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Mapping climate change, natural hazards and Tokyo's built heritage

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Abstract: Although climate change is well recognised as an important issue in Japan, there has been little interest from scientists or the public on the potential threat it poses to heritage. The present study maps the impact of emerging pressures on museums, temples and shrines in the Tokyo Area. We examine a context to the threat in terms of fluctuating levels of visitors as a response to environmental issues from SARS and COVID-19, through to earthquakes. GIS mapping allows a range of natural and anthropogenic hazards to be expressed as the spatial spread of risk. Temperature is increasing and Tokyo has a heat island which makes the city hotter than its surroundings. This adds to the effects of climate change. Temperature increases and a decline in relative humidity alter the potential for mould growth and change insect life cycles. The region is vulnerable to sea level rise, but also flooding is a likely outcome of increasingly intense falls of rain, especially during typhoons. Reclamation has raised the risk of liquefaction during earthquakes that are relatively frequent in Japan. Earthquakes cause structural damage and fires after the rupture of gas pipelines and collapse of pylons. Fires from lightning strikes might also increase in a future Tokyo. These are especially relevant as so much Japanese heritage uses wood. In parallel, the more natural landscapes of the region are affected by a changing climate. The shifting seasons already mean earlier arrival of the cherry blossom and a later arrival of autumn colours and a lack of winter snow. The mapping exercise should highlight the spatial distribution of risk and the way it is likely to change, so can contribute to longer term heritage management plans.

Keywords: earthquakes; fire; floods; historic sites; landslides; museums, insects; sea level rise; typhoons; visitors

1. Introduction

Our heritage is under threat. The need to protect Japanese tangible heritage from disasters has been addressed by government funding increases: 2905 million yen in 2019 to 3907 million yen in 2020. While natural hazards are well recognised issues in Japan and climate science is strong, there has been relatively little interest there from scientists or the public on the potential threat a changing

climate poses on heritage, especially in the way they alter the frequency of meteorologically driven hazards. The present study maps the impact of external pressures on museums, temples and shrines in the Tokyo Area. This is the most populous metropolitan area in the world, which includes some of the Kantō region of Japan, as well as the prefecture of Yamanashi. Tokyo is located almost in the center of the Japanese archipelago at the junction of northeastern and southwestern Japan. Positioned in the southern part of Kantō, it is surrounded by Saitama Prefecture to the north, Tokyo Bay and Kanagawa Prefecture to the south, Chiba Prefecture to the east, and Yamanashi Prefecture to the west. The Tokyo region is elongated from east to west, stretching from mountains which stand in the west to Tokyo Bay to islands scattered over the Pacific Ocean; although in this study islands are excluded, yet it still covers an area of some 1,790 square kilometers. The *Japan Meteorological Agency* (JMA) places Tokyo in the EJP climate zone (Pacific side of eastern Japan), with hot and humid summers and cold winters. Tokyo is protected from the winter monsoon, so the winter is the driest season, thus the season is sunny and fairly mild, but the city experiences hot, humid and rainy summers.

The topography gradually decreases in elevation from the western mountains to the alluvial lowlands, ending at Tokyo Bay (Fig. 1). The terrain can be regarded as defined by the Tama River catchment, and the geographical characteristics are completely different between east and west, with the boundary near Ome City, the estuary settlement in the Kantō Mountains. There is accurate 5-m-mesh data as a quantitative representation of terrain within the Digital Elevation Model (DEM) provided by the Geospatial Information Authority of Japan (GSI 2020).

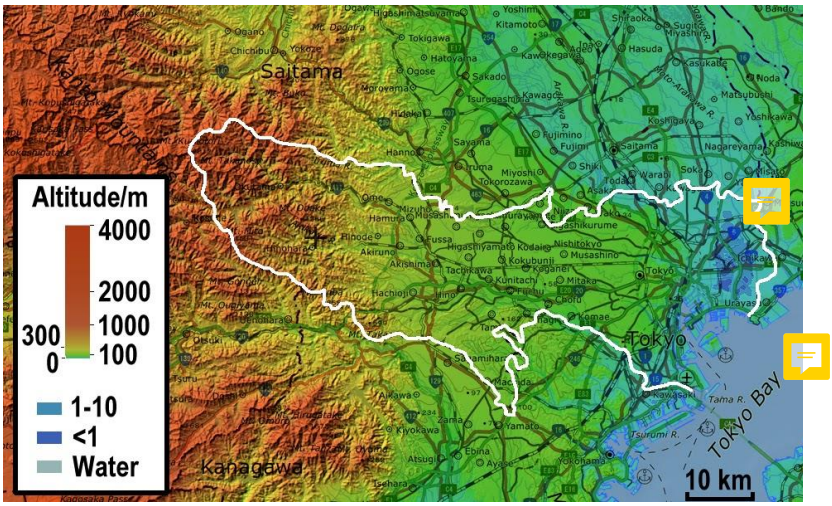

Figure 1. Topography of the Tokyo region discussed in this paper, with a white line denoting the boundary of the Tokyo Area. Note: North is at the top.

Tokyo, as a major city with a lengthy history, has a great wealth of heritage. There are numerous shrines, temples and great buildings, perhaps some favourites being: (i) Meiji Shrine, (ii) Houses of Parliament, (iii) Tokyo Station, (iv) Edo castle, (v) Hamarikyu Garden, (vi) Sensoji Temple, (vii) Tokyo Tower, (viii) Shinjuku Gyoen National Garden, (ix) National Theater and (x) Tokyo Sky Tree. Add to this many historic secular buildings and districts popular with tourists, which include Chidori-ga-fuchi moat along the northwest side of the Imperial Palace and the Kabukiza Theater. Historical sites are marked as 26 points in pink (Fig. 2a). Tokyo has hundreds of museums and galleries some of the favorites being: (i) Tokyo National Museum, (ii) Edo-Tokyo Museum, (iii) Ghibli Museum, (iv) Nezu Museum, (v) Hara Museum of Contemporary Art, (vi) Mori Art Museum, (vii) Tokyo Metropolitan Art Museum, (viii) National Museum of Western Art and (ix) the National Museum of Emerging Science and Innovation. Museums are marked as 232 points in green (Fig. 2b). Maps of heritage and the risk imposed by climate change are often seen as important tools for the strategic management of

heritage (e.g. Sabbioni et al, 2010; Bonazza et al., 20[illegible] with some at a national or regional level (Accardo et al., 2003; De la Fuente et al., 2013; Wang 2015; Wu et al 2[illegible]). Difficulties in such mapping involve the problem of scaling because data is typically collected at national or regional levels rathe than at city scale. It is also problematic to tune the data, often collected for other purposes to heritage. e.g. seismic risk is defined for buildings in general, not heritage, or that meteorological information is collected for many purposes, so the risks imposed on heritage requires considering the notion of heritage climate (Brimblecombe, 2010 ; Sabb[illegible]i et al., 2010)

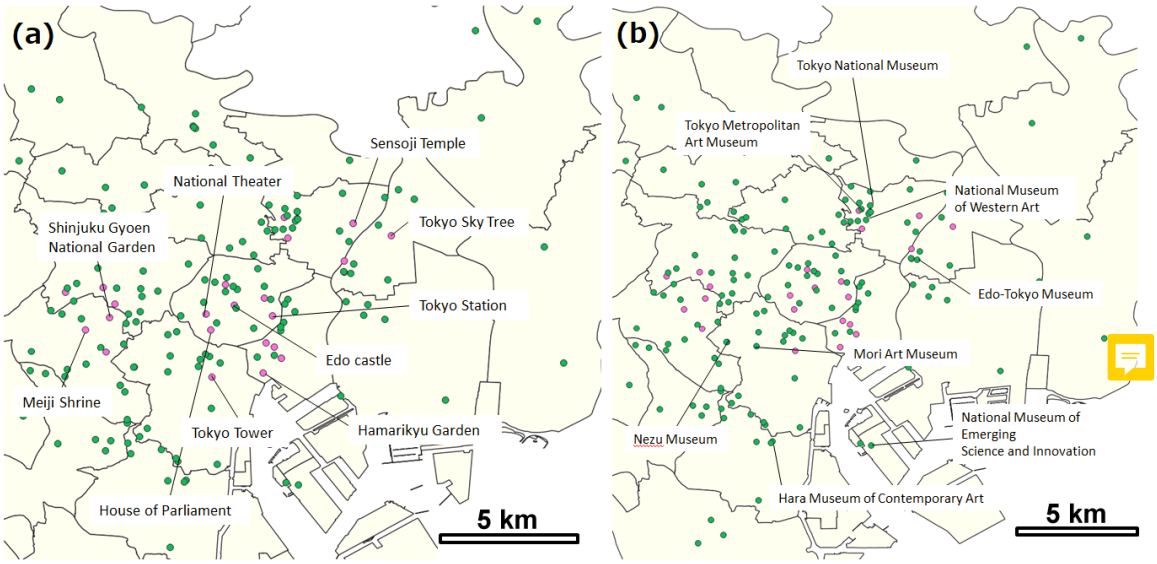

Figure 2. Location of (b) major historic sites (pink) and (b) museums (green) in central Tokyo. Note: North is at the top. Source: (https://nlftp.mlit.go.jp/ksj/index.html)

Special threats to the region are flooding and the increased pressures that climate change may present in terms of both river and sea floods (Yanai et al., 2019; Yasuhara et al., 2011) and the failure of sea defenses (Hoshino et al., 2013). As Tokyo is a coastal city, sea level rise makes low lying areas additionally vulnerable to increased flooding with Estaban et al., (2015) arguing that "The combined effect of an increase in typhoon intensity and sea level rise could pose significant challenges to coastal defences around Tokyo Bay…. around the turn of the twenty-first century." There are also risks from earthquakes, which are regularly mapped in the city as this affects a range of issues in addition to the threat to built heritage, e.g. real estate prices (Nakagawa et al., 2009). The Bureau of City Planning, Tokyo Metropolitan Government (Bureau of Urban Development, 2017) maps earthquake threat in their regional risk measurement survey on earthquakes, but it is also the subject of damage forecasts (Katayama et al., 2000). Although air pollution and acid rain represent threats, they are not treated in this paper. Tokyo has worked hard to improve its air quality (de Oliveira, 2011) and the study of acid rain has a long history in Japan (Ishikawa and Hara, 1997), so despite concerns about the high level of threat especially from Chinaese emissions (Nagase and Silva, 2007) these have been much reduced in the current decade (Cheng et al., 2018).

2. Materials and Methods

This study uses data on climate and natural hazards relevant to looking at long term pressures on built heritage in the Tokyo area. In addition to a range of research articles we make use of government and municipal reports to assess the magnitude of the threat from a changing environment. A range of climate projections available from the Japanese Meteorological Agency

(2018) are especially useful in estimating likely future change. Geographical information software (GIS) allows the threat to be mapped.

We have used the software QGIS, originally *Quantum GIS*, which allows users to analyze and edit spatial information in multiple raster formats and as vector data; which can be stored as either point, line, or polygon features. We particularly adopted 3.6 Noosa developed by the QGIS community. The software provides viewing, editing and analysis capability to overlap a range of natural hazards in the area and their changes over time. Vector data of points and areas, such as the location of built heritage (historical sources and museums), maps of Tokyo, the area of inundation by flooding and area of potential sediment disasters, were obtained from the National Land Numerical Information Download Service (MLIT 2020). Areas of inundation are calculated for each river under designated storm impacts. Where vector data of point and area data was not available, we have resorted to simple counts from manually overlapped data.

3. Results

Pressures on our heritage are much discussed and the impact of external local and global events is clear from Fig. 3, where the numbers of foreign visitors to Japan are plotted. Pressures from epidemics, financial collapse and geophysical events cause fluctuating visitor numbers. The most recent crisis COVID-19 has had a special impact in the heritage sector where it has greatly affected visitor numbers and the attendant loss of income, though in some cases the most fragile sites experience a welcome respite from heavy flows, allowing natural sites to recover a little (Historic England, 2020). There will also be problems with subsequent cleaning the viral contamination from properties and interior surfaces.

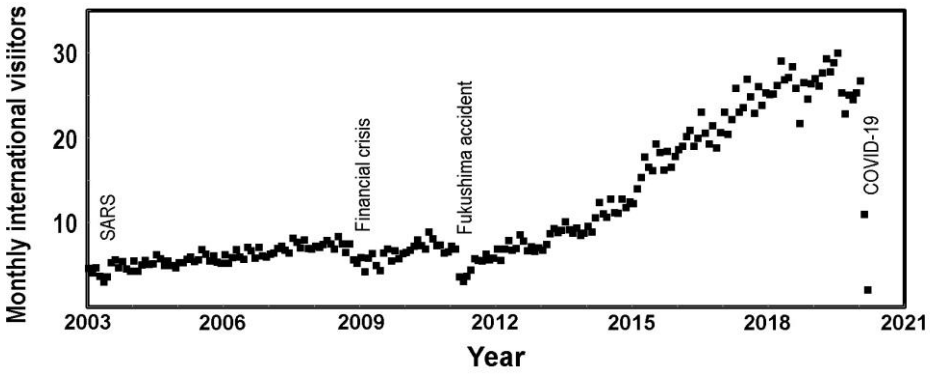

Figure 3. International visitors to Japan from Japan National Tourism Organization.

3.1. Temperature and urban heat island

Temperature is the best understood parameter under a changing climate; likely to be affected through the addition of radiatively active gases to the atmosphere. Globally, the temperature is likely to increase by about 0.8 °C through the 20th century. The Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* suggests that surface temperature will rise a further 0.3 to 1.7 °C during the current century. In Japan from 1931 to 2017, the average temperature in Tokyo increased at a rate of 3.2 °C/century (JMA, 2018). Projecting the regional climate of Eastern Japan over the periods 1980–1999 and 2076–2095 suggests that the annual mean temperature will increase by more than 3 °C.

In recent years, high temperatures in summer have become remarkable in large cities such as Tokyo, and the public interest has been engaged by the added contribution the urban heat island makes to the increase in the number of heat stroke patients. Annual mean temperature in central Tokyo has increased about 3.2 °C/century, which is 4.4 times faster

than global mean temperature (0.73 ℃/century) and 2.1 times faster than Japanese mean temperature of 1.21 ℃/century (JMA, 2019). Part of these increases are due to the development of the urban heat island. The current trends for this effect from Lee et al (2020) suggest that the summer heat island in Tokyo is increasing at 0.85 °C/century, while Manila, Seoul and Mumbai were slower at 0.15, 0.2 and 0.36 °C/century respectively, The heat island clearly adds a substantial amount to the effect of greenhouse warming. The speed of temperature change in Tokyo has drawn popular comment (e.g. RealEstateJapan, 2020) and the urban heat island is generally seen to arise from the decrease of green and water areas, the increase of ground covered with asphalt and concrete, the increase in heat (exhaust heat) generated from cars and buildings and the poor ventilation by wind in the street canyons (Ministry of the Environment in Japan, 2012). Rising temperatures in summer have been a particular problem, because the heat island has helped reduced the comfort of urban life and affected human health. Urban influences are recognized, not only in the production of the heat island, but in other climate effects such as: urban rainfall, wind circulation, number of fog days, relative humidity etc (Mikami, 2006; Matsumoto, 2017). These have impact not only human health, but also materials and the management of built heritage. Although Tokyo has a strong heat island, but there are potentials to mitigate this through urban greening of buildings or increasing the area of open water in central Tokyo (Ichinose et al., 1999; Mochida et al., 1997).

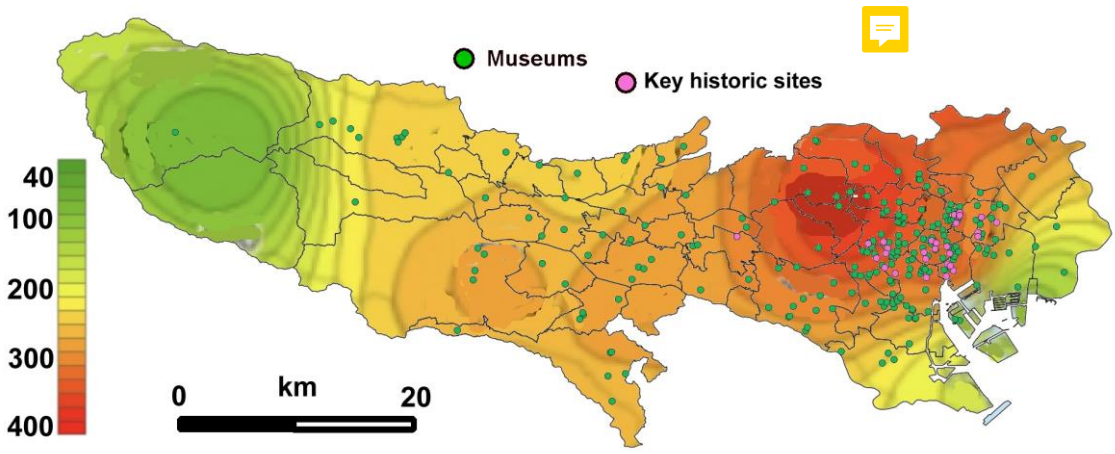

Figure 4. The total number of hours with temperatures above 30 ° C averaged 2003-2007. Note: Base map extracted from RealEstateJapan (2020) and JMA. North is at the top.

Temperature increases and a decline in relative humidity alter the potential for mo growth and change insect life cycles. The total number of hours with above 30 °C are shown in Fig. 4. This will affect comfort within naturally ventilated buildings and put more pressure on the cooling systems aimed at controlling the museum environment. It can also affect mould growth, when accompanied by humid conditions and will favour insect infestations. In Japan, the overwintering survivals of insects has increased along with earlier appearances in the spring, an increase in the number of generations each year, lengthening of the reproductive season etc. However, insects can also be susceptible to heat stress when

temperatures increase to high values ~28 and 32 °C (Kiritani, 2013). The northward movement of insects through the Japanese archipelago has been widely described. The distribution range of many insects have increased: dragonflies (Doi, 2008) and the Great Mormon butterfly, *Papilio memnon* (Yoshio & Ishii, 1998). The southern green stink bug, *Nezara viridula* has moved away from the coasts to warmer regions (Tougou et al., 2009). Looking at parallels in other cities, such as London, it is possible to see a notable increase in insects such as the webbing clothes moth, *Tineola bisselliella* (Pinniger, 2011), which may be partly due to climate change, but also related to food availability, habitat and urban activities (Brimblecombe and Brimblecombe, 2015). The changes in insect populations can be modeled as a function of future climate (Brimblecombe, 2018; Brimblecombe and Lankester, 2013). Such changes create a characteristic problem for Japan, as wood, as a material, is especially important to its heritage. The extensive use of wood makes the heritage particularly vulnerable to insect infestation (Brimblecombe and Hayashi, 2018). In Tokyo, the urban heat island may cause an increase in insect numbers and variety. Additionally there is often greater availability of food in cities, and insects can be transported on objects or display materials. Stag beetles are popular as pets in Japan notably *Dorcus* spp. is an invasive insect from East and Southeast Asia, which can be released or escape (NIES, >2010).

3.2. Storms, typhoons and floods

Historic floods in Tokyo are well described, for example in the great floods of 1742 the Zen monk Enjū was engaged in a pilgrimage and trapped by the intense rain, so left an account of damage to religious buildings (Marceau, 2019). This historic event led the Sumida River to flood, eroding the piles of the Ryōgoku Bridge, as well as damaging Eitai and Shin'ō Bridges (Fig. 5a), while overflowing levees caused extensive flooding in the Kasai district (Fiévé and Waley, 2013). The Heavy Rain Event during July 2018 (Tsuguti et al., 2019), although not affecting Tokyo so strongly, caused tremendous damage elsewhere. There were 221 fatalities, 6296 buildings were completely destroyed and 8929 houses were inundated above the floor level and two key buildings (*National Treasures*), 35 important heritage buildingsn along with 24 registered heritage structures were affected (MECSST, 2018).

Changes in rainfall patterns over Japan mean that rainfall is likely to increase more than 10% over the 21st century (Kimoto et al., 2005). Over the period 1976-2012 the number of hours of heavy rain (>50 mm) have increased across all regions of Japan, which is likely to continue into the future (JMA, 2012: Climate Change Monitoring Report 2011). However, the picture for Tokyo is not particularly clear, although it has been noted some decades ago that the urban heat island enhances convective storm activity over the city (Yonetani, 1982). There was a period with many hours of heavy precipitation during the 1940s, though the 1990s seem to lie within the range of variation for the 20th century (Kanae et al, 2004). Nevertheless, the general view remains that there will be an increase in falls of heavy rain over the coming century (Brimblecombe & Hayashi, 2018). In addition, there has been considerable public concern over increased frequency of stormwater flooding and its impact on residential housing (JPC, 2018). Oddly, despite increases in total precipitation amount, the number of dry days with daily precipitation less than 1mm is expected to increase in almost every region of Japan. In Tokyo a declining water table or soil moisture has the potential to expose sensitive buried archeology or weaken the foundations of buildings.

The GIS mapping shows the potential risk to historic sites and museums. It reveals a high flood risk along the river and the presence of a large area of eastern Tokyo where land has elevations below mean tide level (Figs 5b and 5c). Historical sites such as the Sensōji Temple complex and many museums will be flooded during infrequent, though large storms and in future vulnerability will probably increase more than previously thought under a changing climate. Figures 5b and 5c show the extent of the inundation risk to museums and key historic sites. The risk is calculated adopting the conditions listed in Table 1 for each important river in the catchment. The eastern part of Tokyo can be seriously affected with about 15% of museums at risk from high water. Some 13 museums are likely to be affected when water levels rise 2.0-5.0 m (Table 2). It is thus important to take measures to protect against flooding, especially that storage locations are required to be on upper floors, with water- and fire-proof doors. The collections in art museums are especially sensitive to damper environments. There are four art museums under threat from inundation, but three occupy galleries present on the 4th floor or above, so risk is much reduced. The Museum of Contemporary Art Tokyo and the Tokyo Metropolitan Archives are sensitive to flooding. There are six sites in Tokyo at risk of inundation, so mitigation measures are especially relevant. Longer periods of inundation can cause more damage to museums and sites through a range of secondary hazards, such as mould growth and insect attack. Saraswat et al., (2016) present an overview of stormwater runoff management in Tokyo to guide optimal measures and management policies within the city's governance. An increase in future sea level (Fig. 5d) also makes Tokyo vulnerable and may cause sea defences in Tokyo Bay to fail by the end of the 21st century, with increased typhoon intensity adding further threat (Hoshino et al., 2013).

Table 2. Elevation of museums and sites in flood risk areas.

Elevation/m	Museums	Sites
0-0.5	4	2
0.5-1.0	10	1
1.0-2.0	8	2
2.0-5.0	13	1
>5.0	0	0

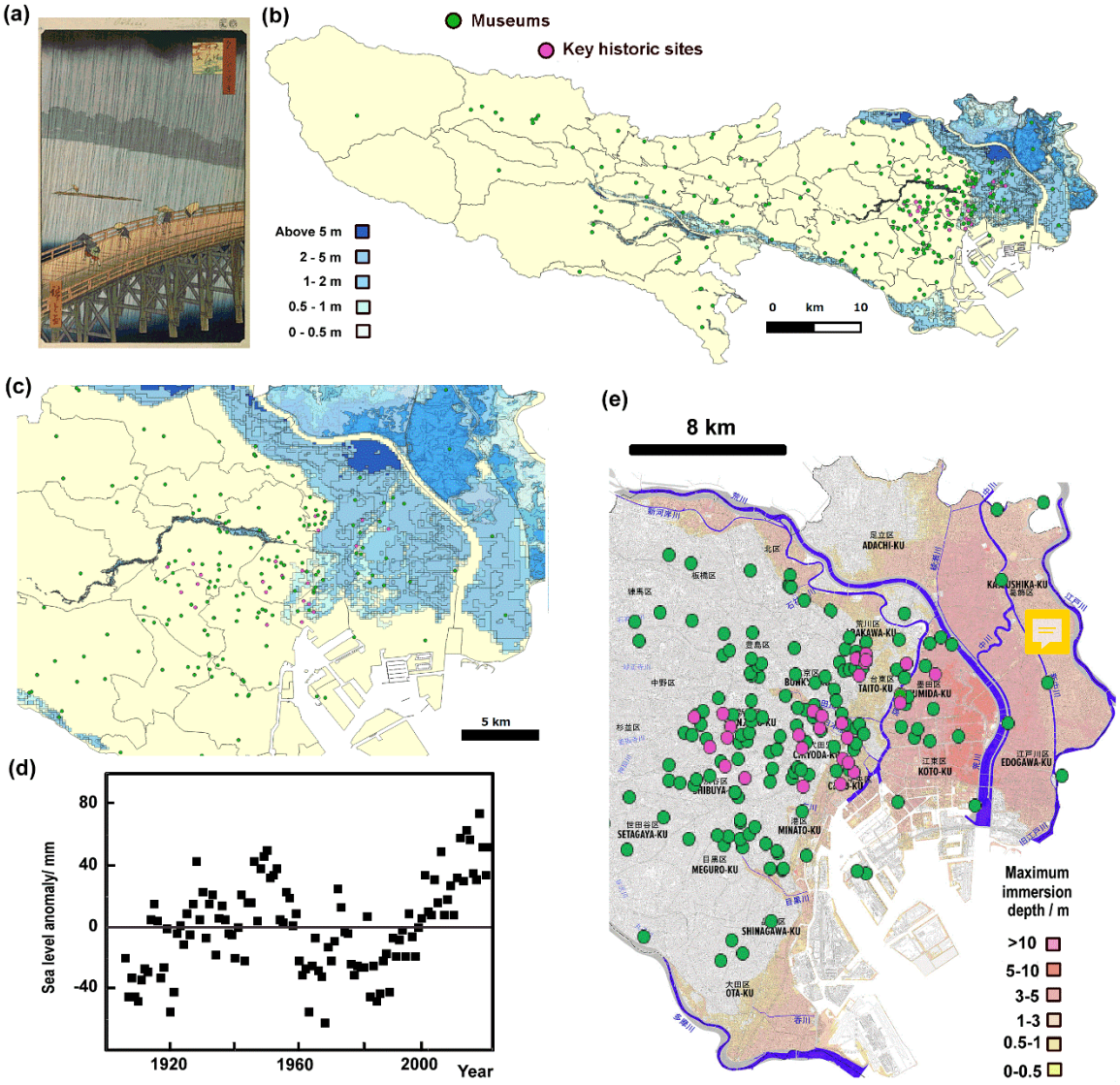

Figure 5. (a) *Sudden Shower Over Shin-Ohashi Bridge and Atake* by Hiroshige (b) Area of inundation under flood conditions of Table 1. Source: (https://nlftp.mlit.go.jp/ksj/index.html) (c) Enlargement of the central area of the inundation. (d) Annual mean sea level anomalies for Japan; source: Japan Meteorological Agency). (e) Immersion depth for the central parts of Tokyo; sources: JPC 2018, The Nikkei Shimbun, March 30, 2018, TBS News, March 30, 2018. Note: North is at the top of the two maps.

Table 1. Designed storms in each river. Note full details in MLIT 2020.

Target river	Designed storm	Rainfall	Cities affected
Shiba River, New Shiba River	Accounts for current development of river and drainage channels, regulating ponds etc. Rise of Shiba Rivers after heavy rain that occurs every 100 years. Inundation from overflow and collapse of levees.	September 1958 flood, *Kano River typhoon*: 2 days rain 411 mm	Adachi, Katsushika
Kanda River	Inundation potential from the Kanda River due to the Tokai heavy rain accounting for channel maintenance. Depth from both river water and inside the levee.	September 2000 *Tokai heavy rainfall:* rain 589 mm, hourly maximum 114 mm	Chiyoda, Chuo, Shinjuku, Bunkyo, Taito, Shibuya, Nakano, Suginami, Toshima, Musashino, Mitaka
Tone River	Account for current state of river channel and flood control. Simulates expectation from heavy rain once in 200 years.	Tone River basin and upper Yattajima: 3 days rain 318 mm	Adachi, Katsushika, Edogawa
Edogawa River	Simulates Edo River overflow due to heavy rain that occurs about once every 200 years.	Upper Yattajima: 3 days rain 318 mm	Adachi, Katsushika, Edogawa
Arakawa River	Accounts for current state of Arakawa River river channel and flood control. Simulates Arakawa River overflows due to heavy rain every 200 years.	Arakawa basin; 3 days rain 548 mm	Chiyoda, Chuo, Minato, Taito, Sumida, Koto, Kita, Arakawa, Itabashi, Adachi, Katsushika, Edogawa
Nakagawa River, Ayase River	Accounts for current state of channel and flood control. Simulates Nakagawa and Ayase River overflows due to 100-year heavy rain, but only inundation from Edo River.	Nakagawa and Ayase basins: 48 hours rain 355 mm	Adachi, Katsushika
Tama River, Oogurigawa River	Accounts for current state of channel and flood control. Simulates Tama River overflow due to a 200-year heavy rain.	Tama River basin and the upstream area of Ishihara site: 2 days rain 457 mm	Ota, Setagaya, Hachioji, Tachikawa, Ome, Fuchu, Akishima, Chofu, Hino, Kunitachi, Fukuo, Komae, Tama, Inagi, Hamura, Akiruno
Asakawa River	Accounts for development of river channels. Simulates Asakawa River overflows due to a 200-year heavy rain.	Tama River basin and the upstream area of Ishihara site: 2 days rain 457 mm	Hachioji, Hino, Tama

Modelling suggests that the frequency of typhoon landfalls will decrease (Fig. 6a) and the mean value of the typhoon central atmospheric pressure will not change significantly. An important point is that the arrival probability of stronger typhoons will increase (bottom right Fig. 6b) under future climate scenarios (Yasuda et al., 2010). This means that flooding is a likely outcome of such increasingly intense falls of rain. Wind speeds in Tokyo in the future (2075–2099) are compared with those of the recent past (1979–2003) in Fig. 6b suggesting that the probabilities of the occurrence of higher annual maximum wind speeds will increase (i.e. exceeding 30 m s^{-1}), while medians of the annual maximum wind speeds decrease (Nishijima et al., 2012). Figure 6c shows the relative typhoon wind risk in Japan, as the number of buildings likely to be damaged each year, under the current and projected future climates. The decrease in frequency is associated with a decline in relevant typhoon events in Japan and although there is an increase in typhoon intensity, it is not enough to compensate for this decrease (Nishijima et al., 2012). Dangers of wind damage in typhoons across East Asia have recently been examined along with factors that affect the intensity of damage and its extent, along with the potential to mitigate future impact (Yang et al., 2018).

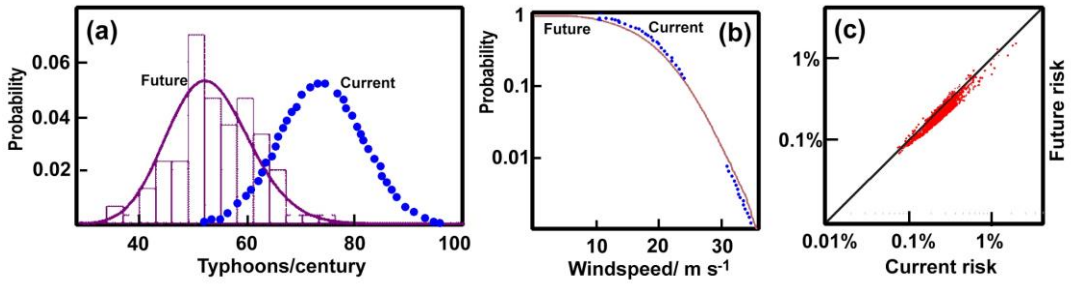

Figure 6. (a) Probable number of typhoons in Tokyo in 100 years from the stochastic typhoon model. Dotted and solid lines indicate present and future projections respectively see also Hoshino et al. (2013). (b) Exceedance probabilities for annual maximum wind speeds in Tokyo under current and projected climate (c) Percentage wing risk for residential buildings in Japan under current and future scenarios (Nishijima et al., 2012).

3.3. Earthquakes and fires

Japan is frequently affected by devastating earthquakes, because of the active seismicity caused by the subduction of the Philippine Sea Plate beneath the continental Amurian Plate and Okinawa Plate. There was a major earthquake in Tokyo in 1703 (Genroku earthquake) and 1894 (Furumura & Takeuchi, 2007), but it is the Great Kantō earthquake of 1923 that has been especially influential. (Fig. 7a). It was so powerful that the 100 ton Great Buddha statue at Kamakura moved almost 60 cm. In the metropolis, the earthquakes often led to fires as it struck at lunchtime, when many people were cooking meals. Today fires are more often caused by the rupture of gas pipelines and collapse of electricity pylons. Extensive coastal reclamation has raised the risk of soil liquefaction during earthquakes so frequent in Japan. Additionally, soil moisture and the water table are likely to change affecting the supporting structures to older buildings.

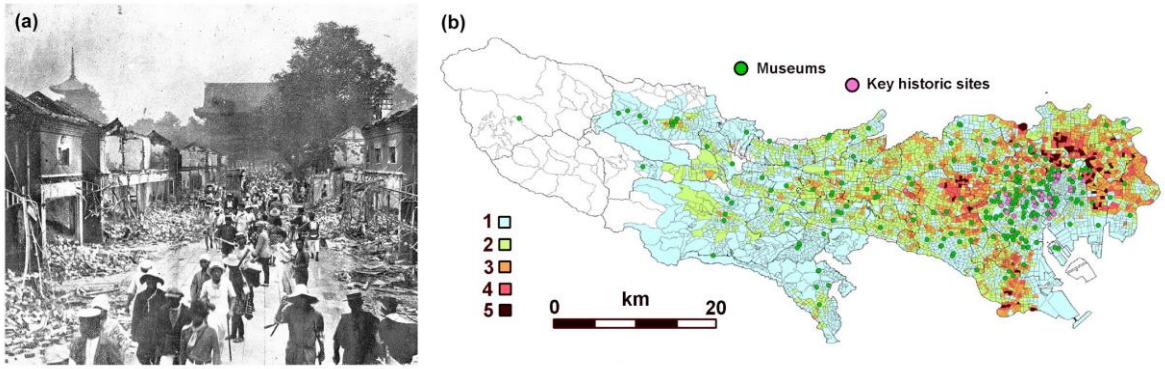

Figure 7. (a) Photograph of devastation in the area around Sensō-ji Temple, Asakusa after the Great Kantō earthquake of 1923, with smoke from fires in the background. (b) The map of combined earthquake risks for Tokyo. Note: North is at the top.

Figure 7b maps the potential risk to buildings from earthquakes. Although it is not tuned to heritage related structures, these sites are marked on the combined risk map of Tokyo. This combination brings together the risk of building collapse with the risk of fire. Older buildings tend to be found in the Shitamachi (downtown) area of Tokyo. Those along the Arakawa and Sumida rivers offer lower earthquake resistance as the structures typically have wooden or light-gauge steel frames. Machiya, Arakawa-ku is one of the worst affected areas in Tokyo, a district of densely packed wooden houses and narrow alleys, with little access for fire trucks. High risk areas are thus characterised by tightly packed buildings. Additionally, shaking can be amplified by ground characteristics, and valley and alluvial lowlands may lead to a higher risk. Fire risk is often enhanced in residential areas because of the wide use of open-flame appliances, and high density adds to the risk of fire spreading as these communities have fewer open spaces, such as parks and wide roads which might act as fire breaks. Overall, such conditions are typical of historic areas where there is likely to be a high concentration of close-set older wooden structures (as mapped for central Tokyo in Fig. 8a), with low resistance to fire (Disaster Management Section, 2018). Thus, the vulnerability of built heritage is not surprising, because it is most frequently associated with the older historic districts. Tokyo has been subjected to many fires. The most notable being *The Great Fire of Meireki*, which seems to have started when fire developed as a supposedly cursed kimono was burnt. The fire spread quickly through the city, because of strong winds from the northwest, which illustrates the role of climate conditions in large scale fires. The conflagration that followed the Great Kantō earthquake destroyed neighbourhoods and some very significant sites, such as the Metropolitan Police Department building (Fig. 8b). There were also enormous losses in fires from wartime bombing.

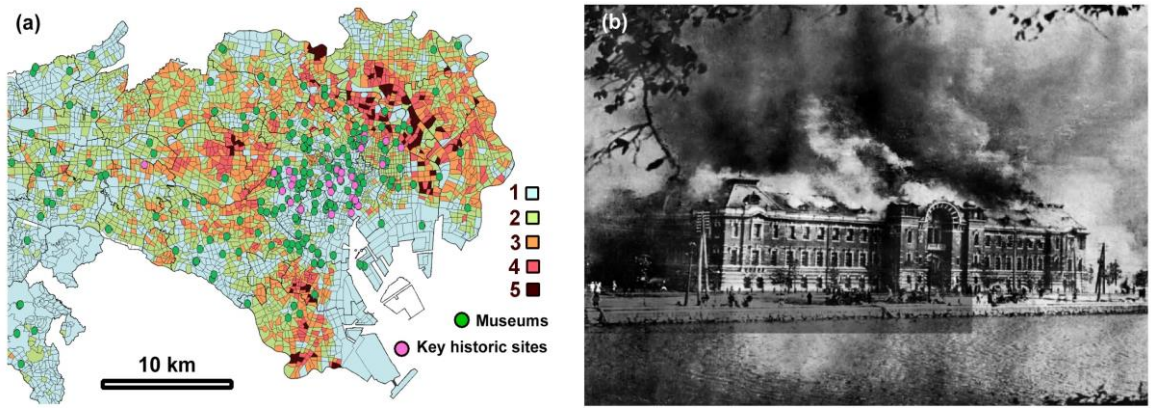

Figure 8. (a) Fire risk for Tokyo. Note: North is at the top. (b) The Metropolitan Police Department building burning after the Great Kantō earthquake.

There is the potential for increased risk of fire both after earthquakes and that induced by lightning strikes. Shindo et al. (2012) shows that the number of lightning flashes per year over Japan and has increased over the period 1992 to 2008. Additionally, Tokyo is likely to see enhanced convective storm activity in future, so an increased frequency of lightning strikes and fires might be expected. The potential for climate change to lead to more lightning strikes can be countered by improved protection against lightning and incorporating fire-suppression devices in buildings. The fire at Notre-Dame de Paris on the evening of 15 April 2019, initiated many concerns in Japan, yet soon after, there was a devastating fire at Okinawa's Shuri Castle in 2019. It was followed almost immediately by a fire in traditional gassho-zukuri houses in Gifu Prefecture. Wooden structures and thatched roofs are especially vulnerable, so have been of great concern for many hundreds of years, so Japan developed a range of approaches to limit the extent of damage from fire (Brimblecombe and Hayashi, 2018). The fires of 2019 encouraged expanded budgets for heritage protection in Japan, but also more modest activities e.g. the Tokyo Fire Department's offer fire prevention guidance to Zojoji temple, a complex which has survived many fires since the early 17th century.

3.4. Debris flow, slope failure and landslides

A range of sediment disasters are induced by heavy rain, but also triggered by earthquakes. These can cause catastrophic damage to built heritage. The sediment flows include (MLITbsd,):

1. Debris flow- soil and rock on a hillside or in a riverbed are washed after heavy or continuous rain, which can reach 20-40 km hr^{-1}
2. Slope failure- abrupt slope collapse under the influence of a rain or an earthquake. This occurs so suddenly that people fail to escape when it occurs near a residential area and can lead to many fatalities.
3. Landslide- massive quantities of soil move slowly downslope under the

influence of groundwater and gravity. The large soil mass means serious damage can occur, and once started, it is extremely difficult to stop.

Sediment hazards are more probable in the western parts of Tokyo, because of the mountainous geography and shown in Fig. 9 which shows the red and yellow risk areas.

Red Zone: Where steep slopes are likely to collapse, buildings are damaged; areas where there is a risk of significant damage to the lives or physical health of residents. In Japan a permit is required for specific development activities and structural regulation for buildings.
Yellow Zone: Where steep slopes are likely to collapse, risking injury or life, and when the danger is apparent, a warning and evacuation system is to be in place.

Red and yellow zones are more predominant in western Tokyo, but there are many popular places in the eastern and central districts such as the NHK Museum of Broadcasting and the Itabashi Art Museum, which even though not in red or yellow zones, there may be some risk as the sites are close to potential sediment threats.

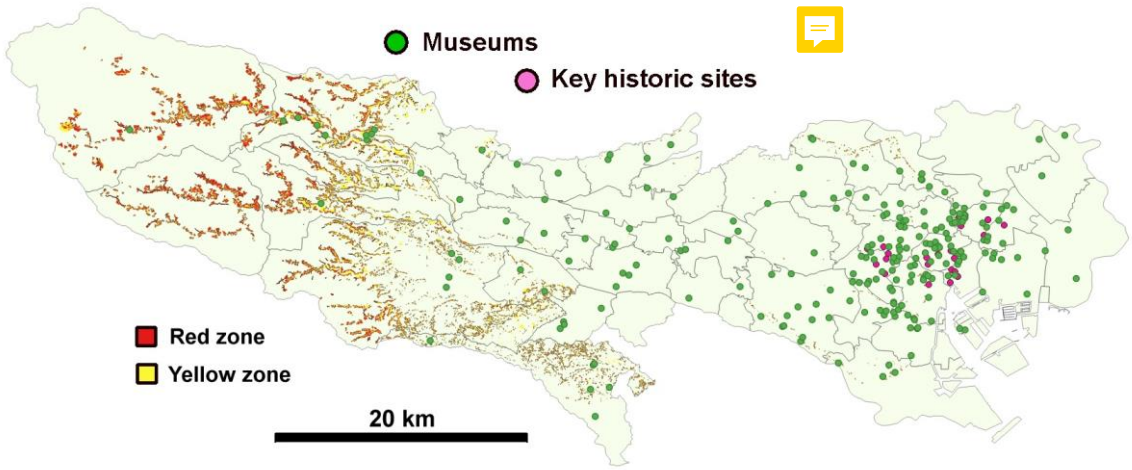

Figure 9. Sediment disaster map. *Red Zone* where slopes can collapse and damage buildings and threaten lives. *Yellow Zone* where steep slopes can collapse, risking injury or life Note: North is at the top. Source: (https://nlftp.mlit.go.jp/ksj/index.html)

There are nine museums in the yellow zone: seven are in the western area and two in the eastern part of Tokyo. The west has fewer historic sources and museums than the east, still there are many small red and yellow zones liable to sediment disaster in central Tokyo. This means that the risk not only to the western part, but also the eastern where there are relatively sites likely to be threatened. In the west, which is more mountainous, the yellow zone is occupied by: Okutama Water and Green Friendship Hall, Gyokudo Art Museum, Ome Kimono Museum, Yoshikawa Eiji Museum, Ome Municipal Museum of Provincial History, Akiruno city Itsukaichi Museum and the Hamurashi Kyodo Museum. Protection can best take the form of slope maintenance, well-practiced in Hong Kong (Geotechnical Engineering Office, 2018), which has steep terrain and receives heavy falls of rain, especially during typhoons.

3.5. Visitor experience under a changing climate

As shown in Fig. 3, many external parameters affect visitor choices. Typically, wet weather can discourage travelling round the city, but on the other hand it can mean a greater tendency to go indoors to shelter (Grossi et al., 2010). Many individuals appear to actively adjust their plans throughout the day in response to rain. However, for others attendance depends upon prior weather forecasts of rain. The duration of a visit is also likely to increase during rainy periods (Cuffe, 2018). However, in hotter weather of the future visitors may want to escape from the oppressive outdoor heat, especially to air-conditioned museum interiors. In historic dwellings where mechanical ventilation is not appropriate, the heat of the interiors may be such that visitors will be driven outside and away from the poor air movement among crowds of visitors. The change in visitor behaviour is obviously not simply a matter of the changing climate. We also have to consider the change in the visitor the type of visitor and the change in their behaviour and expectations in terms of visits to historic sites.

Museums and historic sites are increasingly broadening the range of visitors they attract, so it is no longer the well-informed elderly tourist with guidebook in hand. Plans, for example at the UK's National Trust aim to welcome a wider variety of visitor types they categorise as: (i) active thinkers, (ii) live life to the full (iii) spontaneous characters iv) young experience seekers and among groups with children (v) the family group (vi) kids first families and (vii) home and family. Encouraging these new groups of visitors will inevitably change the way the heritage sites are experienced and used. We can imagine that the gentle tours through historic rooms may be less important than more active pursuits and greater use of the grounds and surroundings.

In recent years, the sunnier urban environments have led to more oxidizing pollutants and meant that the surfaces of buildings have taken on a somewhat warmer tone (Grossi et al., 2007). In addition to chemical drivers, shifting colours may be a product of biological growth. As the climate changes. viewing the beauty of a snowy Tokyo, reminiscent of the paintings of Hiroshige, is likely to be more difficult (Fig. 10). The changing seasons have influenced the viewing of cherry blossoms (sakura) and the autumn, the dates of these activities have had to shift as the warm seasons have grown longer (Brimblecombe and Hayashi, 2017).

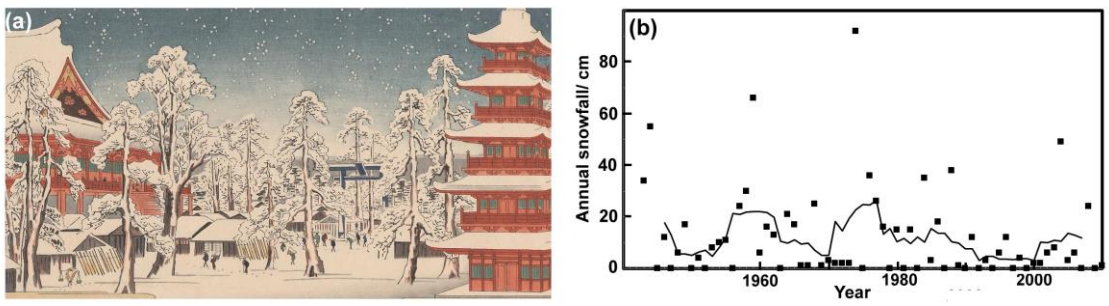

Figure 10. (a) Hiroshige's *Snow Scene at Kinryuzan Buddist Temple, Asakusa District* (b) Annual Tokyo snowfall. The line shows the 7-year running mean. Note: Image is part of *Toto Yukimi Hakkei* (8 Snow Scenes of the Eastern Metropolis): http://mercury.lcs.mit.edu/~jnc/prints/8snow.html. Data from WMO Station ID:47662 of JMA.

4. Discussion and conclusions

This study presents maps of some natural pressures on Tokyo's cultural heritage. Accardo et al (2003) claim maps of heritage risk to be useful because they provide a "deeper and more concise knowledge of risk intensity than may be obtained by comparing the potential danger level of any single cultural property, based on the three static/structural, human impact, and environmental factors, with its state of conservation (vulnerability index) recorded... " It is easy to accept such thoughts, but the translation of maps into management policies is not trivial. Maps of potential risk are strategic, so they seem more useful to large organisations or government agencies. Such entities need to consider the broader picture and prioritise and compare risks over an extensive range of sites. Ultimately they need to allocate limited resources among sites with competing, but necessary demands; and money is always tight. It is also possible that the maps can be of some value to a single museum or site as they may hint at risks of which they are unaware, but often they will know many of the risks that confront them.

Risk maps can reveal the changes in climate and pressures from natural disasters. They can be open and provide information to stakeholders and the public. The risks may become evident to more individuals and encourage risk reduction. While it is possible to create overlapping maps with GIS, the availability of data is often limited with only a few of the desirable maps are available. For instance, Tokyo tsunami data has yet to be made available in a useful format, although the municipality homepage gives tsunami hazard maps. In a publicly available GIS form they can more readily be used to identify and visualise built heritage hazards and sites at risk in an effective way.

Risk management and assessment is relatively advanced in Japan, so there is a hazard map portal site (https://disaportal.gsi.go.jp/index.html). It is possible to link this to the field of built heritage, conservation and management. Up to now preparedness planning has used such material for establishing evacuation routes for visitors and objects, but less for planning mitigation strategies. The maps can also be useful in designing new museums by assessing risks in advance. A general problem in creating risk maps is that most of the publicly available data focusses on general built structures rather than heritage, so it would be best to develop techniques that might tune it for that use. There are other areas worthy of future expansion e.g. much of our knowledge of insects is related to those which are agricultural pests, rather than those that place heritage at risk. A better understanding of the life cycles of wood boring insects in Japan would be useful. An understanding of natural hazards is well developed in Japan and the science of climate change is nicely represented by the Japan Meteorological Agency, but there is only limited effort to tune this to a future heritage climatology. Similarly, a knowledge, of air pollution both indoors and out, has largely been concerned with the impact on human health. It is evident that more work is necessary to improve the health of our heritage.

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