



Original software publication

PPGISr: An R package for Public Participatory GIS

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ABSTRACT

In this paper we present PPGISr, an open source R package for Public Participatory GIS (PPGIS). The online Shiny application and customisable R function enables capturing and using spatial information for participatory planning processes and scientific inquiry. With functionality to add a user-defined editable map, basemaps and mapping categories, the application is highly flexible for guiding decision-making in diverse contexts. Moreover, online functionality reduces time and cost barriers to participation through synchronous and asynchronous engagement. While there are numerous user-friendly decision support tools based on GIS, PPGISr adds novel functionality for the collection and analysis of users' location priority areas.

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Current code version	1.0
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-23-00109
Permanent link to reproducible capsule	
Legal code license	MIT License
Code versioning system used	Git
Software code languages, tools and services used	r, shinyapps.io
Compilation requirements, operating environments and dependencies	
If available, link to developer documentation/manual	https://github.com/GLISA-umich/PPGISr
Support email for questions	dbvanber@umich.edu

1. Motivation and significance

Public Participation Geographic Information Systems (PPGIS) refers to spatially explicit methods for capturing and using spatial information in participatory planning processes, decision-making, and scientific inquiry [1–3]. PPGIS has been used to identify participant preferences for future land use and management [4], pinpoint valued locations for conservation [5,6], and design urban landscapes [7,8] among other applications [9–11]. The medium by which spatial preferences are collected varies from paper maps [12,13] to online digital interfaces [8,14]. Paper maps have the advantage that there are few barriers to use, as they are relatively easy to obtain for a specific area of study, and there are low technical hurdles for participants to indicate their preferences through sketching on the map. The advantages of digital

approaches to PPGIS include access to online maps throughout the globe that can be easily used as reference for the planning process, the ability to include multiple basemaps that can be interactively viewed for enriching discussions of planning priorities (e.g., projection of future floods for stormwater management planning), and the ease with which individual preference maps can be compared and analysed with common mapping frames. There is also increasing anticipation that digital forms of PPGIS can enable online synchronous and asynchronous engagement, reducing barriers to engagement and possibly broadening representative participation in public planning [7,8]. However, to date there are few user-friendly open source tools for implementing PPGIS online, and filling this gap may enhance our capacity to pursue spatially explicit decision-making.

The numerous benefits of PPGIS have been extensively studied. Researchers have noted its ability to increase broad-scale engagement and buy-in by representing geographies and spaces of “personal salience” for engaged participants [15,16]. Studies have

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also found that it offers the ability to frame and guide decision-making and dialogue through the visualisation of exploratory maps (e.g., aerial photography, climate projection) including thematic information of interest [16,17]. As participants interact with provided data, their discussions and sketches are imbued with their own sense of how things work. This is known as the ‘empowerment functionality’ of PPGIS in which local or indigenous technical and spatial knowledge is regarded as equally legitimate as that of ‘experts’ [18]. PPGIS outputs are also highly policy-relevant as they fit formalised methods for spatial planning [17], when compared to normative deliberations (i.e., mind-maps, scenario narratives) that are less translatable to actions and outcomes due to their lack of spatial specificity. Moreover, the power of combining spatial data with stories from constituents has proven particularly persuasive for policy-makers [19].

However, PPGIS applications are often developed on a case-by-case basis, and as a result tend to be experimental, small-scale and underused [5,19,20]. Challenges to its broader uptake include accessibility issues related to: (1) cumbersome workflows in existing GIS software that prevent non-experts from implementation; (2) financial and resource costs of application setup; (3) lack of flexibility when applied to various locations and scales; (4) absence of intuitive data collection functionality; and (5) few resources for rapid analysis of priority maps. While there are numerous open source GIS and proprietary software for visualising spatial data, these require advanced technical training to visualise and manipulate data. This prevents non-experts from successfully applying these tools for expressing their priorities without training or technical aid [19]. While there is an active community developing spatially explicit and user-friendly decision support tools for these platforms, these do not include functionality that would allow users to add their own priority areas to the map [21,22]. User-friendly GIS platforms including uMap [23], Google Earth, and Open Data Kit (ODK) [24] offer this functionality, but would require developing additional workflows and protocols in order to collect user’s spatial-explicit priority areas with ease. Moreover, there is less flexibility to add a “decision layer” for collecting responses that are comparable (e.g., census tract). Purpose-built PPGIS software including Maptionnaire have been widely used in academic research [14,25]. However, this is proprietary software that requires a subscription plan, increasing financial barriers to its use.

In this study we present an R package and an online Shiny website called PPGISr to fill this accessibility gap. The R environment is fully open source and freely available for all users [26]. Moreover, it offers libraries for making dashboards that can be displayed on the internet. With the application, we aim to (1) reduce barriers to collecting geographically explicit information from diverse participants in planning and research contexts; (2) offer those wishing to implement PPGIS the ability for regional and thematic customisation that fit their decision context and inquiry needs; and (3) cut down on challenges in analysis of PPGIS results by giving access to the wide array of spatial analysis and statistical tools available in the R environment.

2. Software description

2.1. Overview

The ‘PPGISr’ R package has been created for use within the R environment [26]. The functions use the Leaflet [27] and Shiny R packages [28] to create an interactive visualisation of a location on the globe. The package captures and organises the results from a user-defined map and respondents’ spatially-explicit choices in a standard R “simple feature” format [29]. We also provide an online user-friendly version of the application that requires

no prior coding knowledge to deploy (<https://derek-van-berkel-shiny.shinyapps.io/PPGISr/>).

For both environments (R package and web-interface), respondents can allocate different categories (e.g., greenspace, urban improvement). Category-preferences are made by pointing and clicking on an interactive map. Categories can be predefined or added by the respondent as deemed necessary (online version only). An editable map layer of spatial polygons (i.e., vector; e.g., census tract) must be supplied by the user. Given that obtaining spatial data is becoming increasingly accessible with rudimentary knowledge of GIS, the software can be parameterized with minimal challenge. This allows specifying priorities that fit the planning or research scale of interest (e.g., vector representing local neighbourhoods, or a regular tessellation that captures finer scales; i.e., 50 m * 50 m), and enables comparison of geographic allocations across individual responses. Both versions include the option to visualise user-defined spatial data interactively. Users can explore thematic information at local, regional and larger scales by turning these map layers on and off and zooming in and out, to help specify location categories/priorities. After their preferences have been allocated, users can use the interface to download the derived data layer, and/or export a screenshot of the choice-map.

2.2. Software architecture

Spatially-explicit choice-classes are registered using a radio button and “map clicks” at the Shiny UI, and received for visualisation and collection at the server. These choices are visualised at the UI with category-specific shading on the chosen “editable map.” Shading colour palettes and corresponding categories can be defined by the user, or by using default settings (maximum of 9). Users can define one vector or raster basemap for interactive viewing. The package also includes several additional base layers (i.e., remotely sensed images, reference maps) that can be toggled along with the user-provided data [27]. The editable map is updated with a SELECTED column where choices are recorded that can be downloaded at the UI. If a spatial-vector is chosen as a basemap, a drop-down is populated with the numerical variables of the dataset, giving the user the option to view the user-defined basemap variables as a choropleth map.

We also provide an online version of the library that includes informational prompts to guide users on how to implement the tool (Fig. 1). For ease of use, the UI handles the upload of a user-defined editable map and a basemap for interactive exploration (i.e., vector or raster datatypes), as well as the definition of choice-classes using an input text box. Adding these map layers is done via an interactive local directory prompt, but there are limitations on the size of data that can be uploaded (i.e., file size larger than 3.5 MB). The different basemaps are controlled by a radio button allowing respondents to choose between them. In both versions, users can download the resulting spatial vector files for use in other GIS applications, and a screenshot of their choices with accompanying legend of categories with corresponding shading.

2.3. Software functionalities:

The ‘PPGISr’ R package allows users to deploy a UI for collecting spatially explicit category-choices (e.g., defining properties for conservation, development) on an interactive map. The `run_app()` function is used to deploy PPGISr in the R library version of the application. Users can define an `editable_map` where preference choices are made, a `base_map` that provides the user with the ability to view different measures (e.g., vulnerability to flooding, social inequity), define prioritisation `mapping_categories`

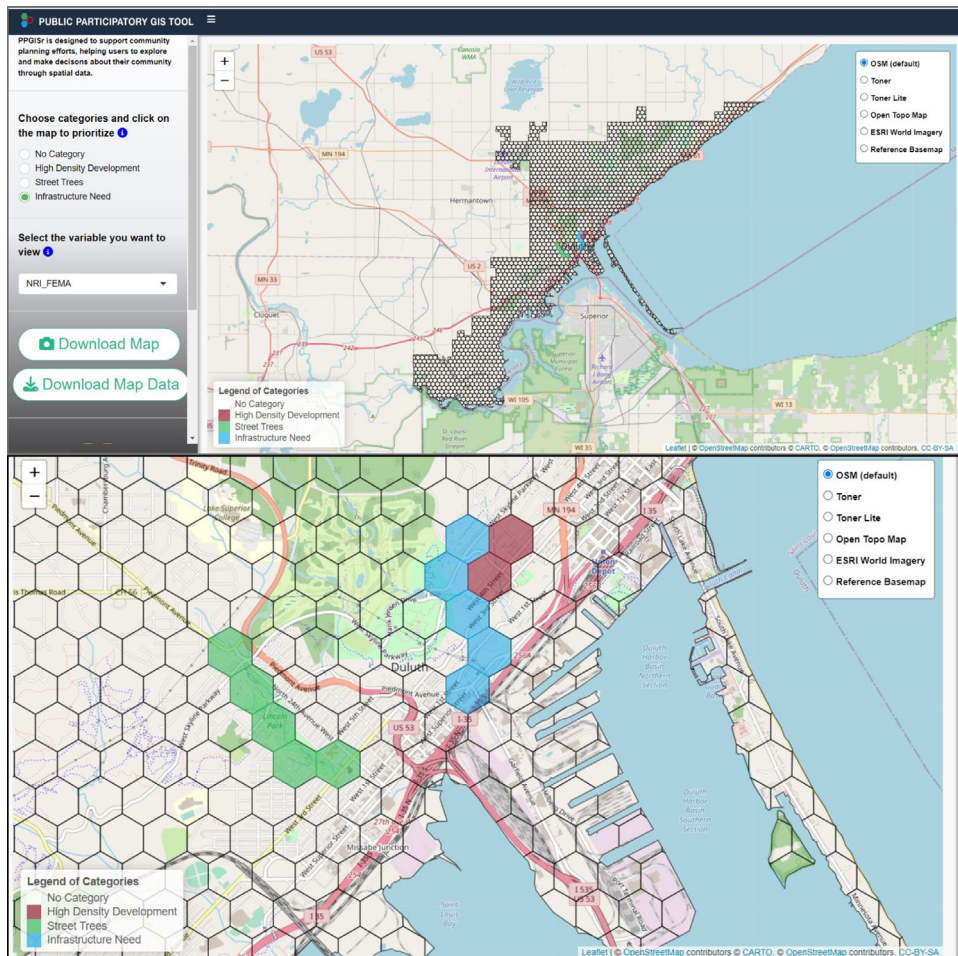


Fig. 1. UI of PPGISr deployed with the R package using the default planning scenario options for the city of Duluth, Minnesota. Top: View of full study extent using a 100 foot hexagonal shape for the decision making frame; bottom: allocation of categories of High Density Development, Street Trees and “Infrastructure Need” (the services needed to accommodate an influx of new residents e.g., public transportation, trash service) for the downtown area.

(e.g., greenspace, infrastructure need), and an associated `mapping_colors` palette for these categories. There is also the option to define the name of the user-defined basemap for the UI using `basemap_name`, and to add additional instructional text in the form of information pop-ups for the `editable_map_info_icon_message` and `basemap_info_icon_message`.

- `run_app()`: define a UI for collection of spatially explicit responses.

Input

`editable_map`: a vector file (e.g., multipolygon, polygon);
`base_map`: a vector (e.g., multipolygon, polygon) or raster (i.e., tif) file;
`basemap_name`: the legend name given to your imported basemap;
`mapping_categories`: a vector of names for mapping categories options (i.e., “Trees”, “Flowers”, “Water”);
`mapping_colors`: a vector of colours corresponding to the vector of names (i.e., “green”, “red”, “blue”);
`editable_map_info_icon_message`: character string of the message for the editable info button;
`basemap_info_icon_message`: character string of the message for basemap info button

Output

- simple feature (e.g., shapefile, geopackage) of the locations of category choices, image of final choice map

2.4. Sample code snippets analysis

PPGISr is deployed using the `run_app()` function. This includes default data for users to explore application functionality.

```
## Install the library from GitHub
library(devtools)
install_github("https://github.com/GLISA-umich/PPGISr")

## Run the application
PPGISr::run_app()
```

Here, we demonstrate how to add categories using the `mapping_categories` variable (e.g., categories of land cover you would like to map).

```
## Customise the mapping categories using a vector of characters
PPGISr::run_app(mapping_categories = c("Trees",
                                       "Flowers",
                                       "Water"))
```

Mapping categories can be accompanied by a corresponding colour palette using the `mapping_colors` variable.


```
## Vectors of categories and colours must be of the same length
PPGISr::run_app(mapping_categories = c("flowers", "lake", "trees"),
  mapping_colors = c("green", "red", "blue"))
```

Add your own editable map using the `editable_map` variable. This requires uploading an appropriate spatial vector (e.g., shapefile, geopackage) that can be read using the `sf` package.

```
## We recommend using the sf library to load spatial vector data
library(sf)

## Spatial data default to the World Geodetic System 1984 (WGS84) ##
coordinate_reference_system(crs)
editable_map <- st_read(system.file("shape/nc.shp", package="sf"))

PPGISr::run_app(editable_map = editable_map, base_map = NULL)
```

3. Illustrative examples

3.1. Climate adaptation planning

Cities in the Great Lakes (GL) of the United States are increasingly vulnerable to climate-related impacts and socioeconomic stressors, in particular extreme precipitation events that lead to flooding in coastal communities [30]. There is growing evidence that these stressors will become more severe, and critically reduce the effectiveness of existing, often ageing, stormwater infrastructure. Planners are increasingly aware of their vulnerability to climate impacts while simultaneously grappling with broader challenges of urban renewal and stormwater planning due to climate-driven lake level variations and possible climate-driven in-migration to the GL region [31], both of which could exacerbate existing problems such as pollution, failing infrastructure, economic downturn, social inequity, and health hazards. There is also increasing awareness that planning prioritises already privileged groups and entrenched interests, leading to adaptation inequities [32], such as targeting marginalised communities for relocation or prioritising green infrastructure investment in affluent neighbourhoods. Developing accessible tools for long-term, sustainable, and just city planning is part of the Great Lakes Integrated Sciences and Assessments' (GLISA) latest plans for strengthening climate science and decision making capacities for GL communities [31].

PPGIS is being deployed in 5 cities throughout the GL to support their efforts to understand, plan for, and respond to climate and equity impacts now and in the future. In each city, community workshops will guide practitioners and community members in prioritising spatially explicit adaptation measures using PPGISr. Including both decision-makers and city residents in these discussions aims to increase the diversity of voices on important themes including identifying areas for densification, and the need for green intervention. Moreover, these discussions will be enriched with maps visualising locations of climate stressors (e.g., urban development projections, flooding areas) and data on themes of interest for city practitioners and the community (e.g., planting trees for city cooling, green stormwater infrastructure, densification of neighbourhoods), that will aid in weighing current interests with future needs. PPGISr is adaptable to the technical expertise of the different cities, allowing those with access to additional data layers to incorporate them. Our pilot programme is focused on the city of Duluth, Minnesota, which is deliberating how to accommodate a possible influx of climate migrants in the future, and the associated broader issues of urban sustainability and livability in the face of climate change. To help answer these questions, workshops will be held to solicit feedback about possible housing densification within the city, and priorities for street trees (Fig. 1).

3.2. PPGIS in a small island developing state

The Republic of Seychelles is a small island archipelago with a population of just under 100,000 people. Its location in the West Indian Ocean means that it is subject to increasing climate threats, including sea level rise, coral bleaching, more intense precipitation during monsoon season and the greater possibility of storm surge and flooding [33]. Given its precarious status as a high-income country and its socialist government structure, it often struggles to qualify for development aid or fund its own adaptation projects, and instead relies on sporadic external funding. This lack of reliable capacity also means that Seychelles suffers from data scarcity, as downscaled climate data is difficult and costly to model at the national scale; adaptation decision-making is often undertaken by non-Seychellois consultants who (intentionally or not) gatekeep data and do not attempt to integrate their work with other projects; government departments that are siloed and spread-thin are unable to effectively synergise their policies and resources, or even maintain current datasets [33,34]. PPGISr offers a way to both supplement Seychelles' data scarcity and visually reconcile its "patchwork" of climate, demographic, and adaptation project data in a way that enables synergistic decision-making.

PPGISr will be deployed in a workshop in early 2024 with government officials from the Seychelles Ministry of Agriculture, Climate Change and Environment (MACCE), which encompasses several relevant departments. Two research teams have conducted preliminary meetings/workshops with government officials from MACCE to understand which forms of data and visualisation would be most useful in adaptation decision-making. The 2024 workshop will allow officials to make spatially-informed adaptation decisions in a cohesive manner, crossing departmental silos to best leverage the country's adaptation resources. The workshop will centre on facilitating strategic climate adaptation by aggregating climate, socioeconomic, landscape and previous project data to create a holistic GIS-based decision support tool, and allowing government officials to "map out" future adaptation plans based on available resources and preferred strategies (Fig. 2).

4. Impact

PPGISr is a powerful tool that reduces barriers for participatory engagement, and includes functionality that can be applied in diverse research contexts, potentially catalysing yet to be revealed research inquiry. Researchers in spatial fields of study, and other community engaged scientists and users will benefit from the ease with which it can be deployed to ask spatial questions of the public. The ability to add user-defined basemaps for decision making and thematic layers gives it tremendous flexibility for numerous applications. Within community engagement research it can potentially be used to: (1) enfranchise the public through formalised democratisation of decision-making [35], (2) tap into the considerable knowledge, labour, and skills from the public to benefit and complement scientific research, (3) capture and analyse stakeholder management preferences in practical and efficient ways [6], and (4) attend to the plurality of knowledge of different stakeholders [36]. Applications outside of engaged research (e.g., spatial planning) include ground-truthing of remotely-sensed images, crowdsourcing urban flooding hazards for improving infrastructure targeting, and eliciting spatially explicit knowledge on the movement of wildlife from experts, to name a few. The inclusion of informational basemap layers presents unique opportunities for the setup of experiments based on dynamic contextualisation of the information presented. For example, a survey collecting desired locations for

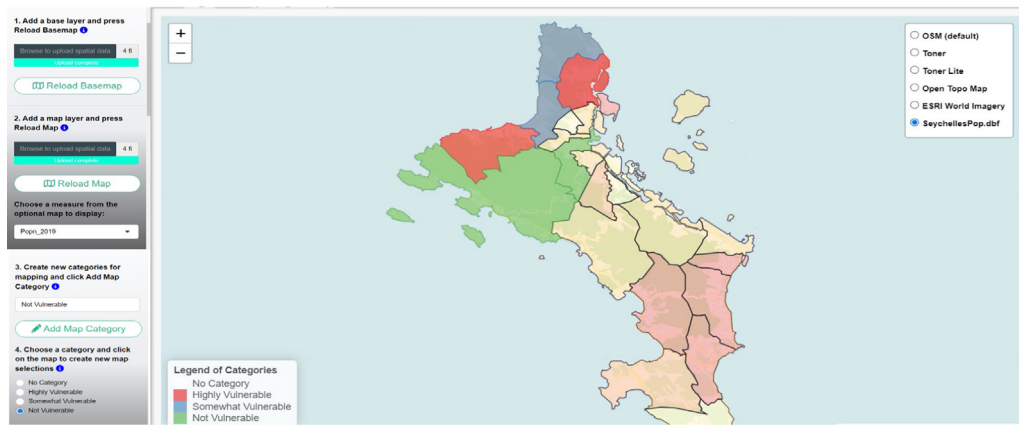


Fig. 2. UI of PPGISr deployed with The Republic of Seychelles. In this scenario, stakeholders are using the online PPGISr tool to plan for vulnerability in the face of climate change. They have added a district editable map, a population basemap, and categories of different vulnerability (Highly, Somewhat, and not Vulnerable).

additional greenspace in a municipality could randomly provide half of the respondent with information on social vulnerability (or another equity-related index) to gain insight into how equity-related considerations affect individual priorities for urban greening.

Given the ease with which it can be deployed online, and the ease with which the data can be downloaded, PPGISr can potentially substitute other GIS software in the task of collecting and documenting spatial information as it is less laborious and more user-friendly than these options. Although existing platforms offer functionality for documenting/prioritising spatial units on a map (ArcGIS, Maptionnaire), they require a licence for use. Existing open-source options (QGIS) do not have a streamlined function for this task and require involved workflows for collecting and analysing this spatially-explicit information. By exporting selections in a common GIS data format, PPGISr enables researchers to collect spatial responses that can easily be integrated into multiple statistical and geospatial workflows.

An advantage of PPGISr is that the editable map is structured around regular geographic units which is convenient for analysis and comparison amongst diverse respondents. However, constraining responses to these regular units could stifle planning discussions and applications that require placing points, and irregular lines and shapes. A future goal should be to add a free form sketch tool for more diversity in its application. The use of regular geographic units also creates computational limitations in the number of mapping units possible for the editable map. Tradeoff between the desired number and resolution of spatial units and the spatial extent of decision-making area will need to be weighed for successful deployment (i.e., lagging response time, timed out from the online server). Future development will attempt to increase computational efficiencies for better spatial scalability. Finally, the authors recognise that despite reducing barriers to applying PPGIS considerably, PPGISr still requires knowledge on how to manipulate and collect spatial data for the editable map and basemap. Future iterations of the application could solve this technical hurdle by automating the development of the editable base through the online interface. Users could be prompted to add a location, and desired size for the regular geographic decision unit for automatically populating the editable map.

5. Conclusions

The PPGISr software increases accessibility of PPGIS, a powerful approach for capturing and using spatial information in participatory planning processes, decision-making, and scientific inquiry. By providing an online PPGIS tool and an R package that can

be further customised to a region and theme of interest, PPGISr reduces barriers to implementing PPGIS, and has the potential to catalyse research inquiry beyond the intended participatory planning application of its initial intent. Its online functionality and customizability could transform the capacity of cities, regions, sectors and communities to pursue decision-making in a spatially explicit manner.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Derek Van Berkel reports financial support was provided by National Oceanic and Atmospheric Administration. Derek Van Berkel reports a relationship with National Oceanic and Atmospheric Administration that includes: funding grants.

Data availability

All data is included in the R package

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