Underground Water Detection Using Radar with Doppler Effect

Prof.Lalitha N

Professor,Department of Electronics and Communication Vidya Vikas Institute of Engineering and Technology Mysore,Karnataka,India
Email:lalithanvviet@gmail.com

Sudhanvi Patel HS

Student,Department of Electronics and Communication Vidya Vikas Institute of Engineering and Technology Mysore,Karnataka,India Email:sudhanvipatel1093@gmail.com

Rachana Prabhudev

Student,Department of Electronics and Communication Vidya Vikas Institute of Engineering and Technology Mysore,Karnataka,India Email:racchanaprabhudev@gmail.com

Abstract : Underground water detection using radar enhanced by Doppler analysis offers a non-invasive and highly sensitive method for identifying subsurface water movement. By transmitting high-frequency electromagnetic waves into the ground, the radar system measures signal reflections that vary according to changes in soil composition and moisture content. The incorporation of the Doppler effect enables the system to distinguish between static geological features and dynamic signatures produced by flowing or shifting groundwater. Frequency shifts in the returned signal provide insight into water velocity, direction, and depth, improving detection accuracy in complex terrains. This approach overcomes limitations of traditional ground - penetrating radar by enhancing sensitivity to subtle motion-induced phase variations. The method is particularly useful in hydrogeological surveys, leak detection, environmental monitoring, and early assessment of aquifer recharge zones. Additionally, Doppler-assisted radar minimizes the need for drilling or intrusive sampling, reducing cost and environmental impact. Its capability to operate in diverse soil conditions makes it suitable for both arid and densely vegetated regions. Overall, integrating Doppler processing with underground radar systems significantly advances the precision and reliability of groundwater mapping.

INTRODUCTION

Underground water detection is essential for effective groundwater management, environmental monitoring, and civil engineering planning, and radar-based sensing has emerged as a powerful non-invasive technique for this purpose. Traditional ground-penetrating radar (GPR) relies on electromagnetic wave reflections to map subsurface layers, but its effectiveness can decrease in complex or heterogeneous soil conditions. To address this limitation, researchers have incorporated the Doppler effect into radar systems, enabling the detection of not only static geological structures but also the motion-related characteristics of groundwater. By analyzing frequency shifts in the returned radar signal, Doppler- enhanced systems can identify flowing water, estimate its velocity, and differentiate it from surrounding soil or rock. This provides a more detailed understanding of aquifer behavior, seepage paths, and underground fluid dynamics. The approach is especially valuable in areas where direct drilling is impractical or where continuous monitoring is required. Furthermore, Doppler-assisted radar improves sensitivity to subtle changes in moisture content, making it a promising tool for leak detection in pipelines, dam inspection, and hydrological research. As the demand for accurate and sustainable groundwater assessment grows, integrating Doppler analysis with radar technology represents a significant advancement in modern subsurface exploration.

Our project addresses this critical and relevant issue by proposing a system that detects underground water within a shallow depth of 1 to 1.5 foot using radar technology enhanced with the Doppler effect. This method leverages electromagnetic wave propagation and Doppler shift analysis to identify the presence of water below the surface, providing a cost-effective and non-invasive alternative to traditional methods.

In the context of increasing water scarcity, rapid urbanization, and unplanned drilling activities that often lead to dry borewells, the need for efficient groundwater detection systems is more urgent than ever. The proposed engineering solution is therefore aligned with current societal and environmental challenges. It presents a promising tool for farmers, land surveyors, and government agencies seeking quick and reliable data on shallow groundwater availability.

By focusing on shallow-depth detection using Doppler-based radar systems, our project integrates fundamental engineering principles of signal processing, embedded system design, and communication technologies. The relevance of this problem lies in its practical applicability and the widespread benefits it offers in improving water resource management, reducing financial losses from failed borewell drilling, and supporting sustainable development initiatives.

LITERATURE SURVEY

Underground water detection using microwave radar, especially Ground Penetrating Radar (GPR), has gained significant attention due to its non-invasive, high-resolution subsurface imaging capabilities. GPR operates by transmitting high- frequency microwave signals into the ground and detecting reflected signals from subsurface structures, with water being easily identifiable due to its high dielectric constant. Research by Daniels (2004) and Jol (2009) has laid foundational principles, while recent advancements focus on integrating machine learning for enhanced data interpretation. Studies show GPR is effective in mapping shallow aquifers and identifying water-saturated zones, especially in arid and semi-arid regions. However, its performance is limited in clay-rich or saline soils due to signal attenuation. Recent developments in multi-frequency and dual-polarization GPR systems have improved detection depth and accuracy. FMCW radar techniques also show promise for enhanced depth penetration. Case studies from India, Australia, and the USA highlight successful real-world applications. Despite challenges, continuous improvements make microwave radar a reliable tool for groundwater exploration.

LITERATURE REVIEW

1. Microwave Detection of Water Pollution in Underground Pipelines

An electromagnetic model is proposed to detect water pollution in underground pipelines. Contaminants present above a certain level in water can be a public health hazard. The contrast in the dielectric constant between contaminated and fresh water is one of the most important parameters to be considered for detecting the presence of pollutants in water. Simulations of frequency response and time domain pulse wave through a multi-layer medium are presented. The complex dielectric permittivity of polluted water has been measured as a function of frequency and analytically represented by Cole-Cole fit model. Water pollution can be detected by observing the variation of the reflection coefficient or reflected signals from unpolluted and polluted water. The experimental set up is described and the procedure followed to obtain an effective permittivity data is outlined. These measurements are, to the best of the author’s knowledge, the first of its kind to be published. Microwave technique discussed in this manuscript for water pollution study is a pioneer technique to detect various pollutants in water.

2. Ground penetrating radar for underground sensing in agriculture

Belowground properties strongly affect agri- cultural productivity. Traditional methods for quantifying below- ground properties are destructive, labor-intensive and point based. Ground penetrating radar can provide non-invasive, areal, and repeatable underground measurements. This article reviews the application of ground penetrating radar for soil and root measurements and discusses potential approaches to overcome challenges facing ground penetrating radar-based sensing in agri culture, especially for soil physical characteristics and crop root measurements. Though advanced data analysis has been deve- loped for ground penetrating radar-based sensing of soil moisture and soil clay content in civil engineering and geosciences, it has not been used widely in agricultural research. Also, past studies using ground penetrating radar in root research have been focused mainly on coarse root measurement. Currently, it is difficult to measure individual crop roots directly using ground penetrating radar, but it is possible to sense root cohorts within a soil volume grid as a functional constituent modifying bulk soil dielectric permittivity. Alternatively, ground penetrating radar based sensing of soil water content, soil nutrition and texture can be utilized to inversely estimate root development by coupling soil water flow modeling with the seasonality of plant root growth patterns. Further benefits of ground penetrating radar applications in agriculture rely on the knowledge, discovery, and integration among differing disciplines adapted to research in agricultural management.

3. etection of underground water distribution piping system and leakages using ground penetrating radar (GPR)

A water pipe is any pipe or tubes designed to transport and deliver water or treated drinking with appropriate quality, quantity and pressure to consumers. The varieties include large diameter main pipes, which supply entire towns, smaller branch lines that supply a street or group of buildings or small diameter pipes located within individual buildings. This distribution system (underground) is used to describe collectively the facilities used to supply water from its source to the point of usage. Therefore, a leaking in the underground water distribution piping system increases the likelihood of safe water leaving the source or treatment facility becoming contaminated before reaching the consumer. Most importantly, leaking can result in wastage of water which is precious natural resources. Furthermore, they create substantial damage to the transportation system and structure within urban and suburban environments. This paper presents a study on the possibility of using ground penetrating radar (GPR) with frequency of 1GHz to detect pipes and leakages in underground water distribution piping system. Series of laboratory experiment was designed to investigate the capability and efficiency of GPR in detecting underground pipes (metal and PVC) and water leakages. The data was divided into two parts: 1. detecting/ locating underground water pipe, 2. detecting leakage of underground water pipe. Despite its simplicity, the attained data is proved to generate a satisfactory result indicating GPR is capable and efficient, in which it is able to detect the underground pipe and presence of leak of the underground pipe.

4. DETECTION OF WATER LEAKS USING GROUND PENETRATING RADAR

Laboratory experiments were used to investigate the potential of using ground penetrating radar (GPR) to detect water leaks in the underground distribution system. Leaks not only waste precious natural resources, they create substantial damage to the transportation system and structure within urban and suburban environments. Surface geophysical methods are non invasive, trenchless tools used to characterize the physical properties of the subsurface material. This characterization is then used to interpret the geologic and hydrogeologic conditions of the subsurface. Many geophysical techniques have been suggested as candidates for detecting water leakage, including GPR, acoustic devices, gas sampling devices and pressure wave detectors. GPR is a reflection technique which uses high frequency electromagnetic waves to acquire subsurface information. GPR responds to changes in electrical properties, which are a function of soil and rock material and moisture content. A series of laboratory experiments were conducted to determine the validity and effectiveness of GPR technology in detecting water leakage in metal and plastic PVC pipes. Initially, a prototype laboratory model was designed to simulate a pipe leak. Holes were drilled in the middle of the pipe to allow the water leak into a simulated soil (sand). The metal and PVC pipes were tested separately by burying them in sand to a depth of

18 and 20 cm, respectively. Water was then injected into the pipe from the surface through a plastic hose. A 1.5 GHz antenna was used to collect GPR data. Although the experiment was very well controlled, results obtained so far indicate that GPR is effective in detecting water leaks. An outdoor test bed is currently under construction in collaboration with Central Arkansas Water (CAW) to simulate and detect water leaks in underground water systems using the GPR technique. Pipes that are commonly used for water distribution in the city of Little Rock, AR, will be used for the test. The test bed will be constructed using soil material that is representative of the region. Advanced digital signal processing will be implemented to enhance the anomalies. Also model simulations will be used to select an appropriate equipment configuration (frequency band, type of antenna and real-time imaging software) prior to data acquisition

RESULT AND DISCUSSION

In this experiment, an empty steel pipe and PVC pipe with imitate leak (hole) was buried horizontally in the test bed at a depth of 30cm. The direction of the pipe was perpendicular to the long axis of the box. After that, the experiment was continued by injecting water inside both pipe, steel and PVC pipe. From this benchmark test, the best ground velocity will be determined. The best ground velocity that gives correct depth is 90m/us. The results of the GPR for this experiment are shown below.

This shows two GPR profiles recorded for steel pipe, (a), empty steel pipe data, (b) fresh water inside the steel pipe. The data was recorded using 1GHz GPR antenna where the long axis of the antenna is perpendicular to the direction of the steel pipe. The length of the pipe is 250mm with diameter of 6mm. In both profiles, sharp anomalous changes was observed and have taken places. These changes occured close to the middle of the profile and exactly exhibit a hyperbola pattern coincide with the location of the steel pipe. It appears at a depth of 0.31m rather than the pipe's actual depth which are 0.3m. From both data (a and b), we can see the patern produced slightly different hyperbolas. It is observed that the anomalous for steel pipe with fresh water inside has bigger hyperbola compare to empty steel pipe. As expected the water although fresh has substantially changed the dielectric constant of the steel pipe. Graph of amplitude shows the wave started to reduce when fresh water was put inside the steel pipe. This is due to the loss of energy when electromagnet wave traveled from sand to water medium. The wave propagation from different medium has an effect to the signal amplitude. This experiment shows that GPR also has capability to detect this type of change (Eyuboglu, 2003).

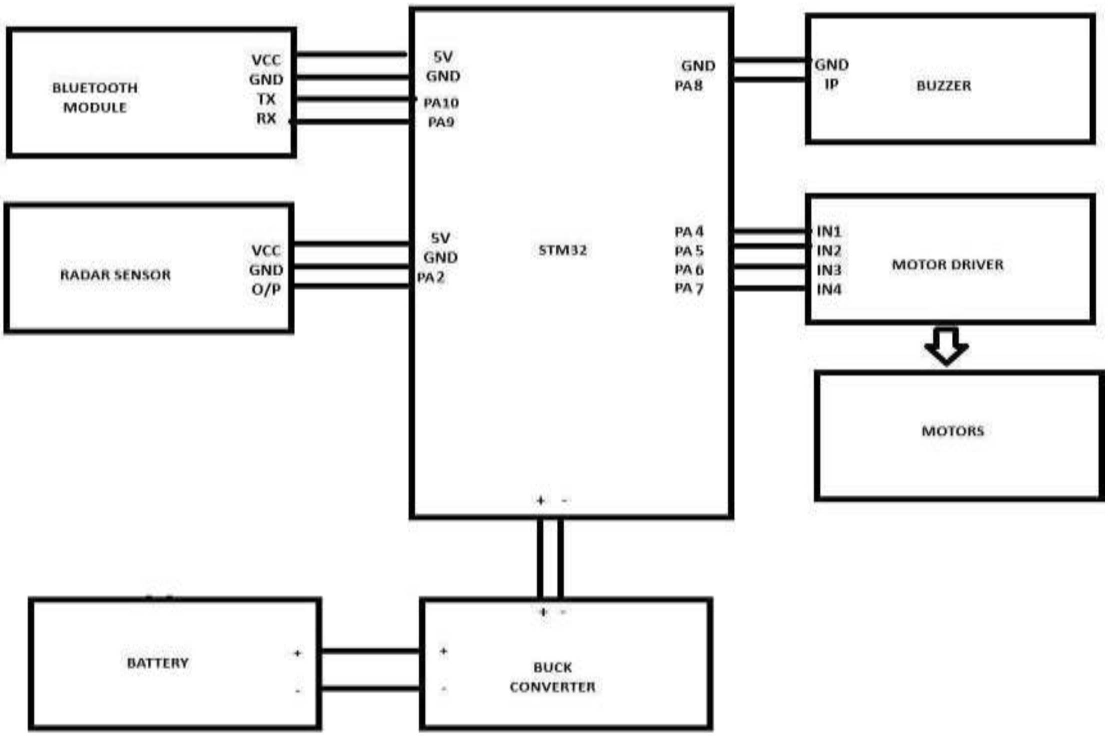
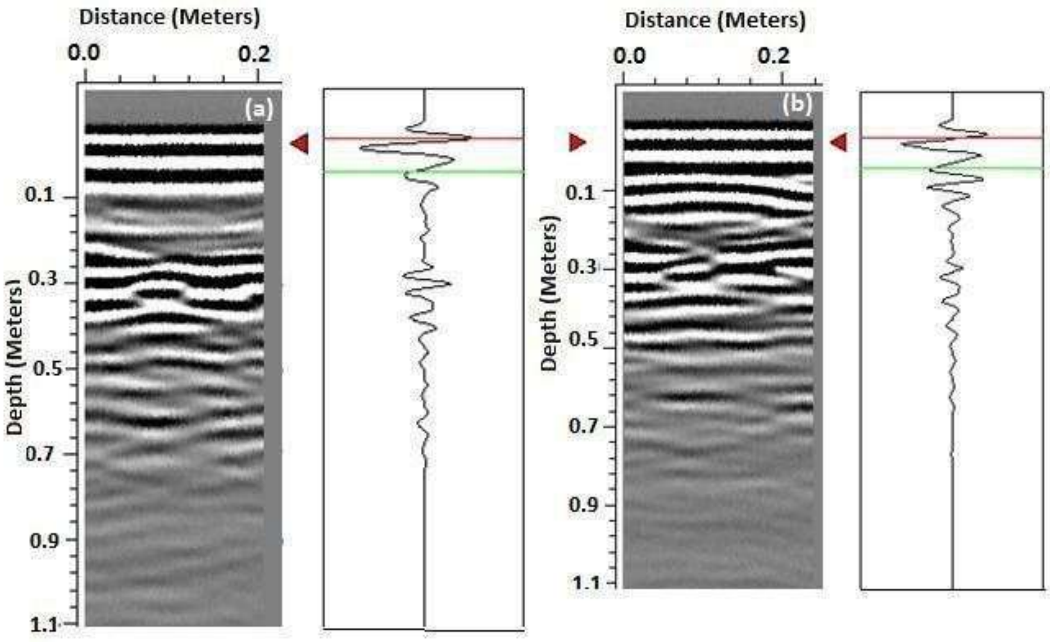


FIGURE 1.cicuit interface

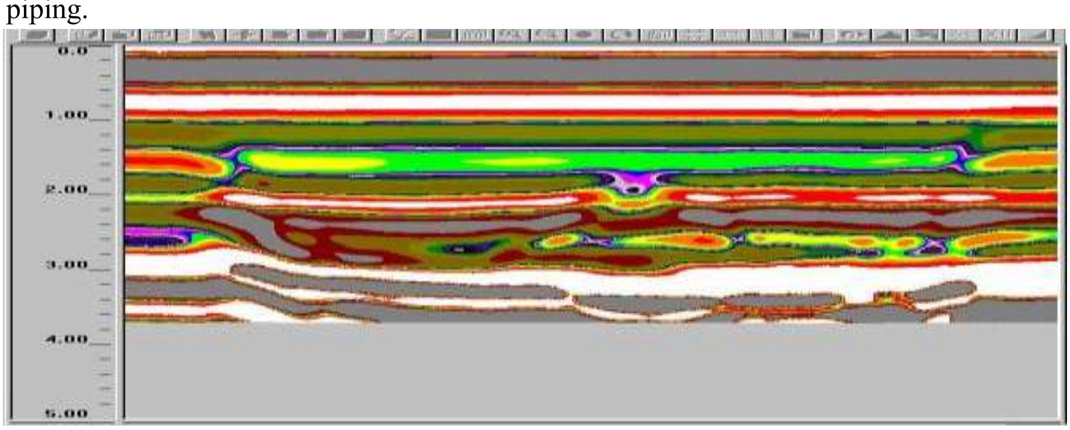


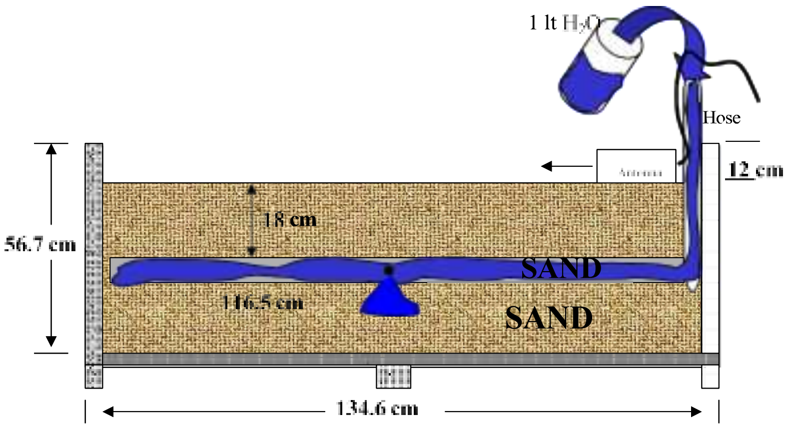
(a) (b)

FIGURE 2. GPR data for (a) empty pipe and (b) fresh water inside the pipe.

Comparison Between Empty Pipe and Empty Pipe

In Figure 2, the GPR profiles recorded using 1GHz GPR antenna for (a) empty steel pipe and (b) empty PVC pipe were shown. From this figure, we can see the pattern produced slightly different hyperbolas sizes. Different responses are observed from the different dielectric constant from different material. It is observed that the sharp anomalous for steel pipe has greater reflection compared to PVC. This experiment indicated that GPR has greater capability of detecting steel pipe compare to PVC pipe. This was illustrated by the study by Lee *et. al* . [4], where they observed that the two-way travel-time curves of non-metal (Polyethylene and PVC) piping are all weaker than those of metal (iron) piping.

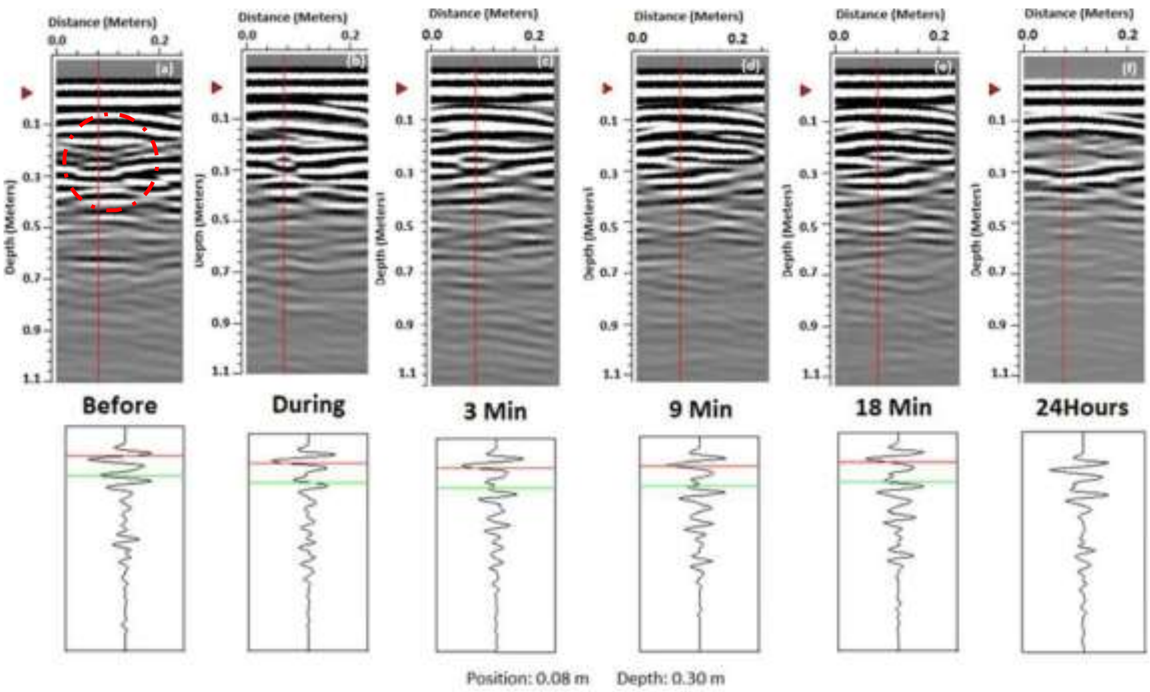




(a) (b)

FIGURE 3. . GPR profiles for wet model (immediately after injecting one liter of fresh water). Profiles and schematic diagram arrangement

Figure 6 shows the GPR recorded data using 1GHz GPR antenna for (a) fresh water inside the steel pipe, and (b) fresh water inside PVC pipe data. Different responses were observed from the different materials. It is observed that the anomalous for steel pipe was clearer compare to PVC pipe. PVC pipe show slightly broaden hyperbola compared to steel pipe. Furthermore, the graph amplitude on the trace window for steel pipe is higher than PVC pipe. These responses occur due to the reflection of radar wave from the steel pipe is greater compared to PVC pipe. This gave a strong indication that GPR has greater capability of detecting steel pipe compare to PVC pipe, even though when it is full of water inside the pipe.



(a) (b) (c) (d) (e) (f)

FIGURE 7. GPR data underground (a) before fresh water injection, (b) during injection, and after (c) 3 min, (d) 9 min, (e) 18 min, and (f) 24 hours injection.

Comparison of PVC Pipe between Before, During, and After Water Injection.

Data recorded by GPR antenna 1 GHz on PVC pipe at 6 intervals, before water injection (a), during water injection (b), and after the injection were shown in Figure 8. Data for after water injection are divided into 4 intervals: after 3 minutes (c), 9 minutes (d), 18 minutes (e), and finally after 24 hours (f). The anomalous indicated by the circle shown in the profiles is the location of the pipe. All the trace window is taken from point 0.3 m for depth and 0.08 m for the position. Even though the point is the same, but there are differences at the trace window. The anomalous features caused by the water leak in the profiles have clearly loss their sharpness and become less pronounced when compared with the profiles before water injection. The water rapidly migrated upward to the top surface of the pipe that reduces the sharpness of the anomaly. Twenty-four hours after the water injection the amplitude graph shows similar profile to before water injection. This indicates that most of the saturation water has dissipated downward to the bottom of the box. This experiment shows that effectiveness of GPR technology in detecting water leaks [6] from both metal and PVC pipes. However sharp anomalous for steel pipe in water leak profiles show greater reflection compared to PVC pipe.

CONCLUSION

The fast development of sensing element and wireless communication technologies has exaggerated the use of wireless sensors in environmental observance. The water consumption is rising day by day, as the water supplies for various social units and for industrial purposes is rising. And that is why surface water isn't really capable of meeting water needs. This subterranean need for water has been misunderstood. This work is based on meeting the challenge of easily sorting the underground water with the aid of a robot. This robot based on Arduino Mega will examine the surface in relation to Wenner methodology to look for the existence of water body beneath the earth's surface. It will define the location of underground water with respect to a GPS module connected to the Arduino. The location data obtained from the GPS module is used to record at that particular depth the exact location and volume of water present. This knowledge can help to map underground water in that geographical area.

REFERENCES

1. O. Hunaidi, W. Chu, A. Wang, and W. Guan, " Detecting Leaks in Plastic Water Distribution Pipes", in *Journal AWWA*, Vol 92, No 2, pp 88-94 (February 2000).
2. O. Hunaidi and P. Giamou, "Ground Penetrating Radar for Detection of Leaks in buried Plastic water distribution Pipes," in *GPR98 Conf.,* Kansas, USA, pp 783-786 (May 1998).
3. S. Eyuboglu, H. Mahdi,H. Al-Shukri, and L.Rock, "Detection of Water Leaks using Ground Penetrating Radar," in *3rd International Conference on Applied Geophysics—Geophysics 2003* (2003).
4. K.F. Lee, T.K. Wang, Y.M. Kang, C.S. Wang and K.A. Lin, "Identification of Pipelines from the Secondary Reflect Wave Travel Time of Ground-Penetrating Radar Waves," in *Journal of Marine Science and Technology*, 21(4), 2013, 417-422.
5. M. Nakhkash and M.R. Mahmood-Zadeh, "Water Leak Detection using ground Penetrating Radar," in *Tenth International Conference on Ground Penetrating Radar*, Delft, The Netherland (21-24 June,2004).
6. A.E. Hasan, "The Use of Ground Penetrating Radar with a Frequency 1 GHz to detect water Leaks from Pipelines,"in *Sixteenth International Water Technology Conference,* IWTC 16 Istanbul, Turkey (2012).