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RISK ASSESMENT OF SINKHOLE OCCURRENCE IN BANGLADESH BY ANALYZING TRIGGER FACTORS OF SOUTH ASIAN SINKHOLE COLLAPSE INCIDENTS WITH SUGGESTIONS FOR POSSIBLE PREVENTIVE MEASURES

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ABSTRACT

Sinkholes are naturally generating Karst formation in limestone topography which eventually results in the sudden collapse of the soil surface. Sinkholes can be of two types-natural, and man-made. Natural sinkholes induce due to topographical factors and other consequent reasons whereas man-made or urban sinkholes may occur due to large underground excavation which may cause fatigue in construction elements. Reasons behind sinkhole formation are many, occurrences of sinkholes can lead to huge economic loss and high fatality rates. In the past few decades, sinkhole occurrences were observed in the south Asian countries like- India, Pakistan Sri Lanka, Nepal, Malaysia, Thailand with triggering factors such as-lowering of water levels due to drought, earthquake, groundwater pumping, disturbance of the soil- soil removal, drilling, concentration of water flow, stormwater drainage, etc. Recently, a sudden sinkhole collapse was seen in Ghatkopar residence, Mumbai in June 2021. In this paper, we performed a review and analyzed the possible reasons responsible for sinkhole formation and collapse in the South Asian countries and did a probabilistic risk study for sinkhole formation in Bangladesh. Also we suggested preventive measures and appropriate quick steps in case of sinkhole collapse. Although there has been no recorded incidence of sinkhole collapse so far, it is possible that Bangladesh may experience a sinkhole occurrence. The existence of limestone in Joypurhat and some northern regions, drought-prone regions of northern Bangladesh, soil with high liquefaction potential at Sylhet, landslides prone, heavily water-clogged Chittagong city roads are the most vulnerable areas. Bangladesh is also critically vulnerable to earthquakes, another triggering factor for sinkholes. Recent research showed most of the seismic events are of moderate rank (magnitude 4-6) and lie at a shallow depth, which suggest that the recent movements occurred in the sediments overlying the basement rocks. The events also indicate shallow displacement in the faults separating the block from the alluvium which can lead to sinkholes. Large amounts of rainfall in a short time can expose a subsurface feature that has been hidden for many years. Heavy rainfall can possibly work as a triggering factor for sinkhole activation. Urban sinkhole collapse can be generated due to huge excavation and resulting cavity formation in asphalt. The authors analyzed the most probable triggering factors and assessed risk by making a susceptibility map using ARCGIS for sinkhole occurrence in the context of Bangladesh and suggested preventive measures with the considerations for sustainability and economy in Bangladesh context.

Keywords: *sinkhole formation; soil liquefaction; preventive measures; karst topography; GIS*

1. INTRODUCTION

Sinkholes are becoming a common geohazard nowadays globally. These can be formed in karstic areas where soluble bedrock is present as well as few other anthropogenic factors like heavy rainfall, loose soil, groundwater abstraction, defective pipes and seismic events may trigger urban sinkhole formation and collapse. Several genetic classification of sinkholes are published among them two main groups are- solution and subsidence sinkhole. Solution sinkholes ultimately show ground depression whereas subsidence sinkholes result from subsurface dissolution and downward gravitational movement of overlying soil due to erosion. Further classification proposed by (Gutiérrez et al., 2007; Waltham & Fookes, 2003) describes material affected (cover, bedrock, caprock) and subsidence process (collapse, suffosion and sagging). From a construction engineering point of view sinkholes are a significant geohazard and need to be studied for structural integrity and stability at vulnerable zones.

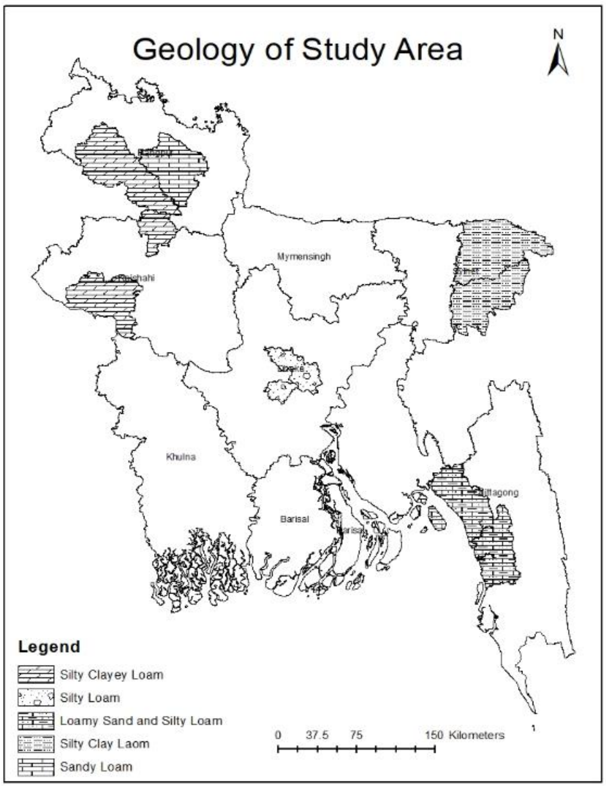

Fig 1: Geology of Study Area

The review will examine the risk assessment of sinkhole occurrence in Bangladesh by analyzing trigger factors of recent Asian sinkhole collapse incidents in India, Nepal, Vietnam, Malaysia, Philippines, South Korea. The review is composed of two parts. Based on the factors, processes to identify and investigate sinkhole genesis and geometry, risk mitigation strategies adopted by those Asian countries, we will analyze sinkhole risk for Bangladesh. Observations from this study is used to create a susceptibility map from which highest risk factor as well as risk-prone zone are analyzed. It is evident for Bangladesh to assess sinkhole risk for public safety and structural stability.

2. STUDY AREA

Bangladesh is located in South Asia, and its physical coordinates are 23°41'6'' N 90°21.38' E. In terms of land area, Bangladesh occupies about 144,000 square kilometers. Both the deltaic plain and the small hilly region make up this region. As a result of its expansive size and exceptionally fertile soil, the deltaic plain is by far the better place to live. In addition, flooding is a common occurrence here. The hilly region is located in the country's southeast and comprises the Chittagong Hills. Our study area includes Northern part of Bangladesh, Sylhet division, capital city Dhaka and port city Chittagong (Bangladesh Statistics 2020 - bbs.portal.gov.bd) and the geology of these area is shown in Fig:1.

3. SINKHOLE COLLAPSES IN OTHER ASIAN COUNTRIES

Sinkholes are seen in the sub-continent and other Asian countries in recent years. Soil condition, fault region, pipe layout, excessive rainfall are some of the triggering factors for these collapses. Different investigation methods are adopted and sinkhole geometry, genesis are analyzed. Table 1 contains sinkhole collapse incidents of 6 Asian countries, their timeline, causes, soil types, investigation method and remarks. Different reasons were behind varieties sinkhole type and genesis, as well as multiple factors, investigation methods were adopted which are shown in Table 1. We included these sinkhole occurrences from South Asian and other neighboring Asian countries because of their versatility.

Table 1 Analysis of Sinkhole Occurrences in Asian Countries

Source	Country And Timeline	Sinkhole and Soil Type	Causes	Factors Considered	Test and Procedure	Objective	Remarks
Prasad et al., (2019)	Cuddapah Basin, India, 2007, 2015	Natural, Sedimentary basin with dolomite and limestone	Heavy rainfall	Soil type, rainfall, sinkhole geometry	Global Positioning System (GPS) for inventory data, ARCGIS mapping	To make integrated geo-sinkhole map from inventory data	Inventory data is primary key to analyze sinkhole risk in river beds
R. M. Pokhrel et al., (2015)	Pokhara Valley, Nepal, 2013	Natural, Silt containing lime, Fluvial deposit	Erosion of riverbank	Thickness of cavity formation soil layer	Dynamic Cone Penetration Test (DCPT), Sub-surface Wave Exploration for soil data	To analyze cavity forming soil layer using non-destructive method	Backfilling was not adequate as some of the cavity reactivated
Kim et al., (2018)	Ho Chi Minh City, Vietnam, 2010 2011	Urban, Asphalt	Geological and environmental condition	Electromagnetic wave	Ground Penetrating Radar (GPR) was used to collect soil data	To investigate sinkhole formation area using GPR	GPR is a successful method to diagnose sinkhole
Nguyen Van Giang et al., (2012)	Seoul, South Korea 2010, 2014	Urban, Asphalt	Defective Sewer Pipe	pipe length, age, radius, burial depth, elevation, slope, pipe material	Statistical Analysis was applied for pipe parameters and QGIS	Regression analysis were done to understand factors	Only pipe parameters were used, geological factors were not included

Zabidi & De Freitas, (2013)	Cebu City, Philippines 2017	Natural, Limestone bearing sediments	Karst topography	Age of underlying karst, slope, elevation	GIS based spatial analysis was used to investigate sinkhole formation	To identify sinkhole genesis, frequency, shape and orientation	Most sinkholes are formed in flat sloped, low elevated, near streams and old aged bedrock.
Lumongsod et al., (2020)	Kuala Lumpur, Malaysia 2018	Natural, Kuala Lumpur Limestone	Limestone Formation and Ampang Fault system	Strike-slip fault, Granite intrusion, Flash Flood	Geospatial Analysis was used to analyze multiple factors	To identify cavity distribution around fault system	Investigation of cavity near SMART tunnel was performed

4. TRIGGERING FACTORS FOR SINKHOLE COLLAPSES

4.1 Soil Liquefaction

Liquefaction is a phenomenon that occurs in loose, sandy, granulated soil while earthquake shaking, static loading or traffic induced vibration on roads. Soil mass loses shear strength and acts like liquid creating a gap void zone (Scott, 1986). Bangladesh consists of loose alluvial soil deposits. Soil liquefaction phenomena can be observed after several earthquakes in 1885 and 1897 (Middlemiss CS). Moulvibazar town of Sylhet which is in earthquake prone region of zone-4, high LPI as well as factor of safety<1 (Hossain et al., 2020) confirms presence of liquefying loose soil (Hossain et al., 2020 & Seed et al., 1970). Propagation of liquefying soil toward void space like- pipes may create sinkholes amidst roads which are responsible for engulfing vehicles (C.A. Davis & S. Giovinazzi), creating massive holes etc. (Davis, 2019). Capability of high erosion by this mobile layer of loose soil is responsible for cavity formation (Del Prete et al., 2010). Cone Penetration Test and further analysis of the Raveling Index from it may indicate the risk prone zones for subsidence type sinkholes in Sylhet region (Shamet & Nam, 2020). Ground improvement by compaction, dynamic compaction, use of fiber reinforced cement, geotextile may mitigate soil liquefaction (Bao et al., 2019).

4.2 Limestone Formation

Limestone of Pleistocene age found in the northern region of Bangladesh is used in cement factories as a raw material. Bangladesh has discovered its biggest limestone mine in the Naogaon district in Rajshahi division (Correspondent, 2016). It is also found near the surface zone at St. Martin’s Island in Cox’s Bazar, Bhangerghat-Lalghat-Takerghat in Sunamganj district, Sitakund limestone (Miocene age) and near the Dauki River, Jaflong, Sylhet district. Subsurface deposits of limestone are found at Joypurhat district, Bogra, Patnitala, and Tajpur, Naogaon (Ali & Author, 2021). The reasons behind natural sinkhole formation and ground subsidence are karst topography and underlying dissolving carbonate geology (Waltham et al., 2005; Ford & Williams, 2008). The limestones of South-East Asia are of the Palaeozoic to Mesozoic era (Stauffer, 1983). Four types of karst terrain can be found in South-East Asia (Jiang et al., 2020): karst on plateau (Vietnam, Thailand), karst on plain (Malaysia), karst on mountains (Laos, China, Thailand, Vietnam) and karst on islands (Indonesia, Philippines) (Jiang et al., 2014). Malaysia (Zabidi & De Freitas, 2013) stands on loose karst topography. Though Bangladesh does not consist of massive limestone deposition or active karst topography, unexpected sinkholes or ground subsidence may occur due to negligence. Proper geophysical survey, drilling and probing, and trenching should be done to inspect the risk-prone area. Subtle fissures or cracks may become catastrophic if proper risk mitigation steps are not taken (Gutiérrez et al., 2007).

4.3 Pipe Leakage

One of the reasons for urban sinkhole collapse and road subsidence is defective sewer pipes or pipe leakage (Choi et al., 2017; Ali & Choi, 2019). Dhaka, the capital city, has an underground pipe network and is considered to be a vulnerable zone. Another high-risk zone is the Chittagong City Corporation. A very recent incident in Mumbai's Ghatkopar region, India (A car drowns in a sinkhole in Mumbai; viral video shocks Twitter; watch 2021), in Jeju, Korea, and Fukuoka, Japan are seen (MailOnline, 2016). In Japan, the sinkhole was reactivated due to excavation. Researchers have integrated flow type, time, soil type, and simulated urban sinkholes (Ali & Choi, 2019). Dhaka city will go through some massive underground mega projects, including the Dhaka MRT project, which requires heavy excavation, and this may damage the pipe network and trigger leakage. (Kuliczkowska, 2016). On September 28th, 2021, a young female passer-by lost her life by falling into an open drain in Agrabad, Chittagong (A young woman dies after falling into an open drain in Chittagong in 2021). These faulty drains are called death traps and can cause sudden urban sinkholes. These make Chittagong vulnerable to sudden sinkhole collapse. For risk mitigation, pipe material should be chosen carefully, avoiding long, numerous-jointed, corrosion-prone pipes (Kim et al., 2018). Studies show that finer particles are prone to faster cavity formation than coarser particles. The evaluation of the sinkhole risk index (SRI) for Dhaka and Chittagong may reduce the risk of sudden road depression and sinkhole formation. Non-destructive methods and technologies such as vibration, thermal line sensing, ultrasonic methods, wireless sensors, and so on should be used to detect deformation and cracks in pipe lines and must be repaired on a regular basis (Indiketiya et al., 2019).

4.4 Seismic Events

Bangladesh is one of the largest alluvial plains in the world, surrounded by Himalayan and Burman Arcs at the north and east respectively (R. Bilham, 2009). Several massive earthquakes in the past and surrounding reverse and strike-slip fault systems including Dauki fault suggest Bengal Basin being seismically active and thus Sylhet is a vulnerable zone (Bilham & England, 2001). In the strike-slip, reverse fault of Shillong Plateau, Dauki, soil liquefaction, sand dyke formation these seismic events are seen and proved by excavating trenches and experimental studies (Morino et al., 2011). Seismic events induced sinkhole and cavity formation and ground subsidence are seen in South Asia. (R. M. Pokhrel et al.) Distance to fault was used as an important parameter (Orhan et al., 2020) for Konya, Turkey near Tilkier fault. Several studies were carried out in the past to show positive correlation between strike slip fault and cavity formation. Strike slip fault inhibits horizontal groundwater flow as a result water flows parallel to fault plane which creates erosion and ground subsidence, (Wadas et al., 2017) thin overburden consisting of loose soil gradually results in deep sinkhole or cavity formation (Gutiérrez et al., 2014). Shear wave reflection seismic is a valuable non-destructive method which can be adopted in the Dauki region to prevent future sinkhole collapse and huge fatality and economic loss (Wadas et al., 2017). Steel casing and riprap filling should be used for construction and gravels must be used to fill up the voids.

4.5 High Groundwater Extraction

Groundwater abstraction, which accounts for 79% of total water demand, has been used for drinking, irrigation, industrial and household purposes (Bangladesh Statistics 2020 bbs.portal.gov.bd). Groundwater is a renewable source and it is duly recharged by rainfall, irrigation water seepage, percolation, and infiltration of surface runoff (Neumann et al., 2009). The North-Western region of Bangladesh is a flood-free region and here groundwater declination is seen the most, which is also a major rice and wheat producing region of the country (Bangladesh Integrated Water Resources Assessment) with a thick clay top layer of the Barind Tract (Rahman & Mahbub, 2012) and very low average rainfall. These make Dinajpur, Joypurhat, Rajshahi, and Rangpur vulnerable to groundwater extraction-induced sinkholes. (Mojid et al., 2019). In Al Jouf, Saudi Arabia (Youssef et al., 2020), and Turkey (Orhan et al., 2020), rainfall and groundwater level simultaneously affected sinkhole occurrence (Choi et al., 2017). High hydraulic gradients and quick water table drops (Gongyu et al., 2020) create erosion and cavity formation. Following a prolonged drought, heavy rainfall acts as a dynamic load, causing groundwater levels to fluctuate abruptly, making strata more vulnerable to erosion and damage, as seen in southern China, Pakistan (Qian et al., 2009), and Zhao et al., 2011.This type of similar weather condition was seen in Rajshahi (Rahman & Mahbub, 2012). Preventing measures are: rainwater harvesting for drinking and irrigation purposes; inserting recharge wells; providing flat slopes; fissures must be filled out with compacted clay or granular material. Table 2 consists of different triggering factors, indications in Bangladesh and respective preventive measures.

Table 2: Sinkhole Triggering Factors with Risk Prone Areas, Indications, Mechanism and Preventive Measures

Triggering Factors	Risk Prone Districts	Sinkhole Mechanism	Global Sinkhole Occurrences due to similar factors	Indication in Bangladesh	Suitable Sub-surface Soil Exploration Methods
Soil Liquefaction	Sylhet, Moulvibazar	Loose liquefying soil creates gap zone	New Zealand, Italy	Soil with high LPI is found in Moulvibazar	Cone Penetration Test and Raveling Index
Limestone Topography	North-Eastern Districts and Sylhet	Limestone dissolves and cavity forms	Vietnam, Thailand, Malaysia, Laos, China	Limestone mines in Northern region	Geophysical survey, drilling and probing, trenching
Pipe Leakage	Dhaka and Chittagong Metropolitan City	Faulty pipe network, pipe leakage	South Korea, Japan, India	Dhaka and Chittagong city's faulty pipe system	Thermal line sensing, wireless sensor, ultrasonic methods to detect leak
Seismic Events	Dauki fault region, Sylhet	Strike slip fault plane affects groundwater flow	Thailand, Indonesia, Turkey	Dauki fault is an active, reverse and strike slip fault	Shear wave Seismic, steel casing, rip rap filing
Groundwater Extraction, Heavy Rainfall	North-Eastern Districts, Dhaka	Water table declination and high hydraulic gradient induce cavity formation	Saudi Arabia, Turkey, China, Pakistan	350 dug well data indicates groundwater abstraction in North-Eastern districts	Rainwater harvesting, recharge wells, filling with granular material

A sinkhole susceptibility map (Fig:2) was created for Bangladesh using ARCGIS and districts which are vulnerable due to different triggering factors were shown. From the map, it is evident that capital city Dhaka is in a remarkably vulnerable region due to three factors- defective pipe layout, groundwater abstraction and probability of earthquake. Massive construction projects require ground excavation which increases the risk (Dhaka Mass Transit Company Limited (DMTCL)-government owned company). However, north eastern and north western regions may be at risk of natural subsidence type cover collapse or suffusion sinkhole due to liquefying loose soil and presence of limestone.

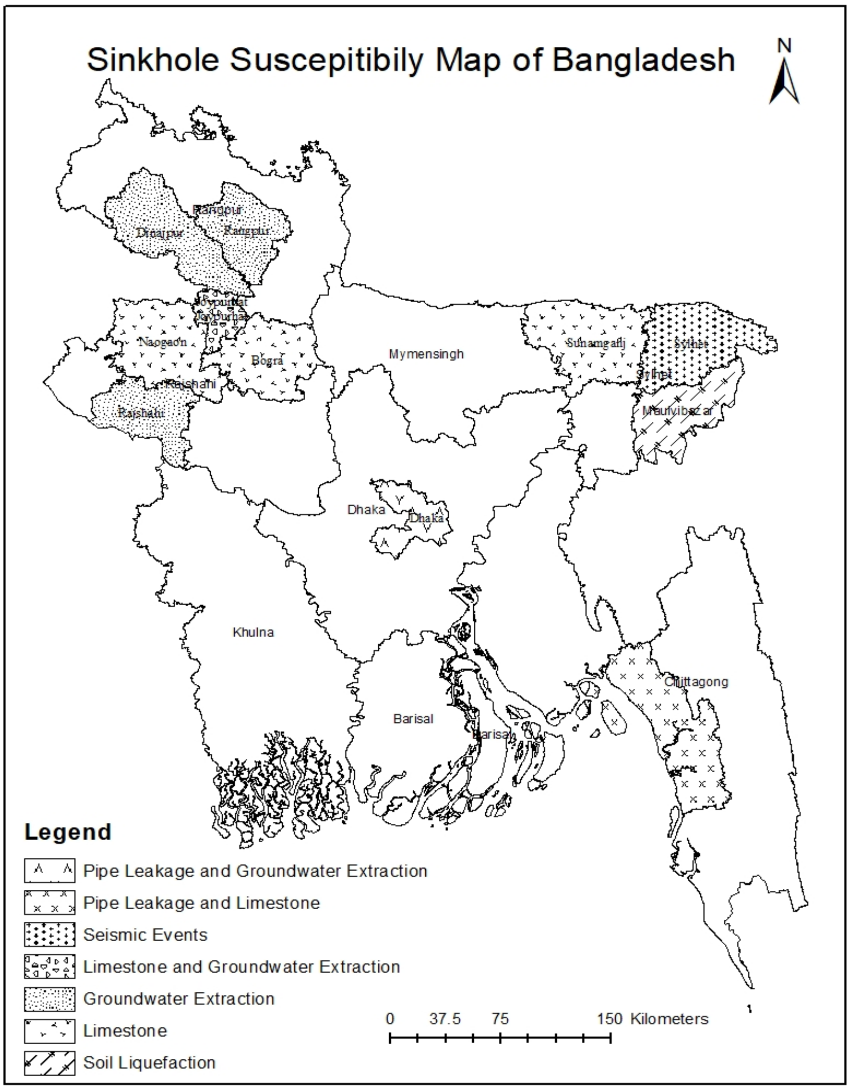

Fig: 2 Sinkhole Susceptibility Map of Bangladesh

5. CONCLUSIONS AND RECOMMENDATION

Bangladesh does not consist of vast limestone stratum which decreases the possibility of solution type natural cavity formation and collapse. However, phenomena such as heavy rainfall after prolonged drought, defective pipe layout and erosion due to leakage and seismic event induced erosion may trigger subsidence type urban sinkholes in asphalt in Bangladesh. From analyzing different triggering factors, we came to a conclusion that high groundwater abstraction can be the highest risk factor for sinkhole collapse in Bangladesh as it is evident in almost all districts. Due to water table delineation recent occurrence in soil subsidence may further result into bedrock collapse. Defective underground pipe, presence of loose liquefying soil, presence of strike-slip fault overlap with it may multiply the risk.

Although no sinkhole collapse has occurred in Bangladesh till date, it may collapse in the risk-prone areas without prior notification. So, further studies on vulnerable zones by analyzing different parameters such as slope, elevation, land use, land cover, groundwater potential zone, seismic zone, pipe age and dimension, etc., should be conducted. A more quantitative and rigorous calculation of the susceptibility index and map for Bangladesh should be prepared.

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