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SHORT REPORT

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Analyzing the 27 July 2021 rainfall-induced catastrophic landslide event in the Kutupalong Rohingya Camp in Cox's Bazar, Bangladesh

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Abstract

This article critically investigates a catastrophic rainfall-induced landslide event that occurred on 27 July 2021 in the Kutupalong Rohingya Camp (KRC) in Cox's Bazar, Bangladesh, from geological and geomorphological perspectives. Large-scale anthropogenic interventions mainly caused the disastrous landslide event in the KRC in addition to intense rainfall. Before the landslide occurrence, about 300 mm of cumulative rainfall was recorded in the previous seven days and 120 mm of rainfall during the landslide event. A preliminary investigation was conducted to understand the extent, causative factors, and landslide characteristics. The landslide is of mud-flow type, but on the nearby slope, slumping was also visible. The landslide length was about 33 m, width 31 m, and area 612 m^2. The approximate volume of slope materials displaced during the landslide event was about 2450 m^3. The displaced slope materials mainly were silt and sand. The landslide event caused five fatalities and damaged nearly 5000 shelters in the KRC area. The devastation from such a small landslide event was attributed to dense households on the slope's hilltop, slope, and toe. The camp areas and host communities are subjected to frequent and fatal landslides in the years to come due to intense human interventions and climatic conditions. The modifications of the slopes have been reducing the cohesion and the shear strength of the slope materials. Therefore, it is recommended to undertake proper mitigation and preparedness measures, including developing and implementing a landslide early warning system to address the emerging humanitarian crisis in the KRC and its surroundings.

Keywords: Rainfall, Landslides, Rohingya, Bangladesh, Floods

Introduction

Chittagong Hill District (CHD) consists of Chittagong, Rangamati, Khagrachari, Bandarban, and Cox's Bazar districts in the south-eastern part of Bangladesh. CHD is the only extensive hilly terrain in the country and is especially prone to landslide hazards, causing severe loss of life and property (Islam et al. 2017; Rabby and Li 2019; Ahmed, 2021). In this technical report, we have critically analyzed a catastrophic landslide event that occurred in the Kutupalong Rohingya Camp (KRC) in Cox's Bazar District (CBD), Bangladesh (Fig. 1). Approximately 257 landslides or slope failures were also reported in the KRC area (IOM 2021). The landslides washed away a large volume of slope materials, including temporary makeshift shelters for the refugees and other critical facilities inside the camps. In this study, twenty-six landslides were mapped in detail during the fieldwork (Fig. 1b). Among these landslides, two separate landslides incidents in camp 10 caused the death of 5 Rohingya people. One of these landslides has been critically discussed in this report because most of the landslides have similar characteristics and mechanisms. The reported landslide incidents occurred at 21° 11′ 12.14″ N, 92° 09′ 15.20″ E coordinate following a 7-day consistent rainfall of about 300 mm on 27 July 2021 at approximately 10:00 pm

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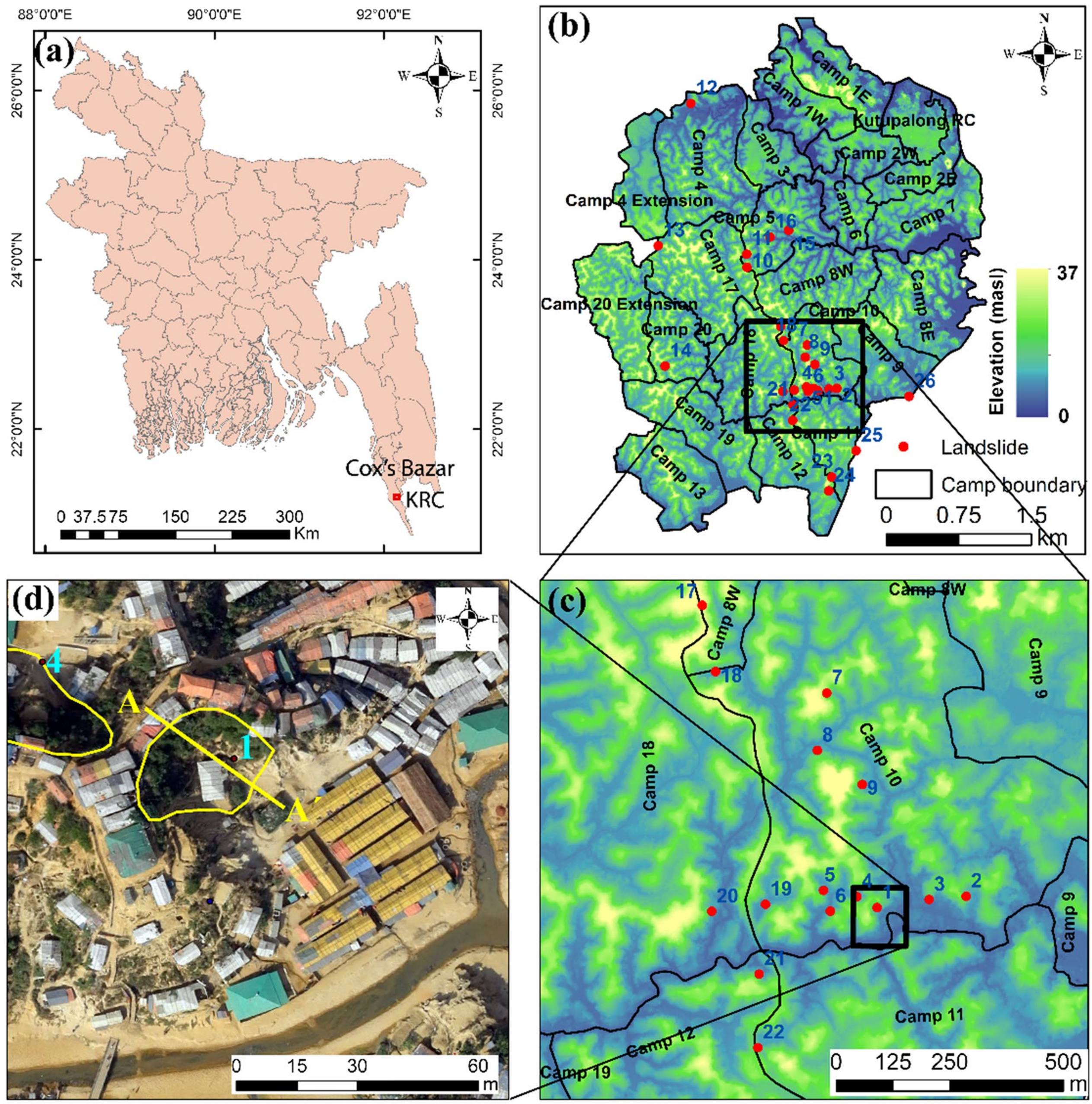

Fig. 1 Location of the landslide occurrence area: **a** location of the Kutupalong Rohingya camps (KRC) on the administrative map of Bangladesh; **b** field-collected landslide inventory on the elevation map (0.5 m × 0.5 m) of the KRC; **c** enlarged view of the worst landslide affected camp 10 and the adjacent area; and **d** reported landslide extent on a pre-disaster drone image of 0.1 m resolution. *Image Source* IOM

(GMT + 6.00). The extreme rainfall events also caused widespread flash-flooding in the KRC valley (Fig. 2).

The KRC currently hosts over 630,000 stateless Rohingya population (see Appendix 1), also known as Forcibly Displaced Myanmar Nationals (FDMN). Since August 2017, over one million Rohingyas have temporarily lived in Cox's Bazar district as they fled genocide and crimes against humanity in their homeland in the Rakhine State of Myanmar (ICJ 2021; Martuscelli et al. 2022). They live in temporary make-shift camps made of bamboo, polythene, and other non-reinforced materials. The KRC is prone to natural hazards such as cyclones, floods, and landslides owing to its geological, morphological, and climatic conditions (Alam et al. 2020). After

Fig. 2 **a** Landslide scar, uprooted trees, and houses built on the slope base, and **b** extreme flooding due to intense rainfall in the Kutupalong Rohingya camp. *Source* The authors, fieldwork, 2021

the settlement of Rohingya refugees, extensive deforestation and slope cutting eventually resulted in numerous landslide occurrences (Braun et al. 2019; Hasan et al. 2020; Hossain and Moniruzzaman 2021). Kamal et al. (2022) showed that anthropogenic interventions and low strength of residual soil are the major causes of landslide occurrence in the KRC. The large scarp of slope washed away with a massive volume of materials during the 27 July 2021 landslide event directly buried some houses on the modified slope and completely/partially destroyed them. We carried out an extensive field investigation of the landslide sites. The areal extent, geological setting, landslide dimensions, and slope materials composition were comprehensively investigated to identify the cause and extent of the disaster.

Landslides have become a regular phenomenon in the KRC since the August 2017 Rohingya influx (Ahmed et al. 2020; Emberson et al. 2021). The repetitive occurrence of landslide events each year during the rainy season is a key concern for site management and protection issues. Furthermore, it is projected that landslides and other hydrometeorological hazards will increase in the region due to climate change and anthropogenic interventions (Gariano and Guzzetti 2016). As a result, it has been deemed necessary to characterize catastrophic landslide events to identify the triggering factors and areal extent to reduce the landslide-induced vulnerabilities (Alam and Ray-Bennett 2021). This short report discusses the landslide triggering factors, rainfall patterns, anthropogenic interventions, loss and damage, and future risks.

Site description

Every year landslide incidents are reported from the south-eastern hill districts of Bangladesh (Abedin et al. 2020; Sultana 2020). In the monsoon of 2021, numerous landslide incidents caused the death of at least 23 people in the CBD. The Kutupalong Rohingya camps are located in the Ukhia sub-district and were once covered with dense hilly forests. However, after the Rohingya settlement, extensive deforestation and unplanned slope cuts occurred (Ahmed 2021; Braun et al. 2019; Quader et al. 2021). Which immediately resulted in 422 landslides in 2018 that affected 4150 households (Fig. 3). Before the Rohingya settlement, large-scale landslide occurrences were not reported from the KRC area, although it is located in a treacherous terrain (Ahmed 2021). The households in the KRC were made of non-reinforced materials, which could not sustain landslides. After that, during the rainy season (June–September), landslides, associated casualties, and property loss have been regularly reported in the KRC. However, landslide frequency has been reduced in recent years due to the local authorities and NGOs taking slope stabilization and afforestation measures. For example, in 2021, landslide incidents were significantly reduced, and only about 257 landslides were reported inside the Rohingya camps, resulting in 5 fatalities and 1300 household damage (Fig. 3).

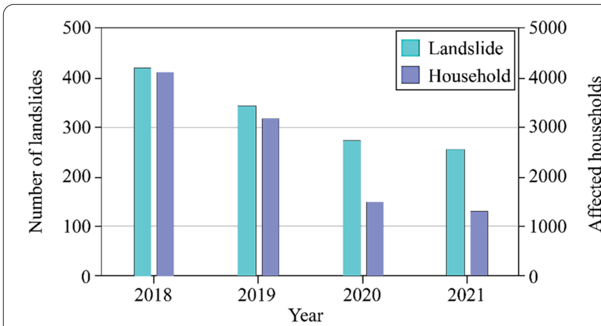

Fig. 3 Yearly occurrence of landslides and affected households in the Kutupalong Rohingya camp. *Data Source* IOM 2021

Methodology

This study is primarily linked to fieldwork-based landslide inventory, soil sample collection, and secondary data analysis. The combined research of landslide inventory information, laboratory analysis of soil mass collected from different stratigraphic layers of the landslide sites and analysis of the cumulative rainfall before the landslide occurrence gives the comprehensive characteristics and causes of landslide occurrence and their future risk. The general methodological framework followed in this study is shown in Fig. 4.

Field visit and data collection

During the field visit in August 2021, the authors collected detailed information on the landslide events in consultation with the Rohingya representatives and site management authorities in the KRC. Before the field investigation location of the landslides, slope angle, land use, and other information were collected utilizing satellite and drone imageries. The field's landslide mechanism, preliminary statistics (length, width, and depth), damages, and possible slope failure causes were also noted. Soil samples from each mapped landslide location were also carried to the laboratory for further investigation.

Particle size distribution

A laboratory-based analysis was conducted to characterize the landslide slope materials and soil particle size distribution. Particle size analysis is one of the critical aspects of landslide characterization (Casagli et al. 2003). It determines the landslide materials' strength and magnitude of water infiltration after rainfall to the subsurface. The grain size analysis of the collected landslide slope materials from the field was done in the laboratory by a combined hydrometer and mechanical sieve analysis following the ASTM standards. In addition, detailed information on shear strength and other engineering parameters of soils in the KRC were collected from Kamal et al. (2022).

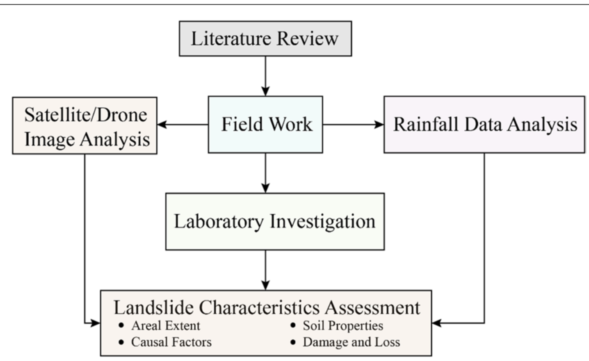

Fig. 4 The methodological framework of this study

Landslide characteristics assessment

It involves determining the actual type and cause of slope failures using preliminary information from field and laboratory investigation and secondary information such as rainfall, elevation model, and drone images. The fatalities and damage that occurred from these landslides are also discussed.

Results and discussion

Based on the field observations and analyzing drone imagery and high-resolution (0.5 m) digital elevation model (DEM) data, it was observed that the landslides occurred on the steep slope and were confined within the small reach of the slope to the valley. The landslides had a complex appearance of slump and mudflow type morphology. The rainwater infiltrated the flat hilltop or crest, and sloping areas caused seepage through the highly disturbed slope. This preferential water flow weakened the cohesion of slope materials and caused slope failure. The runoff flew along a narrow, channelized zone in the slope, dislodging the materials and triggering erosion. The weak lithology of the slope intensified and created favorable conditions for the rainwater to erode and wash the slope materials.

Geological characteristics

The study area is part of the Chittagong-Tripura fold belt (CTFB), consisting of numerous anticlines and synclines. Geologically, the KRC is made of Dupi Tila sandstone, Girujan clay, and Topham sandstone formations. The lithologies are loosely consolidated and sand-silt rich. Flat top, low rounded hillocks and broad valleys are the main geomorphological features present in this area. The surface elevation ranges from 0 to 37 m and is highly undulating. The hills and valleys were vegetated with tropical plants. The KRC area was previously protected, and only community forestry activities were permitted. However, since the influx of Rohingyas in 2017, they set up their shelters by cutting the hilltops and slopes and razing the forest for fuel. This environmental degradation caused an increase in rainwater infiltration in the subsurface. Stratigraphically the sliding slopes were composed of two layers–upper residual soil, predominantly clayey to silty and lower sandstone, mostly silty to sandy. The slumping prominent landslide was observed in the KRC. Still mudflow sometimes occurred after intense rainfall (Fig. 5a). The grain size distribution of the samples collected from landslide sites showed that more than 50% sand and silt were present in the upper and lower sandstone units.

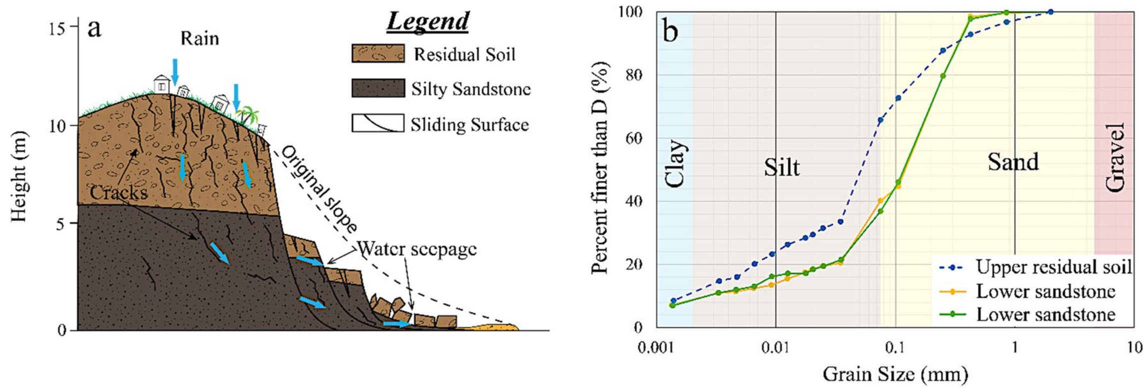

Fig. 5 **a** Generalized stratigraphy of the landslide slope, and **b** grain size distribution of the landslide slope materials

However, the upper soil was more fine-grained than the lower sandstone (Fig. 5b).

Rainfall pattern analysis

The region's tropical monsoon climate is characterized by a very wet monsoon season from June to September. The average annual rainfall of Bangladesh is about 2500 mm, but the south-eastern region, where the study area (Fig. 1) is located, observes around 4000 mm of rainfall every year (Shahid 2011). Torrential rainfall in the monsoon is the primary triggering factor of landslides in the CHD region (Ahmed 2021). Figure 6 shows the recorded rainfall in Cox's Bazar station from June to July 2021. The rainfall data analysis indicates that continuous rainfall occurs from the onset of June. Seven days before the landslide event of 27 July 2021, a continuous rainfall accumulation of about 300 mm was observed. The three-day antecedent rainfall amount was about 200 mm. Approximately 24 h prior to the landslide event, the cumulative rainfall had already accumulated more than 120 mm. Such extreme rainfall in this region can induce catastrophic landslide and flooding events (Fig. 2). The current threshold value for landslide occurrence is 300 mm and 200 mm for antecedent rainfall for 3-days and 1-day, respectively (Ali et al. 2018). During this event, antecedent rainfall for 3-days and 1-day was less

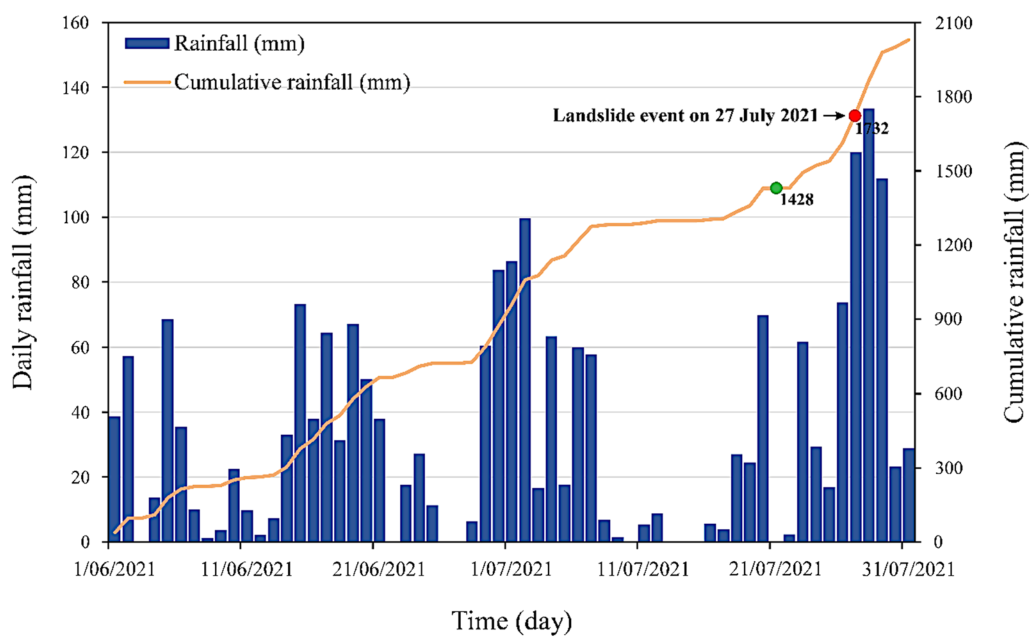

Fig. 6 Daily and cumulative rainfall from June to July 2021. The red dot indicates the 27 July 2021 landslide event. *Data Source* Bangladesh Meteorological Department; https://bmd.gov.bd

than the optimum. However, other factors such as hill cutting, overburden load and long-term (60 days) continuous rainfall from 01 June 2021 influenced the landslide occurrence.

Landslide characteristics and causes

During the 2021 monsoon season, around 257 landslide incidents were reported in the KRC (IOM 2021). However, this study covered a detailed inventory mapping of 26 landslide incidents. Most of the landslides were of flow and fall type. However, some were rotational slides (see Appendix 2). Finally, the specific landslide that caused the fatalities of five Rohingyas in Camp 10 is further investigated in this report.

The reported landslide that occurred on 27 July 2021 in the KRC has been characterized as mudflow type. The slope materials were washed away with rainwater and composed more than 50% of sandy to silty-sized particles. The elevation of the landslide initiation and deposition zones were 25 m and 12 m above sea level, respectively. The longest path of the mudflow was about 33 m, and the width of 31 m. The area and volume of materials dislodged were about 612 m^2 and 2450 m^3, respectively. The depth of the mudflow was about 3 to 4 m (Fig. 7). The leading cause of the landslide was torrential rainfall that quickly infiltrated through the upper soil layer. The water reaching the lower sandstone layer effectively reduced the sliding resistance of the sandstone layer and flowed downslope.

The anthropogenic interventions in the form of forest raze and hazardously modified/cut hill slopes for constructing highly dense fragile shelters made of bamboo and corrugated iron sheet increased the infiltration rate and reduced the shear strength of the slopes. This phenomenon caused rainwater to flow along a channelized zone, facilitating landslides. The large-scale construction and rapid downslope movement of slope materials washed away the houses built on the dangerous hill slope and uprooted several trees. In addition, the dislodged materials deposited in the downslope caused partial damage to some other houses built on the slope toe (Fig. 7b, c). All the further landslides mapped during the fieldwork had identical morphologies and types and had almost similar characteristics as the reported landslide.

Emergency rescue operation

The size and volume of the landslides were minor, but in terms of catastrophe, they caused enormous damage to the structure and human lives. In terms of fatalities, the 27 July 2021 landslide was the most catastrophic event since the August 2017 Rohingya influx in the KRC. The landslide buried houses built on the risky slope and killed

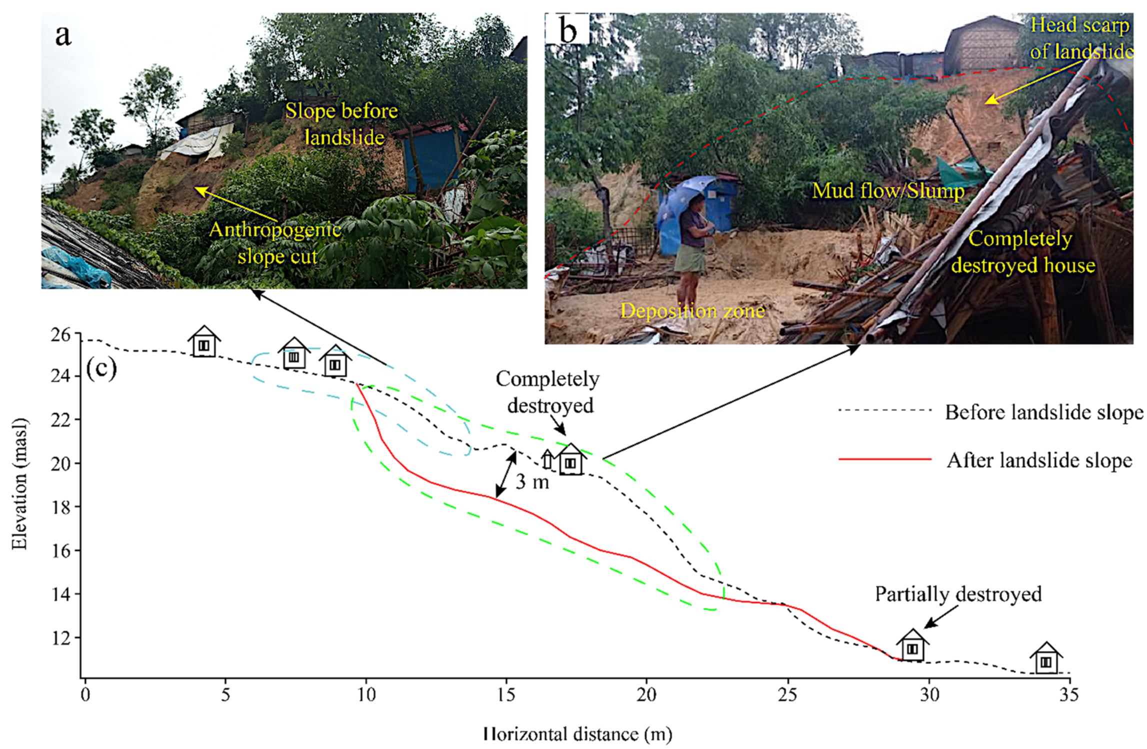

Fig. 7 **a** and **b** landslide features and damages, and **c** schematic profile of the landslide slope along the A-A′ line shown in Fig. 1c

five people, including two children. The intense rainfall-induced landslide and flooding events damaged 5000 shelters and displaced 25,000 Rohingyas (ISCG 2021). Different aid organizations working under the supervision of the Refugee Relief and Repatriation Commission (RRRC) immediately engaged in the rescue operations. The details about the rescue operations are shown in Fig. 8a–d, although the activities were hampered because of continuous rainfall and extreme hilly flash-flooding in the entire region. In addition, the poor road connectivity (landslides blocked some major roads connecting the camps with the city center) and flood inundation disrupted the rescue effort.

Nevertheless, the rescue team evacuated 5000 residents to a safe place and admitted injured persons to the nearest hospital. The highly rapid mudflow with tremendous kinetic energy also uprooted several trees. It damaged some utility and critical infrastructures such as latrines, tube wells, and drainage lines on the hill slope.

Conclusion and recommendations

The catastrophic landslide event on 27 July 2021 in the Kutupalong Rohingya Camp (KRC) was categorized as a mudflow or slump. The primary triggering factor was intense rainfall of about 300 mm and 210 mm on 7 and 3 consecutive days. The landslide caused five fatalities and left several thousand people under the open sky. During the intense monsoon (June–August), it is pervasive to face landslide hazards in the Chittagong hill districts. Nevertheless, anthropogenic modification of the slopes and intense rainfall triggered the landslide in the camp area. The fatalities were also high due to the dense population and temporary shelters built on dangerous slopes without proper protective measures.

It is highly recommended to develop a scientifically valid and end-to-end landslide early warning system (LEWS) for the Kutupalong Rohingya camps and surrounding host communities in Cox's Bazar (Ahmed 2022). Furthermore, the local government authorities, NGOs, and international organizations should also find common ground to implement the LEWS to reduce further damage and losses. In fact, the camps in Cox's Bazar are unsuitable for accommodating over a million Rohingya refugees considering the region's geomorphological, socioeconomic, historical, climatic, and environmental conditions. Therefore, the ultimate solution lies in the successful and sustainable repatriation of the Rohingya population in their home country of Myanmar.

Fig. 8 **a** Mud and garbage deposited on the slope base, **b** and **c** emergency rescue operations by the local people and volunteers, and **d** cleaning of the site and road by an excavator. *Source* The authors, fieldwork, August 2021

Appendix 1

See Fig. 9.

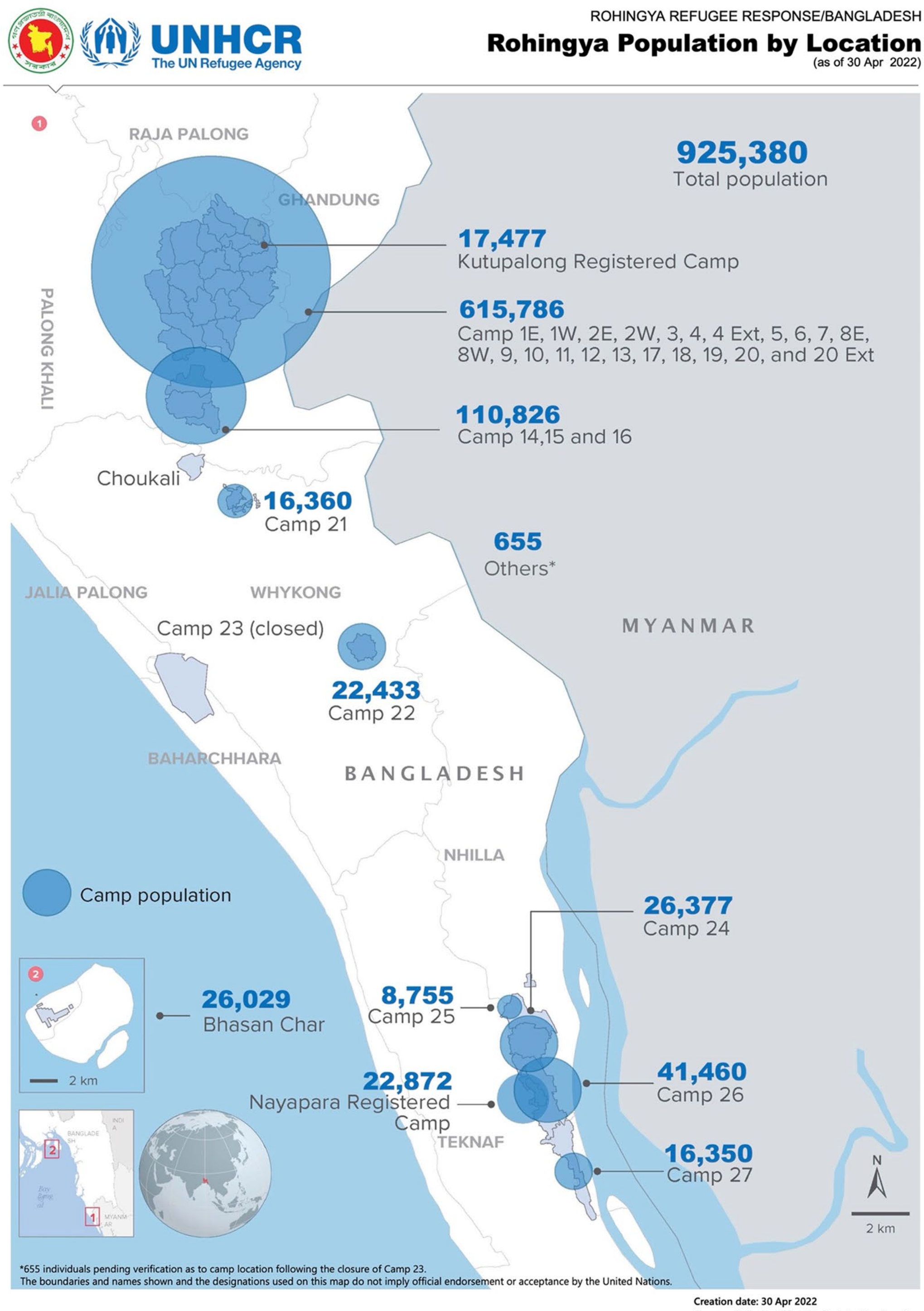

Fig. 9 Joint Government of Bangladesh and UNHCR Rohingya Population map in Bangladesh as of 30 April 2022. *Source* UNHCR 2022

Appendix 2

See Table 1

Table 1 Details of the landslides mapped during the fieldwork in the Kutupalong Rohingya Camp. *Source* The authors, fieldwork, August, 2021

LS. No	Latitude	Longitude	Length (L)	Width (W)	Depth (D)	Area (A)	Volume (V)	Slope (°)	Slope dir	Mov. Dir	Elevation (m)	Material	Movement Type	Type	Risk	Geol. Unit	Soil depth (m)
1*	21.186707	92.154221	33.81	31.8	4	612	2448	40	100	110	13	Earth	Flow	Shallow	H	QTg	1.4
2	21.186942	92.156108	13.90	20.6	2.5	175	437.5	44	106	106	16	Earth	Topple	Shallow	H	Tt	1.8
3	21.186874	92.155319	16.81	24.6	4	259	1036	36	180	180	9	Earth	Flow	Shallow	H	QTg	1.5
4	21.186923	92.153793	30.14	45.8	3	726	2178	42	5	15	17	Earth	Flow	Shallow	H	QTg	1.7
5	21.187047	92.153084	19.17	23.8	2.8	328	918.4	30	50	32	20	Earth	Fall	Shallow	H	QTg	0.8
6	21.186629	92.153231	29.26	14.7	3.5	262	917	26	298	298	17	Earth	Flow	Shallow	H	QTg	2.25
7	21.190961	92.153133	27.36	25.4	5	411	2055	32	90	110	25	Earth	Flow	Deep	H	QTg	1.5
8	21.189821	92.152938	12.96	20.7	2	152	304	46	325	325	21	Debris	Fall	Shallow	H	QTg	0.8
9	21.189148	92.153893	59.18	29.5	4.5	935	4207.5	48	120	135	31	Earth	Flow	Shallow	H	QTg	1
10	21.198213	92.147075	16.39	16.8	2.2	189	415.8	32	117	117	30	Earth	Fall	Shallow	H	QTdt	1.6
11	21.199426	92.147053	19.65	15.3	3	190	570	35	125	132	22	Earth	Rotational Slide	Shallow	H	QTdt	1
12	21.213467	92.141391	26.90	44	2.5	640	1600	48	210	225	22	Earth	Fall	Shallow	L	QTdt	0.8
13	21.200169	92.138221	15.80	20.7	3	219	657	32	285	285	23	Earth	Flow	Shallow	M	QTdt	0.4
14	21.188926	92.138973	25.83	37.7	2	527	1054	50	342	342	24	Earth	Rotational Slide	Shallow	L	QTdt	0.5
15	21.201671	92.151219	15.01	13	2.5	131	327.5	44	284	284	14	Earth	Rotational Slide	Shallow	H	QTg	1.8
16	21.201037	92.149365	16.18	7.4	1.5	90	135	22	180	225	20	Earth	Flow	Shallow	M	QTdt	1.5
17	21.192686	92.150485	18.31	32.4	2.8	452	1265.6	35	240	240	27	Earth	Rotational Slide	Shallow	M	QTg	0.8
18	21.191375	92.150775	19.37	22.3	2	249	498	45	170	170	24	Earth	Flow	Shallow	H	QTg	1
19	21.186761	92.151858	21.47	11.4	4	148	592	26	308	308	15	Earth	Flow	Shallow	H	QTg	1.2
20	21.186615	92.150722	30.28	15.3	3	273	819	35	95	110	23	Earth	Rotational Slide	Shallow	H	QTg	1.1
21	21.185376	92.151731	44.63	17.8	5	361	1805	55	50	50	21	Earth	Flow	Deep	H	QTg	1
22	21.183919	92.151714	10.50	12.8	1.5	88	132	42	255	255	21	Earth	Fall	Shallow	H	QTg	0.4
23	21.178632	92.155635	15.56	18	1	125	125	56	85	85	12	Earth	Flow	Shallow	M	Tt	1.7
24	21.177347	92.155348	22.71	21	4.5	329	1480.5	40	350	352	17	Earth	Flow	Shallow	H	Tt	1.5
25	21.181111	92.158067	31.00	23.4	3.2	311	995.2	60	100	100	19	Earth	Fall	Shallow	M	Tt	2
26	21.186215	92.163301	32.25	52.3	2.5	857	2142.5	55	155	155	9	Earth	Flow	Shallow	M	Tt	1.5

[*] Reported landslide (LS. No. = 1)

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Author contributions
Professor ASMMK was the in-country project lead (physical science) and was responsible for the overall fieldwork management inside the camps. He conducted fieldwork in Cox's Bazar and revised the manuscript. FH conducted the fieldwork, analysed data, produced the maps/figures, and wrote the first draft of the manuscript. BA managed the project, monitored the fieldwork in Cox's Bazar, and revised the manuscript. Professor Peter Sammonds was the Principal Investigator of the project; he reviewed and revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
Data is available on request.

Declarations

Competing interests
The authors declare that they have no known conflicts of interest that could have appeared to influence the work reported in this paper.

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