(x, y, z, u) = (4, 8, 8, 2)$.

<u>Subcase 4.3.</u> $u = 3$. From (2) and (8), it follows that

$$\frac{2}{y} \ge \frac{1}{y} + \frac{1}{z} = \frac{7}{20}.$$

Then $y \le 5$ and $z = \frac{20y}{7y-20}$. Since z is a positive integer, we get $y = 4$. Then $z = 10$ and $(x, y, z, u) = (4, 4, 10, 3)$.

<u>Subcase 4.4.</u> $u = 4$. From (2) and (8), it follows that

$$\frac{2}{y} \ge \frac{1}{y} + \frac{1}{z} = \frac{5}{12}.$$

Then $y \le 4$ and $z = \frac{12y}{5y-12}$. Since z is a positive integer, we get $y = 4$. Then $z = 6$ and $(x, y, z, u) = (4, 4, 6, 4)$.

<u>Subcase 4.5.</u> $u = 5$. From (2) and (8), it follows that

$$\frac{2}{y} \ge \frac{1}{y} + \frac{1}{z} = \frac{13}{28}.$$

Then $y \le 4$ and $z = \frac{28y}{13y-28}$. This is impossible since z is a positive integer.

<u>Subcase 4.6.</u> $u = 6$. From (2) and (8), it follows that

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$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{1}{2}.$$

Then $y \leq 4$ and $z = \frac{2y}{y-2}$. Since z is a positive integer, we have $y = 4$. Then $z = 4$ and so $(x, y, z, u) = (4, 4, 4, 6)$.

Case 5. $\boldsymbol{x} = \mathbf{5}$. From (3) and (1), we have $u \leq 3$ and

$$\frac{1}{y} + \frac{1}{z} = \frac{4u-2}{5u+10}. \quad (9)$$

Subcase 5.1. $u = 1$. From (2) and (9), it follows that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{2}{15}.$$

Then $y \leq 15$ and $z = \frac{15y}{2y-15}$. Since z is a positive integer, we have $y = 8, 9, 10, 12$ or 15.
If $y = 8$, then $z = 120$ and so $(x, y, z, u) = (5, 8, 120, 1)$.
If $y = 9$, then $z = 45$ and so $(x, y, z, u) = (5, 9, 45, 1)$.
If $y = 10$, then $z = 30$ and so $(x, y, z, u) = (5, 10, 30, 1)$.
If $y = 12$, then $z = 20$ and so $(x, y, z, u) = (5, 12, 20, 1)$.
If $y = 15$, then $z = 15$ and so $(x, y, z, u) = (5, 15, 15, 1)$.

Subcase 5.2. $u = 2$. From (2) and (9), it follows that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{3}{10}.$$

Then $y \leq 6$ and $z = \frac{10y}{3y-10}$. Since z is a positive integer, we get $y = 5$. Thus $z = 10$ and $(x, y, z, u) = (5, 5, 10, 2)$.

Subcase 5.3. $u = 3$. From (2) and (9), it follows that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{2}{5}.$$

Then $y \leq 5$ and $z = \frac{5y}{2y-5}$. Since z is a positive integer, we get $y = 5$. Thus $z = 5$ and $(x, y, z, u) = (5, 5, 5, 3)$.

Case 6. $\boldsymbol{x} = \mathbf{6}$. From (3) and (1), we have $u \leq 2$ and

$$\frac{1}{y} + \frac{1}{z} = \frac{5u-2}{6u+12}. \quad (10)$$

Subcase 6.1. $u = 1$. From (2) and (10), it follows that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{1}{6}.$$

Then $y \leq 12$ and $z = \frac{6y}{y-6}$. Since z is a positive integer, we have $y = 7, 8, 9, 10$ or 12.
If $y = 7$, then $z = 42$ and so $(x, y, z, u) = (6, 7, 42, 1)$.
If $y = 8$, then $z = 24$ and so $(x, y, z, u) = (6, 8, 24, 1)$.
If $y = 9$, then $z = 18$ and so $(x, y, z, u) = (6, 9, 18, 1)$.
If $y = 10$, then $z = 15$ and so $(x, y, z, u) = (6, 10, 15, 1)$.
If $y = 12$, then $z = 12$ and so $(x, y, z, u) = (6, 12, 12, 1)$.

Subcase 6.2. $u = 2$. From (2) and (10), it follows that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{1}{3}.$$

Then $y \leq 6$ and $z = \frac{3y}{y-3}$. Since z is a positive integer, we have $y = 6$. Then $z = 6$ and so $(x, y, z, u) = (6, 6, 6, 2)$.

Case 7. $\boldsymbol{x} = \mathbf{7}$. From (3), we have $u = 1$. From (1) and (2), it implies that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{4}{21}.$$

Then $z = \frac{21y}{4y-21}$ and $y \leq 10$, consequently. Since z is a positive integer, we have $y = 7$. Therefore, $z = 21$ and so $(x, y, z, u) = (7, 7, 21, 1)$.

Case 8. $\boldsymbol{x} = \mathbf{8}$. From (3), we have $u = 1$. From (1) and (2), it implies that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{5}{24}.$$

Then $z = \frac{24y}{5y-24}$ and $y \leq 9$, consequently. Since z is a positive integer, we have $y = 8$. Therefore, $z = 12$ and so $(x, y, z, u) = (8, 8, 12, 1)$.

Case 9. $\boldsymbol{x} = \mathbf{9}$. From (3), we have $u = 1$. From (1) and (2), it implies that

$$\frac{2}{y} \geq \frac{1}{y} + \frac{1}{z} = \frac{2}{9}.$$

Then $z = \frac{9y}{2y-9}$ and $y \leq 9$, consequently. Since z is a positive integer, we have $y = 9$. Therefore, $z = 9$ and so $(x, y, z, u) = (9, 9, 9, 1)$.

RESULTS AND DISCUSSION

In the previous section, we show all positive integer solutions of the Diophantine equation.

$$\frac{1}{x} + \frac{1}{y} + \frac{1}{z} = \frac{u}{u+2},$$

where x, y, z and u are positive integers with $x \leq y \leq z$, are exactly eighty-seven solutions including: $(x, y, z, u) =$
$(2, 3, 78, 11)$, $(2, 3, 42, 12)$, $(2, 3, 30, 13)$, $(2, 3, 24, 14)$, $(2, 3, 18, 16)$, $(2, 3, 15, 18)$, $(2, 3, 14, 19)$, $(2, 3, 12, 22)$, $(2, 3, 10, 28)$, $(2, 3, 9, 34)$, $(2, 3, 8, 46)$, $(2, 3, 7, 82)$, $(2, 4, 36, 7)$, $(2, 4, 20, 8)$, $(2, 4, 12, 10)$, $(2, 4, 8, 14)$, $(2, 4, 6, 22)$, $(2, 4, 5, 38)$, $(2, 5, 70, 5)$, $(2, 5, 20, 6)$, $(2, 5, 10, 8)$, $(2, 5, 6, 13)$, $(2, 5, 5, 18)$, $(2, 6, 21, 5)$, $(2, 6, 12, 6)$, $(2, 6, 9, 7)$, $(2, 6, 6, 10)$, $(2, 7, 42, 4)$, $(2, 7, 14, 5)$, $(2, 8, 24, 4)$, $(2, 8, 8, 6)$, $(2, 9, 18, 4)$, $(2, 10, 15, 4)$, $(2, 11, 110, 3)$, $(2, 12, 60, 3)$, $(2, 12, 12, 4)$, $(2, 14, 35, 3)$, $(2, 15, 30, 3)$, $(2, 20, 20, 3)$, $(3, 3, 21, 5)$, $(3, 3, 12, 6)$, $(3, 3, 9, 7)$, $(3, 3, 6, 10)$, $(3, 3, 5, 13)$, $(3, 3, 4, 22)$, $(3, 4, 60, 3)$, $(3, 4, 12, 4)$, $(3, 4, 6, 6)$,

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$(3,4,4,10)$, $(3,5,15,3)$, $(3,6,10,3)$, $(3,6,6,4)$, $(3,7,42,2)$, $(3,8,24,2)$, $(3,9,18,2)$, $(3,10,15,2)$, $(3,12,12,2)$, $(4,13,156,1)$, $(4,14,84,1)$, $(4,15,60,1)$, $(4,16,48,1)$, $(4,18,36,1)$, $(4,20,30,1)$, $(4,21,28,1)$, $(4,24,24,1)$, $(4,5,20,2)$, $(4,6,12,2)$, $(4,8,8,2)$, $(4,4,10,3)$, $(4,4,6,4)$, $(4,4,4,6)$, $(5,8,120,1)$, $(5,9,45,1)$, $(5,10,30,1)$, $(5,12,20,1)$, $(5,15,15,1)$, $(5,5,10,2)$, $(5,5,5,3)$, $(6,7,42,1)$, $(6,8,24,1)$, $(6,9,18,1)$, $(6,10,15,1)$, $(6,12,12,1)$, $(6,6,6,2)$, $(7,7,21,1)$, $(8,8,12,1)$, $(9,9,9,1)$.

CONCLUSIONS

In the process of finding the positive integer solutions of the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+2}$, only basic mathematical knowledge is required. It is expected that the above procedure can be applied to find all positive integer solutions of the Diophantine equation $\frac{1}{x}+\frac{1}{y}+\frac{1}{z}=\frac{u}{u+k}$, where x,y,z,u and k are positive integers with $x\le y\le z$ and $k\ge 3$. Thus, it is interesting to study and research further.

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Mobile random text-based voice authentication for older adults: A pilot study

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ABSTRACT

Thai older adults often struggle to use existing smartphone authentication systems due to age-related problems. Random text-based voice authentication, which resists Replay attacks and reduces the need to memorize information, is a suitable alternative. Nevertheless, past studies have insufficiently focused on usability, leading this research effort to improve the usability of voice authentication for older adults. As part of the research, this study seeks to develop a random text-based voice authentication suitable for older adults. The prototype was implemented as a mobile application, VAuth, with Voice User Interface (VUI) as a primary interaction method. Formative Usability Testing was conducted iteratively and incrementally to evaluate and refine VAuth. The first version of VAuth was well-received despite initial problems, which were resolved subsequently. Overall results indicated that VAuth is usable for older adults. Participants could complete all given tasks (enrollment and verification) through VUIs. They responded favorably to VUIs in general and acknowledged their advantages. Moreover, the results from the SEQ and SUS questionnaires aligned with participants' positive opinions. The dialogue design was adequate, and older adults could correctly pronounce Thai-word passphrases in most cases. While the accuracy of Thai speech recognition remains an issue, progress in voice recognition may eventually overcome it. Despite these encouraging results, this study still has limitations. While the test helped determine if VAuth is a viable solution, it did not confirm whether VAuth remains usable when deployed in larger, different contexts, such as a noisy environment or public places. Thus, further studies are needed to compare VAuth with existing authentication methods with an enlarged sample size in multiple usage scenarios.

Keywords: Authentication, Voice authentication, Smartphone, Older adult

INTRODUCTION

Background

Smartphones have become an essential device for the older Thai population. However, they often face challenges in using smartphone authentication systems due to multiple age-related problems [1] and limitations of existing methods. Consequently, many older adults resort to insecure practices such as disabling authentication systems. Thus, this research is part of an effort to overcome these problems by finding a suitable alternative for older adults.

Voice authentication, the technique to verify users' claim of identity from unique features of their voice, is among the promising alternatives, and much progress has been achieved over the years, such as new feature extraction technique [2], utilizing deep learning [3], and security measure against injection of inaudible/hidden commands [4].

However, many studies primarily focus on improving voice authentication accuracy and security. At the same time, the system's usability receives less attention. Thus, the research's primary goal is to improve voice authentication so that it is secure and usable for older adults whose requirements are more restrictive than those of younger users. This study is part of the research and aims to develop a random text-based voice authentication system, utilizing lessons learned from past studies.

Random text-based voice authentication

One potentially suitable voice authentication for older adults is the random text-based system. The main idea is that the system provides a random text that a user will read aloud. Suppose the recognized text is the same as the provided text, and the voice matches the enrolled user. In that case, the user's identity claim is verified.

Random text can be numeric sequences, alphanumeric sequences, or common words. For example, the work of Yan and Zhao [5] presented a voice authentication system where users read a randomly

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generated 6-character pattern code aloud. Bella et al. [3] also proposed a comparable system model using one-time password (OTP) digits in Bahasa Indonesia. Rehman and Lee [6] chose a different approach and introduced a random text-dependent voice-based smartphone authentication protocol. Users read one of five possible English words randomly displayed in each login attempt.

Like traditional one-time text passwords [7], the main advantage of random text-based voice authentication is resistance to Replay Attacks [8]. Successful authentication requires matching text and voice, so the attacker will face difficulties preparing a speech sample that matches the randomly chosen text. Furthermore, the random text-based system reduces users' burdens in memorizing information since they only need to speak a text the system selects.

Nevertheless, there are still problems in these past works, like the user-friendliness of random numeric and alphanumeric codes. Furthermore, these proposed systems have limited usage for Thai subjects, who are often not fluent in foreign languages. Therefore, this research aims to design a usable random text-based voice authentication for Thai older adults.

Using numeric [3] and alphanumeric [5] sequences can pose challenges to older adults. Reading aloud already requires working memory, which is low capacity and volatile. Moreover, age-related deterioration is the most visible in working memory [1], and older adults read aloud more slowly and make more errors than younger adults [9]. Therefore, using complex numeric or alphanumeric sequences will negatively impact older users' experience with the system. On the other hand, using common words, like the system of Rehman and Lee, appears to be more appropriate. Especially if they are the words older adults are familiar with, their performance in reading aloud will improve significantly [9].

Another problem is related to the Graphical User Interface (GUI). Many past works used GUIs as a primary interaction method for their systems. For example, Yan and Zhao's system [5] Informs users of a pattern code they have to speak through the device's screen. While this approach seems sufficient for younger people, it may not be the best choice for older users.

For instance, older adults usually have vision problems [1], causing myriad challenges when using GUI. As its name suggests, performing tasks via GUI relies on visual comprehension of the provided graphics. Therefore, if users have trouble seeing, their performance in tasks like speed and accuracy will suffer accordingly [10].

Furthermore, many older users lack familiarity with interfaces and controls [10]. Additionally, they may easily be confused when controls work differently from the norm, such as pressing and holding a button [11], which are often required to use advanced functions, such as audio recording.

Due to the limitations of GUIs, Voice User Interface (VUI) is a viable alternative. It is consistently suggested as a more usable interaction method for older adults, particularly novice users [12]. Due to their intuitive interaction, VUIs can be utilized to provide a step-by-step guide [13]. VUIs are also simple, easy to use, and ideal for older users with visual and motor impairments [14]. They can be a substitute method for text entry [10]. Although the novelty of the technology can be a significant obstacle, older adults can overcome it once they become accustomed [15,16].

The work of Chang and Dupuis [17] demonstrates the integration of VUIs and random text-based voice authentication. They propose a 2-step authentication for virtual assistants, where users must correctly speak a random sequence of numbers after voice commands. Despite many slightly negative opinions, the method appears more acceptable once users become aware of the security risks.

With these lessons from past systems, the following requirements are established. The system is a text-dependent voice authentication with VUIs as the primary interaction interface. It is also a random text-based system, utilizing standard Thai vocabulary as a passphrase.

MATERIALS AND METHODS

The new voice authentication is implemented as a mobile application named VAuth. The conceptual framework of VAuth is shown in Figure 1, which consists of six primary components: interfaces (GUI and VUI), processes, speech recognition service, speaker recognition service, passphrase list, and Thai word collection.

VAuth has two processes: Enrollment and Verification, which require speech recognition and speaker verification services. Speech recognition service is meant to identify a word that users have spoken. Meanwhile, the speaker verification service will determine whether the voice VAuth hears belongs to a legitimate user.

The interfaces are the channels for users to interact with VAuth. The voice interface is the primary channel, while the graphical interface will support the voice interface. An internal collection contains Thai words to be selected as a passphrase and stored in the list during enrollment. Then, the selected words in the list will be used during the verification process.

Enrollment is required before users can use the verification function. VAuth will ask users to speak a specific number of words to collect voice samples with the correct pronunciation. As a measure against replay attacks, all words are selected randomly from a predefined list.

In the verification process, VAuth will tell users to speak one of the words chosen during enrollment. The users' identity claims will be verified to see if the

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recognized word matches the chosen word and if their voice matches the recorded data. They have another attempt in the case of rejection. However, VAuth will end the process on the second rejection. In the real-world scenario, users will switch to the default method, such as text passwords.

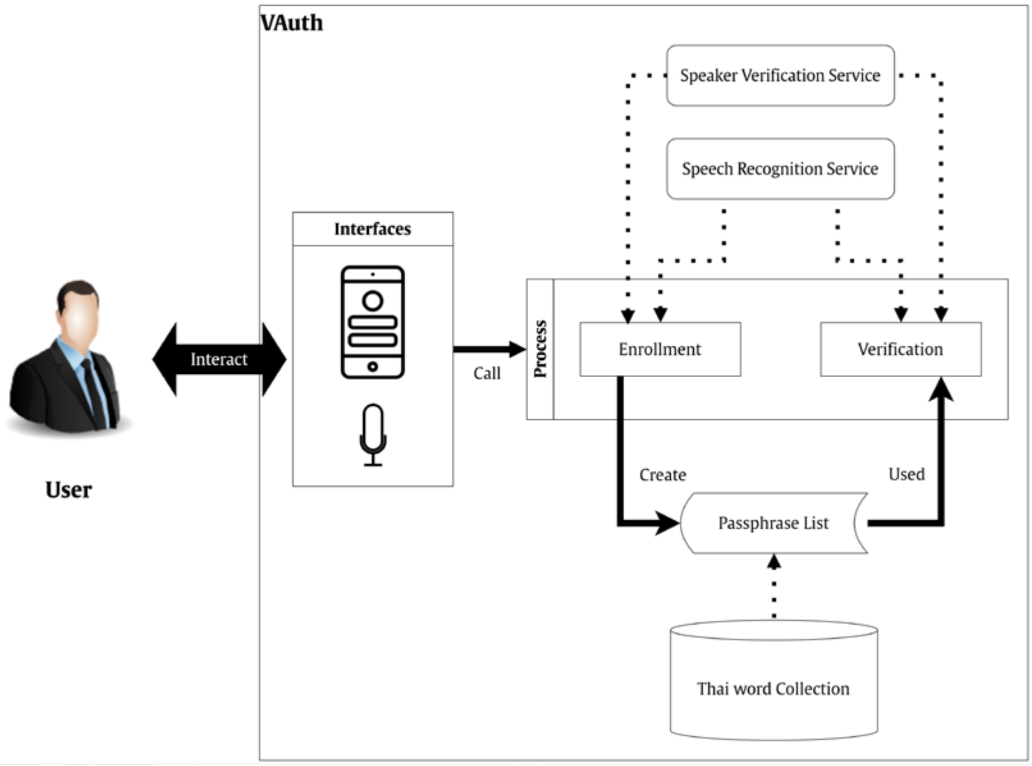

Figure 1 VAuth's conceptual framework.

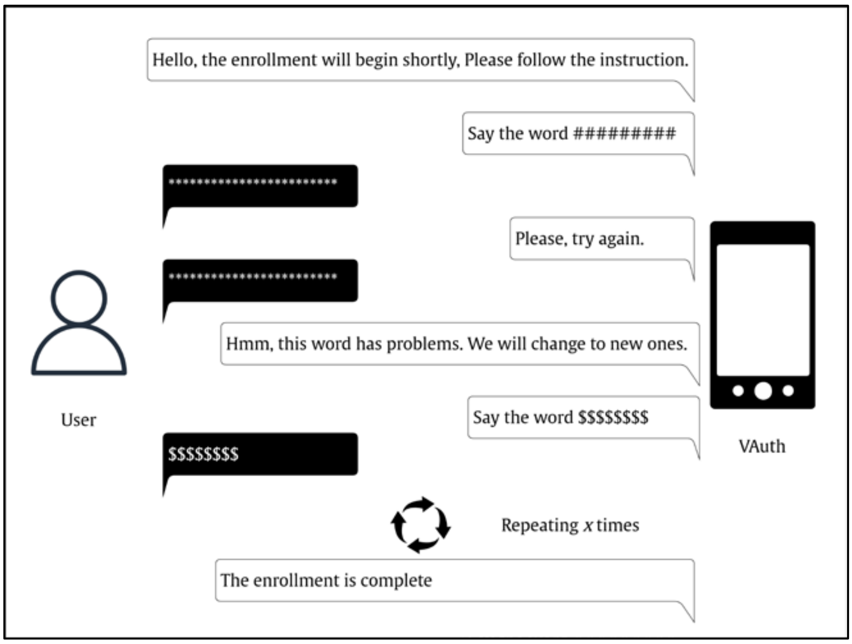

Figure 2 Enrollment dialogue.

VAuth has two primary dialogue flows: enrollment and verification dialogues, designed in line with the guidelines [18] based on Grice's maxims of conversations. Figure 2 illustrates the dialogue for enrollment. When the process begins, VAuth will greet a user and introduce the task he/she is about to perform. Then, VAuth will ask the user to repeat random words one at a time. After the user finishes the task, VAuth will say that voice authentication is ready. If a recognized word does not match one VAuth provides to the user, the system will ask the user to repeat the same word. VAuth will have the user attempt a new word if the second attempt is unsuccessful.

In the verification dialogue shown in Figure 3, VAuth will ask users to speak one of the words selected during enrollment. The system will inform

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users about the result if the verification is successful. However, if either voice or word is incorrect, VAuth will also inform the user, who has another chance for verification.

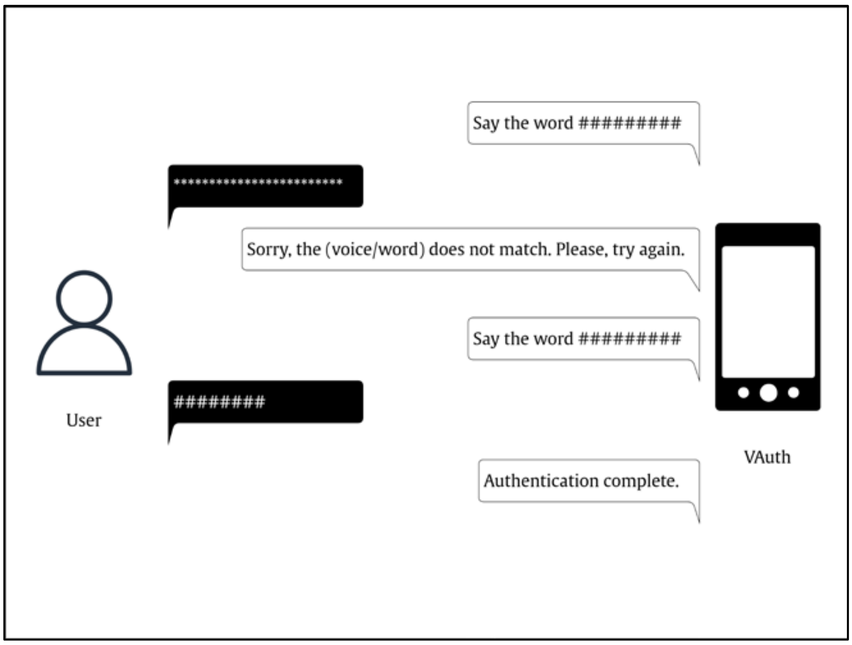

Figure 3 Verification dialogue.

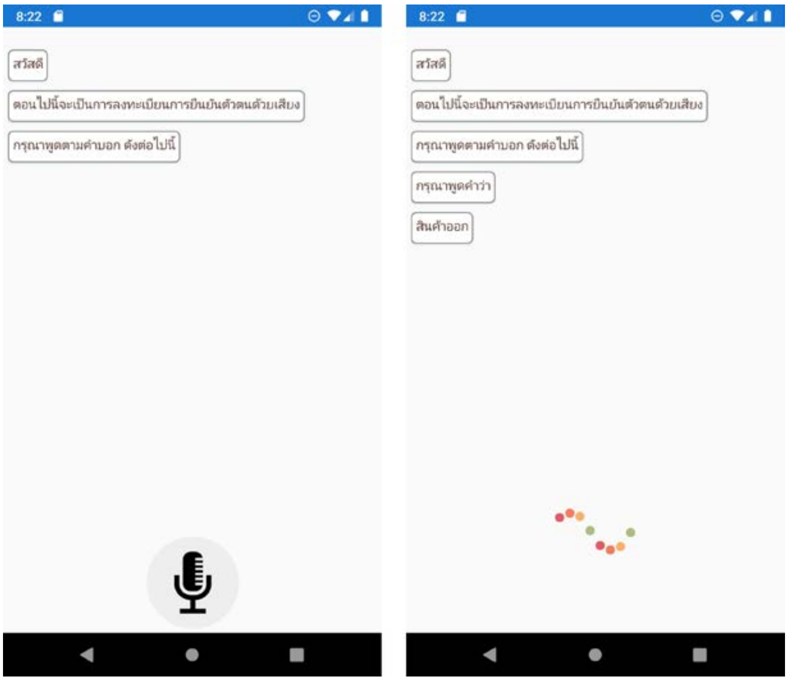

Figure 4 VAuth's GUIs used in the experiment.

A collection of Thai words is prepared for enrollment and verification. However, VUIs place a more considerable burden on short-term memory than the GUI [19]. Moreover, older adults' cognitive decline is most noticeable in short-term memory [1]. Therefore, the words in the collection are relatively short, which minimizes the effort of pronunciation.

The design

The GUIs of VAuth were based on designs for well-known applications, such as Siri and Google Assistant. It consists of a microphone button and a dialogue panel, as illustrated in Figure 4. The microphone button is for users to resume manually, and the panel displays past dialogue, which helps users keep track of the conversation.

VAuth was implemented into an Android application using the Xamarin Mobile app development platform. Both Thai word collection and passphrase list were stored within the application. A speech-to-text service from Microsoft Azure Cognitive Speech Services [20] was used to transcribe texts users have

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spoken because of its relatively good accuracy. Unfortunately, a speaker verification service from Microsoft Azure did not support the Thai language when the study was conducted. Moreover, the proper voice verification system could not be implemented due to time and resource constraints. Nevertheless, since this research focuses on human-computer interaction, this issue was circumvented by simulating the voice verification process and assuming that the speaker's voice always matched the record.

Assessment

Formative Usability Testing [21] was employed for the assessment. Although it typically lacks statistical power due to a small sample group (5-8 persons in general), this approach was suitable for evaluating a new idea and discovering a problem in the early stages.

The testing process was conducted iteratively and incrementally, consisting of three iterations. Participants would perform enrollment and verification with VAuth in each iteration. Participants would receive explanations before beginning the test, and they could use VAuth freely and repeat as many tasks as they wanted. Participants' behaviors and thoughts were noted and later analyzed by researchers to improve the system further. The testing process is intentionally less formal to avoid creating a restrictive atmosphere and encourage participants to express their thoughts.

Participants were recruited from the local community in Don Mueang district, Bangkok. Each testing iteration has five participants. They had to be 60 years old or older and have prior experience regarding smartphone usage. However, experiences in authentication and VUIs were optional. Persons of unsound mind, incompetent, or quasi-incompetent were excluded from participation. The testing was conducted with the cooperation of the local clinic in the same district to select people who fit within the criteria.

Two standardized questionnaires were employed as additional tools to assess the perceived usability of VAuth. The first questionnaire was the Single Ease Question (SEQ) [22], a popular tool to gauge the perceived difficulty of a specific task. The questionnaire typically queries users with a simple question, such as "How easy was it to complete task Number 1?" Users will respond on a scale corresponding to their perceived level of easiness. For this study, a 7-point scale was used; Level One meant the task was very difficult, while Level Seven suggested that the task was very easy.

Another questionnaire was the System Usability Scale (SUS) [23], which measures the perceived ease of use of a system. Figure 5 shows a ten-item questionnaire, each with five scale steps. The odd-numbered items have a positive tone, while the even-numbered items have a negative tone. Participants shall answer how much they agree or disagree with each item, from position one on the leftmost (Strongly Disagree) to position five on the rightmost (Strongly Agree).

	The System Usability Scale Standard Version	Strongly disagree 1	2	3	Strongly disagree 4	5
1	I think that I would like to use this system frequently.	○	○	○	○	○
2	I found the system unnecessarily complex.	○	○	○	○	○
3	I though the system was easy to use.	○	○	○	○	○
4	I think that I would need the support of a technical person to be abe to use this system.	○	○	○	○	○
5	I found the various functions in the system were well integrated.	○	○	○	○	○
6	I thought there was too much inconsistency in this system.	○	○	○	○	○
7	I would imagine that most people would learn to use this system very quickly.	○	○	○	○	○
8	I found the system very awkward to use.	○	○	○	○	○
9	I felt very confident using the system.	○	○	○	○	○
10	I needed to learn a lot of things before I could get going with this system.	○	○	○	○	○

Figure 5 SUS Questionnaire.

Scoring the SUS starts with calculating the score for each item. Scores range from zero to four. For items with positive wording (odd-numbered questions), the score is the scale position minus one (e.g., if the response is 3, the score is 2). For items with negative wording (even-numbered questions), the score is five minus the scale position (e.g., if the response is 3, the score is 2). The overall SUS score is obtained by summing

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these item scores and multiplying by 2.5, giving a final score between 0 and 100 in steps of 2.5.

In this research, the modified SUS was used because item five from the original version ("I found the various functions in the system were well integrated") was unsuitable for the study. According to Lewis and Sauro [24], SUS items can be removed if the multiplier used for scoring is adjusted. Instead of the original multiplier of 2.5, the multiplier of 2.78 was used to account for the dropped item, ensuring the final score remained accurate.

The adjective rating from the work of Bangor, Kortum, and Miller [25] was used to interpret and analyze the SUS scores. The rating is described in Table 1.

Table 1 Adjective Rating Scale.

SUS Score	Adjective Rating
< 20.3	Worst Imaginable
< 35.7	Awful
< 50.9	Poor
< 71.1	Okay
< 85.5	Good
< 90.9	Excellent
>= 90.9	Best Imaginable

RESULTS AND DISCUSSION

Participants

In the first iteration, the participants comprised one male and four females aged 64 to 71. One participant held a bachelor's degree, while the rest had an upper-secondary school diploma or equivalent. All participants use Android phones, though the two used no authentication scheme. None of the participants had used VUIs.

Participants in the second iteration were one male and four females, aged between 62 and 76. One participant had a diploma from an upper-secondary school, while four only completed lower-secondary school. Three participants use iPhones, and the other two use Android phones. Two participants had experience with at least one authentication scheme. Two participants had used VUIs in the past.

Finally, participants in the third iteration were one male and four females whose ages ranged from 66 to 75. Only four of them completed lower-secondary schools. Only one participant had the device's authentication feature enabled. Four participants did not have experience with VUIs.

Observation

In the first iteration, while there was awkwardness at the first attempt, participants quickly understood the tasks after receiving instructions. Nonetheless, the system occasionally incorrectly transcribed words. When misrecognition occurred, the participant required assistance from the researcher. During the test, participants completed tasks quietly and would speak only when the researcher talked to them.

There was a minor GUI issue during the second iteration when the conversation was not displayed correctly. The long texts overflowed outside the screen instead of wrapping onto the following line. Regarding user errors, the participants remained idle on multiple occasions after an unsuccessful voice recognition. One participant was unaware that a microphone button was clickable, and another also spoke multiple times before the recording started.

As in the first iteration, the misrecognition Occasionally occurred. For instance, when pronouncing a Thai word with "ส" as an initial, participants had to say the word louder than usual. Otherwise, the system would miss the word entirely. The system also wrongly recognized "ข" as "ข่," the same consonant but with a different tone.

In the third iteration, when failed recognition occurred, Participants could follow the instructions and respond correctly. The problem of speaking too early happened occasionally. Nevertheless, participants made no more mistakes after learning to wait for signals.

Participants' opinions

Participants from the first iteration praised VAuth for its straightforward process with a minimum number of steps. They also had positive opinions about its advantages, such as operating the phone hands-free and its self-intuitive nature. Participants gave additional comments regarding voice authentication. For instance, they stated that most older adults would prefer the old familiar method and might require encouragement from trusted individuals before adopting a new system.

In the second iteration, participants also received VAuth favorably. They noted its quick and uncomplicated process and appreciated that they only needed to follow instructions. Participants also had favorable opinions about the advantages of VUI, such as the hands-free feature. Furthermore, participants like the simplicity of GUIs with minimum controls on the screen.

Likewise, participants in the third iteration had positive opinions about VAuth. They considered it simple and easy to use, with similar reasons to participants in previous iterations. Most participants did not find notable problems in VAuth. Nevertheless, one participant raised concerns about common issues of VUIs, such as noise in the environment and the awkwardness of using VUIs in public places.

Questionnaire

Table 2 shows the SEQ scores rated by participants from all three iterations. Overall, Participants provided high SEQ scores for enrollment and verification tasks, with the lowest score being five.

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The SUS scores are shown in Table 3, along with the Geometric mean of scores in each iteration. The Adjective Rates of the scores are stated in the final column. In line with the SEQ scores, all participants provided relatively high SUS scores. However, the scores from the first iteration are slightly lower than others.

Table 2 SEQ scores.

Iteration	Participant ID	Enrollment	Verification
1st	1	6	6
	2	5	5
	3	6	6
	4	5	5
	5	6	6
2nd	6	6	6
	7	6	6
	8	7	7
	9	5	5
	10	5	5
3rd	11	6	6
	12	5	5
	13	6	6
	14	7	7
	15	6	6

Table 3 SUS scores and adjective rates.

Iteration	Participant ID	SUS score	Adjective Rating
1st	1	78.13	Good
	2	71.88	Good
	3	78.13	Good
	4	56.25	Okay
	5	53.13	Okay
	Geometric Mean	66.61	Okay
2nd	6	87.50	Excellent
	7	87.50	Excellent
	8	81.25	Good
	9	59.38	Okay
	10	62.50	Okay
	Geometric Mean	74.59	Good
3rd	11	84.38	Good
	12	62.50	Okay
	13	90.63	Excellent
	14	87.50	Excellent
	15	68.75	Okay
	Geometric Mean	77.93	Good

System adjustment

During the first iteration, some participants encountered an issue where VAuth confused a word with a similar word having a different tone. Thus, frequently misrecognized words were replaced to remedy this issue.

Unfortunately, these changes did not completely solve the issue, which still occurred in the second iteration. Hence, the mechanism to replace a word after two misrecognitions was introduced to ensure users could complete enrollment. An additional dialogue was also included to guide participants when misrecognition happened. As one participant in the second iteration spoke too early multiple times, voice and vibrating

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notifications were added to signal the start and end of the voice recording period.

The second round of changes eventually mitigated most previous problems. The last remaining issue is accuracy, where misrecognition still occurs. However, there was no further possible adjustment since VAuth relied on a third-party voice recognition service beyond the researchers' control.

Discussions

The results signify the design's suitability for older adults. Participants generally gave positive opinions about VAuth. Their views are supported by SEQ and SUS scores indicating substantial ease of use. Although some problems still occurred during the test, they did not significantly impact user experience and were gradually resolved.

The adoption of VUIs produced encouraging results. While some participants displayed awkwardness due to unfamiliarity, they quickly adapted to VUIs after a brief period. Participants also had favorable opinions about the VUIs, albeit some still had concerns like privacy, security, and user preference. These results are aligned with past works [12-16] and reconfirm the viability of VUIs for older adults.

The dialogues were designed to avoid situations requiring the user's contemplation. All instructions were concise and explicit, while users' responses were limited to speaking passphrases. Although participants did not specifically comment on VAuth's dialogue design, their task completion, high SEQ scores, and lack of criticism meant the dialogues worked as intended, which implied the design approach ' s appropriateness.

Using common Thai words as a passphrase delivered a satisfying outcome. Participants could correctly pronounce almost all passphrases, albeit with some conscious effort. The SEQ scores also indicate a significant ease of tasks. Therefore, it can be concluded that utilizing common words as passphrases, like Rehman and Lee's approach [6], is appropriate with voice authentication.

There is still a persistent issue regarding the accuracy of speech recognition. Although Microsoft's services mostly could recognize the central Thai dialect, there were instances where the service misrecognized words repeatedly, as mentioned previously. The issue raises concerns about whether VAuth can recognize other dialects and accents.

Nonetheless, there has been progress in voice authentication techniques to improve the accuracy of Thai speech recognition. For example, the work of Kantithammakorn et al. [26] proposes a model to assess Thai language fluency and identify patients with mild cognitive impairment. Muangjaroen and Udomsiri's work [27] presents techniques for automatic speech recognition in Thai, with a case study on speech command control of mobile robots. Lastly, Rukwong and Pongpinigpinyo's work [28] applies a deep learning technique to recognize Thai vowels in speech.

Finally, there was another issue about the Think-aloud protocol. According to the protocol, participants will say their thoughts while completing the task. So, researchers can gain insight into the participants' cognitive processes in addition to the outcome. However, older adults rarely spoke during the test, and researchers often needed to ask them questions to get responses after the task.

The explanation is that not all people are comfortable verbalizing their thoughts while occupied with some tasks [29]. In the case of older adults, verbalizing their activities may create a dual-task situation, overloading their already diminished mental capacity and producing inaccurate results. Thus, it is more appropriate to allow older adults to complete the task before verbalizing their thoughts.

CONCLUSIONS

The results of this pilot study suggest that VAuth is usable for older Thai users. Consequently, VAuth's key characteristics, such as VUIs as a primary interface, concise and explicit dialogue, and utilizing Thai words as passphrases, can be considered suitable for older Thai adults. Although there are concerns regarding accuracy, progress has been made in voice authentication techniques to overcome this problem.

Despite encouraging outcomes, this work still has issues. The test does not confirm whether that solution will work when deployed in a bigger context. Furthermore, the test happened in the optimal environment for VUIs, and there are multiple scenarios that this work does not cover, such as the test in environments with various noise levels. Finally, VAuth has yet to be tested against existing authentication methods to confirm its advantages. Therefore, additional studies are necessary to confirm the benefits of VAuth. Those studies will be conducted in other usage conditions to compare VAuth with existing authentication methods with an increasing number of subjects to enable statistical tests.

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Strategic environmental assessment of Thai river basins: Incorporating climate change considerations

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ABSTRACT

It is globally recognized that climate change is increasingly affecting sustainable development. Given these challenges, it is imperative to incorporate climate change considerations as part of Strategic Environmental Assessment (SEA), a tool used for sustainable development and planning strategies. The Thai government is in the process of developing river basin management schemes and updating SEA for all the river basins in the country. Considering climate change in future development planning processes would ensure that the outcomes enable more sustainable development. In this article, SEA reports for Thai river basins that have been completed were examined to determine if climate change was considered and how it was done. Analyses were conducted for each of the four phases of SEA, i.e., establishing the context for SEA, implementing SEA, informing, and influencing decisions, monitoring and evaluating plans. The checklist criteria were used to analyze climate change impacts in the river basin SEA reports, focusing specifically on climate change or global warming impacts that lead to serious disasters in the river basins. The results showed that 7 out of the 9 reports currently consider climate change impacts, but not in all phases of the SEA. The linkage of climate change impact analyses between the different phases was weak. There were only 4 reports that sufficiently considered climate change impacts in the second phase of the SEA. These reports used both qualitative and quantitative tools that were appropriate for predicting climate change impacts and with a link to the third and fourth phases. As a result, most of the SEA reports were insufficient in considering climate change impacts.

Keywords: Climate change, Global warming, River basin management, Strategic environmental assessment, Water resources management

INTRODUCTION

Climate change is the change in the state of the climate that can be detected (e.g., by statistical tests) and that change persists over an extended period of time, usually decades or longer [1, 2]. The impacts of climate change are now global and unprecedented in scale. The headquarters of the UN just issued a warning that the era of global warming has ended and "the era of global boiling has arrived" because July 2023 was on track to be the warmest month ever [3]. The World Meteorological Organization (WMO) scientists indicate that long-term warming is continuing and that the likelihood of a temporary exceedance of the 1.5 °C upper limit set by the Paris Agreement is increasing over time [4].

Regarding the impacts on river basins, climate change has significant impacts on the hydrological cycle that lead to serious environmental problems and disasters in river basins. Globally, rivers have experienced dramatic changes in their discharge, reducing their natural ability to adapt to and absorb disturbances. Given the expected changes in global climate change and water demand, this may lead to the loss of native biodiversity and risks to ecosystems and people from increased flooding or water scarcity [5].

Thailand ranks 9th in the world as the country with the highest risk of climate change. In addition, Thailand's ability to cope with disasters is quite low (39th out of 48 countries) [6]. In 2011, Thailand was damaged by floods. The damage amounted to around 1.43 trillion baht, which corresponds to 12.6 percent of the GDP. This does not take into account the opportunity cost of investing in other activities that could be more productive for the economy than repair and rehabilitation work [7]. Thus, if drastic actions are not taken, adaptation to these impacts will be even more difficult and costly in the future [2, 8, 9].

Strategic Environmental Assessment (SEA) is

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a systematic and internationally recognized process used in strategic planning for the future to propose a policy, plan, or program (PPP) that serves sustainability. It was developed in the late 1960s and first applied in the United States of America with the National Environmental Policy Act of 1969. It has evolved and is now used in a variety of sectors to assess and predict potential impacts, achieve sustainability, and make adequate adaptation decisions [9-14].

Thailand has been making efforts to promote the concept of sustainability. In 2009, the 10th National Plan for Economic and Social Development (2007-2011) published the first general guideline for SEA practitioners [15]. In 2017, a general guideline was published under the 12th National Plan for Economic and Social Development (2017-2022) and the National Strategy 2018-2037 [16]. The Office of National Water Resources (OWNR), a government agency responsible for the nation's water policy, commissioned a committee composed of experts from all relevant departments and consulting firms to prepare SEA reports for 22 major river basins for sustainable water management. The plan was to publish the SEA reports starting in 2020 and complete them by 2027. At this stage (August 2023), there are SEA reports available for 9 river basins, as shown in Figure 1.

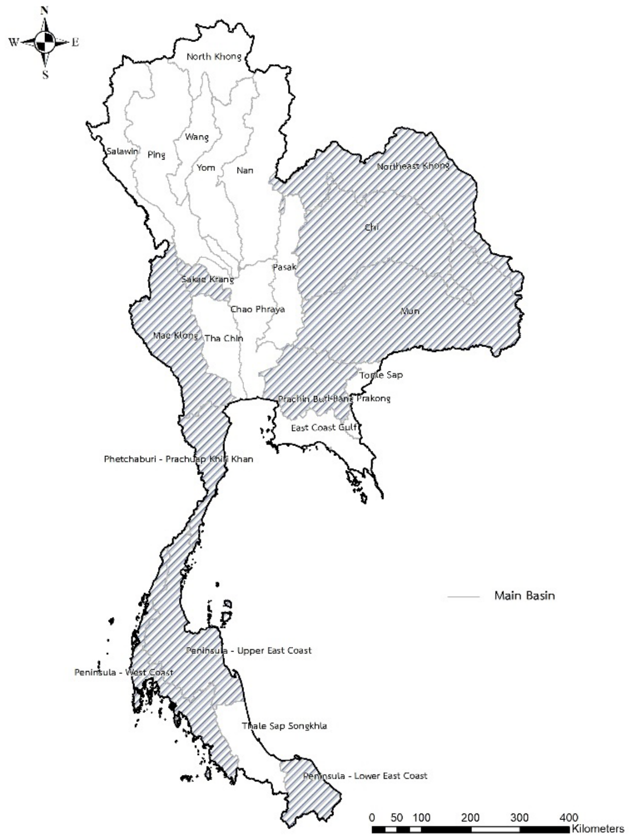

Figure 1 The current publications of river basin SEA reports (shaded areas).

Basically, SEA should include four phases [9, 16-26]. The first phase (i.e., establishing the context for the SEA) is reviewing the need for the SEA, scanning for targets, and initiating the preparatory tasks. Identifying the main issues of focus (extreme or exceptional events) from climate change and defining the objectives of SEA, i.e., how to improve the planning process, as well as, identifying interested and affected stakeholders [27] and planning their participation [28].

In the second phase (i.e., implementing the SEA), historical data on floods, droughts, extreme weather events, and water demand are collected. The observed (historical) data or scenario model is scoped and used to determine the extent of water stress and forecast the potential impacts of climate change on river basins [12, 29-31]. Climate change mitigation strategies are then formulated (i.e., identify actions to reduce adverse impacts or improve resilience) [32], as well as reports on policy reforms and potential environmental linkages.

In the third phase (i.e., informing and influencing decisions), the presentation of the final report, policy summary, and infographics that are important for influencing key decisions, are prepared. A clear, understandable, and concise briefing or issue paper can help ensure that decision makers are aware of the key environmental issues related to the PPP, particularly the climate change impacts analyzed.

In the fourth phase, monitoring and evaluation plans are established to minimize the climate change impacts of implementing the strategic policy, plan, or program, and to ensure that the goals of the SEA are met. These mechanisms allow for the timely detection of adverse impacts and the implementation of corrective actions.

The consideration of climate change is to ensure that future development outcomes of policy plans and programs can withstand climate change and protect the ecosystems of the basin and the welfare of the people to achieve sustainable water management. This article investigated whether climate change was adequately considered in the assessment process, and examined how climate change was considered and presented in the Thai river basin SEA process.

MATERIALS AND METHODS

The 9 SEA reports published on Thai River Basins were reviewed to determine the extent to which climate change was addressed. The reports, i.e., Chi [33], Sakae Krang [34], Prachin Buri-Bang Pakong [35], Peninsula-East Coast [36], Mun [37], Phetchaburi-Prachuap Khiri Khan [38], Peninsula-West Coast [39], Mae Klong[40], and Northeast Kong[41], were published by the Office of the National Water Resources (ONWR) between 2020 and 2022. They can be downloaded online at http://sea.nesdc.go.th.

Climate change impacts addressed in the river basin SEA reports focus specifically on climate change or global warming impacts, such as seasonal fluctuations in water balance, inadequate water supplies for

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consumption, and the frequency and severity of droughts and floods [42-44]. Content analyses were conducted in all the main SEA phases. Checklists were used to rate climate change impacts considered in the reports as 'Y' (yes - the criterion was met) or 'N' (no - the criterion was not met) to determine whether the stated criteria were met (Figure 2). There were 3 levels of outcome:

1. Does not consider; none of the criteria were met.
2. Insufficient; some criteria were met.
3. Sufficient; all criteria were met.

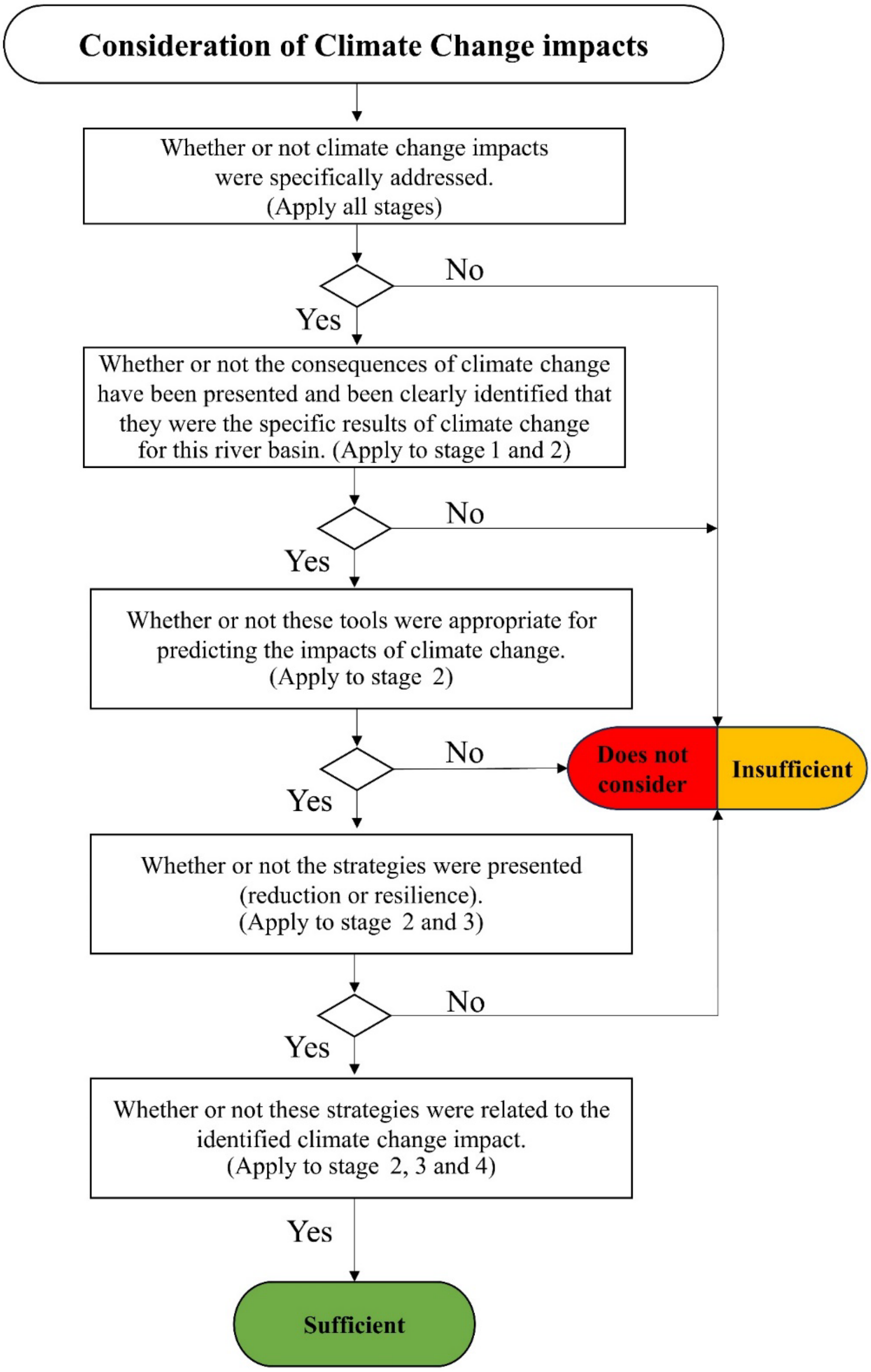

Figure 2 Criteria for consideration of climate change impacts in the SEA.

The first screening criterion was to inspect the content in all phases of the SEA to determine whether or not climate change impacts were specifically addressed. This was done by looking up specific words or contexts that explicitly mentioned climate change, greenhouse gases, greenhouse effects, global warming, climate anomaly, and their effects on river basins. If climate change was specifically addressed, this criterion would be rated "yes". Otherwise, it would be rated "no".

The second criterion, only applying to phases 1 and 2, was to examine whether or not the consequences of climate change had been presented and clearly

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identified, such that they were the specific impacts of climate change for those particular river basins. If the general consequences of climate change were presented but they were not clearly identified and were specific to those river basins, this criterion would be rated "no".

The third criterion, only applying to phase 2, was to identify whether or not there were tools applied to predict the impacts of climate change. The usage of study tools, e.g., data gathering-spatial and temporal data in the form of databases or reviews, physical/conceptual/mathematical (stochastic/deterministic) models, risk or consequences assessment matrices, or expert judgements, must be appropriate to evaluate the climate change impacts, and the corresponding quantitative or qualitative results must be presented. If there were no applications of tools or the applied tools were not appropriate to evaluate the impacts, this criterion would be rated "no".

The fourth criterion, applying to phases 2 and 3, was to examine whether or not the strategies were presented. The specific strategies for that particular river basin that resulted from the SEA to mitigate or reduce climate change or create resilience to climate change must be presented. If the presented strategies were gathered from other sources, this criterion would be rated "no".

The fifth criterion, applying to phases 2, 3, and 4, was to examine whether or not the presented strategies were related to the identified climate change impact of that particular river basin. If there were no related strategies presented or the presented strategies were not related to the identified impacts, this criterion would be rated "no".

For all the criteria, if there were no relevant information or data presented, that criterion would be rated "does not consider".

RESULTS AND DISCUSSION

Overall, all the reports were structured and formulated according to the general SEA guide for Thailand [16]. The results of the review are presented in Table 1 and summarized in Figure 3. The results showed that 7 out of the 9 SEAs included climate change impact considerations, but these were not sufficient in all the phases.

It was noticeable that none of the reports considered climate change in the first phase of establishing context for the SEA. For the second phase of the implementation of SEA, the results showed that there were 4 reports that sufficiently considered climate change, including the Prachin Buri-Bang Pakong, Peninsula East Coast, Mun, and Northeast Khong River Basins. It was insufficiently considered in the Chi, Peninsula-West Coast, and Mea Klong River Basins. However, the Phetchaburi-Prachuap Khiri khan river basin was insufficiently considered, but not in the form of a climate change impact analysis as part of the SEA process, as the climate change strategies originate from the existing water management plans. The rest of the reports did not consider climate change at all. For the third phase on informing and influencing decisions, the results showed that there were 3 reports that sufficiently considered climate change, including the Prachin Buri-Bang Pakong, Mun, and Northeast Khong River Basins, while it was insufficiently considered for the Mea Klong River Basin. The other reports did not consider climate change. For the fourth phase of the monitoring and evaluation plans, the results showed that there were 4 reports that sufficiently considered climate change, including the Prachin Buri-Bang Pakong, Peninsula East Coast, Mun, and Northeast Khong River Basins, while the other reports did not consider it.

Table 1 The consideration of climate change impacts in the SEA reports for the Thai River Basin.

SEA Reports	Criteria	SEA Process* 1	2	3	4
1. Chi River Basin (Jan-2020)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	N	N
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		Y		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		N	N	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		N	N	N
	Result**	DC	IS	DC	DC

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SEA Reports	Criteria	SEA Process* 1	2	3	4
2. Sakae Krang River Basin (Jan-2020)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	N	N	N
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	N		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		N		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		N	N	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		N	N	N
	Result**	DC	DC	DC	DC
3. Prachin Buri-Bang Pakong River Basin (Mar-2020)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	Y	Y
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		Y		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		Y	Y	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		Y	Y	Y
	Result**	DC	S	S	S
4. Peninsula-East Coast River Basin (Sep-2020)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	N	Y
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		Y		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		Y	N	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		Y	N	Y
	Result**	DC	S	DC	S

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SEA Reports	Criteria	SEA Process*			
		1	2	3	4
5. Mun River Basin (Mar-2021)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	Y	Y
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		Y		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		Y	Y	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		Y	Y	Y
	Result**	DC	S	S	S
6. Phetchaburi-Prachuap Khiri Khan (Sep-2021)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	N	N	N
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	N		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		N		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		N***	N	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		N	N	N
	Result**	DC	IS	DC	DC
7. Peninsula-West Coast River Basin (Sep-2021)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	N	N
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		Y		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		N	N	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		N	N	N
	Result**	DC	IS	DC	DC

SEA Reports	Criteria	SEA Process* 1	2	3	4
8. Mae Klong River Basin (May-2022)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	Y	N
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		N		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		N	Y	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		N	N	N
	Result**	DC	IS	IS	DC
9. Northeast Khong River Basin (May-2022)	1. Whether or not climate change impacts were specifically addressed. (Apply to all phases)	N	Y	Y	Y
	2. Whether or not the consequences of climate change were presented and they were clearly identified to be the specific results for this river basin. (Apply to phase 1 and 2)	N	Y		
	3. Whether or not the tools used for predicting the impacts of climate change were appropriate. (Apply to phase 2)		Y		
	4. Whether or not reduction or resilience-related strategies were presented. (Apply to phase 2 and 3)		Y	Y	
	5. Whether or not the strategies identified were related to the climate change impacts assessed. (Apply to phase 2, 3 and 4)		Y	Y	Y
	Result**	DC	S	S	S

*SEA Process number 1 is establishing the context for SEA, 2 is implementing SEA, 3 is informing and influencing decisions, and 4 is the monitoring and evaluation phase.
**DC stands for Does not consider, IS for Insufficient, and S for Sufficient.
***The strategies related to climate change come from the existing water management plans, not from the SEA.

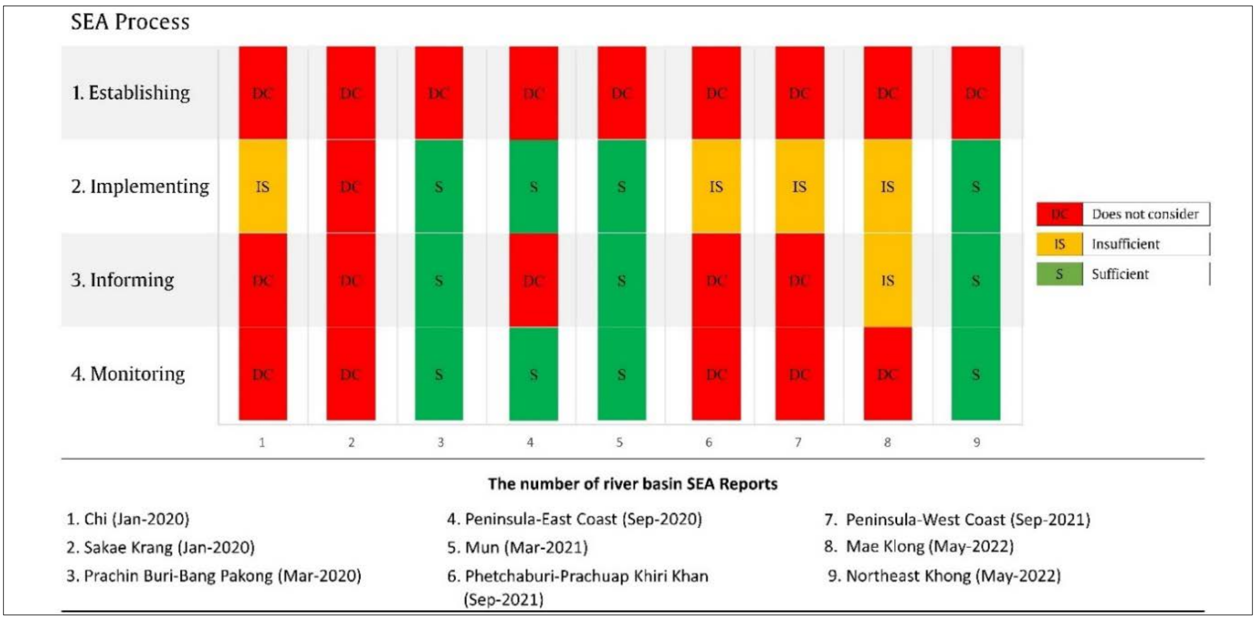

Figure 3 The summary result of addressing climate change impacts in the SEA reports for the Thai river basin.

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In the first phase of SEA, climate change impacts were not specifically addressed in all the reports investigated because there was no clear distinction between the scanning task in the first phase and the scoping task in the second phase. The purpose of the scanning process, described in public guidance documents, was to target what was likely to have significant impacts on or be significantly affected by climate change, to consider whether the context for SEA was comprehensive in the first phase [2]. The scoping task in the second phase was to collect data to predict climate change impacts and identify relevant actions. All these reports integrated the scanning task of the first phase with the scoping task of the second phase, and most of them considered climate change impacts in the context of the scoping task. Therefore, all reports were rated "do not consider".

The second phase, implementation of SEA, begins with the scoping task and the prediction of future climate change impacts and the development of a policy plan or program. All tasks should be sufficiently considered and linked to each other's. In particular, the identification of climate change impacts has been analyzed through the choice of assessment tools [45, 46]. Both qualitative and quantitative tools should be chosen for comprehensive tools [47, 48], especially the quantitative tools with statistical data analysis and scenario modeling for future prediction of climate change impacts [49].

It was found that 4 SEA reports for the Prachin Buri-Bang Pakong, Peninsula-East Coast, Mun, and Northeast Khong River Basins fully considered the impacts of climate change and were linked to each task, producing sufficient results. These reports first used qualitative tools such as literature reviews, expert judgment, and public workshops to identify the most important issues. Then, quantitative tools such as GIS, basic statistical data analysis, climate modeling, or scenario modeling were used to assess climate change impacts. Then qualitative tools were used again, including analysis of strengths, weaknesses, opportunities, and threats (SWOT), analysis of strengths, opportunities, aspirations, and results (SOAR), multi-criteria decision making (MCDM), expert judgment, and public workshops for priority setting, action, and policy program creation. Thus, these 4 reports were rated "sufficient". In addition, two of these reports, the Prachin Buri-Bang Pakong and Mun River Basins, used scenario modeling instead of statistical data analysis. It was developed by the IPCC [30] to assess the impacts of climate change, taking into account changes in the hydrological cycle, and to present representative concentration pathways (RCPs) of the climate change scenarios to provide a reliable and comprehensive prediction [50].

For the 4 reports, including the Chi, Peninsula-West Coast, Phetchaburi-Prachuap Khiri Khan, and Mea Klong River Basins, the considerations were not presented for every task in the second phase; the result was "insufficient". The Chi and Peninsula-West Coast River Basin reports addressed climate change impacts and used both qualitative and quantitative tools, particularly, the Peninsula-West Coast River Basin report used IPCC scenario models, but neither report assessed the link to policymaking. The Mea Klong River Basin report examined climate change impacts using only qualitative tools such as SWOT, TOWS, MCDM, expert judgement, and public workshops, which were less comprehensive and not linked to next tasks. The report for the Phetchaburi-Prachuap Khiri Khan River Basin did not specifically address climate change impacts as the first task and the use of statistics based on satellite imagery (area-based mapping) was addressed as part of the task to develop strategies that came from the existing water management plans and not from the SEA.

For the rest of the report, the Sakae Krang River Basin, the result was "does not consider" because it did not specifically address climate change impacts. Only the main problems (floods and droughts) were addressed and analyzed using statistics based on satellite imagery (area-based mapping) and did not compare to climate modeling. There were no linkages between each task.

In the third phase, strategic summaries in the form of reports or infographics were prepared for decision-makers who needed to know how climate change would affect future development, the impact of their decisions, and the consequences of not making such decisions. It was determined that 3 reports, the Prachin Buri-Bang Pakong, Mun, and Northeast Khong River Basins, were "sufficient" as they comprehensively analyzed the climate change impacts associated with the above phase and presented their significance. Climate change mitigation and resilience measures were presented in both summary reports and infographics. The report on the Mae Klong River Basin was "insufficient" because, although it presented climate change impacts, these were only from existing water management plans and not from SEA. The other reports were rated "does not consider" because they did not present climate change impacts and related actions in their summaries.

The final phase reviewed reports on monitoring and evaluation plans to track progress on climate change mitigation or resilience strategies described in the reports from SEA. It was found that 4 reports, the Prachin Buri-Bang Pakong, Peninsula East Coast, Mun, and Northeast Khong River Basins, were rated "sufficient" as they presented the measures to monitor the impacts of climate change and identified the agencies responsible for the plans. In the other reports, climate change impacts were not presented at all in the monitoring plans, which resulted in a rating of "does not consider".

In addition, if climate change impacts are more effectively addressed, the policy plan or program established during the SEA process, particularly in the informing and monitoring phases, should develop rapporteurs and make open data resources available

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to the private sector. These strategies would provide early warning of climate change impacts to local people and give them time to prepare, adapt, or build networks that could provide information more quickly. In this way, they could be helped, and losses and damages could be reduced [50-52].

CONCLUSIONS

The results showed that 7 of the 9 SEA reports on Thai River Basins consider the impacts of climate change, but not for all the phases. All the reports that consider climate change impacts were found to start with the second phase, i.e., the implementation of the SEA. In the SEA reports for the Prachin Buri-Bang Pakong, Mun, and Northeast Khong river basins, climate change impacts were found to be fully considered and to be linked to the next phases, leading to sufficient outcomes in phases 2, 3, and 4. Two of these reports, the Prachin Buri-Bang Pakong and Mun River Basins, used both qualitative and quantitative tools to analyze the impacts of climate change. They used scenario models developed by the IPCC to assess the impacts of climate change, which were more reliable and appropriate in comparison to the statistical data analyses.

Based on the results of this study, the government should pay more attention to the impacts of climate change in the SEA process, e.g., by publishing guidelines for the SEA of Thai river basins for practitioners that incorporate climate change impacts. The guidelines should consider the impacts of climate change from the initial phase and focus on systematic analyses in all subsequence phases.

The findings can be applied to the development of the SEA guidance document for Thai river basins and contribute to a more comprehensive consideration of climate change impacts in SEA reports to ensure more sustainable development results.

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