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Research Paper

Modeling of Subsurface Pipe Conditions at a Depth of 30, 45, and 60 cm Using the GPR Method

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ABSTRACT: *Water leakage is a case that is often found in an area. Determination of the location of the leak and the condition after repairs on the subsurface is an obstacle to be faced. GPR is a geophysical method that can be used to identify subsurface conditions. This study uses GPR Scudo which has specifications in the form of a central frequency of 500 MHz and a frequency bandwidth of 30 MHz–900 MHz. The results of the time cut can be used in determining the general characteristics of the pipe condition. The condition of the empty pipe is characterized by a hyperbolic pattern with a weakening of the wave amplitude. The condition of the half-filled pipe with water is characterized by a hyperbolic pattern with a contrast between the water and air contained in the pipe. The condition of the pipe filled with water has a characteristic hyperbolic pattern with contrast on the part filled with water. The condition of pipe leakage is characterized by multiple conditions in hyperbola and absorption. The deeper the pipe, the weaker the amplitude caused by the attenuation. The percentage of errors in the pipe diameter produced in this 30 cm depth study obtained a value of 10.01% in an empty pipe condition, 23.73% in a half-filled pipe condition, 1.24% in a full-water-filled pipe condition, and 12.49 % on pipe leakage conditions. The depth of 45 cm resulted in a value of 1.24% for an empty pipe, 23.73% for a half-filled pipe with water, 23.73% for a full-water pipe, and 12.49% for a pipe leak. The depth of 60 cm resulted in a value of 10.01% in an empty pipe condition, 23.73% in a half-filled pipe condition, 12.49% in a full-water pipe condition, and 10.01% in a pipe leak condition.*

KEYWORDS: ***GPR,*** *pipe leakage*

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I. INTRODUCTION

Pipes have an important role in distributing water. Disturbances in water distribution are often experienced by water supply companies and the public as consumers. An example of a disturbance that is often experienced is a water leak in the pipe. The problem experienced is in determining the location and condition of the pipe that has been closed with road pavement or filled with soil without having to dig it first, so a special method is needed to detect subsurface pipes.

GPR is a geophysical method that is fast, precise, and effective in surveying underground targets with shallow depths [4]. Based on previous research conducted by Lai et al. [10], the reflection on the pipe leak will completely produce a blurred image. This is caused by the reflection coefficient in the leakage area. The factor that influences the leakage is the water content contained in the dielectric medium. The pipe leak point can be obtained due to the higher water content compared to the surrounding area [11]. Amran et al. [2] stated that the pipe leak caused a new hyperbolic reflection pattern. According to Ayala-Cabrera [3] detection of pipes with empty pipes shows a weak image contrast in the pipe image section. This is due to the low contrast between the soil and the pipe.

The impact of a pipe leak is that there are several conditions in the pipe, namely the condition of the pipe being empty, the pipe being partially filled with water, the pipe being full of water, and the pipe leaking. This research was conducted to identify the general characteristics of each condition, especially in the condition of the half-filled pipe as a model of the partially filled pipe and full water pipe which was previously rarely studied. The diameter of the pipe is one of the important pieces of information in identifying pipe leaks and dealing with them. The difficulty that is often experienced is in determining the value of the diameter of the pipe containing water, oil, and gas [13]. These problems can be overcome by processing data on the image. Data

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processing is one of the important research stages in determining the pipe diameter in the image. This research was also conducted to obtain the error results in the pipe diameter after data processing.

GPR or better known as Ground Penetrating Radar is an active geophysical method that transmits radar waves into the soil layer which then receives the reflected radar waves to the receiver. The results of the acquisition of the GPR method are the amplitude, frequency of the waves, the time between sending, and receiving waves at the receiver which will then be processed by processing the data from the acquisition to determine the results of the underground image [6].

Permittivity can be defined as the ability of a material to store and release electromagnetic energy in the form of an electric charge. The relative permittivity can be written as the ratio between the permittivity of material and the permittivity of a vacuum, which can be written as follows [9]:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \qquad (1)$$

with a value of 0 is 8.8542 x 10-12 F/m. The relative dielectric permittivity is also known as the dielectric constant.

Table 1: Value of relative permittivity, electrical conductivity, velocity and attenuation in a material [7]

Material	ε_r	σ (mS/m)	α (dB/m)
Air	1	0	
Freshwater	81	$10^{-6} – 10^{-2}$	10^{-2}
Sea Water	81	10^{2}	100
Sand dry	2-6	10^{-7} - 10^{-3}	10^{-2} - 1
Sand wet	10-30	$10^{-3} – 10^{-2}$	0.5 - 5
Soil clay dry	4-10	$10^{-2} – 10^{-1}$	0.3 - 3
Soil clay wet	10-30	10^{-3} - 1	5 - 50
Soil loamy wet	4-10	$10^{-4} – 10^{-2}$	0.5 - 3
Soil sandy dry	10-30	$10^{-2} – 10^{-1}$	0.1 -2
Rock salt dry	4-7	$10^{-4} – 10^{-2}$	10^{-2} - 1
Coal dry	3.5	$10^{-3} – 10^{-2}$	1 - 10

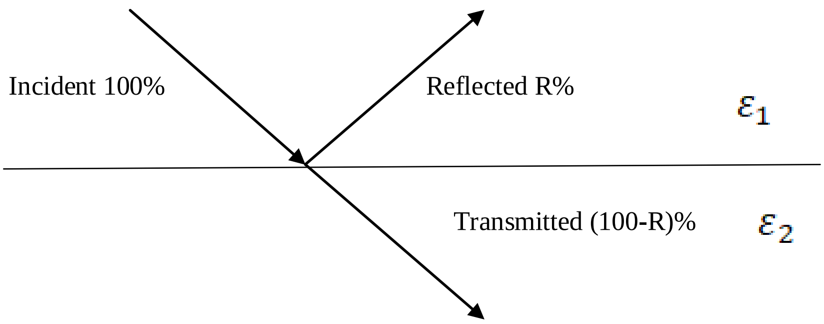

Figure1: Reflected GPR [5]

The reflection coefficient can be written with the following equation (2) [5]:

$$R = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \qquad (2)$$

where 1 is the relative dielectric permittivity 1 and 2 is the relative dielectric permittivity 2.

The maximum depth that can be obtained by the image depends on the time window value and the relative dielectric permittivity which can be written by the following equation (3) [9]:

$$R_{max} = \frac{c\, T_r}{2\sqrt{\varepsilon_r}} \qquad (3)$$

where c is the speed of light whose value is 0.3 m/ns, Tr is the time window value, and r is the relative dielectric permittivity.

II. METHODS

The acquisition of this research was carried out on 3-13 August 2021. Research tools and materials used included meters, pipes, water, laptops, GPS, and GPR Scudo.

Figure 2 Pipe design

The data acquisition in this study used the reflection profiling method, which was carried out by pushing the GPR Scudo device with a central frequency of 500 MHz above ground level with a space of 0.4 m. The acquisition was carried out in four stages at each depth. The first stage is an acquisition with an empty pipe condition. The second stage is the acquisition with the condition of the pipe half-filled with water. The third stage is the acquisition with the condition of the pipe being filled with water. The fourth stage is the acquisition with the condition of a pipe leak. The acquisition process begins with burying the pipe, the pipe is then adjusted according to the assumptions according to each condition, then data is collected, after data collection using Scudo GPR is complete then the data is stored. The depth of the pipe used is a depth of 0.3 m, 0.45 m, and 0.6 m

The use of data processing steps in this study can be seen in **Figure 3**. The image data processing results in the diameter of the PVC pipe. The diameter of the PVC pipe can be used to calculate the error according to the following equation (4) **[1]:**

$$err\% = \frac{|P_{mod} - P_{ref}|}{P_{ref}} \; x\; 100 \qquad (4)$$

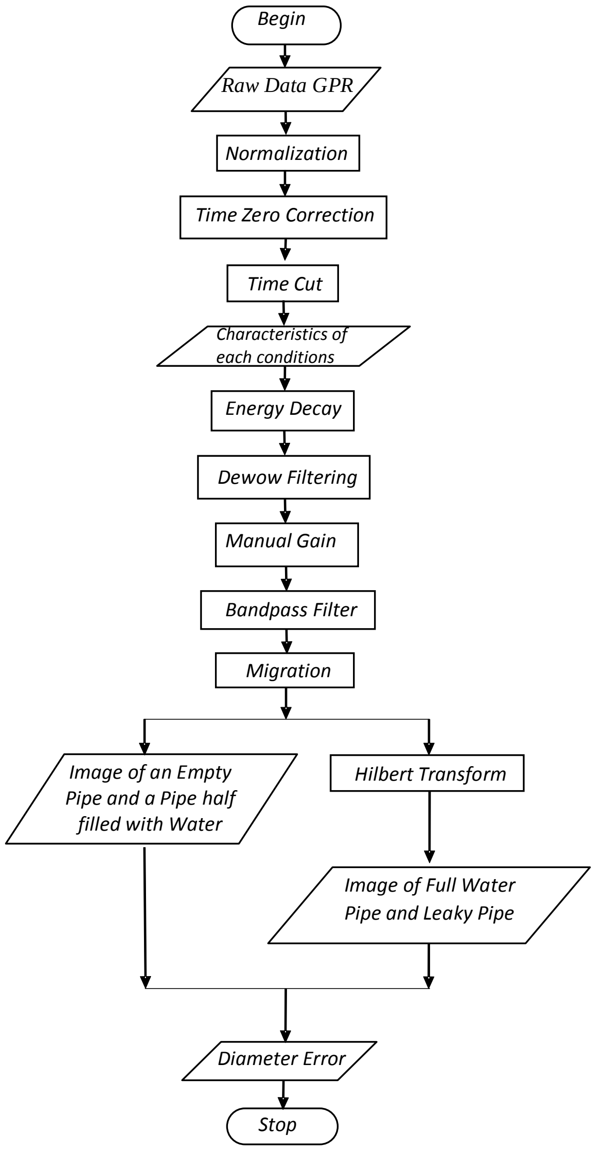

Figure 3 Flowchart of data processing

III. RESULTS AND DISCUSSIONS

The results of this study are 30 image lines with the provisions of 10 lines at each depth, namely 30 cm, 45 cm, and 60 cm. Each depth produces 3 lines with an empty pipe condition, 3 lines with a half-water condition of the pipe, 3 lines with a full-water condition of the pipe, and 1 line with a pipe leak condition.

According to Reynolds [12], the relative value of dielectric permittivity on PVC material is 3. The relative value of dielectric permittivity on dry soil, wet soil, air, and water materials refers to Table 1 so that the calculation of the R-value in equation (2) is obtained as in Table 2.

The results in Figure 4(a) time cut conditions of an empty pipe with a depth of 30 cm show a hyperbolic pattern with attenuation of wave amplitude. The attenuation of the amplitude is caused by the reflection coefficient that varies according to the material or object media that the wave signal passes through. The absolute R-value for empty pipe conditions in percent on dry soil-PVC is 7.18%, on PVC-air 26.75%, air-PVC 26.75%. The attenuation value of R produces a hyperbolic pattern with blur in the part of Figure 4(a) shown in a circle. The results of the study according to the statement of Ayala-Cabrera et al. [3] that the condition of the empty pipe causes a weak image contrast in the pipe image section. The calculation of the reflection coefficient can be used as a reference for estimating the empty pipe, which previously had known the location and condition of the pipe.

Table 2: Calculation of R value

Object	R-Empty pipe	R-The pipe is half filled with water	R-The pipe is full of water	R-leaky pipe
Dry soil-wet soil	-	-	-	-0.4650
Wet soil-PVC	-	-	-	0;5195
Dry soil-PVC	0.0718	0.0718	0.0718	-
PVC-Air	0.2675	0.2675	-	-
PVC-Water	-	-	0.6772	0.6772
Air-Water	-	-0.8	-	-
Air-PVC	-0.2675	-	-	-
Water-PVC	-	-0.6772	-0.6772	-0.6772

The results in Figure 4(b) time cut condition of the pipe half-filled with water with a depth of 30 cm show a hyperbolic pattern with image contrast between water and air contained in the PVC pipe. The absolute R-value for the condition of the pipe is half-filled with water in percent on dry soil-PVC 7.18%, on PVC-air 26.79%, on air-water 80%, and on water-PVC 67.72%. The R-value produces a hyperbolic pattern with blur at the top and contrast at the bottom as shown in Figure 4(b) in a circle. The difference in the image between the condition of the pipe half-filled with water and the condition of the empty pipe is the resulting R and the image of the condition of the empty pipe which initially produces a blurred pattern on the hyperbola, while in the condition of the half-filled pipe with water the hyperbola pattern becomes a blurred pattern at the top and contrasts with the bottom. which indicates the pipe is half-filled with water.

The results in Figure 4(c) time cut condition of the pipe filled with water with a depth of 30 cm show a hyperbolic pattern with contrast in the part filled with water. The absolute R-value for the condition of the pipe being filled with water in percent on dry soil-PVC was 7.18%, on PVC-water 67.72%, and on water-PVC 67.72%. The R-value produces a hyperbolic pattern with the contrast shown in Figure 4(c) in a circle. The difference with the condition of the empty pipe is that the R is generated and the image of the condition of the empty pipe which initially produces a blurred pattern in the hyperbola becomes a contrast pattern on the inside of the pipe which indicates the pipe is full of water.

The results in Figure 4(d) time cut pipe leakage conditions with a depth of 30 cm indicate that there are 2 conditions in the leakage area, namely reflection and absorption conditions. The absolute R-value for the condition of the pipe being full of water in percent on soil-wet soil is 46.50%, on wet soil-PVC 51.95%, on PVC-water 67.72%, and on water-PVC 67.72%. The R-value produces a blurred pattern in the area around the pipe image and multiple patterns at the bottom as shown in Figure 4(d). The occurrence of a reflection pattern at the bottom of the pipe image is following the statement of Amran et al. [2]. The occurrence of pipe leaks causes the image of the anomalous area to be blurred due to water moving towards the top of the pipe leak. These results are following the results of research by Lai et al. [9]. Reflection and absorption mechanisms are mechanisms that occur in identifying pipe leaks [9]. The difference with the pipe filled with water is the resulting R and the image of the pipe filled with water which initially produces a contrast pattern in the hyperbola to a blurred pattern around the pipe section and the presence of multiples at the bottom of the pipe.

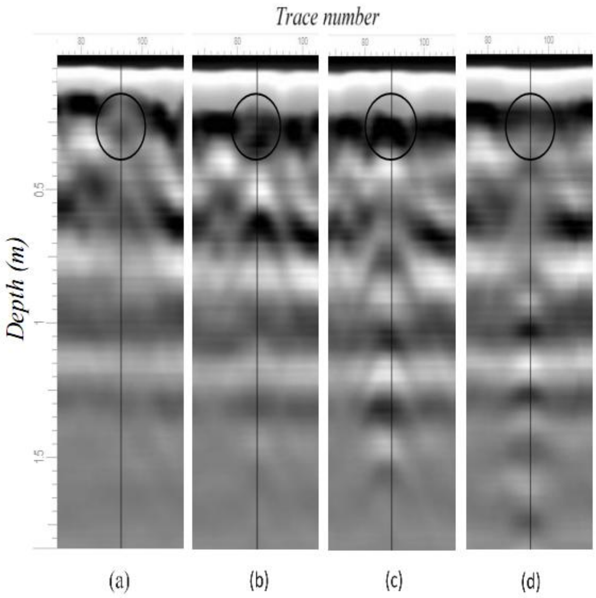

Figure 4 Time Cut with a depth of 30 cm with the conditions (a) the pipe is empty, (b) the pipe is half-filled with water, (c) the pipe is full of water, and (d) the pipe is leaking

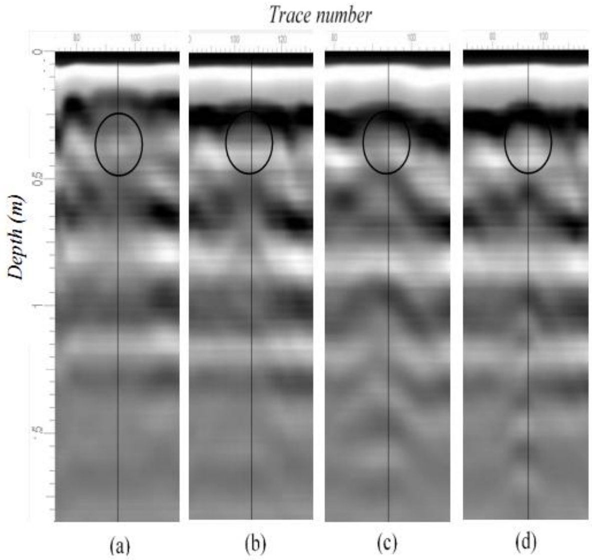

Figure 5 Time Cut with a depth of 45 cm with the conditions (a) the pipe is empty, (b) the pipe is half-filled with water, (c) the pipe is full of water, and (d) the pipe is leaking

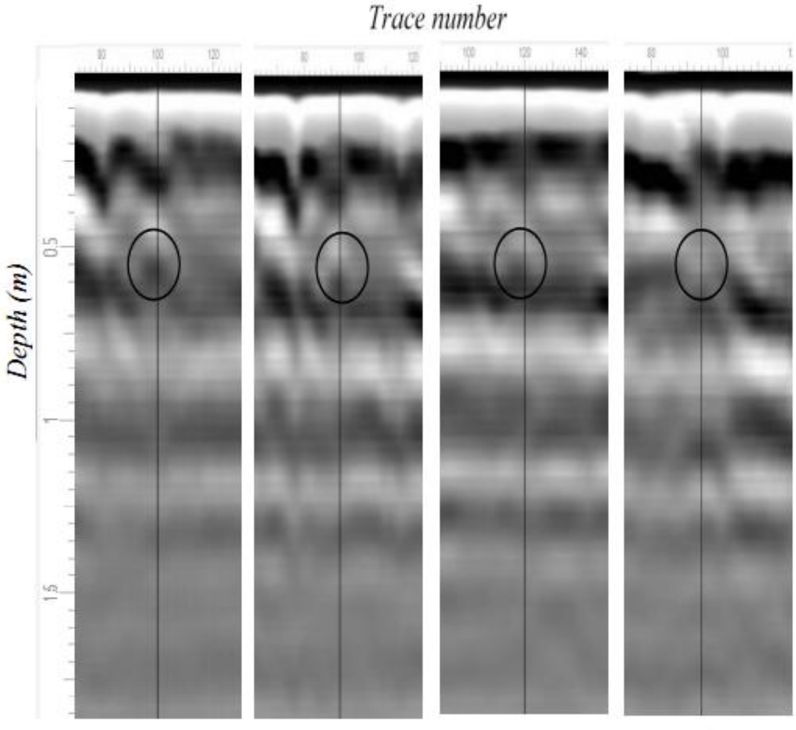

Figure 6 Time Cut with a depth of 60 cm with the conditions (a) the pipe is empty, (b) the pipe is half-filled with water, (c) the pipe is full of water, and (d) the pipe is leaking

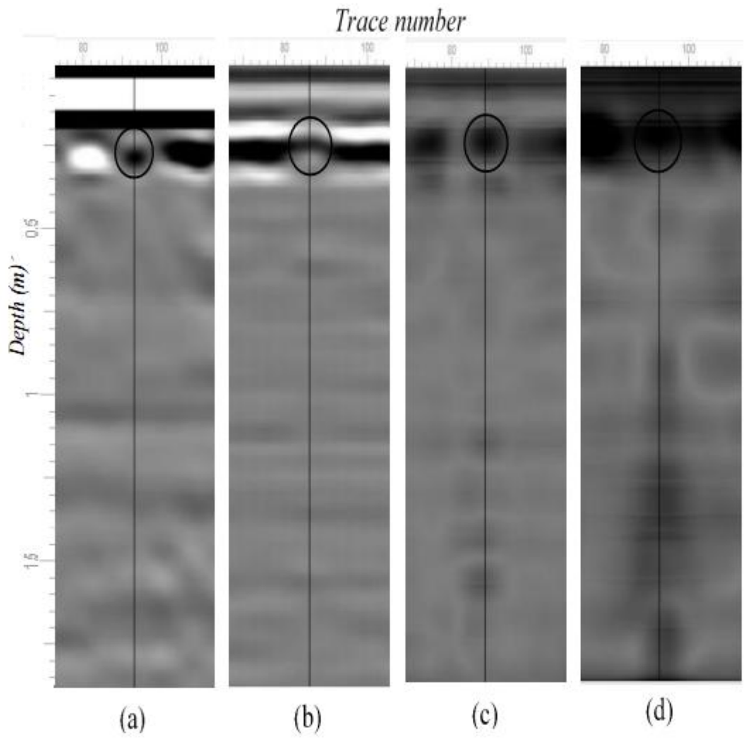

Figure 7 The results of data processing at a depth of 30 cm with the conditions (a) the pipe is empty, (b) the pipe is half-filled with water, (c) the pipe is full of water, and (d) the pipe is leaking

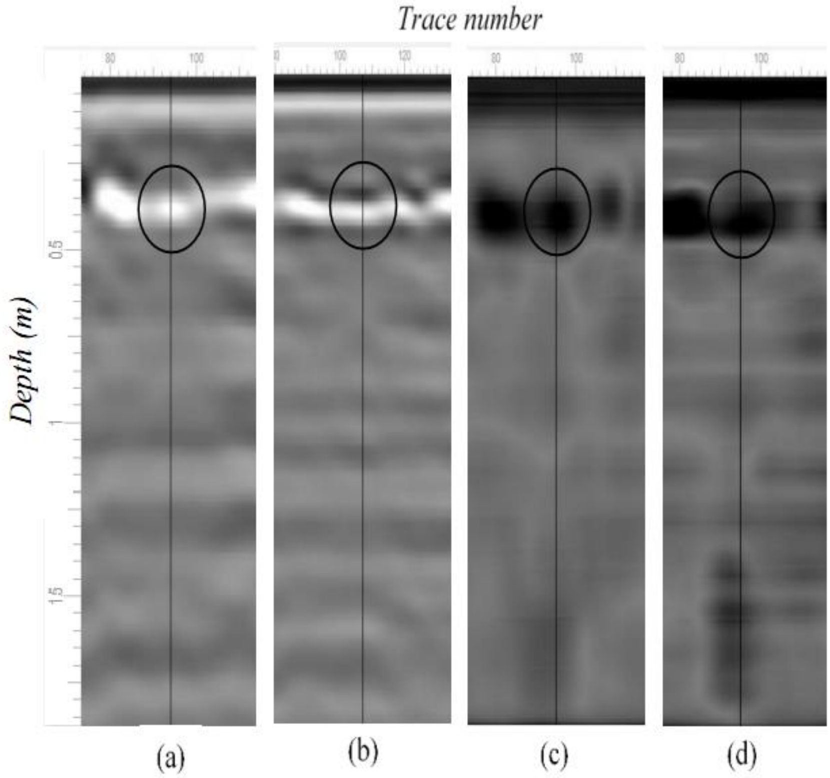

Figure 8 The results of data processing at a depth of 45 cm with the conditions (a) the pipe is empty, (b) the pipe is half-filled with water, (c) the pipe is full of water, and (d) the pipe leaks

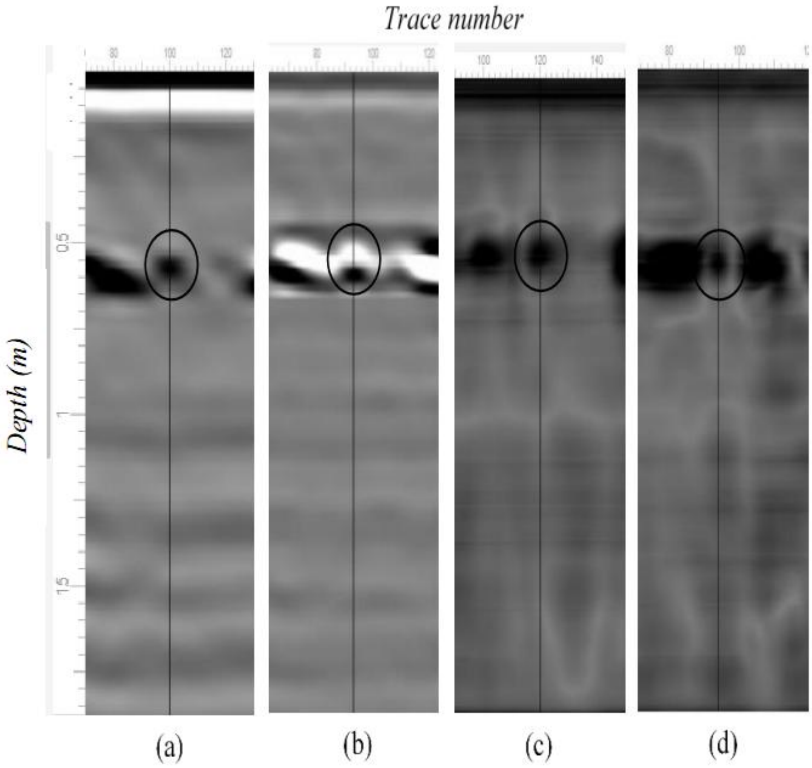

Figure 9 The results of data processing at a depth of 60 cm with the conditions (a) the pipe is empty, (b) the pipe is half-filled with water, (c) the pipe is full of water, and (d) the pipe leaks

The results of the processing are then calculated the pipe diameter according to the image in Figure 7 above. Measurement of diameter at an empty pipe with a depth of 30 cm obtained a value of 8 cm which is shown in the image results in Figure 7(a) in a black circle which shows the image of the pipe with an empty condition. The diameter measurement in the condition of the half-filled pipe with water at a depth of 30 cm obtained a value of 11 cm which is shown in the image results in Figure 7(b) in a black circle which indicates a contrast between the presence of water and air in the pipe. The diameter measurement in the condition of the pipe being filled with water at a depth of 30 cm obtained a value of 9 cm which is shown in the image results in Figure 7(c) in a black circle which indicates the pipe has been filled with water. Measurement of the diameter at a pipe leak condition of a depth of 30 cm obtained a value of 10 cm which is shown in the image results in Figure 7(d) in a black circle which indicates the location of the pipe in the soil. The actual diameter of the pipe is 8.89 cm. The error value of the diameter of the pipe image can be calculated using equation (4). The error results obtained 10.01% in the condition of the empty pipe, 23.73% in the half-filled pipe with water, 1.24% in the full-water-filled pipe, and 12.49% in the leaking pipe.

The image at a depth of 30 cm previously explained the effect of wave reflection or commonly known as reflection. The image at a depth of 45 cm will explain the absorption effect. Amplitude attenuation due to absorption is caused by the conductivity of the medium. The higher the conductivity of a material, the faster the wave will disappear due to absorption [8].

The results of Figure 5(a), with an empty pipe state indicate the presence of absorption, which when compared with the empty pipe at a depth of 30 cm, then the empty pipe at a depth of 45 cm is seen to experience a weakening of the amplitude. The condition of the half-filled pipe in Figure 5(b) also shows a weakening of the amplitude in the image contrast between water and air. Figure 5 with the condition of the pipe filled with water and the pipe leak also shows a decrease in the amplitude in each condition, but this can be overcome by the characteristics of the image in the condition of the pipe filled with water and the condition of the pipe leak. The difference in the image between the condition of the pipe being filled with water and the condition of the pipe leaking is that there is a pattern of absorption by water in the leaking pipe which is shown in Figure 5(d) with a blurred pattern around the pipe section and multiple at the bottom of the pipe.

The results of the processing are then calculated the pipe diameter according to the image in Figure 8. Measurement of diameter at an empty pipe with a depth of 45 cm obtained a value of 9 cm which is shown in the image results in Figure 8(a) in a black circle which shows the image of a pipe with an empty condition. The diameter measurement in the condition of the half-filled pipe with water at a depth of 45 cm obtained a value of 11 cm which is shown in the image results in Figure 4(b) in a black circle which shows the contrast of the presence of water and air in the pipe. The diameter measurement in the condition of the pipe being filled with water at a depth of 45 cm obtained a value of 11 cm which is shown in the image results in Figure 8(c) in a black circle which indicates the pipe has been filled with water. Measurement of diameter at a pipe leak condition of 45 cm depth obtained a value of 9 cm which is shown in the image results in Figure 8(d) in a black circle which indicates the location of the pipe in the ground. The error value of the diameter of the pipe image can be calculated using the equation (4). The result of the error is 1.24% for the empty pipe, 23.73% for the half-filled pipe, 23.73% for the full-water pipe, and 1.24% for the leaking pipe.

Comparison of the time cut between the depths of 30 cm, 45 cm, and 60 cm shows the effect of attenuation of the GPR signal. The comparison shows a weakening of energy at each depth. The deeper the pipe condition, the weaker the amplitude caused by the attenuation as shown in Figure 6 when compared to Figure 4 and Figure 5. Attenuation is caused by the reflection previously described at a depth of 30 cm and absorption at a depth of 45 cm. When the transmitter emits energy, the wave will reflect and transmit. The energy will continue to spread through the depths of the ground until the energy dissipates due to attenuation. The image captured on the display unit is the result of a reflection whose waves can return to the ground surface and are captured by the receiver [6].

The results of the processing are then calculated the pipe diameter according to the image in Figure 9. Measurement of diameter at an empty pipe with a depth of 60 cm obtained a value of 8 cm which is shown in the image results in Figure 9(a) in a black circle which shows the image of the pipe with an empty condition. The diameter measurement in the condition of the half-filled pipe with water at a depth of 60 cm obtained a value of 11 cm which is shown in the image results in Figure 9(b) in a black circle which shows the contrast of the presence of water and air in the pipe. The diameter measurement in the condition of the pipe being filled with water at a depth of 60 cm obtained a value of 10 cm which is shown in the image results in Figure 9(c) in a black circle which indicates the pipe is full of water. Measurement of diameter at a pipe leak condition with a depth of 60 cm obtained a value of 8 cm which is shown in the image results in Figure 9(d) in a black circle which indicates the location of the pipe in the ground. The error value of the diameter of the pipe image can be calculated using equation (3.1). The results for the error are 10.01% in the empty pipe condition, 23.73% in the half-filled pipe with water, 12.49% in the full-water-filled pipe, and 10.01% in the leaking pipe.

IV. CONCLUSION

The conclusions that can be drawn from this study are, among others, the condition of the empty pipe has the characteristics of a hyperbolic pattern with attenuation of amplitude. The condition of the half-filled pipe with water has the characteristics of a hyperbolic pattern with image contrast between water and air so that there is a pattern of attenuation of amplitude at the top and contrast at the bottom. The condition of the pipe filled with water has the characteristics of a hyperbolic pattern with contrast on the part that is filled with water. The condition of the pipe leak has the characteristics of a blurred pattern on the pipe section and has multiple at the bottom of the pipe image. The pipe leak indicates the presence of reflection and absorption conditions. These characteristics apply when the depth of the PVC pipe is at a shallow depth, so data processing is necessary if you want to produce a more accurate image of the condition of the pipe. The error percentage in this study is the pipe diameter error in each condition and the depth is less than 25%.

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