Melioidosis case clusters in a tropical urban setting: Association with soil type and geomorphology

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Abstract
Geospatial analysis of the distribution of clinical cases of melioidosis, an often fatal tropical disease, in the Townsville region indicated case clustering in distinct geomorphic settings and characteristic soil associations. Two significant clusters were identified. Cluster 1 is associated with piedmont slopes adjacent to granitic hill and mountain slopes. The soils developed on colluvium are typically Kandosols with dark grey-brown loamy sand to silty loam A horizon, grading into dark red or yellow sandy clay loam to sandy clay subsoils. Cluster 2 is associated with Pleistocene floodplains, levees and channel-fill. The duplex soils typically grade from acidic to alkaline at depth. These soils are poorly draining due to a shallow impermeable B horizon in Sodosols. It is postulated that the two geomorphic positions and soil types are predisposed to soil wetness following periods of intense rainfall. Cluster 1 is located where large amounts of runoff are received from the adjacent granitic hill, whereas Cluster 2 associates with poorly drained soils at the lower edges of poorly drained alluvial plains. This preliminary study has generated the hypothesis that melioidosis distribution in the Townsville region is controlled by environmental factors, specifically soil type, geomorphic position and drainage. A detailed multidisciplinary field-based study investigating soil physico-chemical features, field isolates of *Burkholderia pseudomallei*, and epidemiological considerations is now underway to test this hypothesis.

Key Words
Melioidosis, soil type, GIS, disease cluster, environment

Introduction
Melioidosis is a potentially fatal bacterial infection endemic across northern Australia, southeast Asia and other parts of the tropics (Currie *et al.* 2008). The causative organism is the soil borne bacterium *Burkholderia pseudomallei*. Clinical manifestations of melioidosis range from localised infection to its most acute form of rapidly fatal fulminant sepsis. Despite the initiation of intensive therapy, mortality remains at 21% in patients with melioidosis in Australia (Currie *et al.* 2000). Contact with soil or contaminated water is believed to be a precursor to disease onset and cases occur mainly in association with periods of heavy rain during the wet season, in northern Australia between January and May (Thomas *et al.* 1979; Currie and Jacups 2003; Cheng *et al.* 2005).

Melioidosis is an environmental disease (Inglis *et al.* 2001). Biogeochemical factors will determine the geographic distribution of *Burkholderia pseudomallei* in its environmental setting. Pathogenicity, exposure and acquisition modes and human physiological response will determine disease distribution and presentation. Significant progress in understanding the human response to exposure to *Burkholderia pseudomallei* is being made (Wiersinga *et al.* 2006), but our understanding of the environmental conditions that determine the geographic range of the bacteria, and hence areas of risk for human activity, is limited (see Inglis and Sagripanti 2006; Palasatien *et al.* 2008).

Within North Queensland, the city of Townsville and its suburbs are overrepresented in cases of melioidosis (Malczewski *et al.* 2005). Anecdotal evidence suggested that the distribution of melioidosis cases based on residential addresses clustered in particular suburbs. A pilot project (Corkeron *et al.* 2009) sought to test this idea and identify any potential environmental features geospatially associated with clusters. The aim of this study was to test whether regional environmental parameters such as geological substrate, soil type, geomorphology and drainage correlate to case clusters in Townsville.

Methodology
This study utilised a GIS framework (ArcMap 9.3; ESRI Inc. Redland, Ca) to integrate regional data sources

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including elevation, geology, local soil classifications, drainage systems, roads, Australian Bureau of Statistics population census data and cadastral data. A 12-year melioidosis case distribution database from the Townsville region (based on residential addresses) was linked to the cadastral layer. Soil data and distribution was derived from previous soil mapping and soils reports on the Townsville region (Murtha, 1975; 1982).

Results

Within ArcGIS the case distribution was compared against the general urban population distribution using Ripley's K-function. Two significant case clusters were identified (Clusters 1 and 2, Table 1) and a third minor cluster noted (Cluster 3, Table 1). Geospatial comparison of case distribution with soil and geomorphic features allowed identification of key landscape units associated with case distribution (Figure 1). Cluster 1 is associated with the soils formed in the colluvium from the granite out crop at Castle Hill and Mount Stuart. This cluster is identified in the 'piedmont slope and uplands' landscape unit. Cluster 2 is associated with Pleistocene alluvial soils and identified in the 'older alluvial plain, fan and channel infill' landscape unit. Within this cluster, several cases are associated with 'younger alluvial terraces and channel infill'. Cluster 3, with 12 cases, is associated with 'beach ridges and littoral' landscape unit.

Table 1. Key environmental parameters associated with disease clusters.

Parameter	Cluster 1	Cluster 2	Cluster 3
No. of cases	18 (27.7%)	35 (53.8%)	12 (18.5%)
Landscape Unit/ Geomorphology	Piedmont slopes and colluvial fans derived from granitic hills.	Both Holocene and Pleistocene alluvial plains, terraces, levees, in-filled channels and meanders.	Frontal beach ridges, swales and salt pans.
Geology	Castle Hill Granite. Biotite leucogranite, microgranite; minor granophyre, granodiorite.	Stratified alluvial clay, silt, sand and gravel	Siliceous and calcareous sand, some carbonate nodules
Soil types	Mostly Kandosols. Dark grey-brown loamy sand to silty loam A horizon, grading into dark red or yellow sandy clay loam to sandy clay subsoils. Some Kurosols, light grey brown sandy loam A horizon with abrupt change to mottled brown-yellow heavy clay B horizon.	Pleistocene alluvium mainly Sodosols. Abrupt texture contrast between sandy or silty loam A horizon and sodic clay B horizon. Mottling and redoximorphic features common in B horizon. Frequent Kandosols in recent alluvium, sandy loam A horizon grading to sandy loam and clay loam.	Rudosols and Tenosols, mostly as beach ridges. Minimal pedological development. Loose pale brown loamy sand grading into light brown or yellowish brown loose single grain sand. Occasional Sodosols in swales between ridges, associated with salt pans.
pH and drainage	Acid topsoil and subsoil. Fair drainage, but high risk of short-term water logging after heavy rainfall due to landscape position at base of Castle Hill. Higher risk of water logging for Kurosols.	Acidic A horizons, and alkaline, sodic subsoils, poor drainage due to shallow, impermeable B horizon in Sodosols, frequent seasonal water logging. Kandosols are acid throughout, lack impermeable B horizon, high soil moisture due to proximity to river.	No detailed soil information available. Drainage from ridges is good, but poor in Sodosol swales and saltpans.
Elevation and proximity to drainage	Hilly and mountainous elevation from ~300-600m asl. Cases confined to elevations from 40m to ~ 10 m asl. Localised gully drainage; colluvium and soil development localised to break of slope, mostly on lower slopes.	Low elevation across coastal plain; ~ 25 m asl in headwaters and ~ 5 m asl in lower reaches. Proximity to streams and creeks; soil associations (defined by Murtha, 1972) occur parallel to modern drainage. Pleistocene soil associations are commonly adjacent to modern streams and creeks. The modern fluvial system dominating the Townsville flood plain is geomorphically consistent with the ancient fluvial system.	Less than ~5 m asl. Dune systems sporadically cut by meandering mangrove creeks. In undeveloped areas, swales may be inundated by king tides and flood events.

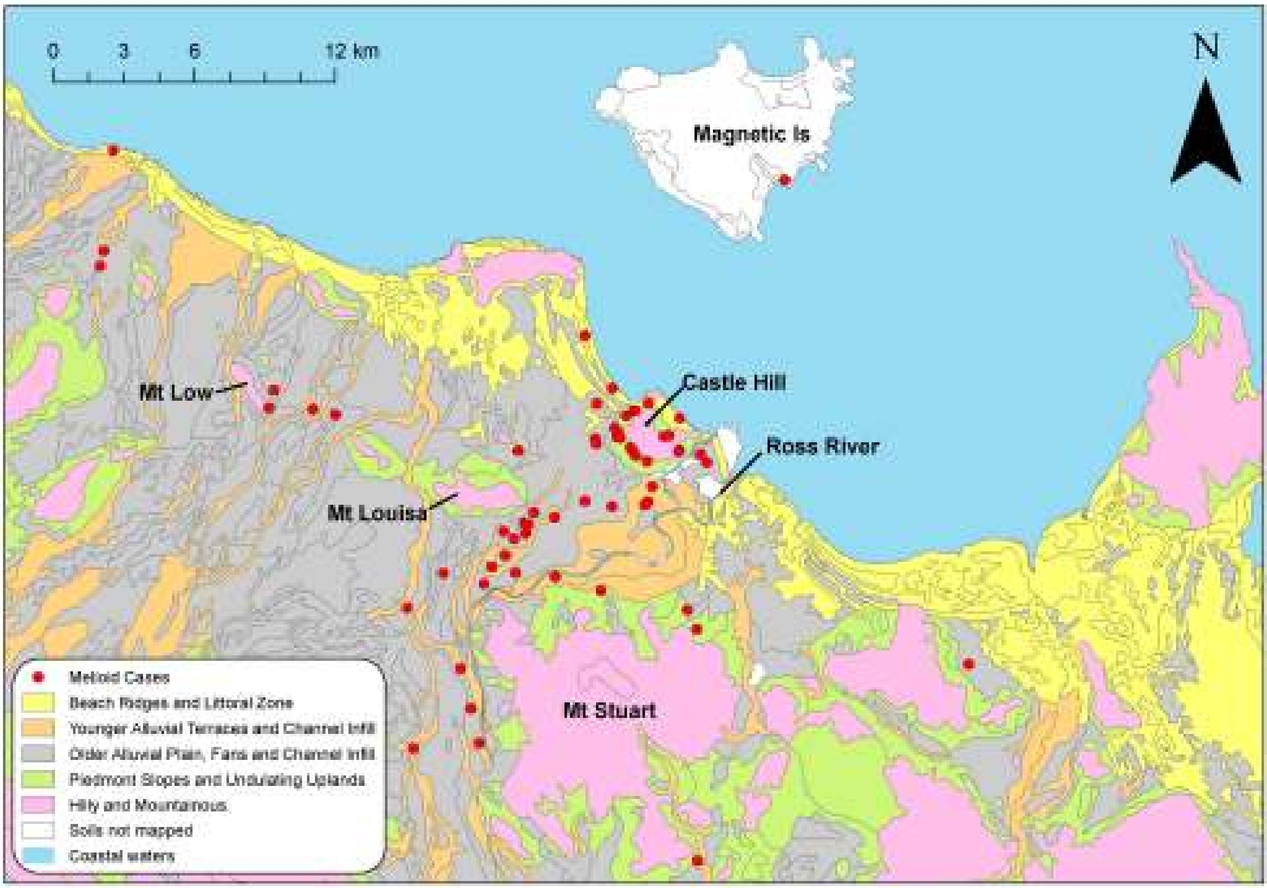

Figure 1. Case distribution in the Townsville region and distribution of associated landscape units (see Table 1 for descriptions). Adapted from Corkeron *et al.* (2010).

Discussion and Conclusions

The cases in Cluster 1 primarily occur on piedmont slopes (3-15%) of colluvium derived from the granitic Castle Hill. The soils are prone to erosion, and gullies dissecting the soils are common. A complex association of soil types has formed in this landscape unit, but the most frequent soils are mildly acidic gradational soil types (Kandosol) and less frequent Kurosols. These soils, commonly developed on the break of slope, likely experience transient waterlogging when large amounts of runoff are received from the adjacent granitic hill during the wet season.

The majority of cases in Cluster 2 are associated with soils with a clay-rich B horizon (sandy clay-heavy clay texture) within 40-50 cm of the surface. Most common of these clayey soils are Sodosols (25 out of 35 cases), texture contrast soils with an alkaline B horizon and a coarser textured mildly acidic A horizon. They have formed in Pleistocene floodplain, levees and channel infill. These soils are prone to waterlogging, as shown by the common mottling and redoximorphic features of the B horizons. Minor cases are associated with Kandosols, which occur in the recent alluvium, mainly as terraces, levees and channel infill. These typically have sandy clay loam A horizons grading to sandy loam and clay loam. Considering the environmental preferences of the pathogen (acidic, high soil moisture; Palasatien *et al.* 2008), this suggests that the pathogen is most likely to occur in the acidic, coarse A horizons of clay-rich soils which are prone to water logging, i.e. in the top 30-40 cm of the soils.

Cluster 3, comprising 12 cases, occurs in areas mapped as beach ridges and littoral zone. Soils on the ridges have been classified as Rudosols and Tenosols, poorly developed soils formed in siliceous and calcareous sands of marine origin. While the sandy Rudosols and Tenosols occuring on the beach ridges are well-drained, this is not the case for the Sodosols which are found in some of the swales and salt pans between beach ridges. These swales may represent localised areas of waterlogging. However, Corkeron *et al.* (2010) noted that 6 of these cases in this cluster are from nursing home addresses, probably reflecting human risk factors over environmental factors as drivers for disease acquisition.

This study demonstrates a geospatial relationship between disease distribution and identifiable soil and geomorphic features, as well as underlying geology, presumably a significant control on clay composition in overlying soils. This association supports the hypothesis that soil is the environmental reservoir of *B. pseudomallei.* Whereas an association between *B. pseudomallei* and particular soil properties in the North Queensland area was first reported in 1979 (Thomas *et al.* 1979), the precise ecological niche of *B.pseudomallei* is unclear. In the Northern Territory there is a demonstrated association between environmental isolates and the presence of grasses, disturbed soil, acid pH, livestock usage and soil texture (Kaestli *et al.* 2009). In endemic areas in Thailand, sandy soils, soil pH, depth of at least 30cm, moisture content of >10%, higher total nitrogen and oxygen demand, all predispose to finding the organism in soil (Palasatien *et al.* 2008).

Future research will extend this project to a field-based program in Townsville to delineate geomorphic features in detail, and fully characterise soil types within a geomorphic framework. A microbiological analysis integrated with the soil study will attempt to isolate *B. pseudomallei* at soil sampling sites, and at variable depths within the soil profile. Thus, the distribution of the causative organism in the environmental reservoir can be directly correlated with soil properties and case distribution. Resolution of the physico-chemical parameters that characterise soils with positive bacterial isolates may clarify processes of pathogen-soil interaction, providing a foundation for understanding the ecology of the pathogen within its environment.

Whereas understanding the environmental aspect *B. pseudomallei* lifecycle is essential to understanding the pathogenesis of melioidosis, linking disease distribution to environmental controls is complicated by predisposing human health factors and socioeconomic influences. For this reason, an epidemiological analysis of case characteristics as recorded by the Tropical Public Health Unit in Townsville will also be undertaken and synthesised with the environmental findings. The multidisciplinary approach in this case-study will provide findings and a research template applicable to other melioidosis endemic sites in Australia and developing tropical countries such as Thailand and Papua New Guinea, where health burden is not well supported by health resources.

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