Geohazards in Greater London: the Ground Stability Layer of the EU FP7 PanGeo project

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Abstract

Validated geohazard layers depicting areas of observed and potential ground instability are being generated by the EU FP7 PanGeo project for 52 of the largest towns across all 27 countries of Europe. The first product generated by the BGS covers the administrative area of Greater London, and consists of a polygon-wise Ground Stability Layer and associated Geohazard Description document. The identification of geohazards was performed through combined interpretation of geological, landuse and other geospatial layers, together with satellite Persistent Scatterers (PS) ground motion data for 1992-2010. The PanGeo product identifies ~450 km^2 of observed and ~1,240 km^2 of potential geohazards over London. Potential for natural ground movements (shrink-swell clays, and compressible ground) is observed for the majority of the area. Geohazards observed through the PS data include both natural processes (compaction of the River Thames sediments) and anthropogenic instability due to water abstraction and recent engineering works (e.g., Jubilee Line Extension).

Keywords: *geohazards, ground instability, Persistent Scatterer Interferometry*

1. Introduction

Started in 2011, the EU FP7 PanGeo project is enabling free and open access to geohazard information in Europe in support of the Global Monitoring for Environment and Security (GMES) initiative (http://www.pangeoproject.eu). For 52 of the largest towns across all 27 countries of Europe, the project is now generating validated geohazard data layers depicting the areas of observed and potential ground instability. These will be made freely accessible and usable via a portal based on One Geology Europe infrastructure, to the general public, local authority planners and regulators, geological surveys, geoscience institutes and policy-makers involved in the assessment, mapping and management of geological risks (http://pangeo.brgm-rec.fr/pangeoportal).

The British Geological Survey is responsible for the generation of the PanGeo products for London and Stoke-On-Trent. For each town, the product consists of the polygon-wise Ground Stability Layer (GSL) showing location, extent and typology of the observed and potential geohazards, and the GeoHazard Description (GHD) document, a supporting report which describes in detail the geological setting and places of interest affected by each geohazard, the confidence and any additional evidence associated with the interpretation. Integration of the GSL with the GMES Land Theme's Urban Atlas (EEA 2010) shows the landcover/landuse classes influenced by such hazards and supports the end-users in the management of hazards and induced risks within the concerned areas.

The area covered by the GSL of London corresponds to Greater London, a ~1,580 km^2 area that includes the City of London and 32 other surrounding boroughs, with a total population of more than 8 million inhabitants in 2011 (~5,200 inhab/km^2). The topography of the study area is dominated by the drainage network formed by the River Thames and its tributaries. This network is associated with an alluvial tract which lies at about 10m OD in the west of the area, falling towards sea level to the east of the district. Gently sloping valley sides, rising to approximately 30m OD, are underlain by river terrace deposits. Interfluves in north-west of the area are formed of dissected London Clay with capping, in places, by the Bagshot Formation. Sparse outliers of glaciofluvial deposits are also present. In the north-east of the study area the ground rises to a dissected plateau of till at about 100m OD. South of the River Thames the land rises gently across the London Clay towards the southern extremity of the district where Chalk is present at surface. Deposits of the Lambeth Group and Thanet Sand Formation are present at surface between the areas of London Clay and Chalk (Table 1; Ellison *et al.* 2004).

Period	***Group***	***Formation***
Quaternary		Alluvium: silty clay, clayey silty, sand River terrace deposits: gravel, subordinate sand Till: variably silty and sandy clay Glaciofluvial deposits: clayey sand, gravel Marine deposits: clay, silt, sand
Palaeogene	Bracklesham	Bagshot Formation: sand, fine-grained with thin clay beds
	Thames	London Clay Formation: clay, silty
		Harwich Formation: sand, clayey fine-grained sand and pebble beds
	Lambeth	Clay, mottled with fine-grained sand, laminated clay, flint pebble beds and shelly clay
		Thanet Sand Formation
Cretaceous	Chalk	Chalk, white to grey

Table 1: *Simplified stratigraphical table of Greater London (modified after Ellison et al. 2004).*

2. Methodology and input data

The identification of the observed and potential geohazards mapped in the GSL was performed through the combined interpretation and integration of geological data, terrain motion estimates, land use information and other geospatial layers available at the BGS/NERC for the area of Greater London. Background input data used to map geohazards over Greater London include: (i) Topographic maps at 1:10,000 and 1:50,000 scale, and aerial photographs at 0.25m resolution; (ii) Bedrock geology, superficial deposits, mass movements and artificial ground from the Digital Geological Map of Great Britain at different scales; (iii) Depth of the bedrock surface from the Superficial Deposits Thickness Model of Great Britain at the 1:50,000 scale; (iv) Parent Material Model of Great Britain at the 1:50,000 scale; (v) National Landslide, Karst and Mining Databases of Great Britain; (vi) Ground water pumping records from recent surveys carried out by the Environment Agency; and (vii) Existing literature.

Terrain motion data estimated from the multi-temporal processing of satellite radar imagery with Persistent Scatterer Interferometry (PSI) were exploited to analyze the deformation history of the area in the last 20 years. These datasets consist of two clusters of radar scatterers derived by FugroNPA by means of the Interferometric Point Target Analysis (Werner *et al.* 2003) of one stack of 27 ERS1/2 ascending scenes acquired in 1992-2000, and another stack of 45 ENVISAT descending scenes acquired in 2002-2010, both characterized by 35 days nominal repeat cycles.

The methodological approach employed to map potential and observed geohazards is extensively described in the PanGeo Production Manual (Bateson *et al.* 2012), a freely downloadable document that was distributed to the Geological Surveys to support the generation of their GSLs in accordance with the PanGeo product Specification.

3. Results and discussion

The PanGeo GSL identifies more than 25 geohazard polygons over Greater London, six of which correspond to potential geohazards, and the remaining to areas of observed geohazards. All the GSL polygons are attributed using hazard categories and classifications compliant with the Natural Risk Zones data specification of INSPIRE, which are also used in the project portal to provide a summary of the geohazard identified within the area. A measure of the confidence in the interpretation is also attributed to each geohazard, by using a scale of low, medium and high (depending on the number of datasets used in the interpretation), or external for those geohazards mapped from an external source (e.g. landslide inventory).

Areas with the potential for geohazards include more than 1,240 km^2, which correspond to ~78% of the entire administrative area of Greater London (Figure 1). The potential for natural ground movements is observed for the majority of the area, i.e. ~1,133 km^2. Within this area, about 868 km^2 have the potential for shrink-swell of clays and include portions of the alluvium, marine and residual deposits, till and silt members, as well as the London Clay formation and the Lambeth Group at the surface. About 266 km^2 are identified as areas with potential for compressible ground, and include the alluvium and marine deposits. Potential for natural ground instability is observed over about 566 km^2. Within this area, 190 km^2 have the potential for ground dissolution and therefore opening of cavities potentially leading to collapses. This includes those areas where the alluvium, residual and river terrace deposits are overlapped onto the White Chalk Subgroup, as well as the former when it is found at the surface. Areas with the potential for collapsible ground cover approximately 139 km^2, and correspond to the Ilford, Enfield and Langley Silt members, while the potential for sand liquefaction is identified over an area of 237 km^2, and includes portions of the alluvium as well as the Bracklesham and Barton Groups, Harwich and Thanet Sand formations at the surface. About 164 km^2 of made ground are also mapped over the area, and include sectors of infilled, worked and made ground, mainly concentrated in the western sector of Greater London, in the Hillingdon and Hounslow Boroughs, and in the north-eastern sector, in the Waltham Forest, Newham, Redbridge, Barking and Dagenham, Havering, Bexley and Greenwich Boroughs.

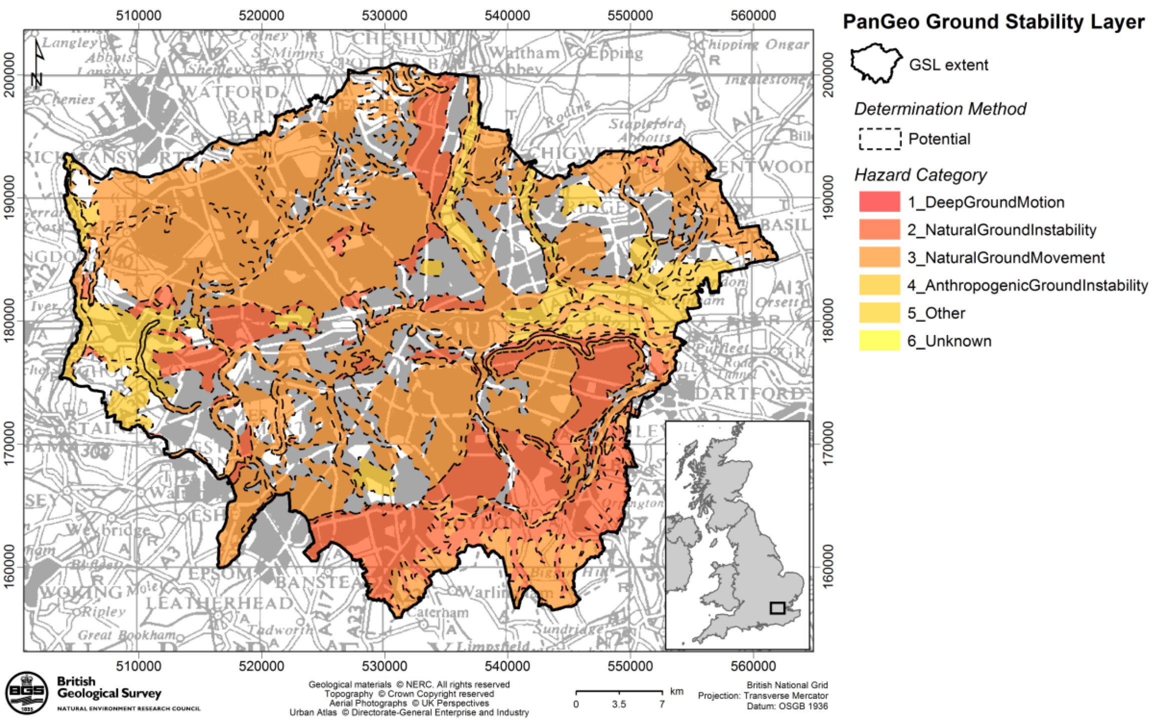

Figure 1: *Potential geohazards mapped in the PanGeo GSL of Greater London classified by PanGeo Hazard Category.*

Although the ground motion data from the ERS1/2 and ENVISAT PSI datasets show that the entire city is generally stable in the period 1992-2010, significant motions away from the satellite are observed for some sectors of the city located along the River Thames valley, and in the Fulham, Battersea, Clapham areas, especially in 2002-2010.

Geohazards observed by means of the PSI data cover a total of ~450 km^2, and include areas affected by natural processes such as compaction of deposits on the River Thames flood plain, as well as anthropogenic ground instability due to groundwater abstraction and recent engineering works. In particular, the latter involves the Westminster, Lambeth, Southwark and Wandsworth Boroughs, where significant terrain motions were observed as a result of the underground works for the construction of the Jubilee Line Extension and an electricity utility tunnel south of the Battersea Park and underneath the A3205 road, between Nine Elms and Wandsworth. The instability caused by the Jubilee Line Extension works includes a narrow 6 km-long branch running between the Green Park and Bermondsey stations, opened at the end of 1999 (Page 1995). For this area, maximum PS velocities estimated along the satellite LOS are approximately -15.9 mm/yr in 1992-2000, amounting to a maximum total displacement of 13 cm over a period of 8 years. Although average velocities decrease to less than -4.1 mm/yr in 2002-2010, motions due to the underground works are still identifiable from the ENVISAT monitoring data and are discernible from the natural compaction of the alluvium affecting a wider sector of the city (Figure 2).

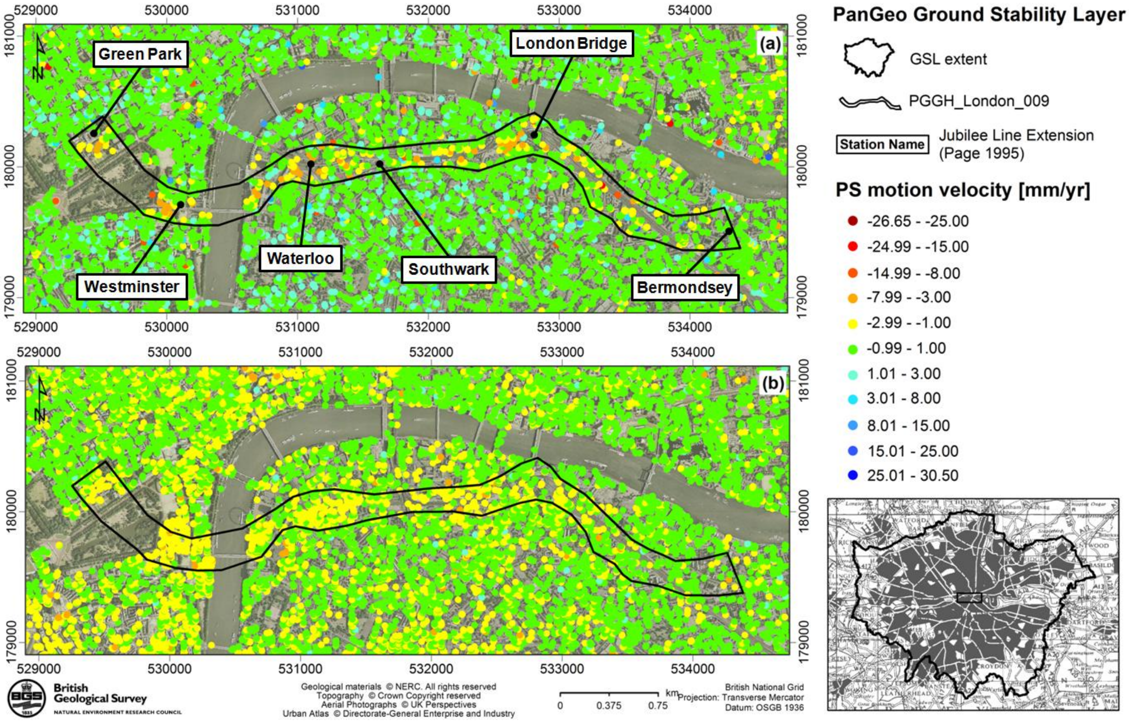

Figure 2: (a) *ERS1/2 (1992-2000) and (b) ENVISAT (2002-2010) PSI data for the observed anthropogenic geohazard due to the Jubilee Line Extension engineering works (1993-1999).*

4. Conclusions

Combined interpretation and integration of geological, landuse and other geospatial layers with ground motion estimates derived from Persistent Scatterers data in 1992-2010 allowed the identification and mapping of observed and potential geohazards over Greater London. This information is synthesized and made available to the public through the PanGeo Ground Stability Layer and Geohazard Description document, and will act as a support for local authorities, planners, regulators and decision makers in their long- and short-term landuse planning and risk management activities.

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