Using Watersheds to Define Adaptive Sampling Windows

Shawn Laffan,
School of Resources, Environment and Society, The Australian National University
Shawn.Laffan@anu.edu.au

Abstract. Spatial analyses use geometric sampling shapes such as circles, wedges and ellipses to define the spatial sampling window. These are not always related to the process controlling the spatial distribution of some variable. Consequently, locations that are nearby, but not connected to the central location through the controlling process, are included in the sample. There is thus the potential for significant noise to be introduced to any spatial analysis through the inclusion of data from unconnected locations. This research demonstrates that it is possible to use a model of the controlling process to define the sampling window used in spatial analyses. This will adapt to conditions as they change across a landscape, and potentially generate better and more relevant results. In this case local watersheds are used to analyse a set of hydrologically controlled variables from Weipa, Australia. Comparison of the results with those from circular samples show that the watershed samples are a better model of spatial association for most locations at short distances (<120 m laterally), and these locations reduce into distinct patterns as the scale increases. These areas differ for each variable considered. An interesting outcome of this research is that it is possible to identify locations where the regolith is near equilibrium with present-day surface hydrology, thus enabling a greater understanding of how processes affect a landscape. The approach may be extended to any spatial process that is known and can be reliably modeled.

1. INTRODUCTION

Regardless of the modelling and analysis approach used, be it local or global, with one variable or many, all spatial models assume that the sampling scheme used to define the analysis neighbourhood for each location is relevant to the process being investigated. This paper is concerned with better defining the spatial neighbourhood using a hydrologic model to exclude unrelated data, and thus reduce sample noise in the analysis.

1.1 Spatial sampling schemes

Spatial analysis methods normally use geometric shapes to define the neighbourhood of locations used in the analysis. These neighbourhoods are normally circular in the isotropic case, and ellipse or wedge-shaped where anisotropy is investigated.

However, sampling using geometric shapes, while computationally convenient, ignores environmental processes, for example hydrology. The orientation, shape and extent of hydrological control will vary across the study area. Geometric sampling windows may therefore only be useful within small areas of a dataset where they conform to hydrological conditions.

By using a model of local hydrological conditions it is possible to generate a sample window for each dataset location based on watersheds. These windows are able to adapt to changing conditions of direction, shape and extent of association as they are encountered in the dataset. As such this approach should improve the relevance of any model results, as the analysis should use only those neighbours that are hydrologically connected with the central location.

1.1.1. Assessing the method

The utility of the watershed sampling method is assessed by comparing the results of two spatial association statistics using the watershed sampling scheme and an omnidirectional (circular) sampling scheme. The two statistics are the semivariance and the Getis-Ord G_i* statistic (Getis and Ord, 1992, 1996; Ord and Getis 1995).

Semivariance is calculated to a distance of 3000 m, while G_i* is calculated over 30, 120, 210 and 300 m distances (1, 4, 7 and 10 cells). A DEM with a 30 m cell resolution is used to define the watersheds.

The spatial association statistics are applied to two geochemical variables sand one physical variable from Weipa, in Queensland, Australia. These are oxides of aluminium and silica, and depth of bauxite, sampled at 38,928 drill locations. The distribution of these variables is known to be controlled by hydrological processes, through both solutional and mechanical reworking.

If the watershed sampling does provide a better model of spatial association then the degree of difference between a cell and its neighbours will be reduced, and the degree of spatial clustering will be increased relative to that for the omnidirectional sample. This will result in reduced semivariance values and increased G_i* magnitudes away from zero.

1.2 Results and Discussion

1.1.2. Semivariance

There is little evident change in the variogram response (Figure 1) for aluminium and depth. Their responses indicate only a slight improvement by the watershed sampling, if at all. The only apparent change in variogram response due to watershed sampling is for silica, as the response reaches a sill at 1,200 m in the watershed sampling.

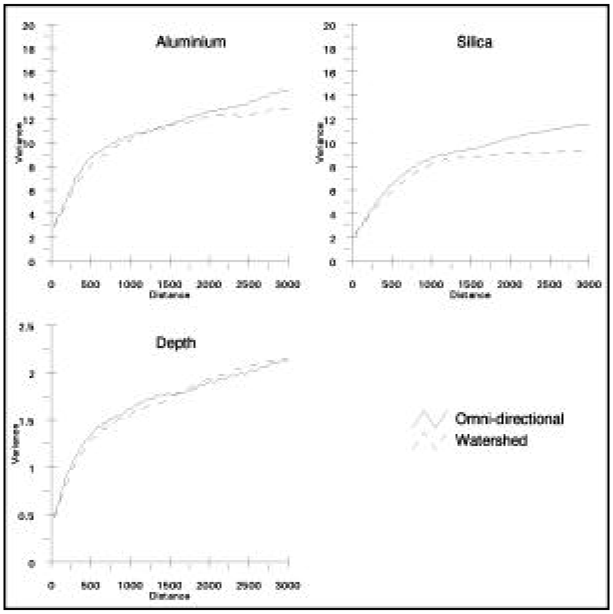

Figure 1: Variograms for omnidirectional and watershed samples.

However, the semivariance is a global statistic, and can thus obscure many relationships by aggregation. The G_i* results are local, and thus considered more informative.

1.1.3. G_i*

A visual inspection of the G_i* surfaces (Figure 2) shows a similar response for both sampling methods. However, there is a consistent response where the watershed sampling returns stronger clustering, and this decreases as the scale increases (Figure 3).

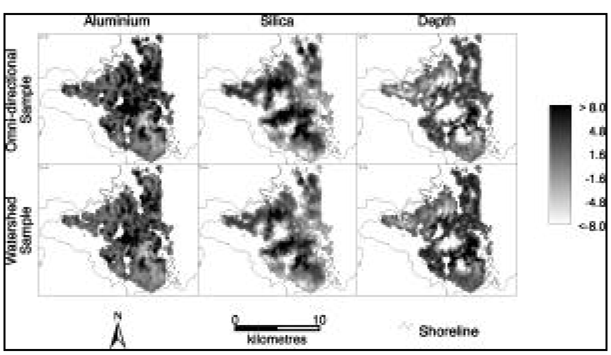

Figure 2: Omnidirectional and watershed G_i* at the ten cell lag (300 m).

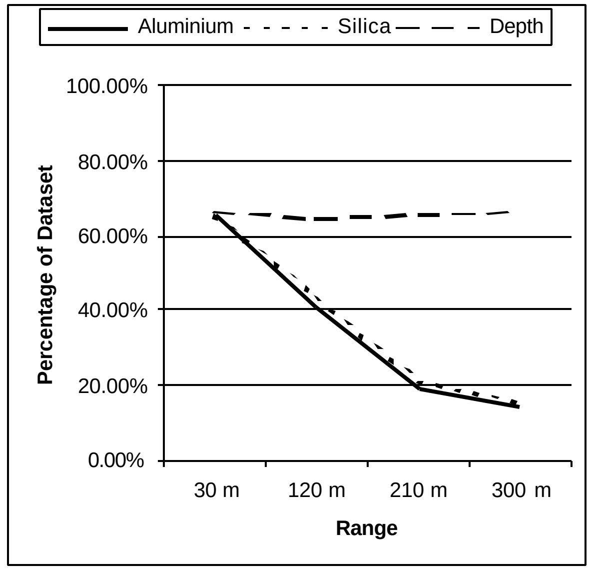

Figure 3: Proportion of sample dataset (38,928 data points) where watershed sampling returns stronger G_i* clustering than omnidirectional sampling.

The relationships in Figure 3 imply that, overall for aluminium and silica, the watershed sampling better represents spatial relationships than omnidirectional sampling for approximately 40% of samples up to 120 m, and 20% at 210 m. Beyond 210 m the rate of change decreases. However, while the decline against omnidirectional sampling is initially rapid, it is into spatially contiguous zones (Figure 4). The results for depth are similar for all sample ranges, indicating more spatially extensive control by hydrology.

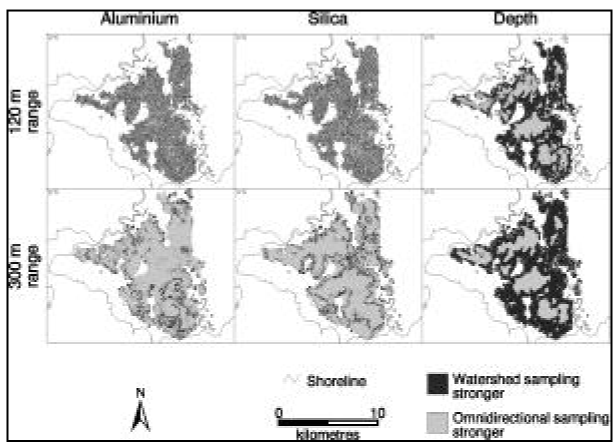

Figure 4: Zones where watershed sampling returns stronger clustering than omnidirectional sampling.

1.1.4. Implications in the study site

Globally, the broad scale hydrological control of silica, and not for aluminium and depth, is inferred to be due to solutional mobility. Development of the bauxite is attributed to desilicification (Tilley, 1998), and the semivariance analysis identifies the global scale at which such processes operate is approximately 1,200 m.

The local variation, investigated using G_i*, is inferred to be the extent to which recent environmental conditions control the distribution of regolith properties at Weipa. This is also largely through solutional redistribution by hydrology, and occurs in spatially contiguous units. Most of this reworking has a spatial range of less than 120 m around each location for aluminium and silica, with distinct zones where the range extends to 300 m. The response for depth of bauxite is near constant across the dataset for all sample ranges.

The silica response pattern appears to be a local expression of regional groundwater processes controlling precipitation of silicate minerals, hence its occurrence lower in the landscape and around drainage lines. The aluminium response is most likely to do with the removal of silica, causing an apparent hydrological control through relative enrichment processes. This conforms with Tilley's (1998) desilicification process controlling bauxitisation. Depth is controlled by mechanical erosion and redox conditions, the latter being regulated by seasonal water table fluctuations. As such, it is expected to be under greater control of the actions of surface hydrology.

The implication of the zones of hydrological control is that the Weipa landscape is approaching geochemical quasi-equilibrium with hillslope hydrology at a range of approximately 120 m around most locations, and further in some areas. The spatial extent of the relationship for depth is yet to be explored. These zones of hydrologic control are not related to the pattern of sampling and appear geomorphically plausible.

That the watershed results appear only sometimes better than the omnidirectional sampling at the larger ranges is not entirely surprising. The landscape at Weipa is extremely flat (mean slope < 0.5°), and so the watershed model used here may not represent the geomorphic and hydrologic relationships in all cases. The landscape has also been evolving continuously for up to 40 million years. During this time it has undergone reworking by many geomorphic process in addition to fluvial action, including marine incursions, storm surges, and aeolian activity. To model the effect of all of these would require a significant increase in analysis complexity.

1.3 Conclusions

The watershed sampling method used in this study generates some improvement over geometric sampling schemes. The degree of improvement is quantifiable, and appears to occur in contiguous regions in the Weipa study area. These are geomorphically plausible and appear to indicate local areas where the landscape is approaching quasi-equilibrium with surface hydrology.

The results of this study indicate there is some potential to improve spatial analysis and modelling by using a model of driving processes to define the sampling window for a spatial variable. Such an approach will not replace geometric sampling windows, but it does provide an additional method in the spatial analysis toolbox by which spatial variables may be investigated, and spatial models devised and operated.

Bibliography

Getis, A. and Ord, J.K. (1992) "The analysis of spatial association by use of distance statistics", *Geographical Analysis*, 24, 189-206.

Getis, A. and Ord, J.K. (1996) "Local spatial statistics: an overview", In *Spatial Analysis: Modelling in a GIS Environment*, edited by P. Longley and M. Batty (Geoinformation International, Cambridge), pp 261-277.

Ord, J.K. and Getis, A. (1995) "Local spatial autocorrelation statistics: Distributional issues ad an application", *Geographical Analysis*, 27, 286-306.

Tilley, D. (1998) "The evolution of bauxitic pisoliths at Weipa in northern Queensland", In *The State of the Regolith*, edited by R.A. Eggleton, Geological Society of Australia Special Publication 20, pp 148-156.