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Exploring local perspectives on flood risk: A participatory GIS approach for bridging the gap between modelled and perceived flood risk zones

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ABSTRACT

As cities continue to expand and climate change exacerbates flooding, development within flood risk zones becomes an increasingly pressing concern. Engineered solutions alone cannot fully address the risks to individuals and communities, especially when local officials and residents have conflicting understanding of the risk. Participatory GIS (PGIS) offers a unique opportunity to bridge this gap by engaging with communities to better understand their perceptions of flood risk. While PGIS has traditionally been used in developing nations as an alternative to numerical flood models, its potential for use in developed nations is largely unexplored. This paper presents a case study of survey-based PGIS conducted in Reading, a large town in Berkshire, UK. Findings suggest that local residents possess a surprisingly accurate understanding of flood risk zones, but discrepancies with modelled flood risk were also identified. These discrepancies may be due to issues with cartographic representation, but also raise concerns about the accuracy of numerical flood models. By examining local perceptions of flood risk, this study highlights the importance of considering community perspectives in flood risk management and offers valuable insights for practitioners seeking to bridge the gap between modelled and perceived flood risk zones.

1. Introduction

Floods are a devastating global hazard, constituting the majority of natural disasters and affecting over 2 billion people between 1998 and 2017 (WHO, 2022). Even with global flood protections in place, riverine flooding is forecasted to cost just C40 cities[1] US$64bn every year, with the impact to GDP being more than double at US$136bn every year (Water Safe Cities, 2022). Extreme weather events globally and large-scale regional floods have been increasingly disastrous due to rising relative sea levels and an increased storm intensity (Blaikie, Cannon, Davis, & Wisner, 2014). In England, around 5.2 million properties are at risk (Environment Agency, 2009), further exacerbated by increased frequency and magnitude of climatic events (Stevens, Clarke, & Nicholls, 2016), as well as an increase in population exposure to flooding as floodplains have been progressively developed, further expanding the potential impacts of hazard events (Evans, 2004; Sultana, Thompson, & Green, 2007, pp. 357–376). Alongside this increase in risk, there has been a surge in hard engineering approaches to manage floods, with projects such as the Thames Barrier (Stevens et al., 2016). This has lessened the impacts of flooding, allowing for the advance of floodplain development to cope with increasing populations, which drastically increases the potential for negative impacts were a flood event to occur (Tockner & Stanford, 2002).

The increased frequency of flooding has resulted in a growing awareness of the need for a more sustainable and holistic approach to Flood Risk Management (FRM) whereby all stakeholders are involved (Bracken et al., 2016; Canevari-Luzardo, Bastide, Choutet, & Liverman, 2017; White & Richards, 2008). An updated FRM approach is required that incorporates natural sciences, social sciences, and engineering (Correia, Fordham, Saraiva, & Bernardo, 1998, pp. 209–227; Jonkman & Dawson, 2012). Historically, risk management focussed on technical expertise with a lack of attention to the social side of risk management (Birkmann, 2006; Cadag & Gaillard, 2012; Van Aalst, Cannon, & Burton, 2008; White, Kingston, & Barker, 2010). Regardless of accuracy, flood modelling will remain ineffective if key stakeholders are not willing to undertake or adhere with FRM strategies and initiatives (Zevenbergen, 2011). Flood model output maps are often designed and presented in a way that is difficult for the public to understand, where local knowledge

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[1] C40 is a network of mayors of nearly 100 world-leading cities collaborating to deliver urgent action to confront the climate crisis.

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is not incorporated and the maps are seen as an information tool as opposed to a communication tool for FRM (telling and poor understanding, rather than discussing and good understanding) (Meyer et al., 2012). Using social sciences as a focal point; risk management and community interest can be stimulated between key stakeholders using participatory approaches where local communities are involved in flood risk identification, or management (White, Kingston, & Barker, 2010).

There is a crucial shift in paradigm, where a sociotechnical, more participatory basis will begin to formulate more traction within the Disaster Risk Reduction (DRR) industry globally, but how this will present itself in practice is still unknown. Among the literature, two current opinions can be observed. One stance understands that the paradigm-shift has already been acted upon in practice (e.g. Nye, Tapsell, & Twigger-Ross, 2011), and the other opposes this and interprets the participatory paradigm-shift as a vital DRR requirement that is not yet being undertaken and that key stakeholders are not substantially involved (Correia et al., 1998, pp. 209–227; Mehring, Geoghegan, Cloke, & Clark, 2022; Ortiz, Aznar-Crespo, & Olcina-Sala, 2021; Unnerstall, 2010). While there is some evidence for this shift in the literature among small communities and usually in developing countries (Mercer, Kelman, Taranis, & Suchet-Pearson, 2009), the shift is rarely represented in More Economically Development Countries (MEDCs). Therefore, a key theme exists that there is significant potential for wider participatory approaches to FRM (Van Aalst et al., 2008; White & Richards, 2008; Yusuf et al., 2018). Some frameworks have been proposed, such as that of Mercer et al. (2009), to facilitate integration strategies whereby local and scientific knowledge will adjoin to give a holistic approach. Despite this, a serious challenge still exists in combining knowledge spanning disparate scales, where scientific knowledge is global and may contrast with local knowledge (Mercer et al., 2009). It is proposed that PGIS may help address this disparity by combining scientific and local knowledge within a common spatial framework.

PGIS applications are many and varied (Sieber, 2006) including ecosystem mapping, site suitability for energy plants, emergency evacuation routes and public health (Ansumana et al., 2010; Brown & Fagerholm, 2015; Dunn, 2007; Mekonnen & Gorsevski, 2015). More recent PGIS applications see further research into management of nuclear risk, hurricane risk, tsunami risk, and flood risk; showing the breadth of application in potential PGIS uses (Chitty & Sprega, 2018; Duval-Diop, Curtis, & Clark, 2010; Hung & Wang, 2011; Kienberger, 2014).

Recent research also explores the idea of incorporating PGIS with technical GIS models into risk management decisions (Chingombe et al., 2015; Gebremedhin, Basco-Carrera, Jonoski, Iliffe, & Winsemius, 2020; Landström, Becker, Odoni, & Whatmore, 2019; Radil & Jiao, 2016, Sieber, 2006). This way locals and a wider variety of stakeholders are involved in the decision-making processes (Krishnamurthy, Fisher, & Johnson, 2011; McCall, 2008; Puzyreva & de Vries, 2021).

In practice, PGIS for risk management is yet to see uptake on a larger scale. Applications of risk management through PGIS are often small scale and in less economically developed countries (LEDCs), where the technological approach is not available (Brandt et al., 2020; Buba, Ojinnaka, Ndukwu, Agbaje, & Orofin, 2021; Chingombe, Pedzisai, Manatsa, Mukwada, & Taru, 2015; Gebremedhin et al., 2020; Joy, Kanga, & Singh, 2019; Kienberger, 2014; Mukherjee, 2015). However, little research can be found regarding the use of PGIS for risk management in MEDCs (Hung & Wang, 2011; Luke et al., 2016; Reichel & Frömming, 2014), though the limited research undertaken indicates promise. This provides a rationale for research into the potential role that PGIS could fulfil for FRM in an MEDC context (where technocratic models are widely available). It is posited that the use of PGIS to consider local knowledge within developed countries can prove valuable in understanding both the depth of knowledge possessed by local people and in explaining discrepancies in public perceptions – for example, demands for additional protection in low-risk areas, or complacency in high-risk ones.

The aim and objectives of this study are outlined below along with a research framework diagram (Fig. 1) which summarises the approach taken.

Aim: To investigate the potential of PGIS for incorporating local knowledge alongside technological flood models within an urban MEDC context.

1.1. Objectives

Undertake a PGIS study to identify perceptions of flood risk within a UK urban context focused on Reading, Berkshire, UK.

Compare flood risk calculated through technical flood models against perceived flood risk mapped through PGIS to identify the degree and consistency of local flood knowledge within Reading, Berkshire, UK.

Formulate a critique of PGIS for Flood Risk Management and make recommendations for potential use of PGIS in future Flood Risk Management strategies.

2. Methodology

2.1. Study area and rationale

Reading is a large town in Central Southern England, in the county of Berkshire, located about 65 km West-South-West of Central London (Fig. 2). The settlement lies on a confluence of the River Thames and the River Kennet with the floodplain of the River Loddon separating the urban areas of Eastern Reading. Reading is the most populous town in the UK not to have city status, with 342,000 inhabitants in 2020 (United Nations Department of Economic and Social Affairs, Population Division, 2018). Reading is built on a series of gravel terraces above the Thames and the Kennet flood plains, with the town centre lying within the river valleys (Brugge & Burt, 2015).

Between 1901 and 2015 there have been 12 recorded flood events in Reading, with a notable cluster of 5 events in the past 25 years (Brugge & Burt, 2015). This follows an increase in the upper extremities of monthly precipitation patterns, following a global trend of increasingly extreme weather events (National Academies of Sciences, Engineering, and Medicine, 2016). In 2014 the area saw its highest recorded rainfall over an 80-day period, with 382 mm of precipitation between December 14, 2013 – March 3, 2014 (Brugge & Burt, 2015). The Winter 2014 floods resulted in the flooding of 37 properties as well as disruption to highways (Reading Borough Council, 2014). Reading's history of flooding, increase in flood events and its status as a large town rather than small rural settlement makes it an interesting location for integrated FRM research.

The primary data for this study was provided by 2D scaled participatory mapping of flood risk and questionnaire surveys collected in November 2017. The PGIS data consists of qualitative and quantitative responses, whereby participatory study can be understood as mainly qualitative but can consist of quantitative detailed analysis (White & Richards, 2008). A baseline for comparison was then provided by secondary numerical flood modelling data, provided in December 2017 from Ambiental Technical Solutions. Modelled flood zones are generally seen as authoritative, therefore a high level agreement between participatory and modelled flood maps can be seen as indicating good local knowledge of flood risk. However, analysis of discrepancies between the two also has the potential to highlight flaws in modelled flood zones which would add weight to the value of local knowledge.

The foundational philosophy behind participatory approaches is to involve stakeholders from the initial phase of research to reach integrated and holistic solutions. The involvement of key stakeholders in each stage of the process is of high value and makes for good research methods that differ from traditional consumer research because it generates knowledge, enhances communication and empowers people in risk management (Atweh, Kemmis, & Weeks, 2002; Ozanne &

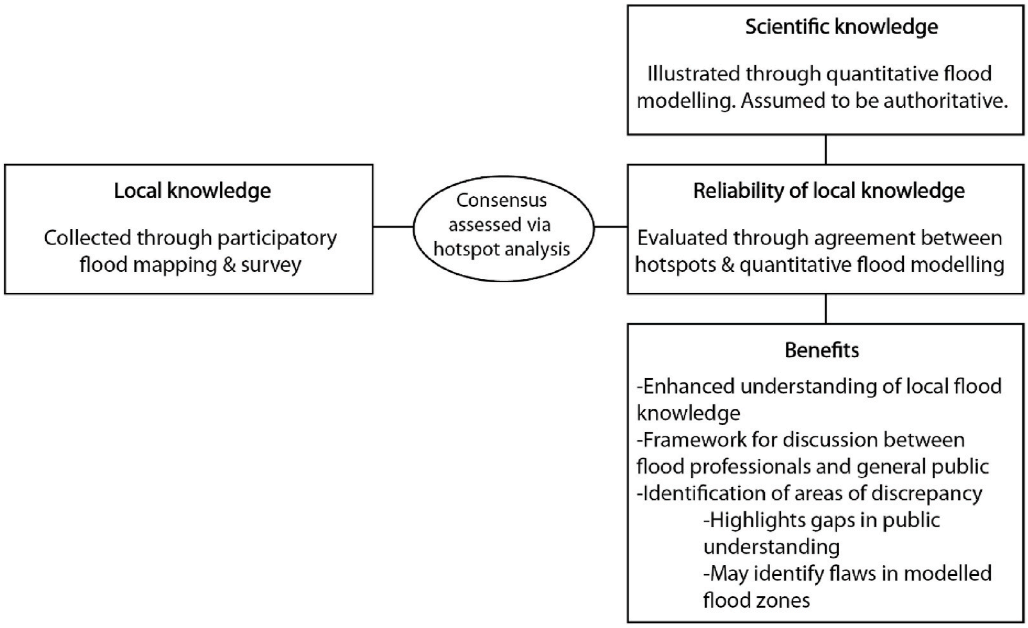

Fig. 1. Research framework diagram for the study.

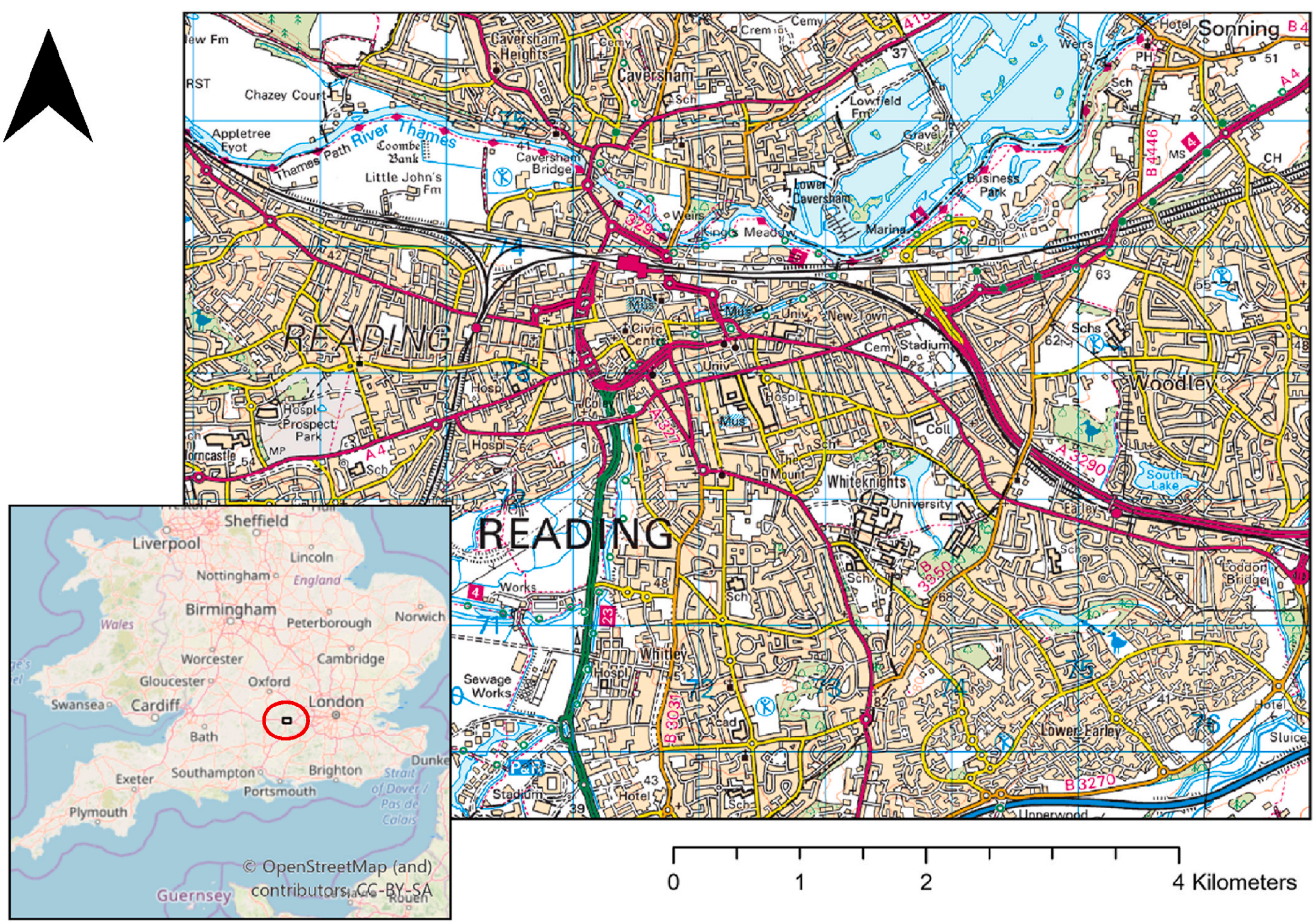

Fig. 2. Location map indicating study area of Reading, UK. Basemap © Crown copyright and database rights "2023" Ordnance Survey (AC0000851941).

Saatcioglu, 2008; Reynolds, 1997). Exploring local knowledge by combining effective PGIS with risk management may be highly beneficial to sustainable risk management (McCall, 2008; Mercer et al., 2009).

Measurable data is required through PGIS for flood risk management to create georeferenced flood maps that can be compared with technical flood model outputs (Birkmann, 2006; Correia et al., 1998, pp. 209–227;

Hoggart, 2002; Meyer et al., 2012). This would be easier to interpret and accept for politicians and decision-makers because it is complementary to traditional top-down planning; involving the local community without having to understand new concepts or try to translate face-to-face requests into community risk maps (Birkmann, 2006; Meyer et al., 2012).

2.2. Data collection

There are a variety of methods of participatory mapping that can be used for risk management in the DRR approach, combining digital cartography, sketch mapping, GPS, and GIS, each with their own strengths and limitations (Weiner & Harris, 2003). A significant challenge remains of integrating local and scientific knowledge, where a digital mapping method is required to combine technical models and participatory maps (Cadag & Gaillard, 2012; Cronin, Petterson, Taylor, & Biliki, 2004; Weiner & Harris, 2003). PGIS can also be either a group or an individual exercise. It has been identified that group exercises can be skewed by the views of a small number of more confident participants and therefore combining the results of individual participatory mapping exercises may provide a more genuine picture of the breadth and accuracy of local knowledge and is the approach used in this study (Brown et al., 2014).

Participants were provided with an A3 Ordnance Survey 1:38,000 paper base map produced using the Digimap portal (digimap.edina.ac.uk) with added annotations of well-known sites/infrastructure to aid orientation. The interviewer was also able to assist participants in interpreting the map, helping overcome limitations with regard to map reading ability. The accompanying questionnaire was made up of a combination of 24 closed and open questions, to obtain both quantifiable data and richer perceptions of participants allowing the study to understand participants views on their involvement in the FRM process, to provide an understanding of how feasible PGIS for FRM might be (Sandelowski, 2000). The questionnaire and participatory activity were piloted with two participants from the Reading area to ensure that efficient data would be received (Clifford, French, & Valentine, 2010). The questionnaire was designed on Survey123 for ArcGIS, to allow use for a tablet to be used in the field and reduce the amount of paper used. Survey123 also undertakes independent data presentation and analytics in a way that the researcher can understand if the data is effective whilst still in the study area. Conducting the mapping activity face to face allowed the researcher to gain an understanding of participants reason for highlighting particular ‘at risk’ areas because often participants would state these aloud. Ethical approval was obtained from the academic department before undertaking the research.

Secondary data was obtained from Ambiental Technical Solutions, an industry leader in flood modelling. This consisted of modelled data representing 1 in 100 year fluvial and pluvial flood extents covering 497 km^2 surrounding Reading was provided in georeferenced raster format suitable for analysis in GIS. This provides a reliable source of scientific knowledge against which to compare the results of the participatory mapping exercise.

2.3. Data analysis methods

ArcGIS Pro was utilised to analyse the data and compare technical flood models with residents’ sketch maps (Luke et al., 2016). Maps were scanned, georeferenced and digitized in ArcGIS, producing a layer totalling 396 polygons containing all areas highlighted as ‘at risk’ by the participants. Once features had been digitized the ‘Count Overlapping Features’ tool withing ArcGIS Pro 2.8 was used to identify the number of participants highlighting any given location, with the ‘dissolve’ tool then applied to resulting polygons in order to combine any adjacent polygons with identical counts and thus improve visual display of the data. This allowed for a visual assessment of hot and cold spots, but in order to ensure a statistically robust analysis the Optimized Hotspot Analysis tool within ArcGIS Pro 2.8 was then used, with the output of ‘Count Overlapping Features’ as its input. This calculates statistically significant hot and cold spots at the 90 and 95% confidence intervals using the Getis-Ord Gi* statistic, analysing the dataset to identify optimal parameters. The Getis-Ord local statistic is calculated using Equation (1) below,

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \overline{X}\sum_{j=1}^{n} w_{ij}}{S\sqrt{\frac{\left[n\sum_{j=i}^{n} w_{ij}^2 - \left(\sum_{j=i}^{n} wij\right)^2\right]}{n-1}}} \qquad \text{(Equation 1)}$$

where x_j is the value for feature j, w_{ij} is the spatial weight between feature i and j, n is the total number of features, $\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}$ and $S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\overline{X})^2}$. The G_i^* statistic is in itself a z-score, so no further statistical calculation is required. A significant positive value indicates the presence of hotspots, while significant negative values indicate cold spots.

In this case the input layer contained 19,137 distinct features, of which 321 were identified as spatial outliers and discarded from the analysis. Analysis of the spatial distribution of features was then used to identify an optimal distance banding. In this case the average distance needed to yield 30 neighbours was used, resulting in a distance banding of 148 m. Following hotspot analysis, visualisations were produced to indicate the level of agreement between participants regarding flood risk zones, and spatial statistics used to identify significant hot and cold spots within the participatory results. The PGIS could then be compared against the flood model layer provided by Ambiental Technical Solutions. The questionnaire results were included as attributes within the GIS analysis, allowing further interrogation of the data by querying polygons based on participant attributes, such as length of residency, to determine whether this impacted upon the level of knowledge.

The most significant source of error within this process arose in the georeferencing and digitising of the flood polygons. However, georeferencing was achieved to within a root mean square error (RMSE) of 10 m and digitising fell within the width of the lines drawn by participants.

3. Results

80 participants made up the sample for the basis of this research, representing just 0.024% of the Reading population. However, a broad range of demographics are represented within the results (Fig. 3), ensuring that a range of themes can be drawn from the data. The majority (84%) of participants lived in the Reading area. The study does not exclude the results of those living outside of the Reading area because these participants worked in the area and, therefore, can still be defined as a stakeholder to FRM in Reading (Lee, 2007). 46% of the sample population responded yes to the question ‘Have you experienced flooding in the area?’ Based on the researcher’s observations this generally meant the participant had seen flooding in the area first-hand, though their home or workplace was not necessarily affected. This further supports a rationale for study into participatory FRM as a significant percentage of the population recognise flooding in their area.

3.1. Evaluating local knowledge

A key objective of this research is to investigate the degree and consistency of local knowledge within an urban setting in a MEDC. Fig. 4 shows the technical model outputs with participatory results overlain. Four main areas of flood risk can be observed around the centre of Reading following the River Kennet, Thames and Loddon. In the Central Business District (CBD), narrower risk zones can be observed whereas towards the suburban areas, flood risk zones are wider with more

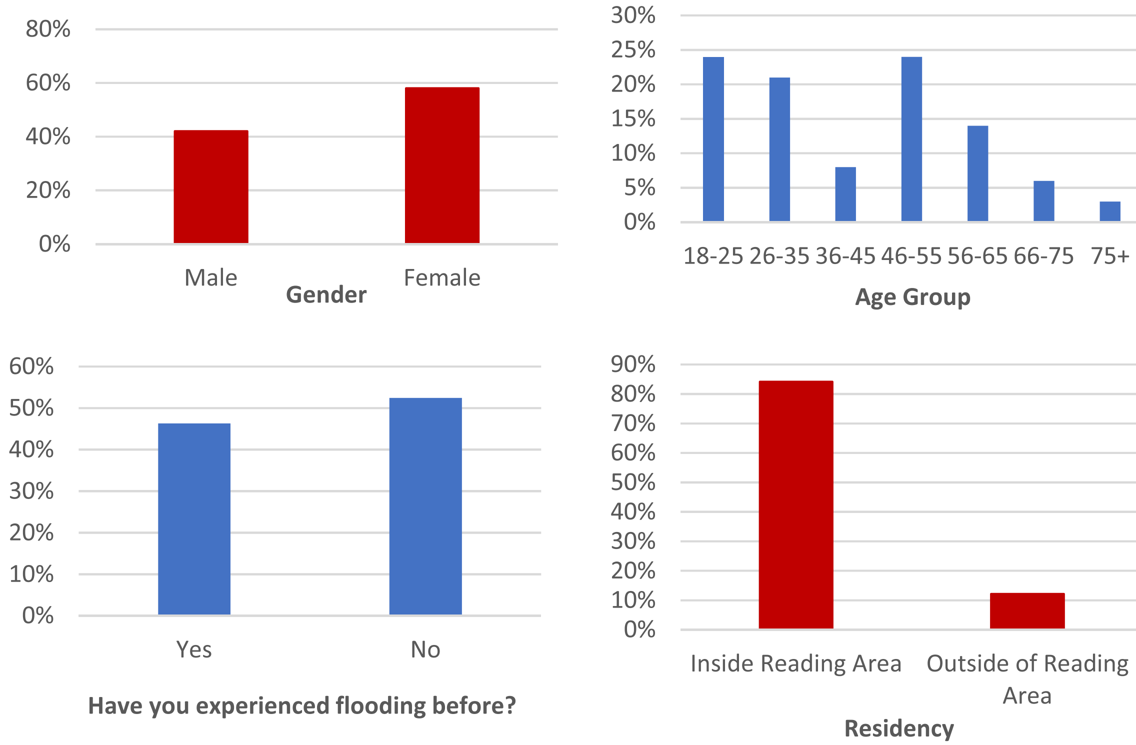

Fig. 3. Participant demographics and flood experience.

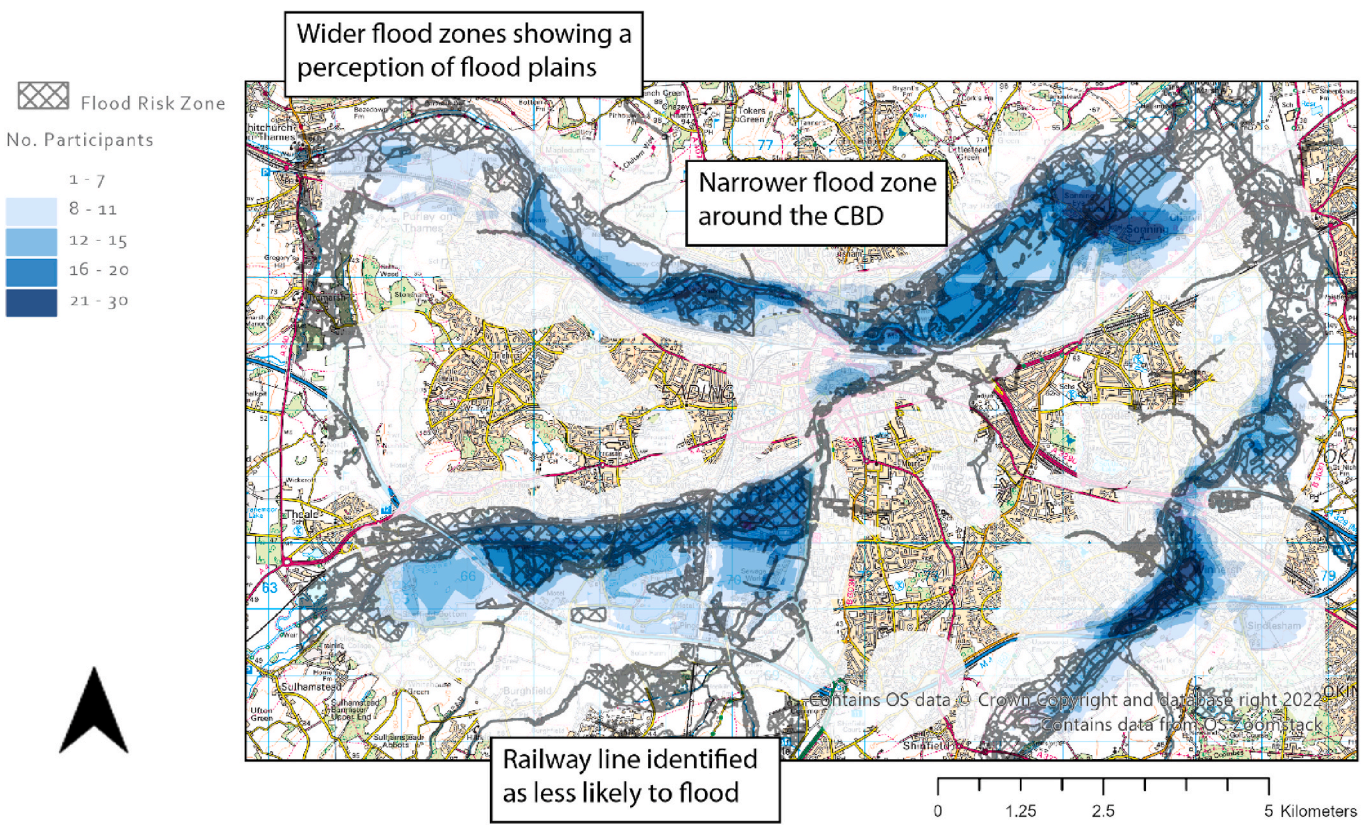

Fig. 4. Areas highlighted as at risk of flooding by participants alongside modelled 1 in 100 year flood depth. Basemap © Crown copyright and database rights "2023" Ordnance Survey (AC0000851941).

obvious flood plains. This could be evidence of channel straightening and hard engineering strategies within the CBD to reduce the risk to the city centre, and local knowledge of those strategies through the PGIS (Stover & Montgomery, 2001).

When focusing only upon risk zones identified by more than 10% of participants (Fig. 4), the results of the PGIS and technical flood model are much more closely aligned. This is further supported by statistical analysis of the participatory flood zones using hotspot analysis (Fig. 5), where areas identified as hotspots with >90% probability closely align with the areas highlighted by >10% participants.

While the broad agreement between modelled and participatory flood zones may provide confidence in local knowledge, areas of discrepancy are arguably of greater interest as they may provide insights into divergences in understanding between local stakeholders and flood professionals. These divergences could then develop into points of conflict when flood mitigation measures are being developed. For example, participants have recognised areas that they consider to be 'at risk' but they are not shown as at risk on the flood model output, such as that shown in Fig. 6a. The other example (Fig. 6b) shows an area identified by participants as being at high risk, but is not identified as at risk by the conventional flood model. While it is tempting to assume local knowledge is flawed, a possible reason could be that the fluvial and pluvial flood models are actually inaccurate. The red oval outlines an isolated area of deep flooding in the model, which could show evidence of flow obstruction (i.e. a bridge) that has not been altered in the DTM (Digital Terrain Model) to make up the flood model. However, it could also be due to some participants identifying the labelled sewage treatment works as at risk.

On the other hand, areas can also be found where participants thought they were not at risk but they are. Fig. 5 shows that there are sections that are shown as confidently not likely to flood based on a hotspot analysis of all of the responses but some of these areas are actually at significant risk to flooding in the technological flood model.

However, the main areas of flooding are recognised to a significant confidence level (99% in most cases). Moreover, when looking at the confidence of the PGIS map overall, there are very few areas that are 'Not Significant', giving evidence that most people's views align when considering where is/is not likely to flood in Reading. Therefore, flood hazard planners could begin to undergo research as to why people think that area is at risk when it is not or why they do not think it is at risk when it is.

3.2. Familiarity and its effect on local knowledge

Knowledge of an area is likely to be a key factor in determining knowledge of flood risk, therefore separate maps were produced from the responses of participants who had lived in the area for five years or fewer and those who had lived there for more than five years. The participants that lived in the area for 5 years or less (22% of participants) observed the Winnersh area as the most at risk (Fig. 7).

On the other hand, the 78% of participants that have lived in the area for over 5 years portray the most at-risk area as Sonning (Fig. 8).

3.3. Willingness of participants to be involved in the FRM process

Despite a number of studies suggesting that the general public are not motivated to be involved in the FRM process (Dufty, 2017; White, Kingston, & Barker, 2010), the results from this research showed that

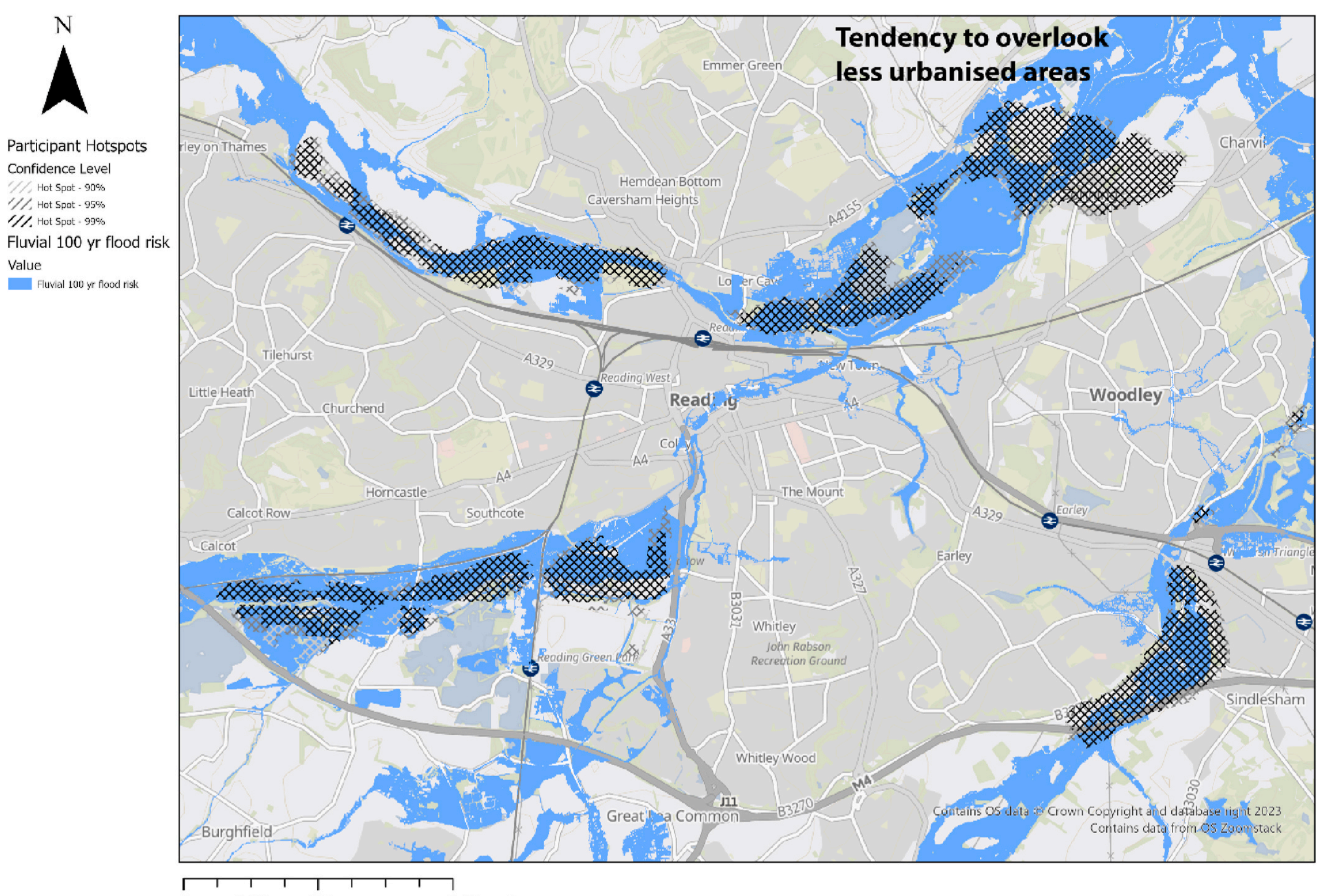

Fig. 5. Statistically significant hotspots calculated from participant responses. These roughly correspond with areas highlighted by >20% participants.

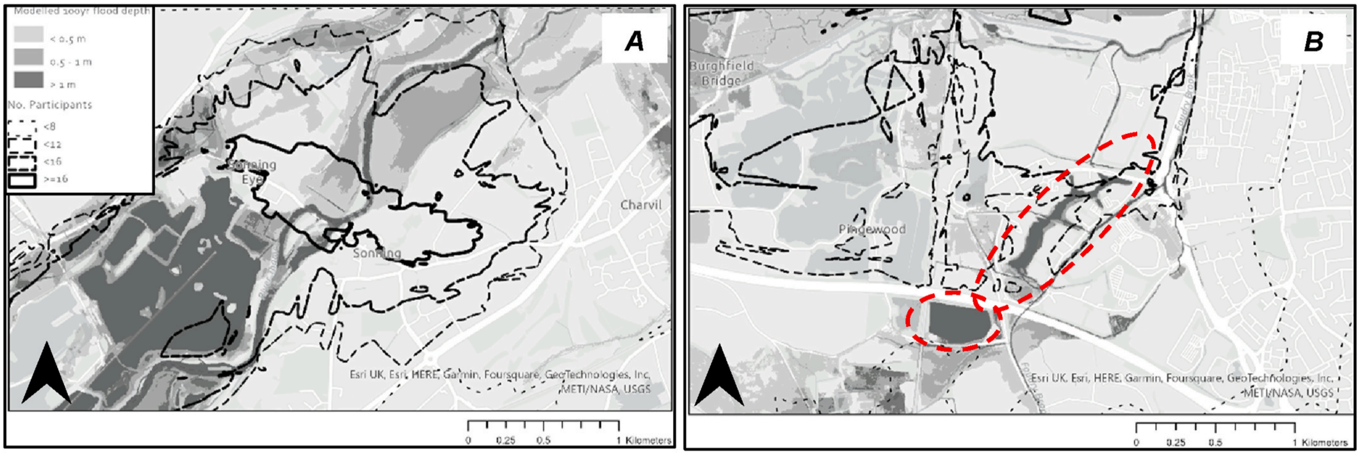

Fig. 6. Pieces of the PGIS map that are considered as 'at risk' by participants but are not 'at risk' in the fluvial and pluvial flood modelling, namely the areas labelled Sonning and Sonning Eye in (A) and the sewage works in (B). Dashed ovals in (B) indicate isolated areas of high flood depth which may indicate quality issues in the conventional flood model.

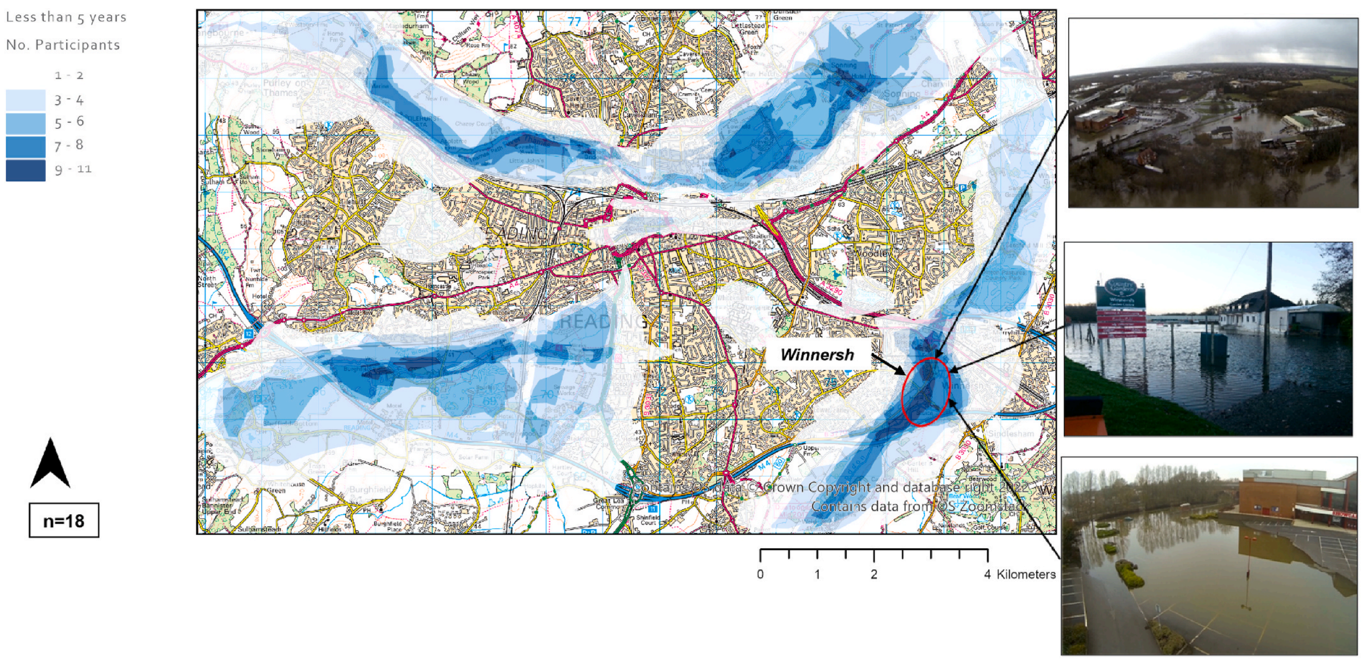

Fig. 7. A PGIS map for participants that lived in the area for 5 years or less with accompanying photos of flooding in the Winnersh area. Darker blue areas are those that more participants highlighted as at risk to flooding (Photograph Source: Fort, 2014; Basemap © Crown copyright and database rights "2023" Ordnance Survey (AC0000851941)).

30% of the sample said they would like to be involved with helping to reduce flood risk in their area, and 35% of the respondents thought that they would benefit from involvement in the FRM process. The key benefits highlighted by participants were awareness of flood risk, preparation for flood events and a closer community. A significant proportion of the sample (33%) highlighted that they would respond differently to flood warnings and education if they had been a part of the FRM process, noting that they would be more likely to heed advice. Some anecdotal statements were also collected, including a participant highlighting they would "have a better idea of how to prepare", another noting they "would pass information on to those who it *does* affect, if I'm not affected", and "helping those less able, and sharing knowledge". This is a crucial finding as it demonstrates a good local understanding of how communities can be a part of the FRM process in Reading, and the benefits it might provide. The sample were also asked how they would like to be involved in reducing flood risk in their area. There were a mixture of responses but the top highlighted initiatives were education (18%), mapping flood risk in their area (9%), taking part in creating a community resilience plan (8%), and planning with neighbours (6%).

4. Discussion

4.1. Implications of findings

When considering all responses, the PGIS risk zones are much wider than the technical flood model risk zones (in some areas 2 km wider. This could be due to heavily localised pluvial flooding from culverts, sewers and drains that the participants believe to have a larger extent of risk than it does, or a lack of understanding in this type of flooding (Houston et al., 2011). It could also be because of the method of highlighting areas on the paper A3 map due to the thickness of the highlighter pens used, and participants may be in a rush and therefore not as

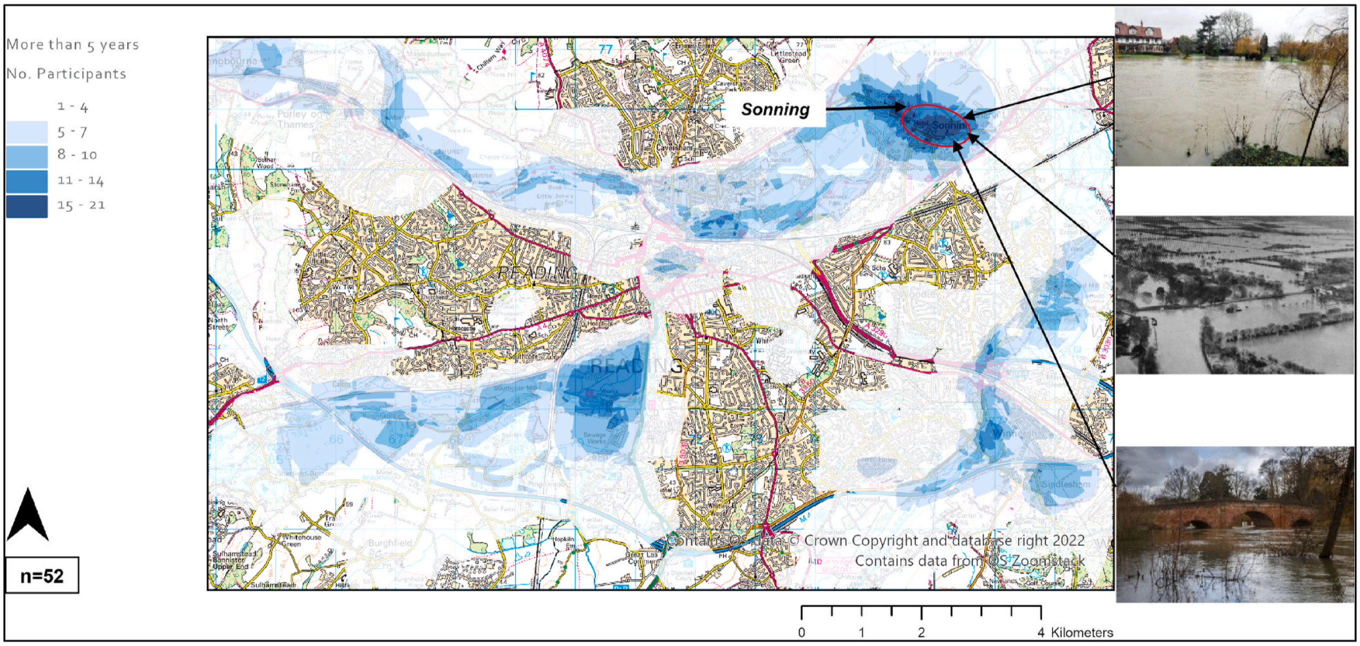

Fig. 8. A map showing a PGIS map for participants that lived in the area for over 5 years with accompanying photos of flooding in the Sonning area. Darker blue areas are those that more participants highlighted as at risk to flooding (Photograph Sources: Top and Bottom Photographs – Fort, 2014 and Middle Photograph – Ashford, 2014; Basemap © Crown copyright and database rights "2023" Ordnance Survey (AC0000851941)).

focussed on small extent localised flooding, with a view of 'wanting to get it right' and consequently highlighting larger areas, which was noted by the researcher during data collection. However, focusing down to those areas highlighted by two or more participants substantially improves the correlation between participatory and modelled flood zones (Fig. 4), which is further emphasised by the hotspot analysis (Fig. 5). This supports the view that local flood knowledge within an urban, MEDC context is remarkably robust, and can form a sound basis for engagement between flood professionals and the wider public. When shared with the Technical Director at Ambiental Technical Solutions, provider of the numerical flood modelling data with which the participatory data is compared, he stated feelings of surprise and being impressed by the locals' knowledge. Areas of interest in relation to the accuracy among the PGIS results are highlighted, with Fig. 4 showing an area where the participants have accurately identified a railway line where flooding is less likely to occur, which is also demonstrated in the flood model. From this it can be inferred that local populations have more knowledge than scientists and perhaps decision-makers think and this is unlikely to be unique to Reading, highlighting the value of PGIS more widely as a framework for discussion. While the high level of overall agreement provides confidence in local knowledge, areas of discrepancy may be equally valuable in facilitating dialogues between flood professionals and members of the public, identifying locations where flood risk is misunderstood and possibly also identifying areas in which further validation of technical flood models is needed.

Considering the length of local residency helps to highlight how public awareness can evolve. For example, there is a good knowledge of the flood risk in Winnersh overall (Figs. 4 and 5), but particularly among new residents because a development for 433 homes and a primary school on the floodplain area was approved in 2011 (BBC News, 2015). Since then, flood risk has increased in the area and it has not been unusual for parts of the area to receive flood depths of up to 3 feet. As a result, in four days over 400 residents had signed a petition against the proposed development (Nurse, 2014). The Flood Protection Association were in agreement with residents and the council and building companies had outlined engineering measures that could face the flooding issue (BBC News, 2015; Nurse, 2014). However, the residents clearly felt that the proposed development would significantly increase flood risk still, as evidenced by the petition. The key stakeholders in this scenario had conflicting views and a poor means of communication, resulting in a challenging top-down decision (Nurse, 2014). With PGIS, these key stakeholders would have been encouraged to communicate and aid decision-makers to a more holistic sustainable outcome.

On the other hand the area of Sonning is surrounded by floodplain and has a long history of flooding (especially in 1947 floods), which may explain why more of the longer-term residents highlighted the area as 'at risk' (Ashford, 2014). However, other areas such as Caversham have flooded just as often (if not more) in historical events. Participants may be highlighting Sonning more than other areas because there has been a larger impact there more recently (reminding them of previous events), where the bridge and several roads had to close in the 2014 flood events causing intense disruption to their personal transport mobility (Ashford, 2014; Brugge & Burt, 2015).

In relation to flood risk management, government and FRM authorities are often restricted to a top-down approach, which can give limited flexibility for collaborative and integrated FRM to be implemented (Haer, Botzen, & Aerts, 2016). The incentivisation to take up a more integrated FRM approach should also be considered by practitioners, but in the first instance a logical next step would be to hold a series of practitioner consultation discussions (for example at Reading Borough Council and Reading Lead Local Flood Authority (LLFA) on the potential for more participatory approaches involving the local community with FRM; potentially building on this research to evaluate the role of different stakeholders and exploring methods of implementation within the existing local FRM frameworks. This is further highlighted by the finding that despite almost a third of respondents indicating a willingness to participate in the FRM process, only two of the eighty participants in the sample had been approached about managing flood risk in their area by stakeholders. This lack of active engagement with communities is mirrored within the literature and is often attributed to a lack of resources or time in key FRM authorities as well as a perception by communities that flood risk management is the responsibility of 'powers that be' (Mehring et al., 2022; Ortiz et al., 2021). As a result, in spite of the paradigm-shift from a technical focus towards a more social focus, a severe lack of uptake in practice can still be observed.

4.2. Limitations and future considerations

The study presented here provides some valuable insights into the potential of participatory GIS for engaging stakeholders and evaluating flood risk within a developed context. However, it is not without limitations. In particular, while 80 respondents allows for broad patterns in understanding of flood risk to be identified and hotspots mapped, gaps in coverage made investigation into more specific demographics (age groups or educational level for example) unfeasible. It would also be desirable to expand the study to a wider range of settlement types in future work, to identify how this impacts on local knowledge.

When considering discrepancies between participatory and modelled flood zones caution must be used, as a significant number of respondents appeared to highlight place names on the map as opposed to the area at risk because of their knowledge of that general place name flooding from local news reports, word of mouth and their own experiences (e.g. Sonning in Fig. 6a) (Wahlberg & Sjoberg, 2000), highlighting a futher limitation of the method of participatory mapping used. Despite these limitations, the broad agreement found between participatory mapping and technical flood models across much of the flood plain gives confidence that the methodology is robust in providing insights into local knowledge of flooding and flood risk.

5. Conclusions

Participatory mapping is often overlooked as a tool for engaging the public with flood risk within a developed context, and little research exists on the benefits it may offer. A survey based participatory GIS exercise was undertaken in the town of Reading, United Kingdom, receiving 80 responses with broad demographic coverage. Results of the participatory exercise were analysed using a GIS approach to identify significant hot and cold spots, which were then compared to conventional flood mapping data in order to provide insights into the local flood knowledge within the town. The results indicated a much higher level of flood knowledge than anticipated by the researchers, with a high level of agreement between participatory and modelled flood data. This is valuable for several reasons; firstly, it indicates that participatory flood maps of this type may have value in regions where technical flood models are unavailable and secondly it suggests that in regions such as the UK, where high quality technical flood models exist, local knowledge is sufficient that shifting the paradigm of flood management (in both theory and practice) from technocratic to collaborative and integrated is appropriate and justified.

However, what may be of even greater value for facilitating improvements to future FRM is the ability to identify discrepancies between local knowledge and conventional flood model outputs. It is suggested that these discrepancies may form a useful focus for discussions when undertaking future flood mitigation exercises, as well as for formulating flood risk education initiatives. Clear benefits of using a collaborative approach have been highlighted, including community empowerment, vulnerability assessment, increased knowledge and improved communication between key stakeholders. It can be concluded that integrating local knowledge with technological flood models has the potential to be critical to future FRM approaches if the proposed solutions are to be considered sustainable, with strong uptake by the local community. This approach should be considered as a valuable tool by planners and flood managers within urban MEDC contexts and well as an alternative to conventional models in areas where availability is lacking.

Credit author statement

James Bullen: Conceptualization, methodology, investigation, writing – original draft, project administration. **Andrew Miles:** Validation, formal analysis, data curation, writing – review & editing, visualization, supervision.

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