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Modelling public social values of flood-prone land use using the GIS application SolVES

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ABSTRACT

Social values of land use are often excluded when undertaking integrated flood management as they are harder to quantify. To fill this research gap, a geographic information system application called Social Values for Ecosystem Services was used to assess, map and quantify the perceived social values of flood-prone land use in Kuala Selangor, Malaysia. This approach was based on a non-monetary value index (VI) calculated from responses to a quantitative social survey on the public's attitude and preference towards flood management across different land uses. The study outcome is the geospatial representation of flood-prone land use with their social values, which local communities perceive as crucial for flood management. The VI was influenced by elevation and slope, with lower elevations and flatter slopes associated with higher values. Farmland is highly favoured by the local community for flood management, whereas oil palm and rubber plantations are opposed. Tourism received the highest monetary allocations from survey respondents, with the popular firefly park consistently associated with the highest social values. This practical framework contributes to integrated flood management in facilitating decision-makers to evaluate land-use trade-offs by considering their social values when prioritising flood mitigation measures or investments.

Key words: flood management, GIS, land use, Malaysia, social values, SolVES

HIGHLIGHTS

- Quantifying social land-use values is challenging compared to economic and environmental aspects in flood management.
- A public geographic information system app modelled these values based on public attitudes.
- Some land uses were seen as more crucial for flood management due to higher local social values.
- This aids decision-makers to evaluate land-use trade-offs when prioritising flood mitigation measures or investments.

1. INTRODUCTION

In its simplest form, flooding happens when water usually inundates dry areas (DEHP 2012). Flood occurs when rainfall exceeds a land's infiltration capacity and water exceeds a watercourse's capacity. For low-lying coastal areas, storm surges or high tides exceed normal levels. Globally, flooding makes up 40–50% of the natural disasters that cause human deaths (Shafiai & Khalid 2016). In all cases, flooding is known to cause devastating damage to buildings, infrastructure, crops, agriculture and communities in terms of environmental, economic and social values (Abbas *et al.* 2018; Jamshed *et al.* 2019; Lwin *et al.* 2020). In addition, the risks caused by a flood highly depend on the flood's location, extent and values of natural and constructed land uses (Mousavi *et al.* 2019).

Located near the equator in the tropics, Malaysia is particularly at risk from flooding, with high rainfalls ranging between 2,000 and 4,000 mm per year, and intensive and continuous rain in the monsoon season (Muhammad 2013; Ishak 2018). Malaysia suffers from devastating annual flood events due to its geographical location between the crosswinds of the Northeast and Southwest monsoons (Loo *et al.* 2015). The Emergency Events Database (EM-DAT), a global database on natural and technological disasters, states that flooding is Malaysia's most frequent natural disaster, constituting 48% of the total catastrophe occurrence (Ishak 2018). Flood-prone areas comprise approximately 9% of the total land area in Malaysia, affecting 4.82 million citizens or 22% of the country's population. Destruction from flooding costs up to $1.26 billion annually

(Pradhan & Youssef 2011). In 2007 alone, Malaysia suffered from one of its costliest flood events in Johor, where total flood damage was calculated at $2.1 billion (Varikoden *et al.* 2011). Poor drainage and other local factors, such as land use and climate, are drivers of flooding in Malaysia (Isahak *et al.* 2018).

There is a recognition in Malaysia of the need to implement more effective flood management and management to alleviate the impact of flooding, which is likely to escalate with climate change (Mohamed *et al.* 2014). Flood damages can be tangible or intangible, including social and psychological impacts. Despite the significant benefits provided by natural (i.e. forests) and production ecosystems (i.e. oil palm, rubber), there has been little research on the social consequences from the land use planning perspective concerning the destruction caused by flooding, particularly in Malaysia. In fact, damages to social values related to land use are rarely recognised compared to other flood damages, such as loss of human lives and infrastructure and property destruction. It may be caused by the loss of social values being less evident and difficult to evaluate (Sherrouse *et al.* 2011). Kumar & Kumar (2008) noted that it is essential to account for social values related to psychological well-being derived from an individual's relationship with nature. Such values are crucial for local authorities to include in planning (Alcamo *et al.* 2003).

Over recent years, remote sensing and geographic information system (GIS) tools have widely facilitated flood management (Wan & Billa 2018). For example, a study by Wan & Billa (2018) incorporated Landsat 8 Operational Land Imager (OLI), thermal infrared sensor data and flood indexing to evaluate the environmental impact of floods on forests, deforested areas, plantations and water bodies. Recent research conducted by Hadadi *et al.* (2022) and Mohammadi *et al.* (2023) has demonstrated the effective application of artificial intelligence (AI) and conceptual models to establish connections between predictors of actual evapotranspiration and topography on water and glacier mass balance, respectively. These studies have highlighted the potential of employing satellite imagery-based predictors as integral components of predictive models. This approach proves valuable in capturing intricate, non-linear relationships, as seen in the context of flood-prone land use and the corresponding perceptions of social values. Remote sensing and GIS flood management can further support the development by local authorities of integrated flood management systems and decision-making.

Social values for flood-prone land use across all categories are insufficiently assessed in Malaysia, especially for their role in decision-making or land use planning. Due to the challenges caused by stakeholders' varying attitudes and preferences, social values are rarely incorporated compared to economic values in most assessments (Raymond *et al.* 2009). In addition, assessing land use in monetary terms may lead to a less meaningful rendering of the services (Daily *et al.* 2009). One popular method for assessing and quantifying social values assigned by stakeholders is the public domain Social Values for Ecosystem Services (SolVES) GIS application (Sherrouse *et al.* 2011). This method incorporates social values via a spatially explicit public participatory GIS mapping social survey (Brown & Fagerholm 2015). Sherrouse *et al.* (2011) successfully used SolVES to quantify and perceive the relationship between social values and public uses in Pike and San Isabel national forests by analysing public preferences obtained through a social survey.

SolVES derives the value index (VI), a measurement index to compare the magnitude of value differences within the survey subgroups that can generate social value maps and associated landscape metrics. The application also considers the underlying environment, such as elevations and slopes, in describing the relationship between the VI and environmental variables. Hotspots or places with overlapping high social and ecological values can then be identified to guide decision-making (Alessa & Brown 2008) and identify flood-prone areas that may require flood management prioritisation. While there are some examples of the application of SolVES globally, this form of analysis has not been demonstrated in Malaysia or in many developing countries, where not only the social and physical contexts (i.e. oil palm production landscapes) are different but the attitude and preferences of local stakeholders can significantly vary. Past studies have also focused on forest and coastal ecosystems without considering flood impacts.

The main aim of this study is to use SolVES as a practical framework to assess, map and quantify the perceived social values of land uses to be prioritised for flood mitigation measures or investments. The study outcome is the geospatial representation of flood-prone land use in Kuala Selangor, Malaysia, with their social values that local communities perceive as crucial for flood management. Using SolVES, the VIs were derived by representing specific land use social values. They were derived using a face-to-face social survey of the local community in the study area's attitude and preferences regarding social values associated with different land use to inform flood management prioritisation. The geospatial approach quantifies the relationship between the local community and nature, and then spatially represents those values across the study area.

2. STUDY AREA

The study area is Kuala Selangor in the state of Selangor in Malaysia, 55 km from Kuala Lumpur (Figure 1). Kuala Selangor is a popular countryside tourism spot at a low elevation of 4.9 m. Thus, this area frequently experiences fluvial and pluvial flooding along the main river channel of the Selangor River. Climate change causing extreme weather and rising seas increases the risk of flooding, particularly in coastal and low-lying areas such as Kuala Selangor. Kuala Selangor consists of approximately 18,834 people, of which a higher population density can be closer downstream and around the river on the coast. The average temperature and annual rainfall in Kuala Selangor are approximately 27.7 °C and 1,987 mm, respectively. The Selangor River flows down the peat swamp forest near the river opening and is eventually released into the Straits of Malacca. The study area spans approximately 14.5 m across from the river channel, based on a major 2010 flood extent provided by the Malaysian Department of Irrigation and Drainage.

The land use map of Kuala Selangor was obtained from the Ordnance Survey Map (OSM) and manually verified, and unrecorded land uses were added as new features. The primary land uses in the study area floodplain were identified as oil palm plantation, orchard, forest, farmland, park, firefly park and rubber plantation. As found in oil palm plantations, orchards, farmlands and rubber plantations, agriculture is one of the main sources of income. In addition, local communities' livelihoods depend on rural tourism, and a firefly park along the Selangor River is a valuable tourist attraction. The park was developed in the 1970s, where visitors come for a boat ride to see fireflies' light displays in the evenings. The middle reach of the area mainly consists of vegetation, including forests and parks.

3. MATERIALS AND METHODS

3.1. Public perception and preference survey data

For data collection, a random face-to-face survey on social values was conducted in Kuala Selangor in April 2020 to gather the local community's perception and preferences for flood management across the identified land uses. Respondents from various demographics and sampling points, either residing or working in the study area, were approached to complete the questionnaire.

During this period, 38 respondents were asked to answer questions divided into five sections based on the study by Sherrouse *et al.* (2011): (1) information regarding each respondent's familiarity with the area, such as when and how often they visited, if they derived any income from the area and their interest level in what happens to the area in the next 10–15 years (i.e. to identify selection bias that might influence how values are weighted and locations are marked on the survey maps); (2) level of concern regarding flood damages on the selected use of the vegetated land use; (3) attitude and preference regarding the use of vegetated land and their priority for flood management, defined by a 5-point Likert scale ranging from

Figure 1 | The location of the Kuala Selangor study area, Malaysia.

1 = strongly favour to 5 = strongly oppose; (4) social values allocation for the selected use of vegetated land; (5) monetary allocation of a hypothetical $100 among the seven social values shown in Table 1. For survey section (5), the respondents were requested to distribute their preference points in increments within the limit of $100 or 100 points based on the importance of each social value. Furthermore, respondents had to mark the locations representing each allocated social value on the land use map, which was later digitised into a GIS layer. For example, if a respondent allocated any dollars to tourism social value, they also had to point on the map at any land use relevant to this social value. The local currency unit was used to reflect the monetary value. The monetary allocation can potentially contribute to trade-off analysis in a relative sense within a specific local context, particularly where various conflicting value layers (i.e. land uses) are combined that would be spatially and quantitatively optimised among management alternatives (i.e. flood management) (Sherrouse *et al.* 2011). The seven main land uses assessed were oil palm plantation, orchard, forest, farmland, park, firefly park and rubber plantation. The spatial and non-spatial responses to survey sections (3) and (4) served as the primary survey data input for SolVES analysis.

3.2. Social Values for Ecosystem Services

The mapped points and their assigned social values from section (4) of the survey were digitised as point features. Data collected from other sections, such as attitudes and preferences regarding uses of the natural lands and their priority in flood management and the monetary allocation of a hypothetical $100 among the seven social values, were separately tabulated in the geodatabase. Each survey was assigned a unique identifier in the SolVES database (Survey_ID) to relate to each other.

Using the mapped point data, SolVES can generate social value maps representing relative values as a spatially explicit 10-point VI. These mapping outputs are derived from the relationship between the point locations and environmental predictor layers. SolVES is integrated with the maximum entropy (MaxEnt) model (Elith *et al.* 2011). MaxEnt is a machine-learning method that compares the location of a set of points to a range of environment layers that are used as predictors to create a mapped surface with values ranging from 0 to 1, representing the likelihood of a value assigned by survey respondents being present in a particular location (Sherrouse *et al.* 2017). As a result, a logistic surface ranging from 0 to 1 is generated, determining locations more likely to have a value assigned to them by survey respondents based on the underlying environmental layers.

The logistic surface describes the relationship between the points and environmental layers. The final output is a social value map, in which the logistic surface associated with a specific social value type is normalised and weighted based on the maximum values from the 10-point scale (Sherrouse *et al.* 2017). A higher VI indicated that the survey subgroup valued a social value more than a VI of 10, indicating that the social value was highly valued at one or more locations. The maximum value weighting was derived from the highest value recorded from a kernel density surface of each social value point. The survey data were also analysed by different subgroups based on whether they favour or oppose a specific land use.

The survey data derived from different subgroups were analysed across the identified social values in this study. The environmental layers included elevation, slope and land use (Table 2). A digital terrain model (DTM) and slope layers

Table 1 | Descriptions of social value types included in the value and preference surveys administered in this study, and as described by Clement & Cheng (2011)

Social value type	Social value description
Aesthetic	I value these land uses because I enjoy the scenery, sights, sounds, smells, etc.
Biodiversity	I value these land uses because they provide a variety of fish, wildlife, plant life, etc.
Cultural	I value these land uses because they are a place for me to continue and pass down the wisdom and knowledge, traditions, and the way of life of my ancestors.
Health	I value these land uses because they improve my feelings, physically and mentally.
Historical	I value these land uses because they have places and things of natural and human history that matter to me, others, or the nation.
Recreation	I value these land uses because they provide a place for my favourite outdoor recreation activities.
Tourism	I value these land uses because they attract tourists from different places.

Table 2 | Environmental data layers included in SolVES analysis

Layer name	Description	Source
Elevation	DTM in metres	SRTM. United States Geological Survey (USGS) Earth Explorer, https://earthexplorer.usgs.gov/
Slope	Per cent slope	Derived from an elevation layer using the ArcGIS Slope tool
Land uses	Seven classes of land uses	Open Street Map (OSM), https://download.geofabrik.de/asia/malaysia-singapore-brunei.html

were analysed as continuous surface grids, while the land use map was categorised into seven types of use. DTM and slope layers were kept as a continuous surface grid, while the land use map was categorised into seven land uses. Such variables provide more precise descriptions of each land use of interest types and locations and enable regression coefficient refinements to consider different factors as predictors (Sherrouse *et al.* 2011).

Weighing survey points by considering the monetary allocation to the social values is optional. The weighted and unweighted survey points were analysed to produce kernel density surfaces for each social value. Survey points with higher monetary allocation would result in greater weightage and produce higher density kernel surfaces. The output cell size was set based on the general rule of thumb, where the cell size is one-thousandth of the dominator on the map scale. The search radius parameter used in kernel density execution was kept default at 10 times the cell size. The buffering function was not activated, as all the survey points were inside the study area's boundary. Values in every cell of the same location were compared among the kernel density surfaces. The maximum values in each cell location were identified and compiled in a single grid. A grid that carried the single, overall maximum kernel density was generated as a 'maximum grid', which was used to normalise the kernel density surfaces (Sherrouse *et al.* 2011). Standardisation was carried out on the normalised surfaces to produce a 10-point kernel density-based VI grid. SolVES then generated a constant grid of maximum value for each VI grid in which MaxEnt was initiated through a batch file.

After the survey points were converted into a comma-delimited file and the environmental layers were converted into ASCII format, MaxEnt generated sets of logistic values for each social value. Area under the curve (AUC) was calculated to indicate the goodness of fit for each social value and the potential performance of the MaxEnt model used in the specific study area in transferring social values to others where primary survey data are not available. The AUC values range from 0 to 1, with 0.7 and above considered acceptable (Hosmer & Lemeshow 2000). VI mapping outputs were analysed based on their zonal statistics for each environmental layer, and a comparison of the magnitude of value differences among and across survey subgroups was conducted. Figure 2 shows the general structure and process flow of SolVES (Sherrouse *et al.* 2011).

4. RESULTS AND DISCUSSION

4.1. Flood-prone land use

Figure 3 portrays the land use prone to flooding in Kuala Selangor as indicated by the flood extent polygon. Orchards are the most significant at 51.3% of the total flood-prone area. Several dwellings can be found amid the orchards, which the villagers

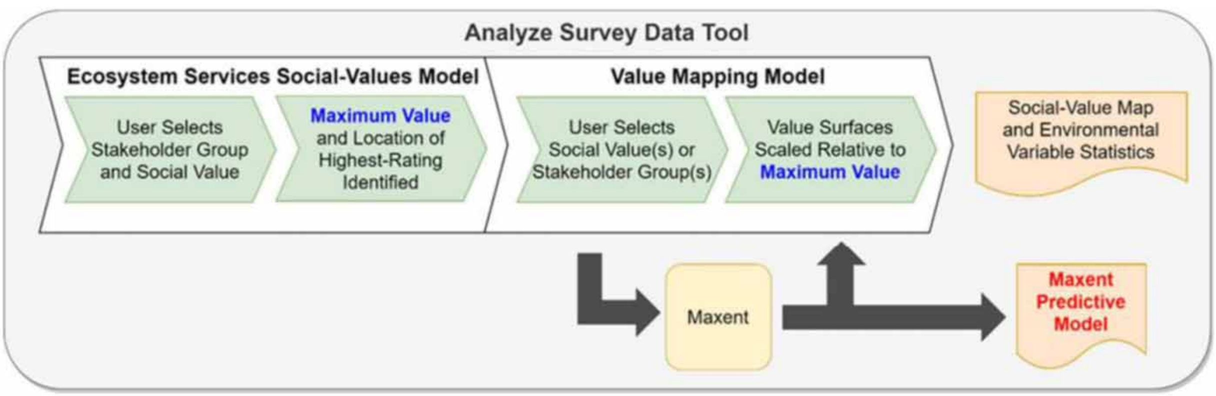

Figure 2 | General process flow of the SolVES modelling framework (Sherrouse *et al.* 2022).

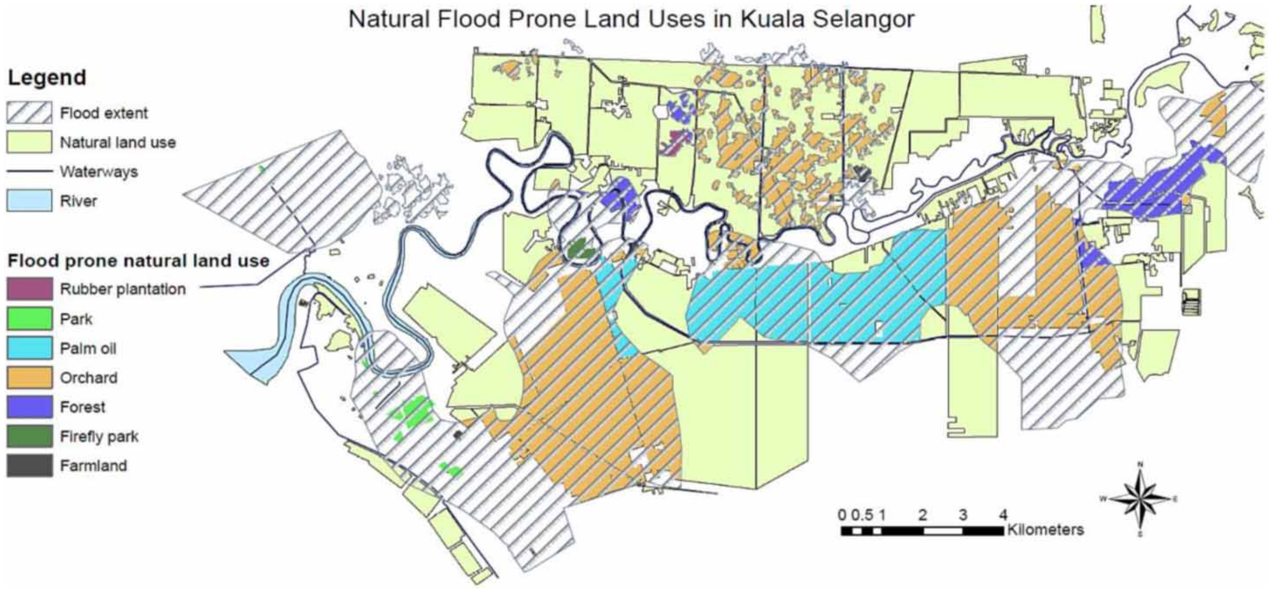

Figure 3 | Flood-prone land use in Kuala Selangor.

manage for various plantations, such as coconut, banana, *durian* and *rambutan*. Within these orchards, it is essential to recognise the coexistence of human habitation and agricultural activities. This multifunctional land use highlights the complex relationship between human settlement and agricultural practices, which can significantly impact flood vulnerability and resilience.

In the middle reach of the Selangor River, a large area of oil palm plantations was identified, comprising 33.7% of the flood-prone area. Oil palm cultivation, a pivotal economic activity in Malaysia, contributes significantly to the country's agricultural output (Dashti *et al.* 2022). The presence of extensive oil palm plantations in flood-prone zones underscores the importance of understanding their susceptibility to flooding and the potential repercussions for both the agricultural sector and the local economy.

In contrast, smaller areas designated as parks are also prone to flooding, primarily concentrated in the western region of the map. Here, population and residential densities are notably higher, reflecting urban development and recreational spaces within the flood-prone landscape. This emphasises the need for strategic flood management and mitigation efforts, particularly in areas where human activities and infrastructure are more densely concentrated (Li *et al.* 2023).

The interplay between various land uses and their vulnerability to flooding highlights the significance of comprehensive flood management strategies. These strategies must consider the diverse factors that influence flood susceptibility, including land use, human activities and environmental conditions, to effectively protect both livelihoods and ecosystems against flooding.

4.2. Distribution and intensity of social value points

From section (5) of the survey, respondents marked points on the land use map corresponding to the social values they had allocated dollars. The social values assigned to each land use were digitised and weighted to different degrees in the kernel density analysis based on the number of points allocated to the land use and the hypothetical monetary allocation assigned to the social values. The monetary allocation to each social value is summarised in Figure 4 with its corresponding number of allocated points. These monetary valuations represent the preferences, priorities, and perceptions of the local community. As such, they provide a critical approach for understanding the community's relationship with the land use and the various ecosystem services it provides.

The monetary allocation was the greatest for tourism and health at 21 and 20% of the total monetary amount, respectively. This aligns with the well-documented role of tourism in contributing to local economies and enhancing livelihoods in regions with diverse natural and cultural assets (Gossling *et al.* 2015). It reflects the economic significance of protecting areas conducive to tourism. The recognition of health as a significant social value reflects an increasing awareness of the link between

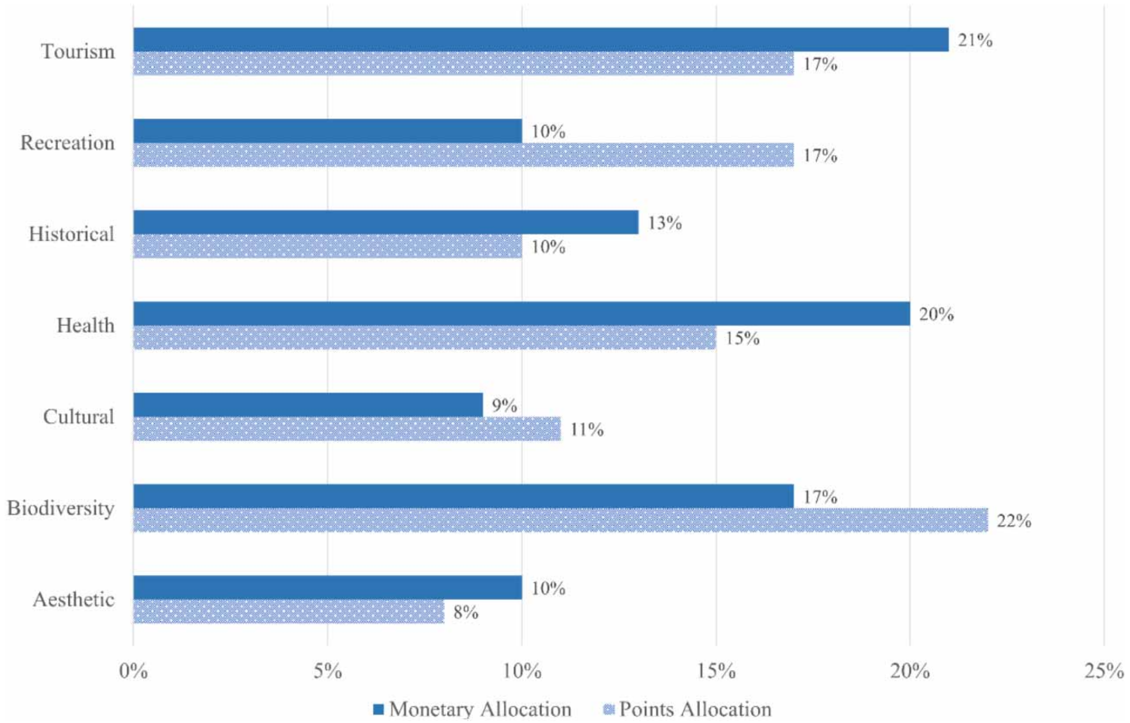

Figure 4 | Percentage of monetary and points allocations for each social value.

natural environments and human well-being (Bratman *et al.* 2019). Proximity to natural land uses can have positive effects on physical and mental health, and this valuation reflects the local community's appreciation of these health-related benefits.

As described by Sherrouse *et al.* (2011), for SolVES-derived results, the survey respondents' attitudes or preferences must be divided into two categories: favouring and opposing flood management prioritisation for each social value and natural land use. This study identified seven land uses, resulting in 14 survey subgroups (favouring and opposing). Table 3 compares the survey subgroups favouring or strongly favouring with those opposing or strongly opposing the land use to be prioritised in flood management. Survey responses with a neutral attitude were not considered for the analysis. Most survey respondents favoured prioritising farmland in flood management, with 74% of total survey respondents. It was followed by forest and firefly park. These results indicated that local communities expect a higher prioritisation for farmland, forest and firefly park in

Table 3 | Comparisons between favouring or strongly favouring with those opposing or strongly opposing each type of land use among 38 respondents

	Favour or strongly favour		Neutral		Oppose or strongly oppose	
Flood management prioritisation	**Count**	**%**	**Count**	**%**	**Count**	**%**
Oil palm plantation	14	37	7	18	17	45
Orchard	15	39	8	21	15	40
Forest	25	66	6	16	7	18
Farmland	28	74	4	10	6	16
Park	16	42	6	16	16	42
Firefly park	22	58	5	13	11	29
Rubber plantation	10	26	11	29	17	45

flood management. In contrast, almost half of the survey respondents opposed or strongly opposed prioritising oil palm and rubber plantations over other land use in flood management, followed closely by the park.

Based on the results (Table 3), most survey respondents (74% of total respondents) favoured prioritising farmland over other land use in flood management. Farmland serves as a source of livelihood for many communities, supplying essential food resources, sustaining rural economies and preserving cultural heritage (Morton 2007). Moreover, vegetated floodplains such as agricultural lands often act as natural flood storage systems, reducing the risk of flooding downstream (Zahidi *et al.* 2018). Recognising the importance of farmland also aligns with the principle of sustainable land management (Critchley *et al.* 2023).

This number was followed by forest and firefly park. These preferences are indicative of the recognition of the ecosystem value of these areas. Forests play a significant role in flood regulation through their capacity to intercept and store rainfall, reducing runoff and flood risk (Zahidi *et al.* 2018). Firefly parks function as ecotourism hotspots, which not only support local economies but also serve as biodiversity conservation areas. The community's inclination towards preserving these natural assets aligns with global trends emphasising the importance of ecosystem-based approaches to disaster risk reduction (Bongaarts 2019).

In contrast, many respondents disagreed with local authorities' prioritisation of palm oil and rubber plantations. Although Malaysia is the second-largest palm oil producer globally, palm oil's benefits may be perceived as more economical. As a result, less concern is placed on the socio-environmental impact of floods on this land use (Cardoba *et al.* 2019). The opposition towards oil palm and rubber plantations may stem from various factors. Palm oil plantations, in particular, have faced international criticism for their environmental impact, including deforestation and habitat loss (Davis *et al.* 2020). The perceived economic benefits of palm oil production may overshadow concerns about its socio-environmental impacts.

There was also no specific preference for the use of land as an orchard or park, with an equal number of respondents expressing agreement and disagreement about prioritising them in flood management. This finding suggests that the community's stance on these land uses may be more balanced and less polarised compared to the preferences for other land use types. The survey results illustrate the complexity of land use prioritisation in the context of flood management. The preferences of local communities, as reflected in the survey, highlight the need for a personalised, community-centred approach to land use planning and disaster risk reduction.

4.3. Value index

The maximum VI obtained for each social value in the weighted analysis is visualised in Figure 4 for each survey subgroup. SolVES generates results using user-related parameters; in this study, a specific natural land use (e.g. oil palm plantation) and an attitude or preference (i.e. favour or oppose). The combination of these defines each specific survey subgroup. Besides tourism, the corresponding land use that attained the maximum VI for other social values was relatively consistent across all survey subgroups. For instance, the park had high recreation and health value, farmland and rubber plantation were most valued for biodiversity, farmland for cultural value, firefly park for aesthetic value and rubber plantation for historical value. For Kuala Selangor communities, oil palm plantation was least valued, especially in terms of aesthetics, which attained a relatively low VI by most of the survey subgroups. Tourism was the only social value with a consistent VI of 10 across all survey subgroups. The natural land use associated with this social value and recognised by almost all subgroups was mainly the firefly park, which indicates the high priority to protect the firefly park against flood risk. According to the subgroups that opposed farmland prioritisation, the park was considered to have the highest tourism value. However, farmland was more valued for tourism for the subgroup that opposed forest prioritisation. Besides tourism, the corresponding land use that attained the maximum VI for other social values was relatively consistent across all survey subgroups. For instance, the park had high recreation and health value, farmland and rubber plantation were most valued for biodiversity, farmland for cultural value, firefly park for aesthetic value and rubber plantation for historical value. For Kuala Selangor communities, oil palm plantation was least valued, especially in terms of aesthetics, which attained a relatively low VI by most of the survey subgroups.

On the contrary, all survey data can be analysed to generate the VIs for each social value regardless of natural land use, attitude or preference. In this case, survey respondents select only the social values they prefer to generate results. Here, survey points with higher monetary allocation would result in higher values, with a maximum value of 10. Tourism attained the maximum VI for the corresponding natural land use of a firefly park, while the aesthetic social value was the lowest. Farmland attained the second-highest VI of 7 for biodiversity after tourism. This result implies that despite the recreation value of the park being more valued than biodiversity, local communities were more willing to invest in preserving and protecting the biodiversity-rich areas from flood impacts. Similarly, the low VI values for cultural and aesthetics indicate that local communities in Kuala Selangor were less likely to spend on preserving these social values.

A comparison of the VIs in Figure 5 showed that firefly park, park and farmland were considered highly valued. They are indirectly linked to greater intensity of human activities (van Riper *et al.* 2012). Biodiversity, health and tourism have on average, higher VIs. Tourism had the highest value in Kuala Selangor compared to other social values out of the three. In relation to this, priority areas can also be defined where firefly park was considered the most highly valued land use due to its high tourism value. Incidentally, the firefly park is one of the most famous tourist attractions in Kuala Selangor and brings thousands of tourists annually (Nadirah *et al.* 2020). In addition, as recorded by several subgroups, firefly park has a widespread appreciation due to its ability to provide other social values, such as aesthetics, cultural and recreation. Hence, firefly park should be prioritised in flood management efforts, such as river restoration or deepening, to reduce the flood risks to these lands.

Social values will differ in other locations and communities based on the relationships with the study area, its conditions and land use (van Riper *et al.* 2012). In contrast, according to a study by Meijaard *et al.* (2013), Borneo villagers who earn their incomes from forests regard these areas as having high cultural and health benefits. For the Kuala Selangor communities, oil palm plantations had the lowest value especially in terms of aesthetic value. However, this value attained a relatively low VI for most survey subgroups and may be related to the insignificant utility of this benefit.

The calculation of VI can direct the management's attention towards the lands based on their use. The prioritisation particularly applies to lands with high biodiversity and tourism social values, which were perceived as the most significant value by most survey subgroups. This perception is not surprising, as 10% of the tourism in Malaysia is derived from ecosystem-related locations and activities (Mohd Shahwahid *et al.* 2016). These data can potentially facilitate local authorities in making decisions on flood management, which should include flood mitigation measures in the priority areas. These areas include the firefly park, eco-resorts or preserved forests open to visitors.

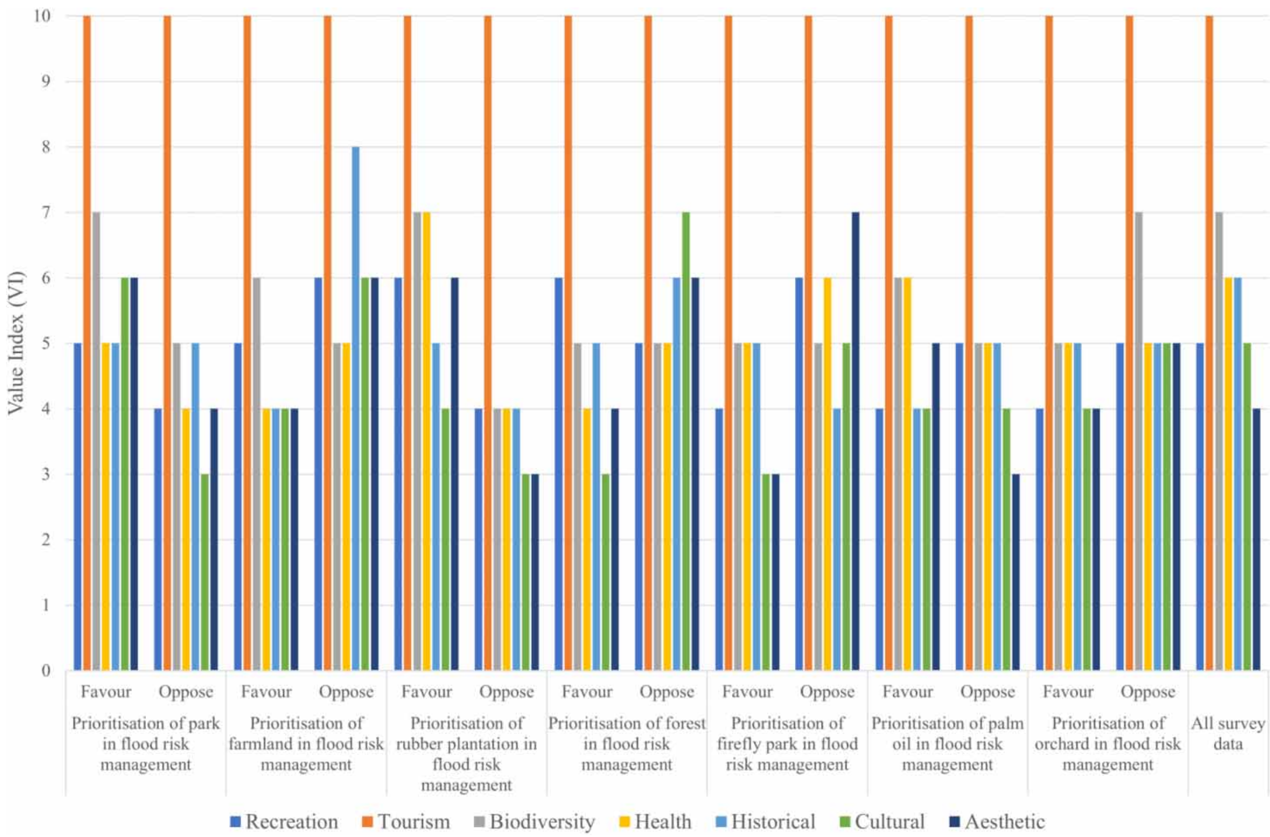

Figure 5 | A summary of the maximum VI attained for each survey subgroup and social value type. *Note*: Values are for all survey data regardless of natural land use, attitude or preference.

4.4. Social value maps and environmental metrics

The social value map displays the range and extent of the VI in the study area for tourism, which was the most valued social value by all survey subgroups. The social value map and its integration with environmental metrics provide valuable insights into the complex relationship between the perceived social values of land use and the physical environment. The emphasis on tourism aligns with the recognition of rural tourism as a significant contributor to local economies and community well-being (Rosalina *et al.* 2021). It underlines the need to preserve and manage areas conducive to tourism, thereby ensuring sustained economic and social benefits.

The environmental metrics are displayed as graphs on the right of the social value map. These metrics provide a generalised statistical description of the relationship between VI and the physical environment. Space and place relative to the social value and the value perceived by the survey respondents can be visually assessed for the social value map. According to the social value map, the maximum VI of 10 was spread across firefly park and farmland. The VI vs land use type in Figure 6 show firefly park and farmland with VIs of approximately 10 and 9.8, respectively, for tourism. The derived results also considered other environmental layers, such as elevations and slopes, where the correlations between VI and elevations were negative. The slope statistics graph revealed that VI did not significantly vary.

VIs changed with location across the study area (Figure 6). The analysis generally indicates that areas of higher elevations or steeper slopes are less valued. Therefore, the northern part of the firefly park, consisting of higher elevations and steeper slopes, has a slightly lower VI. At the same time, the forest on the western side of Kuala Selangor was valued higher than on the eastern side. This observation may be due to the lower elevation on the west side of the downstream river. Likewise, oil palm plantations and orchards in the middle of the river show a decrease in elevation and slope towards the river. This similarly resulted in a higher VI for areas closer to the river. Overall, local communities favour areas with lower elevations and flatter slopes, so decision-makers should prioritise their flood mitigation measures or investments within such areas. This

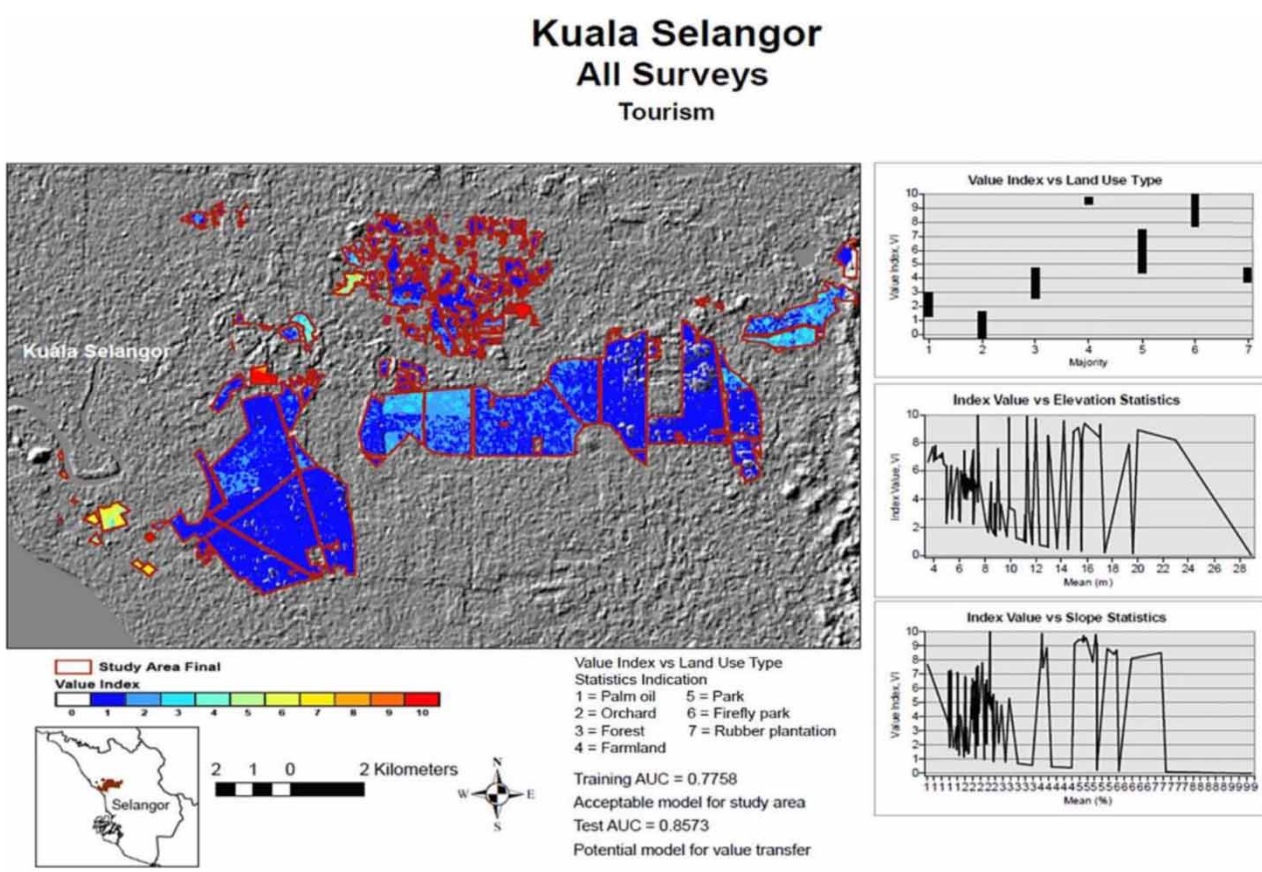

Figure 6 | SolVES output showing the tourism social value type map and environmental metrics for the survey subgroups in Kuala Selangor.

trend is in line with research indicating that recreational activities and tourism tend to thrive in flatter and lower-lying areas (van Riper *et al.* 2012; Sherrouse *et al.* 2014). The preference for areas with lower elevations is likely driven by factors such as accessibility and safety.

In these studies, recreational activities were more favourable in places with lower elevations and flatter slopes. The slope statistics graph in Figure 6 demonstrates that VI does not vary significantly across the slopes, except for a minor reduction of VI when the slopes were increased from 1 to 3%. This suggests that a flatter terrain is generally favoured, but within a reasonable range of slopes, social values are not significantly impacted. This understanding can guide land use planning, especially in areas with varying slopes, ensuring that recreational opportunities are not completely compromised due to flooding.

The generated geospatial representation of flood-prone land use contributes to integrated flood management in facilitating decision-makers to evaluate the trade-offs among their social values. Such evaluations are done by considering the social values of land use when prioritising flood mitigation measures or investments. This approach aligns with the principles of integrated flood management, which emphasise the importance of considering ecological and social aspects in addition to technical and engineering solutions (WMO 2009).

5. CONCLUSIONS

This research provided valuable insights into the complex issue of flood management with a case study in the flood-prone region of Kuala Selangor, Malaysia. This study demonstrated how SolVES is a valuable and effective method for quantifying and weighing social values in considering natural land use in decision-making. The findings from the case study indicate that SolVES provides a practical framework researchers, decision-makers and stakeholders to explicitly measure and portray the local relationships between social values, the attitudes and preferences linked to these values, and the environmental attributes, locations and associated ecosystem services that elicit these values. This approach was done by computing and mapping the relative social values of land use as local stakeholders perceived. The findings identify areas that should be prioritised and integrated into flood management based on the higher social values. The existing research gap in current flood management can be addressed by providing quantitative and spatially explicit information about social values in flood-prone land use.

The research has identified orchards as the predominant land use prone to flooding in Kuala Selangor, followed by oil palm plantations. Farmland emerged as the preferred land use for flood management, reflecting strong support from the local community. Conversely, oil palm and rubber plantations were met with opposition.

The study revealed that social values related to tourism, health, and biodiversity received the highest monetary allocations from survey respondents, signifying their critical role in flood management decisions. The firefly park, a renowned tourist attraction, consistently held the highest social values, emphasising its importance for protection against flood risks. The VI, calculated through SolVES, uncovered areas with varying degrees of social values in the study area. Elevation and slope were found to influence the VI, with lower elevations and flatter slopes associated with higher social values. By taking into account both the societal and physical contexts of values tied to ecosystem services, this application can enhance efforts to incorporate publicly held values into the decision-making processes of land and resource managers, even in situations where primary data about these values may be limited. It can also facilitate communication among decision-makers and various stakeholder groups with diverse interests related to the actual and perceived trade-offs among ecosystem services and their locations.

However, it is essential to acknowledge the limitations of the current work. The face-to-face survey method employed in this study may introduce biases in the data collected, and the sample size may not fully represent the diversity of opinions and preferences within the local community. The findings of this research are specific to the study area of Kuala Selangor and may not be directly transferable to other regions with different socio-environmental contexts and land uses. While the study successfully quantified social values, the use of hypothetical monetary allocations for these values may not fully capture the complex and multifaceted nature of societal preferences.

In conclusion, this research contributes to our understanding of the role of social values in flood management decision-making. The SolVES framework has proven to be a valuable tool for incorporating non-monetary value data into the decision-making process. Future research efforts should consider addressing the limitations of this study, exploring the integration of monetary and non-monetary value data, and expanding the application of the SolVES framework to different regions and contexts to enhance flood management strategies and resilience.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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