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GPR Investigation of Mining Induced Subsidence and its Effects on Surface Structures: A Case Study of Srinagar City, J&K, India, NW Himalayas

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ABSTRACT

The subsidence reported from the Rainawari, 4 kms north west of Lal Chowk (The city centre of Srinagar) in 1999-2000 was mainly restricted to Surateng (which in local language means a mound of ash) locality of the area. Rainawari, 4 km north west of Srinagar city invariably witnessed land subsidence for the past several decades and in this process most of the structures in the area suffered massive damage including collapse, sags, sinking of floors, temporal and spatial evolution of cracks, swaying, sink holes, colloquially numerous structures started sinking and tilting and major potholes appeared on roadways, thus creating panic in the inhabitants of the area. The surface change phenomena in the present study is strictly restricted to a small area, where extensive underground mining related to pottery industry has a history of hundreds of years. In this context, six ground penetrating radar profiles have been acquired from two main sites namely JLNM hospital and Surteng locality of Rainawari using 200, 500 MHz shielded and 100 MHz rough terrain antennas. In order to investigate the shallow sub-surface, possible locations of sink holes, kinematics of the subsidence phenomena, spatial-temporal evolution of sink holes, effects of subsidence on surface structures, to locate underground caves and cavities, seismic liquefaction features, geometry and trends in near surface tectonic deformation, geotechnical characterization and seismic resilience of the surface structures, the subsurface imaging was acquired using GPR. Major sub-surface observations made were underground cavities, room and pillar mining structures and voids. In addition to the sub-surface structures caused by the mining in the historical past, the surface deformations were observed in the form of cracks developed in the construction.

INTRODUCTION

Underground mining activities, often cause horizontal and vertical ground movements or gradual carving which may result in ground subsidence (Eray et al., 2012). Besides subsidence movements can trigger horizontal and vertical displacements of the geological strata, sinking of formation, slope changes, bending underground, cracking, collapse and tilting of surface structures which can be fatal (Andreas, et al., 2019; Akcin, et al., 2006). However, the term is gerenally used to describe the movements of a building/structure relative to the surrounding ground and the damage that may be caused by such movements. The mining subsidence effects usually appear as surface ground settlement, farm land deformation and damage to civil engineering structures, such as retaining walls, roadways, reinforced concrete, and especially masonry structures (Eray et al., 2012; Kratzsch, 1983; Kuscu, 1991). In addition to this, subsidence disturbs the natural balance of the surface and underground water resources, and natural and man-made surface drainage systems. In Rainawari area of Srinagar city, shallow underground mining related to pottery industry, has been carried out for hundreds of years (Lawrence, 1895). With the passage of time various cavities and voids dug by the potters collapsed and gradually turned into present day sinkholes. Sinkhole subsidence can be defined as movement of the ground surface as a result of readjustment of the overburden due to collapse or failure of underground mine workings. (alluvium pillars in present case, as the room and pillar technique of underground mining has been employed). Sinkhole subsidence is common in areas overlying shallow room and pillar mines. Sinkholes occur from the collapse of the mine roof into a mine opening, resulting in caving in of the overlying strata and an abrupt depression in ground surface.

Geophysical methods, in particular, GPR and geodetic techniques have been extensively used to investigate the mining subsidence and damage to infrastructure (Al-fares et al. 2002; Chamberlain, 2000; Coskun, 2012: Beres et al., 2001). GPR data can provide the critical information on the temporal development of the subsidence phenomena (Sevil et al., 2017), precise location of the boundaries of the sink holes (Zarroca et al., 2016) and provide information on structural and stratigraphic features associated with sink holes (Rodriguez et al., 2014). Therefore, in the present study ground penetrating radar (GPR) surveys have been carried out to study the structural and engineering aspects of mining subsidence and sink holes, such as exact location of the boundaries of sink holes, subsidence mechanisms involved in the development of sink holes, kinematics of the subsidence phenomena, geometry and pattern of deformation structures associated with sink holes, various cavities, sags, paleo collapses, groundwater table and seismic liquefaction. The GPR data were acquired with GPR MALA PRO V EX (Sweden made) by using 100, 250 and 500 MHZ antennas configuration at twin sites namely JLNM Hospital and Surteng locality in Rainawari area (Fig. 1).

Geologically the study area consists of a 1300 m thick fluvio-glacial and lacustrine deposits of Plio-Pliestocene age above the basement that is highly vulnerable to earthquakes and related phenomena such as seismic liquefaction, landslides, lateral spreads, fluvial flooding etc. (Bilham and Bali, 2013; Schiffman et al., 2013; Kundu, et al. 2014; Bali et al., 2016; Wani and Bali, 2017; Bali and Wani, 2020) In the past millennium, the Kashmir valley has witnessed several catastrophic earthquakes: in 1555 (Mw 7.4), 1885 (Mw 6.8), and 2005 (Mw 7.6) (Ahmad et al., 2009; Bilham et al., 2010). The geotechnical aspects/properties of the sub-surface formation of Srinagar district and their relationship with geology and hydrology (groundwater conditions) suggest that most parts of the Srinagar city are highly susceptible to seismic liquefaction during moderate ($\geq$Mw 6) to high magnitude earthquakes (Bhat et al., 2016; Wani et al., 2019).

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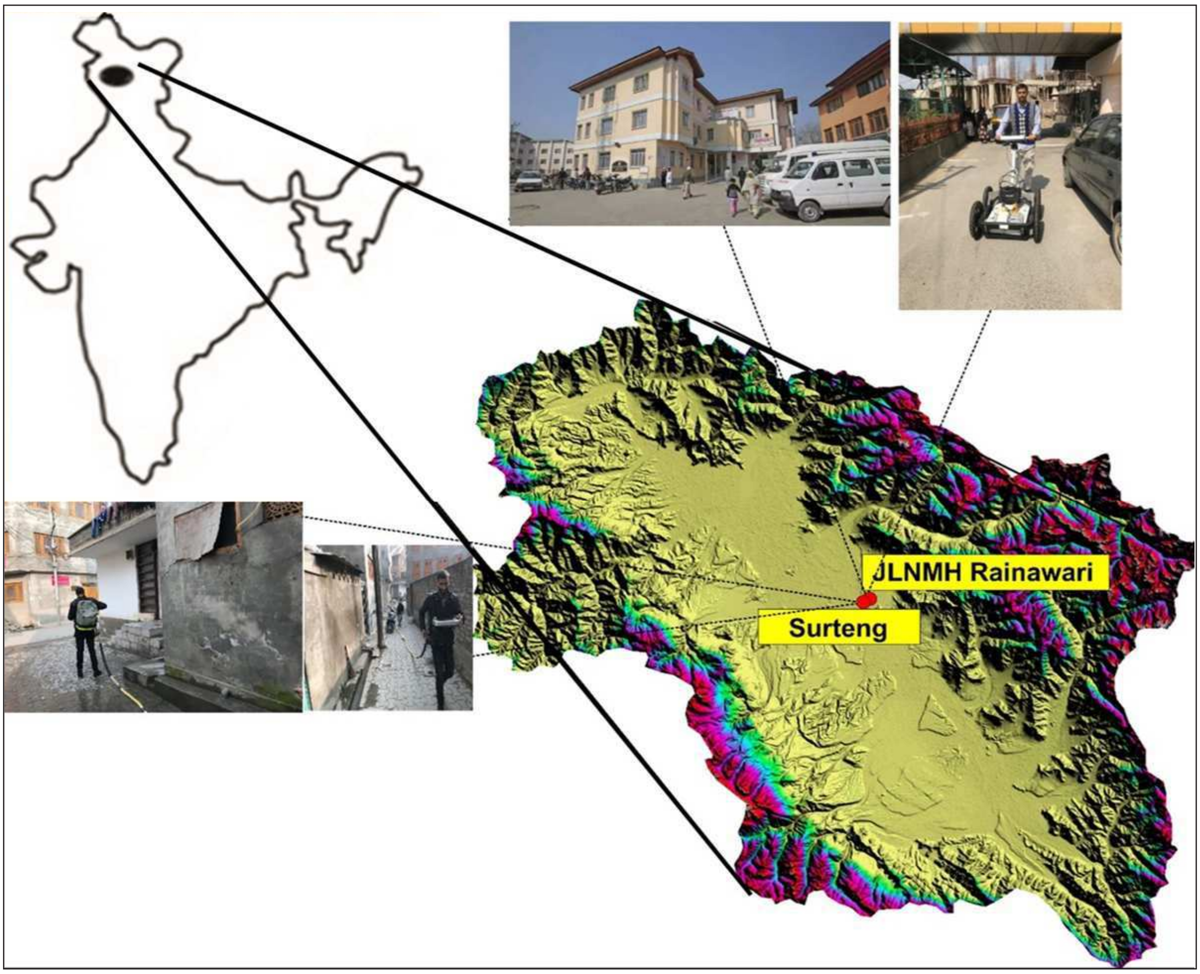

Fig.1. SRTM DEM image shows the location of GPR survey along with field photographs.

STUDY SITE AND HISTORY OF MINING IN THE RAINAWARI

Rainawari 4 km north west of Lal Chowk the city center of Srinagar City lies between N 34°5’52"N 74°49’17"E and is 1585 m amsl. The Rainawari area is one of the most densely populated area of Srinagar city bounded by Jhelum river towards west and Dal Lake towards east. The topography of the area is relatively flat and basin type and major portions of the area lie in the close vicinity of Dal Lake and the sub-surface lithology mainly comprises sand-silt and clay.

In Rainawari area of Srinagar city the main occupation of people was to make earthen pots and other pottery items (Javed, 2013). Rainawari was a very important centre of pottery making in Srinagar city of Kashmir valley (Walter Lawrence, 1885) and earthenware from this area was sent to various parts of the city and rural areas. Dal Lake and river Jhelum formed the main arterial system for transportation. The earthen ware was transported from a nearby tributary of Dal Lake and the quay is still known as Kralyar meaning Potter’s (Kral) quay (yar). Pottery industry in the area was at its peak till the end of 19th century but continuous mining of the raw material (clay) from the area had created many troughs and depressions in the area (Lawrence, 1895; Nerve, 1913). These depressions and low lands were latter used for the cultivation of vegetables and are known as “Aram varees” in local language. However realising that the mining of clay has resulted into conversion of table land into large troughs and depressions, the then Dogra Ruler Maharaja Partap Singh banned all types of clay mining activities in the area (Lawrence, 1895; Nerve, 1913; Seth, 1987). This along with common use of metal and alloy utensils lead to downfall of the pottery industry in the area. The ban on open mining of clay left the potters of the area with only one option and that was transportation of clay from other areas but the transportation of raw material was a very costly option and it increased the cost of finished earthenware many folds than the pottery made anywhere else in the valley. Since the ban on open mining was very strictly adhered to and any infringement invited severe punishment, in order to survive and also to avoid getting noticed the miners resorted to another method of mining known as room and pillar mining (“gouf” mining in local language). GPR measurements were undertaken to map some of the underground mining related structures.

Mining subsidence effects on Surface structures

Construction of masonry buildings has been widely practiced in Srinagar city including Rainawari area for residential purposes and people prefer masonry buildings over tall or high rise buildings. However some very large concrete structures have also come up in last three decades in the area that house various departments of the hospital. Despite knowing that residential area is located over former mining site and several structures have already collapsed, people in large number still live in this area. In Rainawari and nearby settlements the structures have suffered damage and this damage ranges from cosmetic, functional to structural changes (Fig. 3). As some structures have developed cracks in plaster and dry wall, categorized as cosmetic damages. Many other structures have developed crooked doorways and window frames, jamming of doors and windows, sloping and uneven floors, categorized as functional damages. Most of the structures have, however, suffered massive damages which includes appearance of cracks in each face of the building such as supporting walls, corners, overhangs and footings etc., these are known as

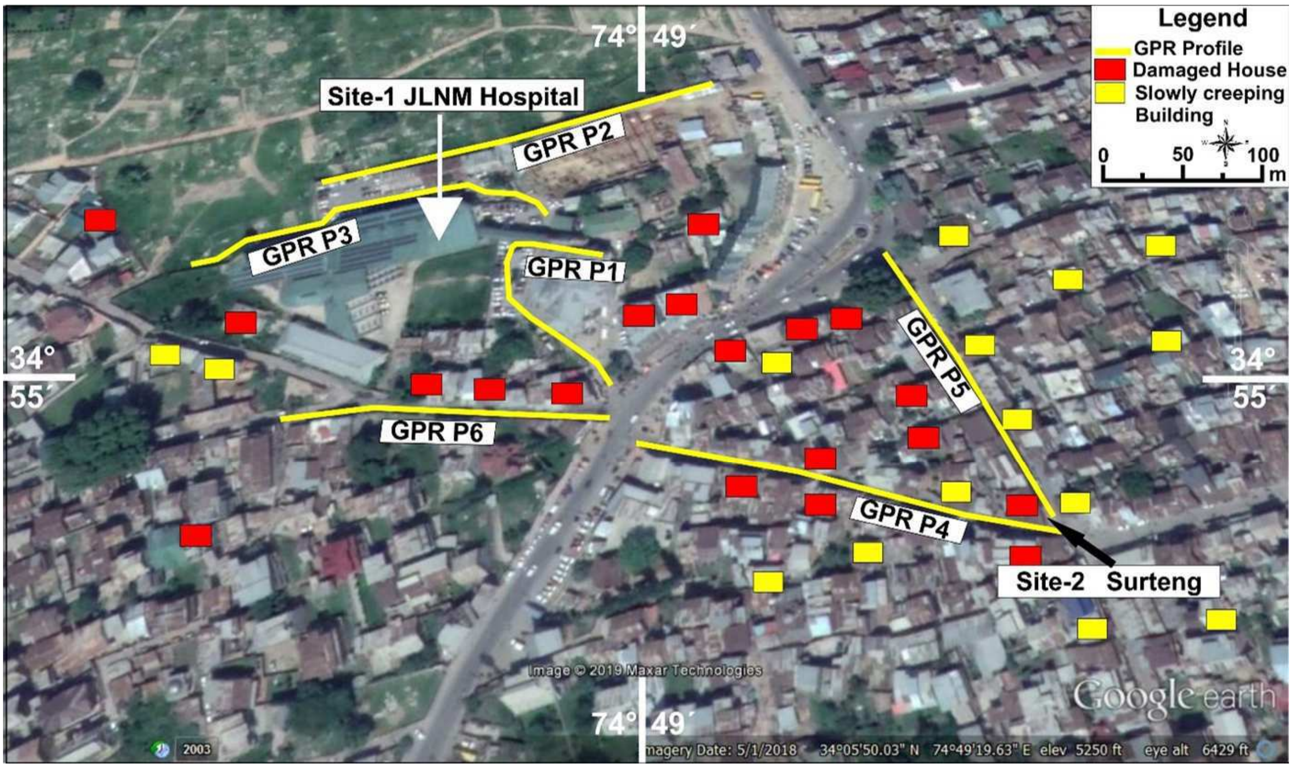

Fig. 2. Location map of two sites investigated using GPR. Satellite picture from Google Earth.

structural damages. Some cracks were small hairline near window panes to very wide up to 4-5 mm and the most common cracks observed are the diagonal to stepped cracks running up or down a wall and follow a line of mortar to create a step like pattern and some cracks go through the bricks rather than following mortar to form a diagonal crack (Fig. 3 b & e). Some cracks were observed running from top to bottom in a more or less straight line, classed as a vertical crack (Fig. 3 a & g). Some cracks follow side to side and the mortar joints. These are classed as horizontal cracks (Fig. 3 d). According to the locals some concrete structures including one in the premises of J.L.N.M hospital (few yards away from the sight of present subsidence) had to be demolished two decades back as their walls and plinth had developed wide cracks. Besides cracks some of the structures have suffered sinking of floors, sags and settlement of basement floors that results in separation of basement concrete floor from partition walls impacting the stability of the building (Fig. 3 f). One of the main issues related to subsidence reported in Rainawari area is tilting of buildings and several houses in the area were abandoned as these are experiencing quite sharp tilting (Fig. 3 c).

METHODOLOGY

The GPR measurements were acquired with MALA PRO EX (Sweden made) by using100, 250 and 500 MHZ antenna configuration in a distance mode. A total of six profiles were obtained at two sites with three profiles at JLNM hospital and three profiles at Surteng locality. The first two profiles at JLNM hospital were acquired with 250 MHZ shielded antenna and third profile was obtained with 100 MHZ antenna, whereas two profiles at Surteng locality along the street were taken with 250 MHZ shielded antenna and last profile was acquired with 100 MHZ antenna respectively. Data collected with 100 MHZ gave greater depth penetration, but data collected with 250 and 500 MHZ antenna has lesser depth of penetration but higher resolution (Malik, et al., 2007: Balaji, et al. 2010). GPR data were systematically processed in Rad explorer 1.4 before interpretation by following routines/processing steps, such as trace edits, spatial interpolation, time zero correction, background removal, topographic correction. 2-D spatial filtering, amplitude correction, predective deconvolution, band pass filtering and depth conversion model (Malik et al. 2007; Xavier et al. 2011; Robinson et al. 2013; Dobrin and Savit, 1988; Neal, 2004 and Joel and Smith, 1991).

RESULTS AND INTERPRETATION

To elucidate the possible location of sink holes and cavities, subsidence impacts on sub-surface lithology and structures, seismic liquefaction and tectonic deformation, two sites were selected for ground penetrating radar (GPR) surveys at Jawaharlal Nehru Memorial hospital (JLNMH) premises and at Surteng colony. Apart from historical evidences of subsidence from the sites and also observations made during field surveys on surface structures, no sub-surface information was available to pinpoint the exact and precise location of the sink holes, subsidence features and their kinematic styles. In this context, GPR surveys are quite useful to provide the high resolution imaging of the sink holes in shallow stratigraphy which were not evident from surface manifestation and thus allowing comprehensive characterization of sink holes and their spatial and spatial-temporal variations.

Site 1: JLNM Hospital Rainawari

The GPR profiles at site 1 JLNMH Rainawari (Fig.2 & 4 a) were acquired using 200 MHZ antenna in the courtyard of the Hospital striking ~NW-SE direction, 205 m in length which yielded a well resolvable penetration depth of 5 m. The GPR results represent room and pillar type structures at near surface (~3 m depth), consisting a series of voids bounded/separated by soil pillars that pose a great threat of seismic liquefaction and erosion owing to shallow groundwater table in the area at 3-4 m. The soil pillars in the GPR profile were marked between 9-15 m, 54-70 m, 82-89 m, 109-113 m, 121-135 m and at 170-183 m horizontal distance marked by solid vertical black lines (Fig. 4 a). The soil pillars are separated by voids and are saturated at base. A thin black dashed line at the base of the images shows water table depth of the site. Most of the soil pillars at base are eroded and weak, which are clearly expressed by discontinuities, offset, warped

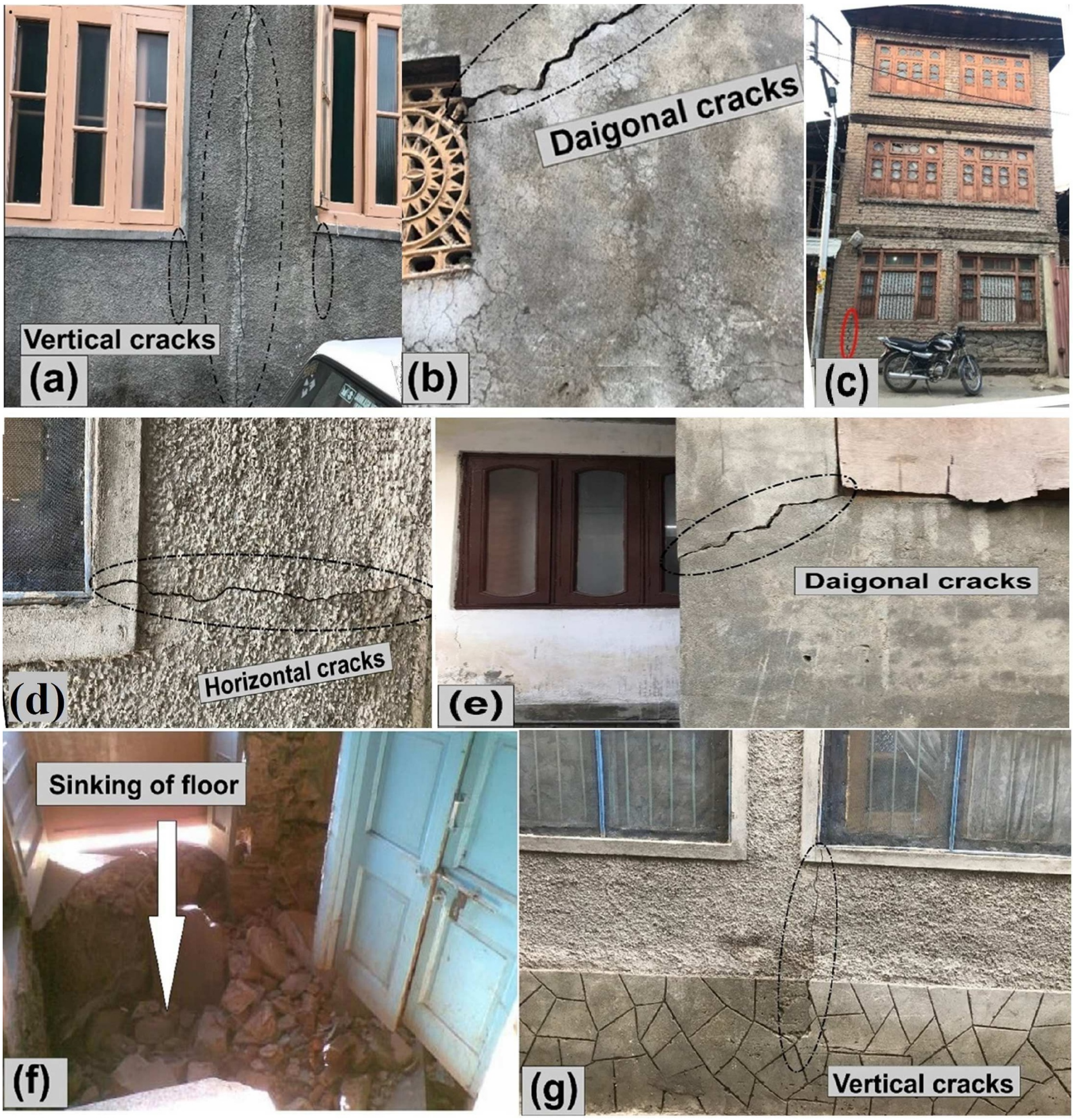

Fig. 3 (a) Deformed wall including an upright wide tension crack at Surteng locality indicating that the foundation of this building is dropping. (b) Front view of the wall showing a large diagonal crack developed in the wall visible on both sides and extends up to the window frame. (c) A colloquial masonry structure experiencing displacement and tilting quite sharply due to impact of the subsidence (d) A horizontal crack displacing the wall and the window pane (e) Front wall shows a wide crack that appear downwards from window frame and shows displacement of the upper column with respect to the lower one. (f) Sinking of the floor near the entrance of a masonry structure due impact of the subsidence. (g) A vertical crack running downward from the window and tapers at the foundation level.

inclined reflection truncations in the georadar reflections. The stronger and coherent reverberations found at the top of the image in the form of red and black reflectors mark the concrete pavement in the courtyard of the hospital. GPR profile 2 JLNMH (Fig. 4b) was taken at the backyard of the hospital and is 105 m long and 4 m deep. Similar room and pillar type of structures were observed up to 4 m depth characterized by cylinder shaped soil pillars separated by cavities/ voids. The soil pillars were marked in the GPR profile between 25-40 m, 50-55 m, 60-70 m and at 85- 90 m horizontal distance marked by black vertical lines and arrows. The voids/rooms are saturated, eroded, sometimes with dissolved soil pillars and are wider than soil pillars. Thin dashed line at the bottom of the profile reflects the groundwater table which coincides with the profile I. A big saturated void is observed between 0-25 m horizontal distance marker suggesting that the soil pillar is either completely eroded or collapsed and is replaced by a big cavity. The coherent reverberations up to 2 m at the top of the profile mark the concrete bed (DPC) of the newly constructed structure at the backyard of the hospital.

GPR profile 3 JLNMH was acquired with 100 MHZ rough terrain antenna along the gentle slope tapering off towards hospital quarters relatively flat/subsided surface (Fig. 4 c). The profile is 105 m long that yields a penetration depth of 6 m. Cylindrical soil pillars were observed marked between 25-40 m, 40-50 and 55-85 m horizontal distance marker separated by saturated voids. The cavities/voids are saturated at base and a black dashed line at the base of the profile reflects the water table of the area and is at 6m depth. A big void is observed, marked between 0-25 m horizontal distance marker reflects either the soil pillar has been completely eroded and dissolved and

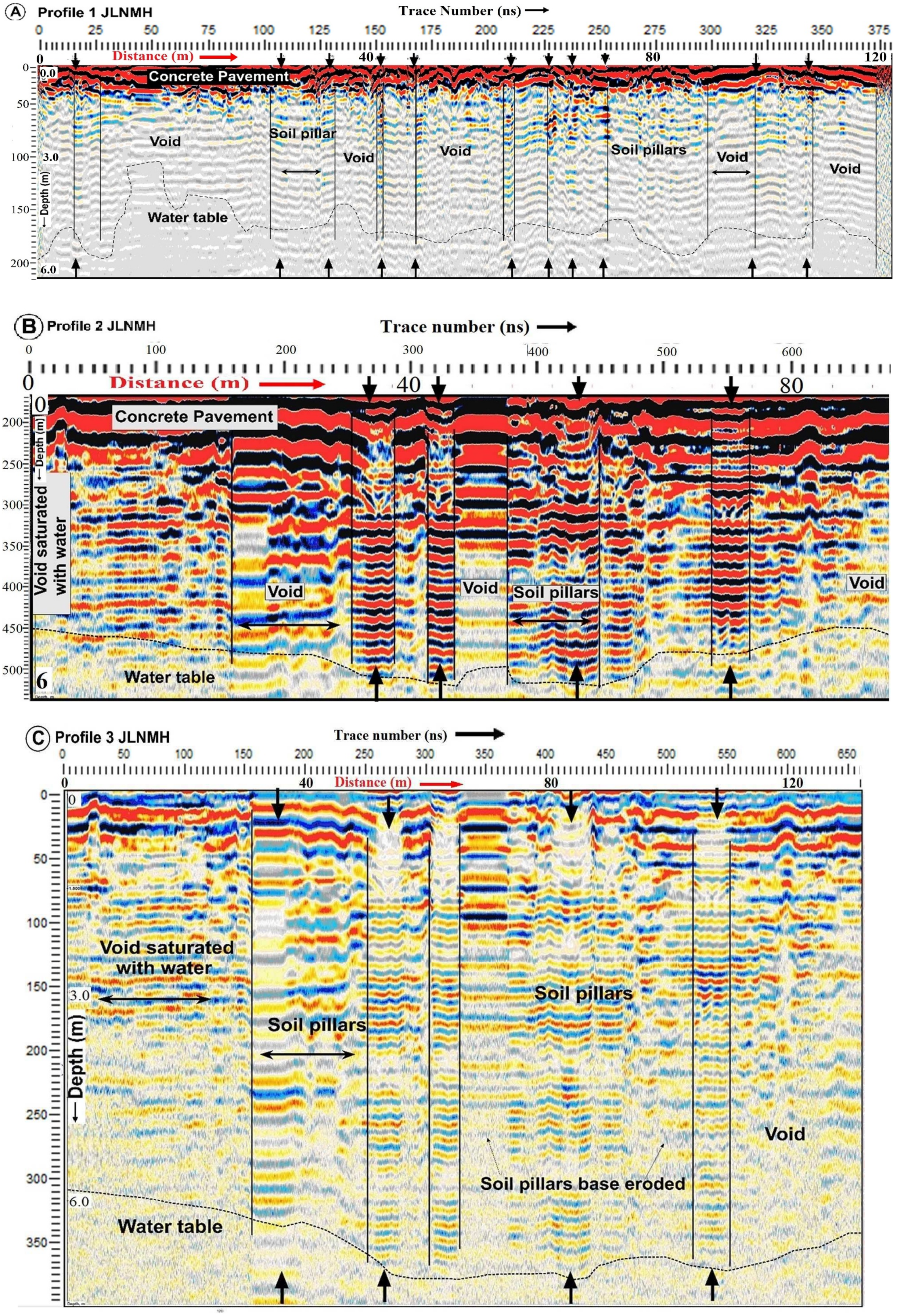

Fig.4. Interpreted JLNMH GPR image profile 1 acquired using 200 MHZ antenna configuration in the courtyard of the hospital showing land subsidence and sink holes. (b) GPR profile 2 JLNMH taken at the backyard of the hospital using 200 MHZ antenna configuration. (c) GPR profile 3 JLNMH acquired with 200 MHZ tapering off hospital quarters illustrating room and pillar structures and subsidence in the shallow stratigraphy of 4-6 m depth.

interlinked two cavities. The soil pillars are of varied height from 4-6 m and are partially eroded and dissolved at base. A network of voids and soil pillars were observed almost in all GPR profiles suggesting that this area was probably used for extraction of soil by room and pillar type of mining methods and most of the voids are saturated at the base.

Survey Site 2: Surteng Locality

A total of three profiles were acquired at Surteng locality along the roadways to delineate the subsurface geometry and pattern of sink holes and deformation structures that accommodate the land subsidence in the area. The GPR profile 4 was taken along the street at Surteng locality with 250 MHZ antenna and is 220 m long with a penetration depth of 5-6 m (Fig. 5 a). The profile illustrates a lateral changes in reflection geometry and pattern is consistent with asymmetrical pillar structures separated by intervening voids and cavities expressed between 2 m to 200 m as reflections with clear reflection termination and displacements. An arch top void is expressed between 75 m to 95 m distance marker that extends up to the near surface and shows upward termination. Several diagonal and vertical wide cracks are expressed between 8 m to 180 m as inclined radar reflections and diffraction hyperbolas that offset georadar reflections. Well defined sharp vertical truncations and offsets are expressed (15 m, 70 m, 150 m) from the base up to 2 m depth and an inclined to down warping radar reflections within upper 2 m depth reflect foundering and sinking of the formation as the arch top void has almost approach to the near surface that could results in the sudden collapse or sink hole formation in the near future at the site. The GPR profile 5 was taken with 250 MHZ antenna along the roadway at Surteng locality is 170 m long striking NW with a penetration depth of 6 m (Fig. 5 b). The profile illustrates upwarping and down warping in the georadar reflections up to 2.5 m depth between 5 m to 150 m and several inclined wide cracks expressed as inclined and disconnected georadar reflections or hyperbolas between 2 m to 165 m distance marker. Very sharp abrupt vertical terminations expressed as diffraction hyperbolas from base to 2.5 m depth between 0 m to 170 m reflect soil pillars bounded by voids and cavities marked with thick vertical black lines. The soil pillars and voids are symmetrical in pattern and geometry and are expressed at equal intervals with almost 20 m wide soil pillars separated by 15 m voids. The higher amplitude and stronger reflections at the base of the voids between 0-15 m, 50 to 65 m and 140-160 m suggest the presence of water. The GPR profile 6 was acquired with 100 MHZ shield antenna striking E-W is 120 m long that yielded penetration depth of 15 m (Fig. 5 c). The profile demonstrates a sink hole expressed as anomalous inclined and disconnected down warping radar reflections interspersed with on lap and vertical reflector geometries between 2 m to 100 m distance marker from the 1.5 m to 10 m depth. The disconnected and offset radar reflections showing an overall syncline geometry suggest internal foundering of the layers and downward movement of the strata and extends up to the base of the image. The deepest part of the sink hole is expressed between 10 m to 50 m as hyperbolas with clear down warping geometry bounded by sharp lateral offset and inclined reflections that forms the collapse structure and truncating upper soil cover almost up to the surface. The sink hole is overlain by discordant reflections and the outward margins of the sink hole is expressed coherent inclined disrupted reflectors and discrete breaks. The upper 1 m from the top reflects various vertical and diagonal cracks expressed as diffraction and offset hyperbolas. Very stronger coherent radar reflections from the base up to 6.5 m represent ground water table and is marked with thin black dashed line.

DISCUSSION

Land level changes or surface change phenomena have been a problem for many regions of the world and have attracted the attention of researchers due to the recognition that ground motion severely affects the masonry structures. Saeidi et al. (2009), Donnelly et al. (2001); Merad et al. 2004); Wang et al. (2008), and Stecchi al. (2009) investigated mining subsidence-induced damages in buildings in their research in various regions around globe. Gayarre et al. (2010) reported ground subsidence triggered by the collapse of abandoned underground mining operations that led to damage to buildings, and the study also included temporal and spatial evolution of the cracks inventoried in buildings. The researchers concluded, from SAR images, that underground mining galleries cause surface subsidence which can cause damage to structures (Perski and Jura 2003; Kutoglu et al. 2008). Similarly, several researchers determined mining subsidence effects using InSAR techniques in Zonguldak–Kozlu hard coal basin. They plotted ground deformations on the SAR images (Kutoglu et al. 2008; Deguchi et al. 2007; Akcin et al. 2006). Deguchi et al. (2007) computed mining induced surface displacements using InSAR technique. Also, Akcin et al., (2006) compared the deformations obtained from the InSAR technique with the ones based on GPS observations and determined the correlation coefûcient as 0.789 between InSAR and GPS methods. Mancini et al. (2009) examined salt mining-induced ground subsidence effects on buildings in the city of Tuzla, Bosnia and Herzegovina. In their study, the analysis of high-resolution satellite data showed the collapse or demolition of approximately 835 buildings the most damaged area. Wu et al. (2009) submitted a study of the inûuences of mining subsidence on the eco- logical environment. Their study discussed public infrastructure in the area of the Haolaigou Iron Ore Mine where serious mine subsidence occurred in 2007, and the study estimated the maximum surface subsidence amount.

Subsidence generally occurs in three main different environments: (a) geologically, soluble rock formations (gypsum, limestone, dolomite and rock salt) that differ from unconsolidated deposits or ancient sink holes filled with unconsolidated deposits. (b) Young unconsolidated deposits in premature basins with high porosity in alluvial fan environments, lacustrine or marine environments. (c) Urban suburbs having very high density of tall buildings, masonry structures, population etc. Various natural or artiûcial factors that may induce subsidence which cause damage to masonry buildings from settlement on the earth's surface are as follows:

(a) subsidence by faulting or seismic excitations. (b) subsidence by isostatic rebound. (c) subsidence due to thermal contraction of lithosphere. (d) subsidence induced by water table management or ground water level changes. (e) subsidence caused by extraction of gas. (f) subsidence by collapse.

(a) The ambient stress in the earth can be accommodated either by geological faulting in the crust or by ductile flow in the hotter and fluid mantle. Occurrence of faults results into absolute subsidence in the hanging wall of normal faults and in reverse (thrust) fault relative subsidence may be measured in the foot wall. In case of faulting the subsidence is enormous, and follows a particular trend (along the direction of the fault) in a large area. However in Rainawari area the subsidence is restricted to a very small area and it does not follow a particular trend. (b) The crust floats buoyantly in the plastic asthenosphere with a ratio of mass below the surface in proportion to its own density. If mass is added to the crust (e.g. through deposition), crust is thought to subside minisculely to compensate and maintain isostatic balance. Thus in this case also the subsidence is spread over a large area. In Rainawari area the subsidence has occurred comparatively in a miniscule area. (c) Stretching of lithosphere, probably due to slab pull causes thinning of lithosphere and rising of asthenosphere into the space that is created. This causes heating of the overlying crust and mantle and thermal expansion of these materials. Over time heat is lost through radiation from the earth's surface and the thermal gradient relaxes. Once temperatures fall the lithosphere will contract causing subsidence at the surface. This phenomenon is

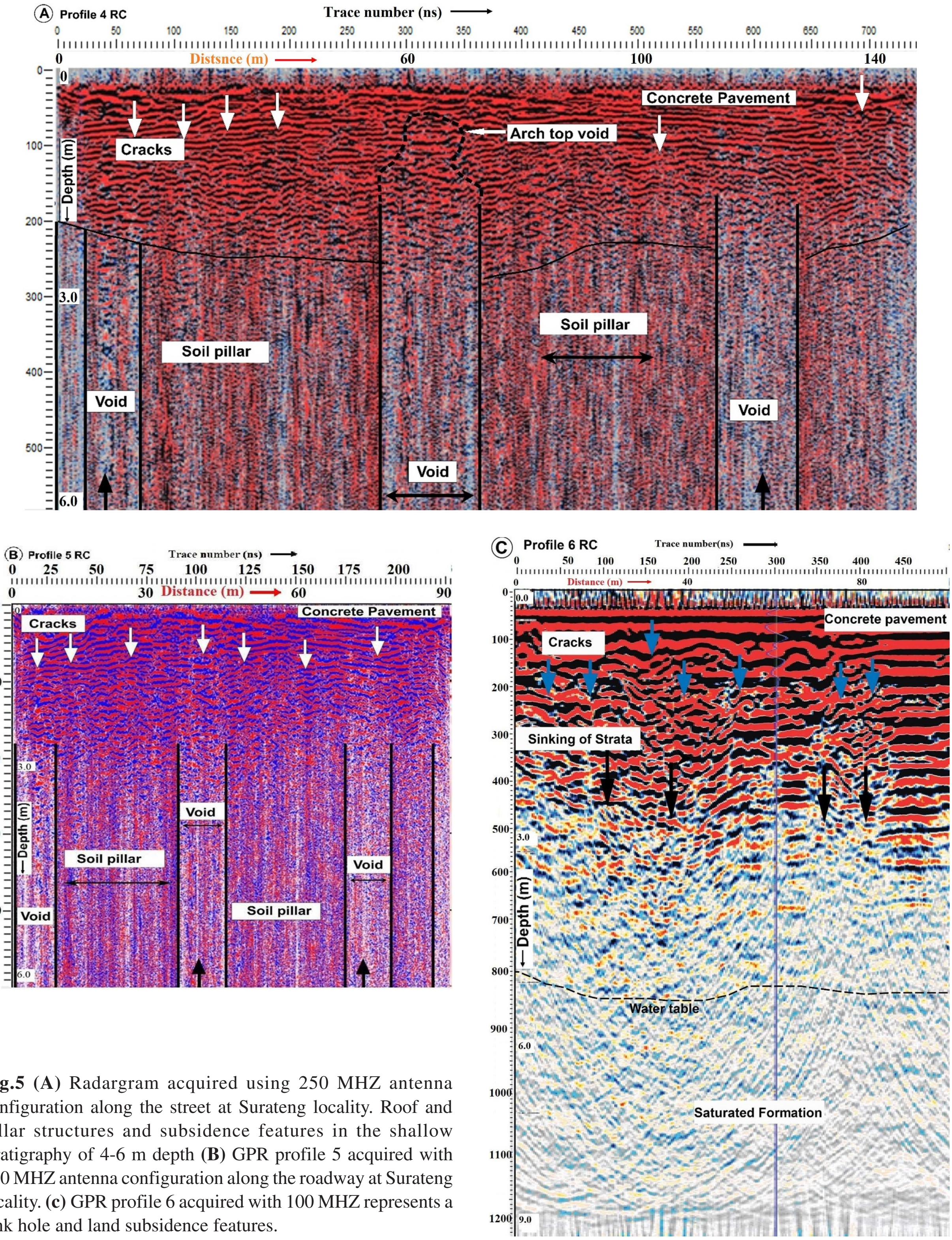

Fig.5 **(A)** Radargram acquired using 250 MHZ antenna configuration along the street at Surateng locality. Roof and pillar structures and subsidence features in the shallow stratigraphy of 4-6 m depth **(B)** GPR profile 5 acquired with 250 MHZ antenna configuration along the roadway at Surateng locality. **(c)** GPR profile 6 acquired with 100 MHZ represents a sink hole and land subsidence features.

not possible in case of Rainawari subsidence. No such phenomenon has been reported from anywhere in the Kashmir valley. (d) This phenomenon is possible in coastal and delta plains, where due to drainage and resulting aeration of soil, oxidation of organic components such as peat takes place and this process leads to significant subsidence. (e) No gas reserves have been reported from anywhere in Kashmir. The valley being a basin of lacustrine sediments, some small patches of methane are found here and there. (f) Subsidence by collapse commonly occurs over man made voids such as tunnels, wells and covered quarries. It is also frequent in karst terrains, where dissolution of limestone by fluid flow in subsurface causes the creation of voids.

The subsidence in Rainawari area is a mining type subsidence. Mining subsidence can be defined as movement of the ground surface as a result of readjustment of the overburden due to collapse or failure of underground mine workings. Mining subsidence is common in areas overlying shallow room and pillar mines. Sinkholes occur from the collapse of the mine roof into a mine opening, resulting in caving of the overlying strata and an abrupt depression in ground surface. The “gouf” mining which is known geologically as room and pillar mining involved making of a small shaft in the ground , the shaft usually used to be inclined and only 10-15 meters deep. The miners would go 10-15 meters deep into the ground and mine out the rooms of clay leaving behind in place a regular pattern of pillars. This mining involved only local crude knowledge and did not follow the geological and mining principles at all. The basic mining principle which is to be adhered to in case of room and pillar mining is that the amount of cover (overhead burden) should be about 100 meters but in no case it should be less than 50 meters. However overhead burden in case of Rainawari area room and pillar mines was less than 20 meters. As a result of readjustment of the over burden due to failure of underground pillars, this type of subsidence has taken place.

The GPR results at JLNM Hospital and Surteng locality in Rainawari area clearly demonstrate network of voids, cavities, sink holes, cracks and corresponding soil pillars, earlier used for extraction of soil through "gouf" mining methods and provide abundant information on sink holes, soil displacements and temporal development of subsidence phenomena that accommodates land subsidence or creep processes at shallow depths in the area. The evidence of subsidence during field Campaign was clearly observed from land level changes to structural changes in the buildings and noted in high resolution GPR images. The obtained GPR results also clearly show that the Rainawari area is highly susceptible to seismic liquefaction also owing to shallow groundwater table (~ 3 m) and presence of fine sedimentary strata of clay, sand and silt. To guide the future excavations, recurrence, acceleration or deceleration of the activity and temporal development of subsidence phenomena, our shallow geophysical investigations provide a great deal of information on key aspect for risk management and hazard assessment.

CONCLUSION

The present paper reports the ground penetrating radar (GPR) survey results using 100, 250 500 MHz antennas at two potential sites namely Jawaharlal Nehru Memorial Hospital (JLNMH) Rainawari and Surteng locality, to characterize the trends and patterns of shallow stratigraphic disturbances associated with mining subsidence and creep processes, kinematics, tension fissuring, ground water table and seismic resilience of various structures on the surface. Our GPR prospecting using high resolution antenna configuration were able to successfully map a network of room and pillar structures, underground fissures and cavities and sink holes responsible for differential land subsidence and creep process in the area. The obtained results indicate that GPR data can contribute critical information to sink holes, characterization of the processes associated with mining subsidence where no surficial evidences exist. A series of differential settlements witnessed land level changes and sinking of buildings by readjustment of the overburden due to collapse or failure of underground saturated cavities/voids. Several structures in the area collapsed, tilted and have developed minor to major cracks in the supporting walls, plinths etc. Further, the old and new concrete structures lack present earthquake resistant measures, although with age the strength of the old structures has decreased manifold because of the decaying construction material, the need of the hour is to renovate these buildings as soon as possible. The GPR profiles at Rainawari clearly delineate a shallow water table of 3.5 m depth that poses a serious risk for seismic liquefaction. The saturated voids and sink holes at shallow depth can easily crumble buildings and other structures during moderate (≤ Mw 6) to high magnitude earthquakes or even by the shaking caused by the heavy vehicular movement on the busy road in the area and could lead to a disaster in future. The most recent developments in the field of seismic hazard assessment should be incorporated in the construction of new structures to reduce future risk.

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