VNC analysis tool manual

Software version 1.0

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Introduction

This manual provides an introduction the the VNC analysis tool and how to use it. The VNC analysis tool is software developed in R for creating and processing Visual Neighbourhood Configurations (VNCs). The tool has an easy-to-use visual user interface, and no prior knowledge of R is required.

The VNC approach was first introduced in the following paper, the software and this manual were created to supplement this paper:

Brughmans, T., Garderen, M. van, & Gillings, M. (in press). Introducing visual neighbourhood configurations for studying visual properties of landscapes. *Journal of Archaeological Science*.

What are Visual Neighbourhood Configurations?

Visual Neighbourhood Configurations (VNCs) is an approach to formally expressing hypotheses about the way in which a particular visual property structures space in a small area. A VNC specifies the size and shape of the surrounding area (i.e. the neighbourhood) that is taken into account when analysing a specific location. A structure, subdividing the neighbourhood into smaller areas for which different visual properties are assumed, and expected visual property values for specific locations within the neighbourhood can also be incorporated in the VNC to explore more complex assumptions. Subsequently a total viewshed of the study area can be analysed with respect to the VNC, computing for each location a value that reflects the visual properties of the neighbourhood. Archaeological assumptions can then be evaluated by comparing the resulting values of the locations of known settlements or other archaeological features to those in areas where no such features are located.

What are total viewsheds?

The VNC approach uses total viewsheds as its input data. A total viewshed is a raster where the value associated with each cell represents the count of other cells from which it is visible, or the opposite (the count of cells that it can notionally 'see'). This raster is created using line-of-sight or viewshed tools in GIS software like QGIS, GRASS or ArcGIS, typically by evaluating whether a line-of-sight between each pair of cells in a Digital Elevation Model (DEM) is not disrupted by the topography represented by the DEM (for more on total viewsheds see Gillings 2009; Lake et al. 1998; Llobera 2003; Llobera et al. 2003). Recently such total viewshed approaches have been used creatively to represent specific theories rather than visibility from everywhere to everywhere in a landscape (e.g. Eve and Crema 2014; Gillings 2015). For example, one can use them to explore the interplay between incoming and outgoing lines-of-sight, or the total viewshed can be used to represent visibility from a subset of the cells in the DEM to another subset (for example, from all sea-based cells to all land-based cells). The VNC analysis tool can be used with both these more focused and traditional total viewsheds.

The software download folder includes an example total viewshed raster (see below).

What you need to get started

The software download folder includes this manual and example data. In addition to this you will need to install RStudio and a set of R packages (see next section). An internet connection is only necessary to download the software and install the R packages, but not for using the VNC analysis tool itself.

1) Download the VNC analysis tool zipped folder from Github: https://github.com/mvgarderen/vnc-tool/blob/master/VNC_app_v-1.0.zip
2) Extract/unzip the zipped folder and move it to your preferred working location.

This folder includes the following files:

- R scripts to run the software: 'computation-functions.R', 'input-functions.R', 'navigation.R', 'output-functions.R', 'package-installer.R', 'server.R', 'ui.R' (and the 'www' folder).
- A folder named 'output' where the software outputs its results and log.
- A folder named 'example_data' including: two example total viewsheds 'views_to.asc' and 'views_from.asc', an example neighbourhood mask 'mask.txt' and an example expectation table 'expectation.txt'
- This manual: 'VNC_tool_manual_v1.0.pdf'

Installing RStudio

The VNC analysis tool runs in RStudio, an integrated development environment for R. An open source edition is freely available for download. Please note: you will need to have a working installation of R on your machine in order to use RStudio.

1) Go to the RStudio website.
2) Navigate to the RStudio Desktop downloads page.
3) Select an installer for your operating system (Mac OS X, Windows, Linux) from the list under 'Installers for Supported Platforms'.
4) Run the installer.
5) Open RStudio.

Installing and opening VNC analysis tool

Running the VNC tool is a two-step process: 1) install the R packages it uses, 2) open the tool's user interface.

1) The R script 'package-installer.R' is included in the VNC tool folder that automatically installs all R packages that the software uses: shiny, reshape2, ggplot2 and markdown.
   a) Open 'package-installer.R' in RStudio (File > Open File …).
   b) Run this file by selecting all of it (press CTRL + A) and then pressing CTRL + ENTER (Fig. 1).

   This file will check which of the required packages are installed already and will proceed to only install the missing ones.

   Note that an internet connection is necessary to install these packages.

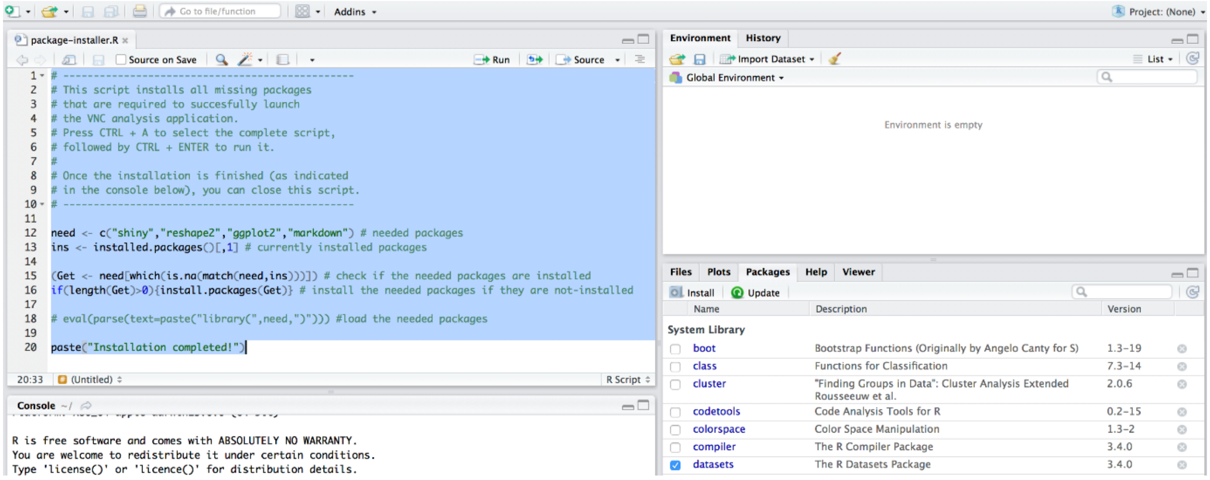


Fig. 1. Select the entire contents of the 'package-installer.R' file.

2) Once all required R packages are installed you can open the VNC analysis tool user interface.
   a) Open 'ui.R' in RStudio (File > Open File ...).
   b) Make sure that 'Run in Window' is selected from the menu that appears when clicking the small downward arrow next 'Run App' (Fig. 2).

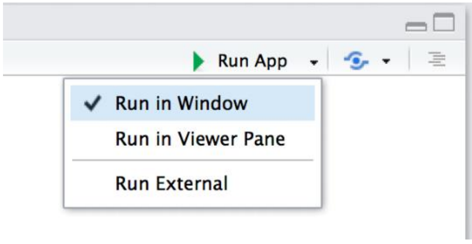


Fig. 2. Make sure 'Run in Window' is selected.

c) Click the green arrow next to ‘Run App’.

The VNC analysis tool user interface will now appear in a separate window (Fig. 3).

Do not close the ‘ui.R’ file or RStudio at any point when using this tool.

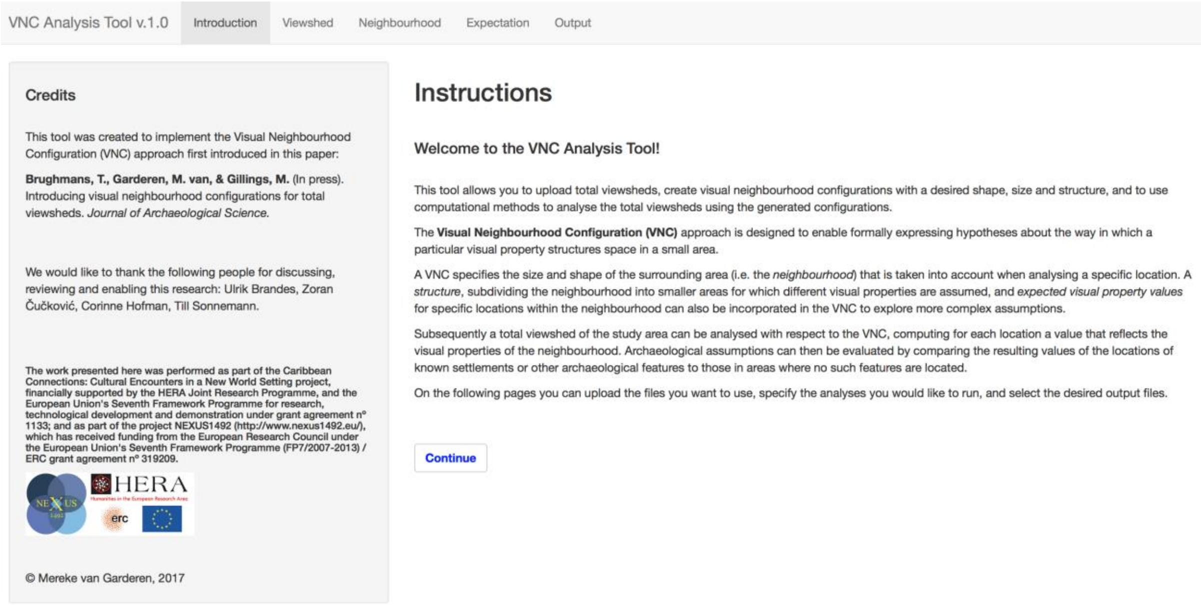


Fig. 3. The VNC analysis tool interface.

Analysis time

Computer hardware aside, the time it takes for an analysis to finish is dependent on four factors: the analysis method, the number of methods used, the neighbourhood size, the research area size.

The most crucial factor is the research area size: the larger the input total viewshed, the longer the analysis. Depending on the other factors, small research areas (e.g. 50 by 50 cells) can be processed in a few minutes to an hour; large research areas (e.g. 500 by 500 cells) can take as long as 20 hours or even multiple days. It therefore pays to think carefully about analysis time before starting an analysis: when working with large research areas it might be preferable to perform different group-based and expectation-based analyses separately one after the other, to limit the damage in case of computer crashes and to limit the effect of slower computer performance over time.

The neighbourhood size affects the analysis time because it affects the number of comparisons that need to be performed for every cell in the input total viewshed. The larger the neighbourhood size the longer the analysis time.

The basic analysis methods can be performed very rapidly, but the group-based and in particular the expectation-based analysis methods are more complex and therefore will take more time.

The more methods you select in the ‘Output’ tab to be performed, the longer it will take for the analysis to finish. If you are very certain about what analysis method is appropriate for your research context, and you are certain that the others will definitely not be appropriate, then selecting only those few appropriate methods will ensure the analysis finishes more quickly. If you want to explore the effect of all or most analysis methods on your input data then you can expect very long analysis times.

Overview of the VNC analysis process

The VNC analysis tool consists of five tabs: introduction, viewshed, neighbourhood, expectation and output. You can walk through the VNC process by clicking on the tabs or on the 'back' and 'continue' buttons at the bottom of each tab.

To create a VNC and use it to analyse a total viewshed, the following steps need to be followed in the VNC analysis tool:

1. Upload the total viewshed(s) which will be used as input data ('Viewshed' tab)
    a. Decide to use one or two viewshed input files
    b. Upload input file(s)
    c. Determine column separator
    d. Does the file contain headers?
    e. Exclude negative values? (yes by default)
    f. Turn off normalization? (no by default)
2. Define a neighbourhood shape, size and structure ('Neighbourhood' tab)
    a. Decide to use a pre-generated mask?
        i. Upload the mask file
        ii. Determine column separator
        iii. Does the file include headers?
    b. Decide to generate a mask with distance bands
        i. Equal-size bands or different band widths?
        ii. Set number of bands
        iii. Separate group for focal cell?
        iv. Set width per band or for all bands
    c. Decide to generate a mask with gradual change of expectation value
        i. Set the radius of the mask (expressed in number of cells)
    d. Decide to generate a mask with wedges
        i. Choose between 8 or 4 wedges (the latter with two different orientations
        ii. Set the radius of the mask (expressed in number of cells)
3. (optional) Set expectation values if expectation-based computational methods are used ('Expectation' tab)
    a. Decide to perform only analyses without expectation values
    b. Decide to upload a table with expectation values per group
        i. Upload the expectation file
        ii. Determine column separator
        iii. Does the file include headers?
    c. Decide to manually enter the expectation values
        i. If a mask with distance bands or wedges is used… (2b, 2d above)
            1. Set expectation value per group
        ii. If a mask with gradual change is used… (2c above)
            1. Set expectation range between 0 and 1
            2. Decide whether it increases or decreases from the focal cell
4. Select the computational methods that you will use to analyse the input total viewshed(s) with the created VNC ('Output' tab)
    a. Select basic analysis methods
    b. Select group-based analysis methods

c. Select expectation-based analysis methods
d. Select the output directory where results will be stored (*/output/ by default)
e. Output both an ASCII table and PDF plot of each analysis result

The following sections explain all functions and options of this process and software tool in detail.

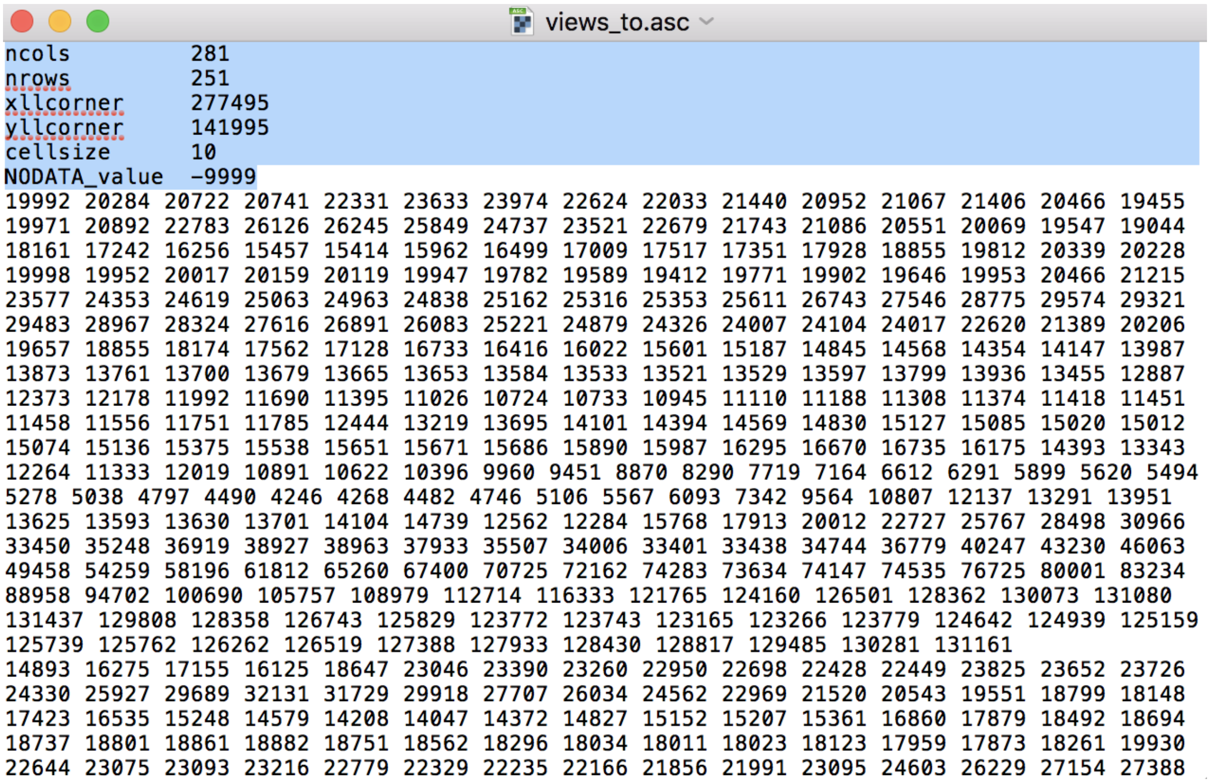
The 'Viewshed' tab and total viewshed input data

An introduction to total viewshed input data

The VNC analysis tool uses a total viewshed in a raster data format as input data (uploaded in the 'Viewshed' tab). Such a raster consists of rows and columns where each cell indicates a spatial location and holds a numerical visual property value usually indicating the number of other cells it is visible from (or vice-versa). Negative values are excluded from the study area by default (unless otherwise specified), and the input raster will be normalised to values between 0 and 1 by default (unless otherwise specified).

The software accepts space, tab, semicolon and comma delimited text-based formats in which each line represents a row and per row cell values are separated by the delimiting symbol. GIS software used to create total viewsheds such as QGIS, GRASS and ArcGIS are able to save or export rasters in such formats (e.g. *.txt, *.csv, *.asc, *.tab, …). Note that some such formats include one or more header or metadata lines. If your input data has a one-line header then select the 'file contains headers' tickbox to disregard these in the analyses, and if your input data has no headers then leave this box unchecked. If your input data has metadata that runs over multiple lines, then copy the input file and remove the header from the copy before uploading it to the tool (see figure 4 below – the lines shaded blue need to be deleted).

For example, the 'views_to.asc' total viewshed file included with the tool has a header that runs over multiple lines. Before using it we should copy the file, open the copy in a texteditor (Notepad on Windows or TextEdit on Mac) and remove the lines highlighted in the figure below. We keep a version of the original file because we will need to manually add the header to the VNC tool output in order to view the output in GIS software.


views_to.asc

```
ncols         281
nrows         251
xllcorner     277495
yllcorner     141995
cellsize      10
NODATA_value  -9999
19992 20284 20722 20741 22331 23633 23974 22624 22033 21440 20952 21067 21406 20466 19455
19971 20892 22783 26126 26245 25849 24737 23521 22679 21743 21086 20551 20069 19547 19044
18161 17242 16256 15457 15414 15962 16499 17009 17517 17351 17928 18855 19812 20339 20228
19998 19952 20017 20159 20119 19947 19782 19589 19412 19771 19902 19646 19953 20466 21215
23577 24353 24619 25063 24963 24838 25162 25316 25353 25611 26743 27546 28775 29574 29321
29483 28967 28324 27616 26891 26083 25221 24879 24326 24007 24104 24017 22620 21389 20206
19657 18855 18174 17562 17128 16733 16416 16022 15601 15187 14845 14568 14354 14147 13987
13873 13761 13700 13679 13665 13653 13584 13533 13521 13529 13597 13799 13936 13455 12887
12373 12178 11992 11690 11395 11026 10724 10733 10945 11110 11188 11308 11374 11418 11451
11458 11556 11751 11785 12444 13219 13695 14101 14394 14569 14830 15127 15085 15020 15012
15074 15136 15375 15538 15651 15671 15686 15890 15987 16295 16670 16735 16175 14393 13343
12264 11333 12019 10891 10622 10396 9960 9451 8870 8290 7719 7164 6612 6291 5899 5620 5494
5278 5038 4797 4490 4246 4268 4482 4746 5106 5567 6093 7342 9564 10807 12137 13291 13951
13625 13593 13630 13701 14104 14739 12562 12284 15768 17913 20012 22727 25767 28498 30966
33450 35248 36919 38927 38963 37933 35507 34006 33401 33438 34744 36779 40247 43230 46063
49458 54259 58196 61812 65260 67400 70725 72162 74283 73634 74147 74535 76725 80001 83234
88958 94702 100690 105757 108979 112714 116333 121765 124160 126501 128362 130073 131080
131437 129808 128358 126743 125829 123772 123743 123165 123266 123779 124642 124939 125159
125739 125762 126262 126519 127388 127933 128430 128817 129485 130281 131161
14893 16275 17155 16125 18647 23046 23390 23260 22950 22698 22428 22449 23825 23652 23726
24330 25927 29689 32131 31729 29918 27707 26034 24562 22969 21520 20543 19551 18799 18148
17423 16535 15248 14579 14208 14047 14372 14827 15152 15207 15361 16860 17879 18492 18694
18737 18801 18861 18882 18751 18562 18296 18034 18011 18023 18123 17959 17873 18261 19930
22644 23075 23093 23216 22779 22329 22235 22166 21856 21991 23095 24603 26229 27154 27388
```

Fig. 4. The 'views_to.asc' example total viewshed file, viewed in a text editor. The first few lines (highlighted) are metadata that will need to be removed before uploading into the VNC tool and will need to be added manually again to the VNC output.

Most theories will be formulated with reference to a single type of visual property, such as the number of cells a cell is visible from, in which case a single total viewshed should be selected. However, more complex theories could be formulated describing expectations for different visual properties within a single neighbourhood configuration. For example, if the goal is to identify locations that fall within zones of low visibility that are themselves surrounded by highly visible areas (i.e. hidden pockets of ground in an otherwise visually exposed landscape), then we need to refer to two different visual properties: the number of incoming lines-of-sight in the former case and the number of outgoing lines-of-sight in the latter. The VNC analysis tool allows for exploring such more complex theories by uploading two total viewsheds.

Viewshed mode

Upload either one or two total viewsheds.

Under ‘Viewshed file 1’ (and ‘Viewshed file 2’ if relevant) click the ‘Browse’ button and navigate to the total viewshed input file to upload it.

Additional file settings

Column separator: select the delimiting symbol (space, tab, semicolon, comma)

File contains headers: select this option if the first row and column are the headers. If selected, the first row and column will be ignored in the analyses.

Exclude negative values from study area: this is selected by default which will ensure that cells with negative values are excluded from the input and not taken into account when normalizing the input. The expectation is that the minimum possible value in a given Total Viewshed is 0 – i.e. a cell can either not be seen or can see nothing. Negative values are not possible. However, we appreciate that some researchers may want to apply the tools developed here to more complex Total Viewshed derivatives (for example the result of subtracting a views-to viewshed from a views-from viewshed in order to flag areas that can see without being seen (and vice versa). Such layers may well encode negative values. You can therefore turn this feature off if you would like to incorporate cells coded with negative values into the analyses.

Turn off normalization: select this option if the input raster data is already normalized to values between 0 and 1 or if you do not wish to normalize the input. Please note that normalization of the input raster is implemented by default. This is a requirement because we specify expectation values between 0 and 1 in expectation based analyses. Normalization further enables comparability of RMSE results where the same VNC and expectation values are applied to different research areas.

The 'Neighbourhood' tab

Neighbourhood masks explained

The specification of a neighbourhood mask is key to the VNC approach as implemented in this tool. A *size*, *shape* and *structure* is given to the neighbourhood that best represents the theory under study.

Size: the size of the area around a focal cell that is relevant to the theory being explored. Neighbourhood size is represented by the radius in the case of a circular neighbourhood shape. The selection of an appropriate neighbourhood size depends entirely on the researcher's theoretical assumptions. It is often useful to explore a range of different sizes in order to examine the sensitivity of the results to changing neighbourhood size.

Shape: in theory, any subset of cells around a focal location can be defined as the neighbourhood, so a neighbourhood can have any desired shape. However, since assumptions about visibility often concern an area within a certain distance from the focal location, a circle centred upon a focal location is the most straightforward and intuitive shape.

Structure: the neighbourhood contains all locations that are considered relevant to the focal location, but they may not all play the same role in the archaeological assumption that is being expressed. The VNC can therefore contain different subgroups of locations for which different visual properties are expected. The simplest structure is a uniform VNC, as shown in Figure 5a. Alternatively, one can specify distance bands (Fig. 5b), a gradual increase or decrease of visibility with increasing distance from the focal location (Fig. 5c), or wedges in different directions from the focal location (Fig. 5d).

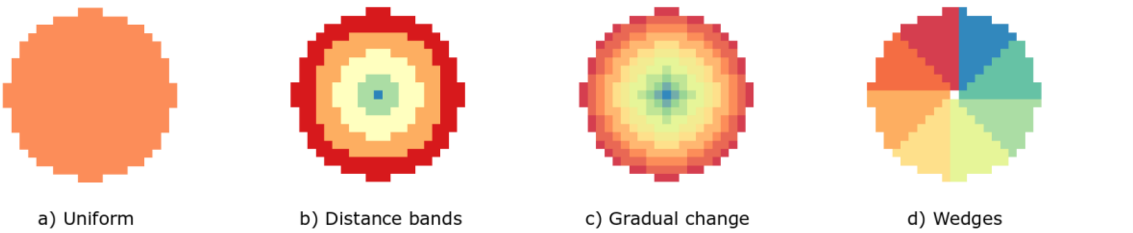


Fig. 5 Example representations of VNCs with different structures where groups of cells are indicated by different colours: an assumption about the visual property values is formulated for each group of cells (from Brughmans et al. in press).

This neighbourhood is represented by a mask file: a raster grid with an uneven but equal number of rows and columns where the central cell is the focal cell; positive cell values indicate the group to which it belongs and negative values indicate cells that are outside of the neighbourhood specification and are therefore not taken into account; the radius of the neighbourhood is represented by the number of cells from the focal cell to the edge of the mask. Here is a very simple example of such a mask, where the cell with value 1 is the focal cell and group 1, surrounded by a distance band of group 2 cells with a radius of 1 cell:

-1	2	-1
2	1	2
-1	2	-1

Note that the spatial horizontal resolution of these neighbourhoods are the same as those of the input total viewshed. For example, if the total viewshed has a resolution of 10m, where each cell represents an area of 10*10m, then the same applies to the neighbourhood mask. The radius of the neighbourhood mask is expressed in the tool in terms of the number of cells but it could also be expressed in spatial units by multiplying the number of cells in the radius by the spatial resolution.

Mask files can be automatically generated by the tool, using sliders to vary size and structure. A visual representation of the mask file is created on-the-fly to help you specify an appropriate mask (Fig. 6).

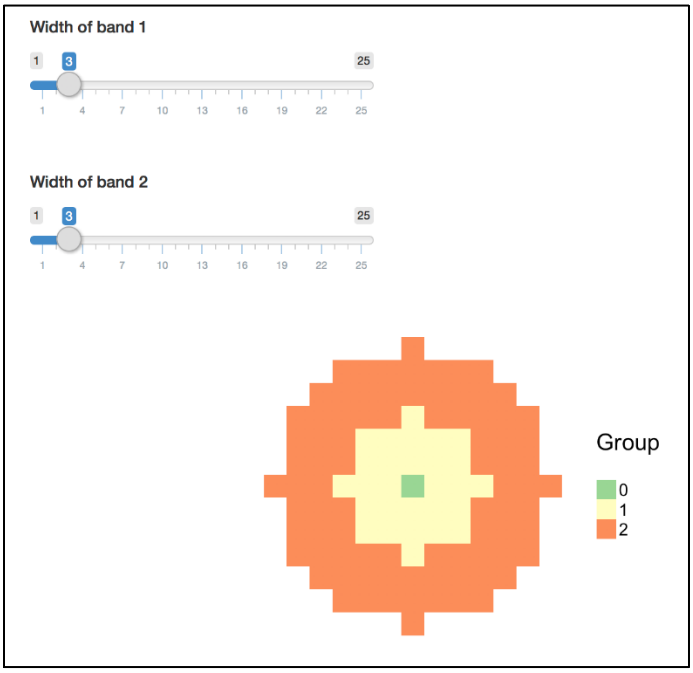


Fig. 6 example of the visual representation of a mask file in the tool.

This software allows for you to develop and upload mask files representing whatever neighbourhood size, shape and structure that best represents the theory you wish to explore. This allows for a huge range of complex and creative theories to be explored. However, manually creating such mask files is non-trivial. To help with this the software tool includes a really useful feature to help you with this: once an analysis is performed the mask file that was automatically generated by the tool will be appended to the log file (created in the output folder). You can simply copy this mask, modify it, and save it to a different file to use in future analyses (Fig. 7).

```
NEIGHBOURHOOD MASK
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 2 2 2 2 2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1
-1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1
-1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1
-1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1
-1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1
-1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1
-1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1
-1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1
-1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
-1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1
-1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1
-1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1
-1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1
-1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1
-1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1
-1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1
-1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1
-1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 2 2 2 2 2 2 2 2 2 2 2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 2 2 2 2 2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

Fig. 7 example of a neighbourhood mask appended to the log file created as part of the output of the tool.

Use existing neighbourhood mask

Select this option if you already have a neighbourhood mask file that you can upload to the tool. If you do not have such a file, please note that the automatically generated masks created when selecting the other options in this tab will be appended to the log file created as part of the output of an analysis. These offer a good starting point for creating your own mask files.

Neighbourhood mask: upload the existing neighbourhood mask.

Column separator: select the delimiting symbol (space, tab, semicolon, comma)

File contains headers: select this option if the first row are the column headers. If selected, the first row and column will be ignored in the analyses.

Generate neighbourhood mask with distance bands

Select this option if you theorize different visual properties for different distance bands away from the focal cell.

Band width: determine whether all distance bands should have the same width or whether the width of each band should be specified individually.

Number of bands: specify the number of bands around the focal cell.

Separate group for focal cell: select this option if you want to consider the focal cell as its own group or if you want to incorporate its visual property value within those of the first distance band around it.

Radius (number of cells): specify the radius of the circular neighbourhood expressed in the number of cells.

Width of band 1, 2, 3…: specify the width of each band in cells.

Generate neighbourhood mask with gradual increase/decrease of expectation value

Select this option if you theorize a gradual increase of decrease of the visual property value with distance away from the focal cell.

Radius (number of cells): specify the radius of the circular neighbourhood expressed in the number of cells.

Generate neighbourhood mask with wedges

Select this option if you theorize differences in the visual property values of locations in the neighbourhood in different directions from the focal cell. This tool uses an implementation based on wedges, where each wedge represents a certain 90° or 45° direction and each wedge is considered a different group.

Number of wedges:

4 wedges (orientation 1): four 90° wedges oriented NE, SE, SW, NW.

4 wedges (orientation 2): four 90° wedges oriented N, E, S, W.

8 wedges: eight 45° wedges.

Radius (number of cells): specify the radius of the circular neighbourhood expressed in the number of cells.

The 'Expectation' tab

Expectation-based approach explained

To express the different visual properties assumed for the different groups in the VNC structure, an expectation value can be assigned to each group. In the expectation-based evaluation methods available on the 'output' tab (rmse_global, rmse_grouped), each cell in the actual neighbourhood of a focal location is then compared to this hypothesized value to compute how well the location matches the assumption expressed by the VNC with expectation values.

Expectations should be expressed on a scale from 0 to 1, where 0 corresponds to the lowest visual property value occurring in the study area, and 1 corresponds to the highest visual property value. In the case of VNC structures with a gradual increase/decrease of the visual property value, you need to specify the range that this visual property value can change from and to, and you need to specify whether it will increase from the focal cell or decrease. This gradual change is implemented as a linear increase/decrease. In the case of VNC structures with distance bands or wedges, different expectation values can be assigned to different groups. Moreover, if two different types of visual properties are included in the theory you can specify whether the group's expectation concerns viewshed 1 or viewshed 2.

Consider the example published in Brughmans et al. (in press) as analysis 2: we theorize that the area immediately around a focal cell is invisible and therefore has low values for the total viewshed representing incoming lines-of-sight, whereas the area around this first area offers good views and therefore has high values for the total viewshed representing outgoing lines-of-sight. To explore this theory we will specify expectation values as in the figure below. For the first distance band (which includes the focal cell) we expect a value of 0 with reference to the uploaded viewshed 1, and for the second distance band we expect a value of 1 with reference to the uploaded viewshed 2 (Fig. 8).

Please note that values should be used here to represent the extreme states of the hypothesis, in this case 0 for 'invisibility' and 1 for 'good views'. The rmse_global and rmse_grouped methods will subsequently calculate the extent to which the actual total viewshed values differ from these extreme expectations.

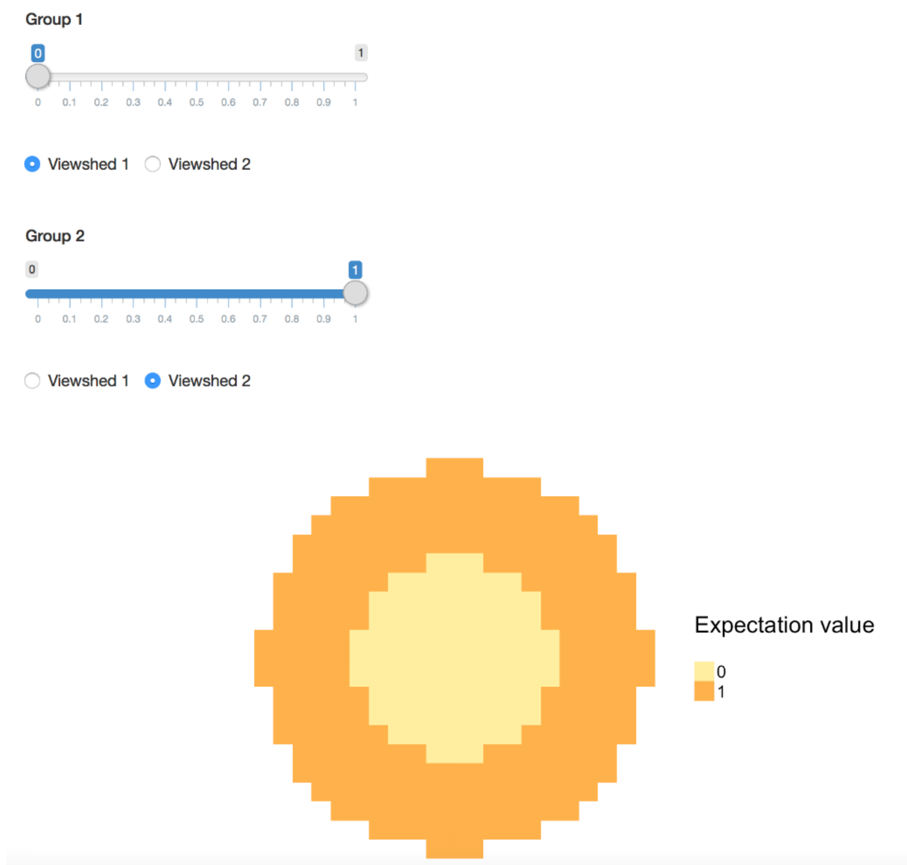


Fig. 8 An example of specifying different expectation values for different groups with reference to different input total viewsheds.

If no expectation-based methods will be selected on the 'output' tab then the expectation mode should be set to 'Analysis without expectation values'.

As with the neighbourhood mask, this software allows for either the automatic generation of expectation tables or for uploading existing ones. The generated expectation tables are included in the log file output of an analysis and can therefore serve as a basis for creating your own expectation tables if desired.

Analysis without expectation values

Select this option if the following computational methods will not be selected in the 'output' tab: rmse_global, rmse_grouped.

Upload expectation table

Select this option if you already have an expectation file that you can upload to the tool. If you do not have such a file, please note that the automatically generated tables created when selecting the last option in this tab will be appended to the log file created as part of the output of an analysis. These offer a good starting point for creating your own expectation files.

Expectation table: upload the existing expectation file.

Column separator: select the delimiting symbol (space, tab, semicolon, comma)

File contains headers: select this option if the first row are the column headers. If selected, the first row and column will be ignored in the analyses.

Enter expectation values manually

This option will be automatically selected in case you theorize a gradual change of visual property values. It can also be used to manually specify expectation values for distance bands and wedges.

In the case of gradual change:

Specify the range that the visual property value can change from and to,

Specify whether it will increase from the focal cell or decrease.

In all other cases:

Specify the expectation value for each group.

(in the case of using two total viewsheds as input: specify which viewshed will be referred to when comparing each group's expectation value with the actual total viewshed value)

The ‘Output’ tab and implemented computational methods

The VNC analysis process

Once VNC shape, size and structure and (if required) the expectation values are specified, you can proceed to analyse the input total viewshed(s) using the range of computational methods available on the ‘output’ tab. All methods are explained in detail in Brughmans et al. (in press). Cells suffering from edge effects will be automatically excluded from the output if the ‘edge effects’ box is ticked (see below for a description of edge effects in VNC analysis). The way in which the analysis happens is as follows:

1. Each cell in the input total viewshed is considered the focal cell in turn
2. For each cell a neighbourhood with the VNC size and shape is considered
3. All cells within the neighbourhood will be subjected to the computational method(s) selected. Three groups of such method are available in this tool:
    a. **Basic analysis methods** perform simple calculations on these cells, such as the maximum or average value of cells in that neighbourhood of the input total viewshed. They do not take into account VNC structure or expectation values.
    The *output* of basic analysis methods is a raster grid the same size as the input total viewshed with for each cell a numerical value between 0 and 1 representing the result of the calculation performed (e.g. the maximum or average value within their neighbourhood). Cells that were excluded from the analysis due to edge effects will be assigned the value -9999. For an example, see Brughmans et al. (in press) Analysis 1.
    b. **Group-based analysis methods** also perform simple calculations (e.g. average or maximum value) but for each of the groups specified in the VNC separately. They do not take expectation values into account.
    The *output* of group-based analysis methods is a raster grid the same size as the input total viewshed with for each cell the group number of the VNC group with the minimum or maximum result (depending on the computational method used). Cells that were excluded from the analysis due to edge effects will be assigned the value -9999. For an example, see Brughmans et al. (in press) Analysis 3.
    c. **Expectation-based analysis methods** calculate the root mean square error (rmse) between the values of cells in the input total viewshed and the expectation values of their corresponding cells specified in the expectation table. This approach has been implemented in two ways: rmse_grouped calculates the rmse per group and compares the error values of the different groups, whereas rmse_global calculates the overall error of the input cell values and their expectation values. Rmse_grouped is therefore appropriate when you want to give equal weight to the different groups regardless of the actual number of cells in each group, and rmse_global is appropriate when the actual number of cells matters (and therefore the actual area covered by each group).
    The *output* of expectation-based analysis methods is a raster grid the same size as the input total viewshed with for each cell the error value between 0 and 1: 0 represents a low error and therefore a good fit between observation and expectation, 1 represents a high error and therefore a bad fit. Cells that

were excluded from the analysis due to edge effects will be assigned the value -9999. For an example, see Brughmans et al. (in press) Analysis 2.

Edge effects

The VNC analysis tool will by default exclude those cells at the borders of the study area which suffer from edge effects. These are cells for which insufficient input information is available to produce analysis results that are comparable to cells for which all information is available (Fig. 9). In order to obtain comparable results, all cells included in the analysis will need to have total viewshed input information for all surrounding cells falling within the neighbourhood of the VNC. This is typically not the case for focal cells located less than the VNC radius away from the edges of the input total viewshed, and therefore the VNC analysis tool excludes these by default. It is possible to deactivate this feature and not to correct for edge effects, although this is not recommended.

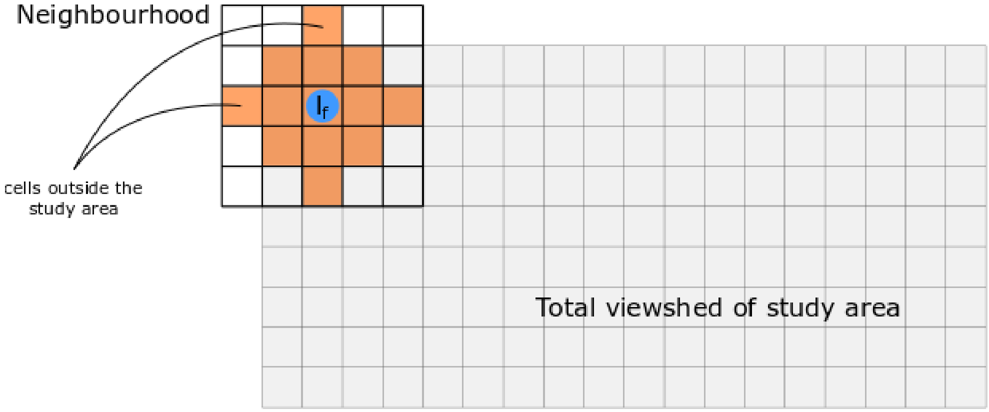


Fig. 9. Example of a cell whose neighbourhood extends beyond the input total viewshed defining the study area. When interpreting VNC analysis results, such cells should be excluded to remove edge-effects.

Outputs and how to use them

Once the analysis has been performed, the outputs will be created in the */output/ folder or any other folder you prefer to use instead. **PLEASE NOTE THAT PREVIOUS FILES WILL ALWAYS BE OVERWRITTEN WHEN NEW ANALYSES ARE PERFORMED**. The outputs include the following files:

- A .PDF (optional) and .asc version of the results per computational method used
- A .asc version of the input total viewshed used
- A logfile which includes all settings used in the analysis:
  a) Time started
  b) Number of viewsheds
  c) File name of viewshed(s)
  d) Dimensions of viewshed(s)
  e) Neighbourhood mask used showing VNC size, shape and structure
  f) Computational methods used
  g) Expectation table
  h) Time finished

Please note that the .asc raster grid version of the output does not have any metadata associated with it, and can therefore not be projected correctly when importing it into GIS software. You will need to manually add the metadata lines at the very top of the input file to the very top of the new output file (using a text editor such as Notepad on Windows or TextEdit on Mac).

Once the .asc versions of the results have their metadata, you can add them as a layer in GIS software. Note that the cells excluded due to edge effects will be assigned the value -9999 whereas all other cells will have the resulting value of the analysis ranging between 0 and 1. To facility the visualisation of the results you could assign -9999 as the 'nodata value' in the metadata of the .asc file or through the GIS software interface.

Basic analysis

These analyses do not take into account groups or expectation values, they are based solely on the input data and the neighbourhood size. The output values are the values of the selected visual property in the neighbourhood of each cell.

- Average (v_avg)
- Prominence (v_prom)
- Minimum (v_min)
- Maximum (v_max)

Group-based analysis

These analyses compare the different groups of the neighbourhood and return the group that contains the selected property value instead of the value itself.

- Minimum average (g_minavg)
- Maximum average (g_maxavg)
- Minimum value (g_minval)
- Maximum value (g_maxval)
- Minimum range (g_minrange)
- Maximum range (g_maxrange)

Expectation-based analysis

These analyses compare the input data to the specified expectation values. The output values indicate the error: a low value means the hypothesis fits well.

- Global root-mean-square error (rmse_global): each cell weighted equally
- Grouped root-mean-square error (rmse_grouped): each group weighted equally

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