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Application of GPR to Detect Lost Valve Chambers in a Utility Network

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ABSTRACT: The exact geographic location of the fresh water transmission network of Dhaka WASA was not known to the agency. With time and development works, access to many underground valve chambers within the network were lost. Their recovery was usually done through manual digging and trenching. This was expensive, time- and labour-consuming, often led to traffic jams, and the rate of success was low. This study was conducted to use the non-intrusive method of Ground Penetrating Radar to locate those valves as an alternative. A total of 27 out of the 41 lost nodes in the network was successfully recovered and their precise location was recorded using RTK-GNSS. The article presents the detail procedure of locating the valve chambers of underground pipeline network. It also highlights how the lack of collaboration between agencies are causing water supply and maintenance problems to this day, and how infrastructure development of one agency may erode successes of another.

Keywords: GPR; Utility Lines; WASA; Dhaka

INTRODUCTION

GPR is a non-destructive geophysical technique that allows for the detection and imaging of the subsurface without the need for excavation or physical probing (Baker et al., 2007; Peters et al., 1994). It is therefore an efficient and cost-effective method for locating utility lines (Daniels, 2004; Jol, 2008). This technology has been used extensively throughout the world for similar purposes. Example includes São Paulo City, Brazil (Porsani et al., 2012); Nantes, France (Grandjean et al., 2000); Walloon Region, Belgium (De Coster et al., 2019); Spain (Ayala-Cabrera et al., 2011); Gujarat, India (Joo and Agrawal, 2021); Seoul, Korea (Tanoli et al., 2019) and Shanghai, China (Kunwei Feng et al., 2014).

Access to safe and clean drinking water is fundamental to maintaining health and well-being of citizens. So a water supply system plays a vital role in public health (Hunter et al., 2010; Lee and Schwab, 2005). Proper sanitation and hygiene practices heavily rely on access to clean water (Hutton and Chase, 2017). This in turn is related to economic development (Chenoweth, 2008). As such, a resilient water supply system is essential for any city.

Dhaka Water Supply & Sewerage Authority (WASA), established in 1963 (under the East Pakistan ordinance XIX), is in charge of water supply and sewage disposal for the dwellers of Dhaka city. Although WASA had been using ground water to meet demands, it has shifted focus to surface water sources. As part of that effort to reduce the continuous decline of groundwater table in the city, it has set up the different Surface Water Treatment Plant since the late 1990s (Institute of Water Modelling and DevConsultants Limited, 2014). The transmission mains network from these plants followed the major roads of the city. However, WASA had not kept the location (in terms of absolute coordinates) for that network. With time, access to many of the nodes (i.e. chambers housing control valves) of that network was lost or forgotten.

In order to find these nodes, WASA often needed to dig up or drill into significant portions of the road. This manual searching was not only time consuming and expensive but also results in public distress, traffic jams, noise and dust pollution (The Daily Star, 2016; The Independent, 2019). In some cases, it takes a long time to rehabilitate the roads to their previous conditions. Moreover, the efficiency is not appreciable either. Nonetheless, access to all the nodes is essential. Access to the control valves enable better management of water supply throughout the city (Li, 2007). Moreover, these valves require maintenance to ensure longevity.

In this study we have utilized Ground Penetrating Radar (GPR) to locate the lost nodes in WASA's transmission

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network, to improve efficiency and reduce sufferings. This article presents the detailed methodology, success and limitations of the survey. Additionally, we discussed how the nodes were lost and the importance of communication and coordination among different agencies involved in the infrastructure development of Dhaka.

STUDY AREA

WASA covers more than 401 km^2 service area (Fig. 1) with over 12.5 million people (Institute of Water Modelling and DevConsultants Limited, 2014). It has two sources of fresh water- ground water from deep tube wells and treated surface water. This treatment happens in their surface water treatment plants (SWTP) situated around Dhaka.

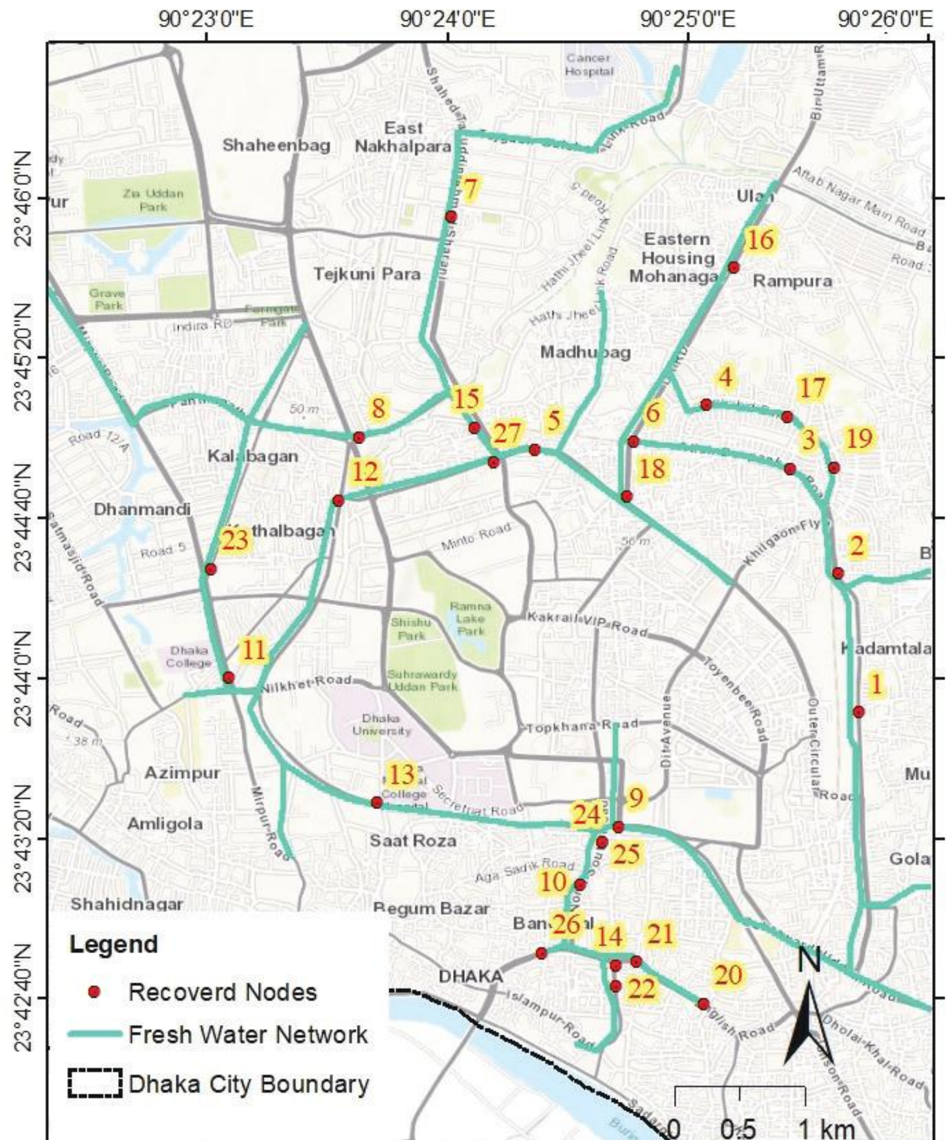

Figure 1: The Light Blue Lines Show the Freshwater Transmission Mains of the Saidabad Surface Water Treatment Plant of Dhaka WASA. The Red Dots Represent the *General* Location of the Nodes in the Network. Their Names can be Found in Appendix A1. From the Transmission Lines Water is Channeled to the Distribution Network of Each Zone, Where it Finally Reaches the Consumers

The largest treatment plant of WASA is Saidabad SWTP, named after the place it is located in. The total transmission network length of this plant (combining both Phase 1 and 2) is around 50 km. The minimum pressure at even the farthest point in this network is above 1 bar. Needless to state that this is not directly connected to consumers. Rather, this is connected to Distribution Network which is then connected to households and industries. The localities served from water of this network include Shyamoli, Azimpur, Jatrabari, Mogbazar, Elephant Road, Malibag, Rajarbag, Gulshan, Sadarghat, Tikatuli, Gulistan, Green Road, Kallyanpur, Mugdapara, Rampura, Lalbag, Noyabazar, Bashabo, Dhanmondi, Tejgaon, Bijoynangar, Mohammadpur, Motijheel, Postagola, Khilgaon, Mouchak, Rampura, and Darussalam.

WASA had provided us with a list of 41 nodes along their Saidabad transmission network, whose exact positions were not known (Appendix A1). These nodes/points are valve chambers, made of concrete and houses various valves that are required to control flow of in the transmission pipes. They include, pressure reducing valve, gate valve, air release valve and wash out valve. The chambers may be empty, partially or completely filled with water. WASA's main transmission network was built under the road network of Dhaka. So, the approximate location of those points is named after the road, area or the nearest landmark.

METHODOLOGY

Survey Procedure

From engineering schematics diagram of the network, which was available with WASA field personnel, the length of the pipes could be estimated to a certain degree of accuracy. Then distance was measured from the preceding and previous nodes using a measuring wheel; the unknown node usually lies between two known nodes. Although the distances did not usually add up but it helped getting a rough idea where the unknown node might be located. After a general reconnaissance of the area, this narrow down technique was utilized. Then the narrowed down area was surveyed using GPR. If the survey in the narrowed down area was not successful, then the rest of the area between the two nodes were surveyed to ensure we did not miss out anything.

Working Principles of GPR

GPR works by sending radio waves into the ground and then calculating the time it takes for the waves to bounce back to the surface after they hit any buried objects (Jol, 2008). This is termed as reflection coefficient (R), a function of the relative permittivities given in equation 1. ε1 is the relative permittivity of the material carrying the incident wave and ε2 is the relative permittivity of the material beyond the interface. This simply means the greater the difference in permittivity values of the materials, stronger the reflection. Dry Concrete has ε of 4 to 6 while Bituminous Asphalt ranges 3 to 6 (depending on the mixture). This means strong reflection from the concrete-asphalt interface may not be expected.

$$R = \frac{\text{Reflected Amplitude}}{\text{Incident Amplitude}} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \qquad \text{Equation 1}$$

All GPR systems can be divided into four components in general. The first one is the Antennae Unit. The transmitter antenna sends series of pulses of electromagnetic waves at a specific frequency into the ground and the receiver antenna detects the strength of waves that reflect back (Jongh et al., 1999). The MALA Pro Ex GPR used for this study used mono static antennae which combines both the transmitter and receiver into a single module. The Power Unit (comprising of battery packs) supports the Antennae, Control and Display Units.

The Control Unit can be considered to be the heart of the GPR system, which includes the electronics, data acquisition, data processing capability, and storage functions. The operator uses it to control the radar system, adjust the settings, and process the data. The electromagnetic waves travel through the ground and attenuates at different speeds depending on the electrical properties (i.e. dielectric permittivity, electric conductivity and magnetic permeability) of the subsurface materials they encounter. A reflection is usually generated at material interfaces with contrasting dielectric permittivity (Baker et al., 2007).

The two-way travel time is recorded in the time domain along with the strength of the reflected signal. In the preprocessing stage the raw GPR data containing various types of interference and noise can be improved by band pass filtering (Fig. 2) and gain correction (Benedetto et al., 2017). Also, time-zero correction has been utilized to ease visualization. When the GPR system sends radio pulses into the ground, it takes some time for the system to start recording data. This delay is called "time-zero" and it can cause a shift in the recorded travel time, which can be adjusted to compensate for the changes in the gap between the antenna and the ground surface (Peters et al., 1994). This change in gap was, in turn, forced due to potholes in the surveyed roads. Furthermore, Direct

Current (DC) correction (Fig. 3) was used to remove the constant or slowly varying signal components from the GPR signal, since it usually masks the weaker signals (Fisher et al., 1992). All traces are then stacked (Fig. 4), where subsequent GPR traces are averaged to reduce noise. All these could be handled using the onboard control unit which runs on proprietary software developed by MALA on a Linux based system through a graphical user interface.

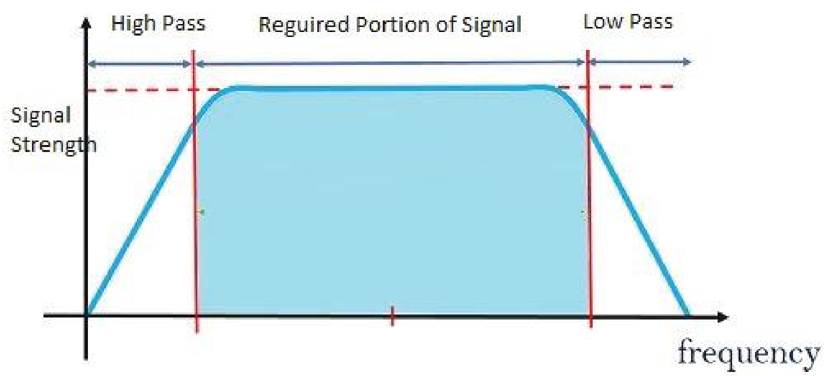

Figure 2: A Band Pass Filter Only Allows the Most Sought after Portion of the GPR Signals to Remain and Removes the Unwanted Lower and Higher Values

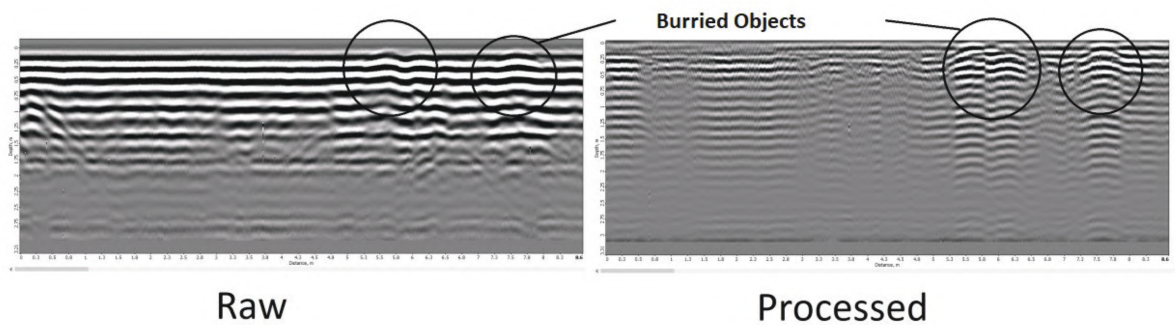

Figure 3: Direct Current Correction and Background Subtraction Reveals Subsurface Anomaly more Distinctly. The Buried Objects (Shown in Black Circles) are Barely Noticeable in the Raw Data Graph in the Left, Whereas They are More Prominent in the Processed and Corrected Graph on the Right

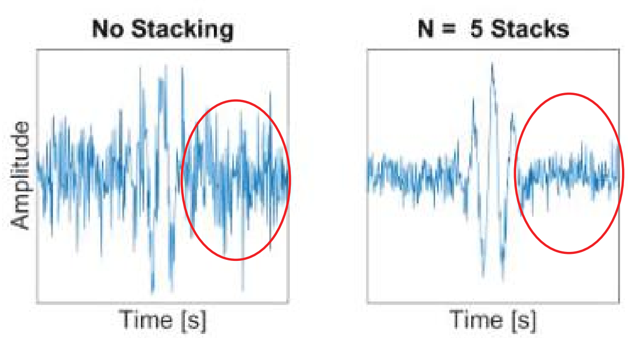

Figure 4: The Signal in Red Circle from the Left Image is Blurry but the Stacked Graph in the Right Shows How Noise is Reduced Through Stacking. (GeoSci Developers, 2017)

Finally, results (i.e. subsurface profile of the surveyed area) are shown in the Display Unit. The vertical axis show time (in nano seconds) of wave penetration whereas the horizontal axis shows the traversed distance (in feet). After gaining confidence that the radargram contains signatures indicative to the presence of a node/chamber, the asphalt covering was removed with pneumatic jackhammer. This was sufficient to confirm its presence or absence.

Once a node was identified, then its location was mapped accurately with the help of Real Time Kinematics Global Positioning System (RTK GPS). The RTK system consists of two GPS receivers, a base station and a rover. The base station is set up on an accurately known location and continuously receives GPS signals from multiple satellites to establish a reference position (Ng et al., 2018). In our case, we used the base station of Survey of Bangladesh near the Airport. The rover is carried by the user and receives GPS signals from the exact same satellites over an unknown location. The system computes an error correction at the base station (since its precise location is already known) and then uses that to calculate the rovers precise position in real-time (Yi et al., 2013). This system is widely used both locally and globally with widespread success.

RESULTS AND DISCUSSION

The GPR survey was successful in locating 27 chambers along the transmission network. This comprises the first 27 nodes in (given in Appendix). In most cases the main transmission pipe line was located at depth greater than 10. The chamber was built above it. The top portion of the chambers was situated between 1 to 4 feet below the road surface. We found maximum penetration depth (of about 2.5 feet) using the 500 MHz antenna compared to the 800 MHz antenna.

In some cases where the chamber was quite close to the surface and had used rebar (i.e. rods) during construction, a characteristic wavy reflection pattern was recognized due to rebars being evenly spaced.

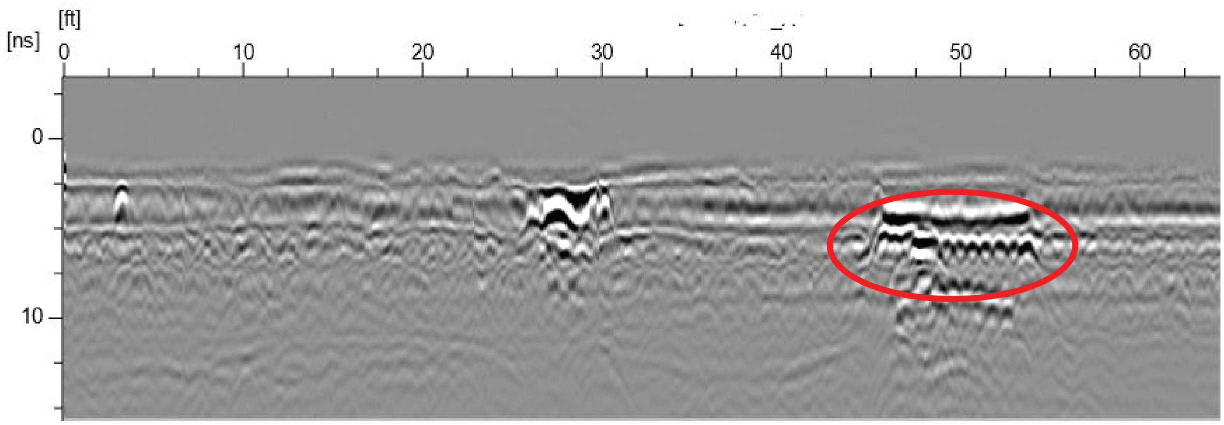

Figure 5: The Radargram from Love Road, Showing the Characteristic Rebar Pattern in the Red Circle

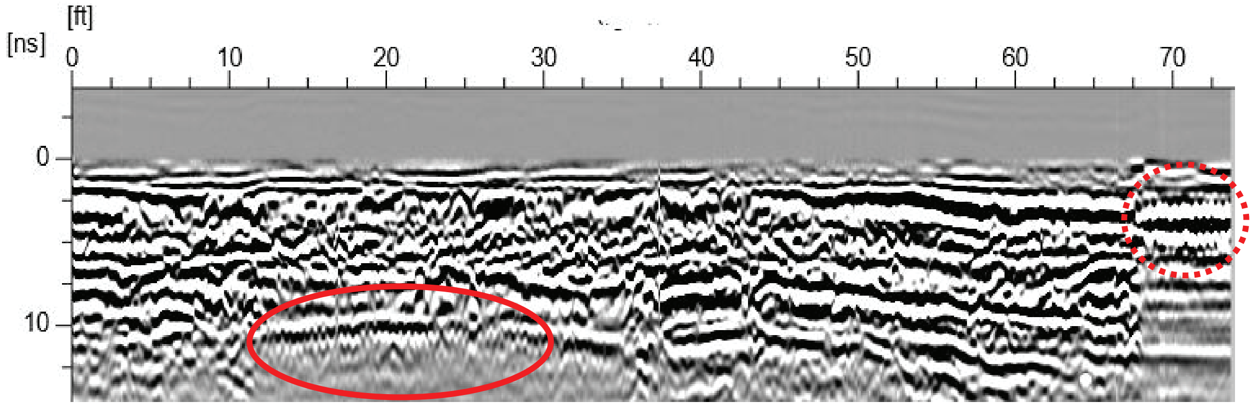

Figure 6: The Radargram from Newmarket, is also Showing the Rebar Pattern in the Red. The Patterns to the Left are Discontinuous and Much Larger and so cannot be Rebars

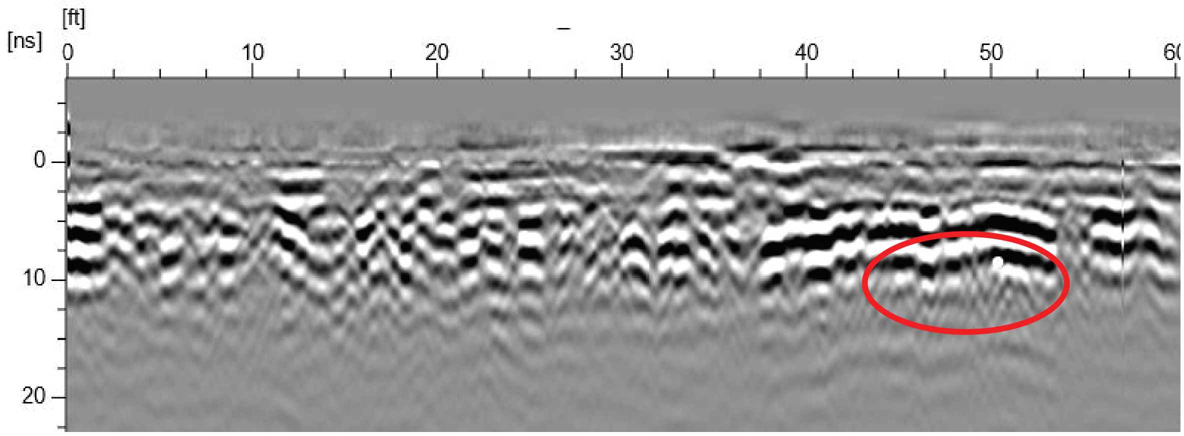

Figure 7: The Radargram from Moghbazar (Near Moin Petrol Pump), is also Showing Similar Pattern. The Dashed Red Circle also Shows the Same Pattern but it Belongs to the Footing of a Flyover

It is noteworthy that such rebar related pattern, as shown in Fig. 5, 6 and 7, is not always present with chambers. As a matter of fact, in addition to these cases, only Dhaka Medical College and Malibagh Mor nodes showed a recognizable rebar presence. That may either be due to the rebars not being present in other chambers, or being present but their arrangement/size is different. Also, chambers located at greater depths do not give off the pattern in a discernable manner, possibly due to greater attenuation. For those cases we tried detecting the manhole cover (Fig. 8 and 9).

The manhole-cover is made of metal and its mass is considerably greater and more concentrated within a smaller space, compared to rebars. In cases like these, the radar signal received is a strong, oscillatory one and thus termed as "Ringing Response" (Daniels, 1989).

Such objects after giving off an initial reflection, absorb a portion of the electromagnetic wave which bounce back and forth within metal object. During each oscillation cycle it continues to emit energy which is received by the antenna. This prolonged and repeated series of signals is what creates strong ringing response (Daniels, 1989; Jol, 2008; Yuan et al., 2018).

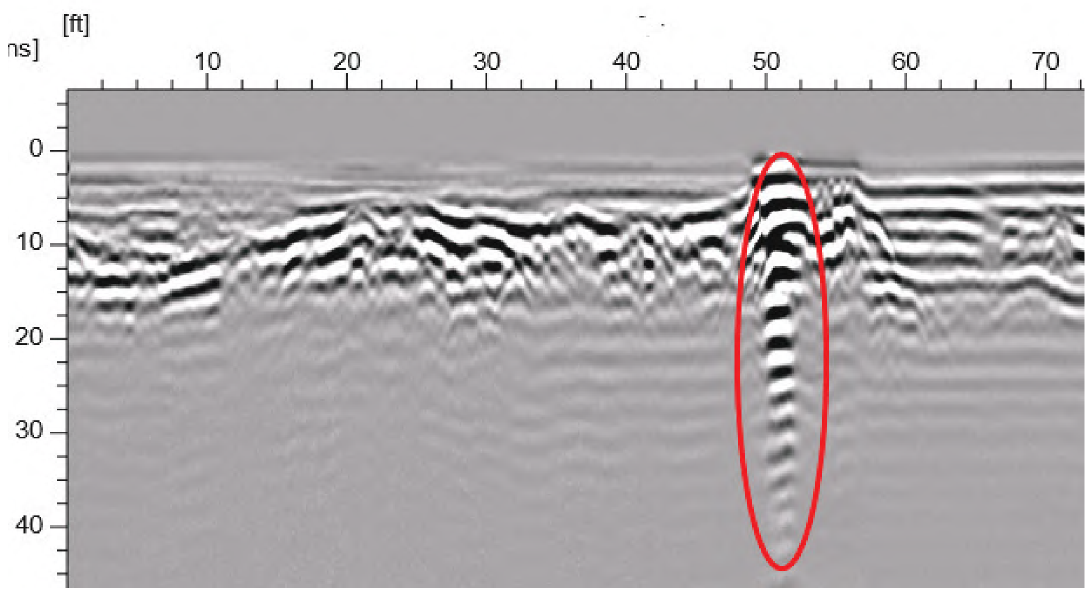

Figure 8: The Komalapur Survey was Accomplished by Searching for Ringing Response, Shown with the Red Circle. Slight Rebar Pattern is also Visible to the Right. Since There are Prolonged Release of Energy the Later Receptions are Processed by the Software as if Coming from Deep Sources. In Reality, the Manhole Cover was Located Near the Surface

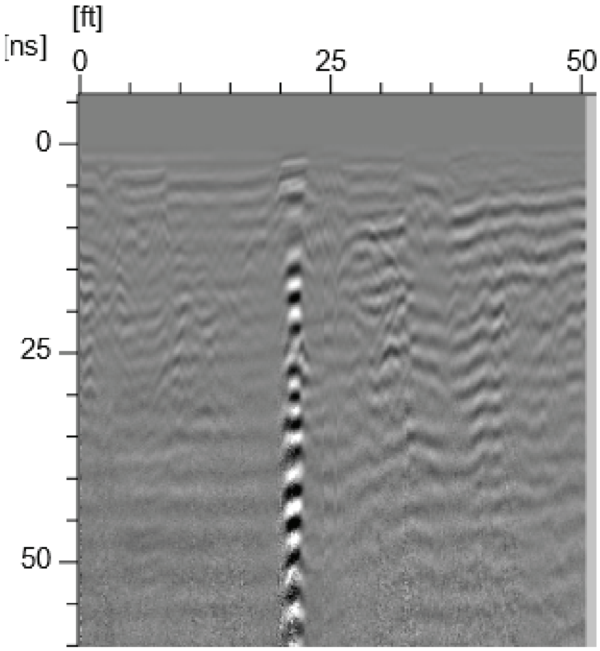

Figure 9: The Moddho Basabo Survey Results also Showed a Distinct Ringing Response

Even though ringing responses are usually strong but it does depend upon chamber depth. The East Rampura survey showed a faint signal (Fig. 10). Since there were no other signal of that strength in the vicinity we assumed that this might be our target object. Drilling confirmed our suspicion.

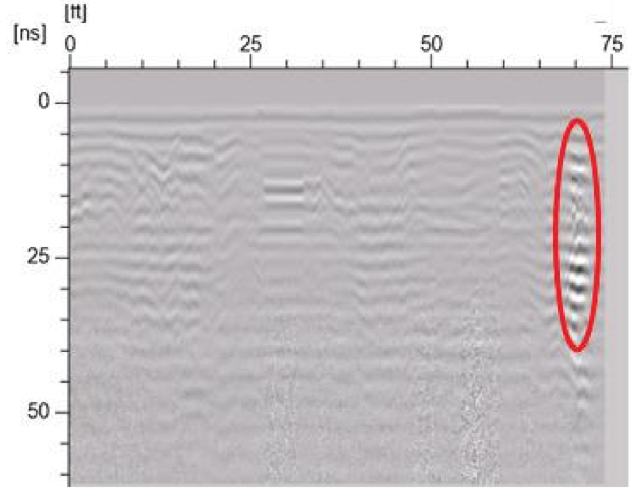

Figure 10: Only a Faint Ringing Response was Found in East Rampura, Indicating that Much Attenuation had Occurred

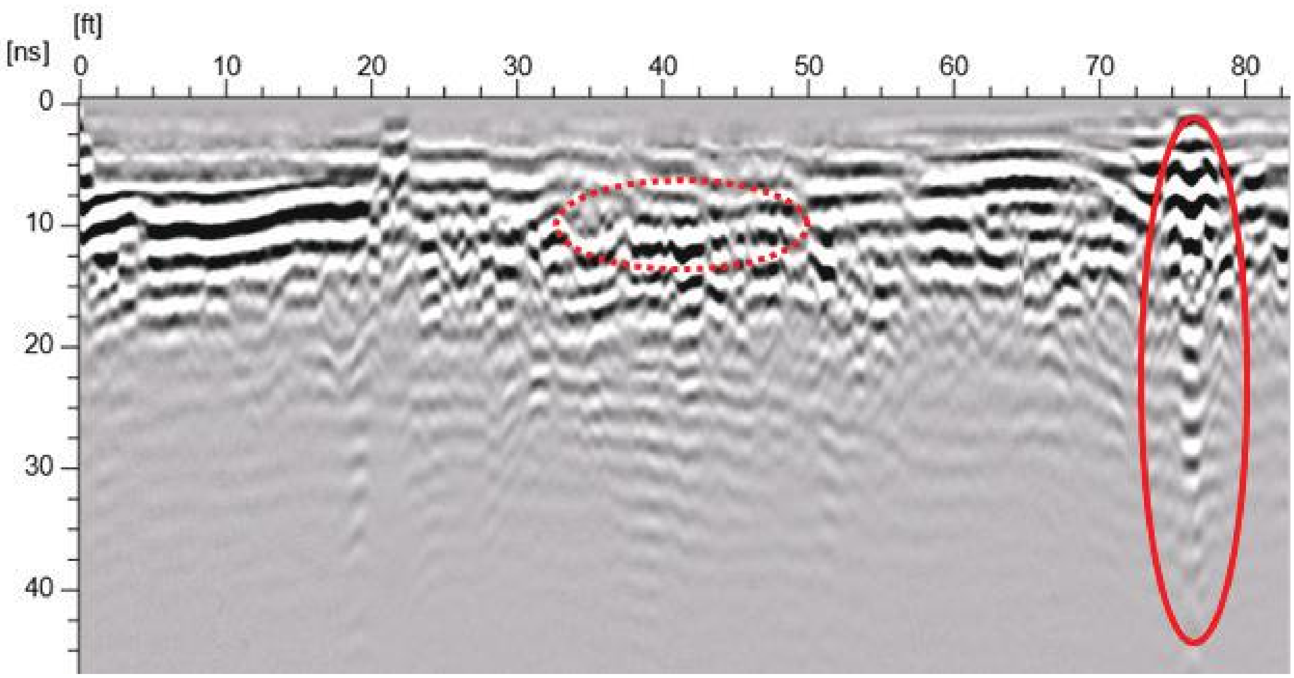

Figure 11: The Chamber Near Hatirpul Mor also Showed Ringing Response from its Manhole Cover

Most of 27 successful cases were found from the ringing responses. However, the problem arises when the roads are underlain by a wide variety of utility lines, as is the case with Dhaka. The Hatirpul Mor radargram (Fig. 11) shows a rebar pattern (indicated with a red dashed line). Initially we assumed that this corresponds to our target. Drilling revealed that it was in fact a chamber but belonged to another network. Oftentimes we found that the fresh water transmission pipes run parallel to the sewerage and storm drain network.

Since each utility network has their own chambers with a manhole cover, this led to serious confusion during the survey stage. An example can be drawn from our experience when working in Green Road North (near Green Life Hospital) (Fig. 12). The first ringing signature was from a chamber cover that belonged to Bangladesh Telegraph and Telephone (TNT) Department. The second ringing belonged isolated sewerage well with a smaller cover. The third faint ringing was from some metallic screws and bolts just below the surface. Locals said it was the foundation of the road divider, which was fell apart a few years ago. Even after several attempts our target could not be located.

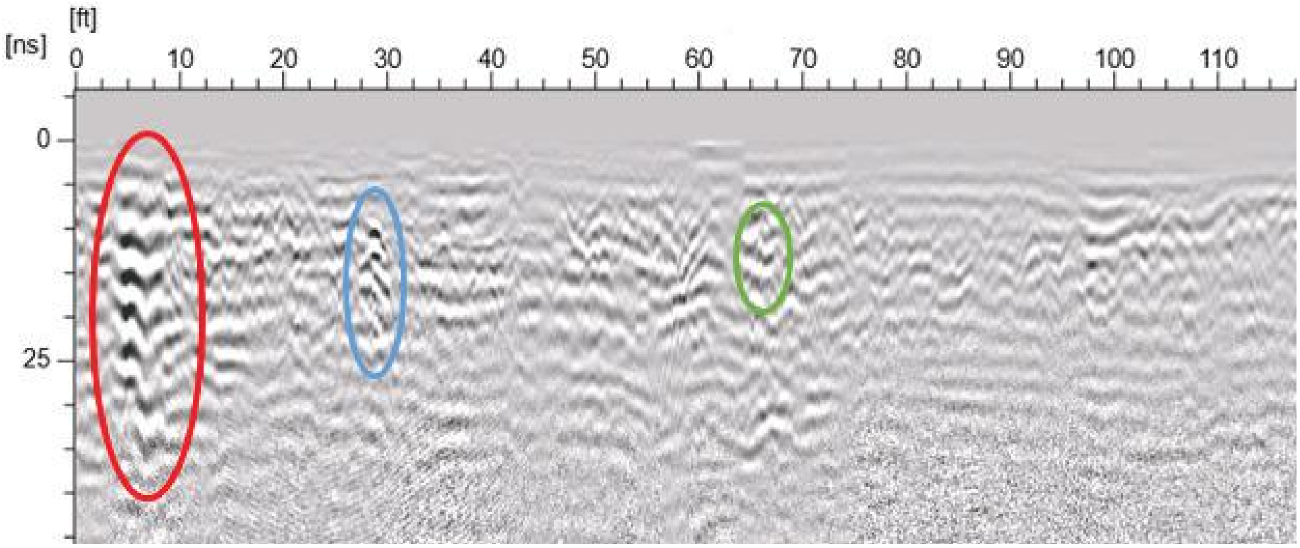

Figure 12: The Red Circle Shows the Response from the TNT Chamber Cover. Just to its Right is the Response from the Rebar Arrangement of that Chamber. The Blue Circle Shows the Response from the Sewer Cover and the Green Circle Indicates the Response from Some Leftover Metals of a Previous Structure

We have faced such problems time and time again. It was noticed that even though WASA was responsible for both the fresh water pipelines and the sewerage lines, people from the former branch did not or could not know the location of the latter network. If the spatial information from both these networks were accurately collected and stored together it would have been much easier to conduct the survey. For the fresh water transmission network only relative location was stored. This means only distance from the edges or median of the road was recorded. As part of development works, when roads expanded or the median was shifted, their relative location information became obsolete. Even if the location of the sewerage network was known then we could simply exclude the false positives from our results. Instead, we had to spend time and resources to dig up the asphalt to verify on a case by case basis.

Moreover, the interference from electrical sources sometimes caused us to repeat the surveys, even though our antennae had some shielding. Band passing filters helped in this regard. Many of the roads had heavy traffic, so only a portion of each lane could be closed down for survey. These caused time delays during fieldwork. This was exacerbated when police or city corporation officials asked us to conduct the survey at some other time, even though WASA had managed prior permissions. This meant we had to close the survey in that area for that day. Permissions were another hassle. They were to be taken from city corporations, and this involved some level of bureaucratic red tape.

To keep up with requirements a city will develop its infrastructure. However, that development planning should be done with consultation of all stakeholders. We shall, at this point, look at how development works impacted water supply network resilience.

In Razarbag area we were informed that pipe line was situated under the flyover. Survey on either side of the accessible road (Fig. 14) seemed to confirm that, as no structures were noticed on the radargram (Fig.13). A similar situation was encountered in Janapoth Mor, Saat Rasta Mor and Hathkhola Road (Fig. 15).

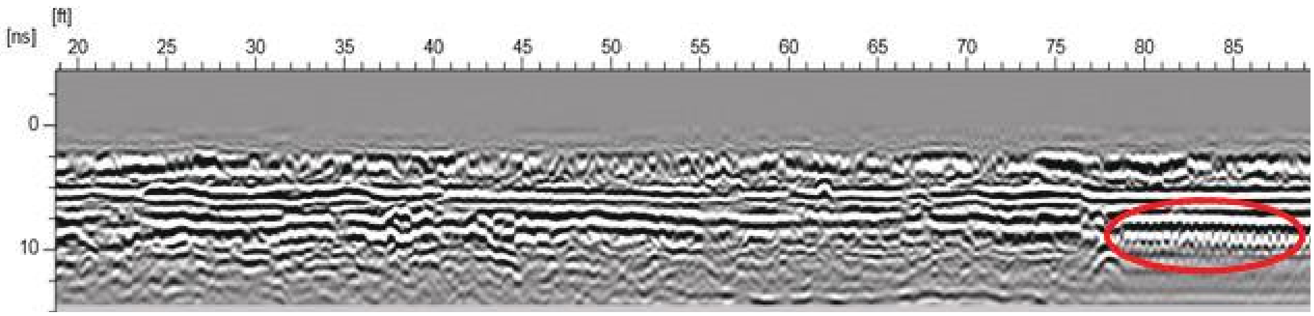

Figure 13: The Only Discernable Pattern is that of the Girder Footing Shown in the Red Circle in Saat Rasta Mor Portion of the Network

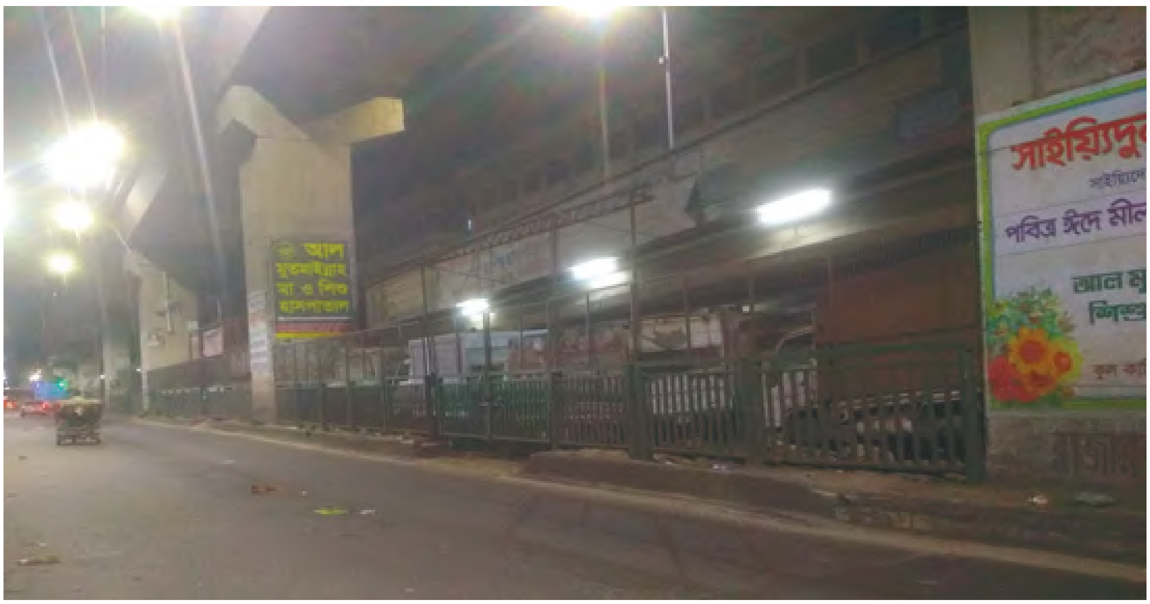

Figure 14: As can been Seen that the Girders are Connected by Barriers. This Prevented Survey Within that Space and so We were Unsuccessful in Finding the Razarbag Node

Figure 15: (Right) A Picture Taken During the Survey Near Janapoth Mor. (Left) Picture of Hatkhola Road, Wari

Figure 16: (Right) In Postogola, a Bridge Ramp was Constructed Over the WASA Network Node. (Left) In Jatrabari a Garbage Storage Station was Constructed Supposedly Over the Chamber. The Road Sections were Surveyed and no Significant Signatures were Noticed. Our Conclusion is Derived from Eye Witness Accounts of Locals and WASA Personnel

The Babubazar area adjacent to Mitford Road was giving off peculiar signals. It indicated the presence of rebars (Fig. 17). The problem was the entire road section had this signature. Upon talking to locals we learnt that to sustain the roads they were in fact underlain by rebars! Since GPR experiences ringing response in presence of metals, we knew our radargram would not be clear enough to distinguish surfaces beneath the rebar layer. We faced this problem in Outer Circular Road as well. As such, we were unable to find any chambers in these cases.

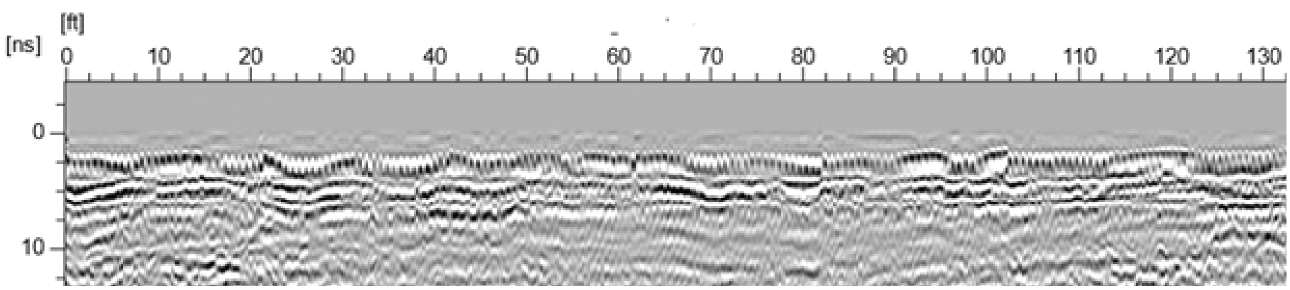

Figure 17: This Type of Radargram is Generated When the Rebar Arrangement is Continuous. Notice the Wavy Pattern at the Top Indicating Their Presence

WASA's freshwater network lines also exists near the Dhaka-Mawa highway. Due to development work this road was raised several feet. The chamber was located near the Geet Sangeet Cinema Hall (Fig. 18). Since the road was raised several feet we believe the chamber was at well below 15 feet from the current ground surface. We were unable to locate this chamber simply because of the limitation of our GPR instrument. In similar works such as in Spain by Ayala-Cabrera et al., (2011) and in Gujarat, India by Joo and Agrawal, (2021) range-adjustable frequency antenna is used that allows better penetration.

Figure 18: This Picture is Intended to Show How Much the Road was Raised. The Current Road Surface is the One Where the Person in Pink T-shirt is Standing Upon. The Road Surface Used to be at the Same Level as the Entry Way (to the Lower Right Hand Side) of the Geet Sangeet Cinema Hall. A Stairway (Center) now Connects the Hall to the Current Road. (Picture by Akash Ariyan is Collected from Google Maps)

It is evident that different agencies have gaps in communication and therefore coordination. Collaboration during the infrastructure planning and implementation is crucial for ensuring successful and sustainable outcomes. It is recommended that WASA and other agencies like the City Corporations (in charge of the Storm Drain Network), TNT Department, Power and Gas Supply/Distribution Authorities should share their network location for better integration. Moreover, most of the development works (like recarpeting of roads) are contractual, so the third-party contractors simply do not care how many chamber coverings are going under the new asphalt. If it was mandated in the recarpeting contracts that all chamber covers were to be “risen” to the new road level, a lot of hassle- and budget-savings are possible. This can help avoid road digging and subsequent potholes, which will cause sufferings to the commuters and the taxpayers’ money will be wasted fixing those later.

CONCLUSION

Out of the 41 nodes 27 had been successfully found. We faced many limitations. One of them was the drawback of instrument itself. Better penetration capacity would have allowed us to know the position of the pipe, which in turn would have narrowed our survey only to specific portion of the roads above the pipes. Since the required chambers are connected to the transmission pipes, this would have helped avoid confusing the radargram signatures with that of chambers from any other agency/service. Even with enough gain settings we were unsuccessful in locating the actual pipe line, possibly due to attenuation associated with greater depths.

It is noteworthy that the presence of nodes which are not accessible is a risk factor for the city’s water supply system. Without proper maintenance the valves may become dysfunctional. After emergencies like earthquakes they may be required to prevent water loss or to control flows. WASA should think of contingencies for the nodes that could not be recovered.

Even with these limitations and the anomalous nature of different utility networks underlying Dhaka’s road, the GPR technique of real time imaging proved to be much more efficient than manual digging. This is in terms of financial and temporal dimensions. Moreover, this saved the commuters from traffic jams, which in turn slashed carbon footprints. Targeted digging also reduced noise and dust pollution. High precision RTK GNSS survey recorded the accurate position of the newly found valve chambers thus ensuring that even if they were to be recarpeted, they can be re-discovered without much hassle. For future surveys it would be better to integrate the positive signals for such chambers into a machine learning model which should drastically improve detection possibilities. One way could be to correlate the signature to the size of the manhole cover. Usually sewerage lines have perforated covers and their signatures are not as strong as those installed on fresh water lines. This should reduce the chance of false positives.

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APPENDIX

A 1: List of 41 Network Nodes Whose Exact Position was Unknown to WASA. The Study has Successfully Recovered the First 27 Nodes

SL	Node Name	SL	Node Name
1	Komalapur	22	Court House Street
2	Moddho Basabo	23	Green Road South
3	Khilgaon	24	Kaptan Bazar
4	Malibagh Mor	25	Nayabazar
5	Moghbazar(Petrol Pump)	26	Yusuf Road
6	Malibag Railgate	27	Moghbazar Mor
7	Love Road	28	Razarbag
8	Kawranbazar	29	Basabo Otithi Cinema Hall
9	Gulistan Mor	30	Panthapath Mor
10	Nazira Bazar	31	Green Road North
11	Newmarket	32	Hatkhola Road
12	Hatirpul Mor	33	Janapoth Mor
13	Dhaka Medical College	34	Palashi Mor
14	Johnson Road	35	Saidabad Rail Gate
15	Moghbazar Rail Gate	36	Jatrabari Bus Stand
16	East Rampura	37	Geet Sangeet Cinema Hall
17	Khilgaon Block A	38	Postogola Bridge
18	Khilgaon Block B	39	Yusuf Road
19	Khilgaon Block C	40	Midford Road
20	Dholaikhal South	41	Outer Circular Road
21	Dholaikhal North		