Utilising geographical information system software in association with radiation data to estimate the extent of the ancient civilisation around Mapungubwe

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Abstract

The extent and impact of the ancient civilisation on and around Mapungubwe is to a large extent still uncertain. A pilot study was undertaken to measure the variations in natural radionuclides in this area with the aim of gaining more insight about this area and the historical human activities that took place there. Soil samples were collected on and around Mapungubwe hill. Laboratory gamma ray spectra were obtained for each of the samples and the concentrations of the natural radionuclides were extracted and compared. The radioactive nuclide concentrations were mapped with the help of GIS software. Triangulation and interpolation methods were employed to draw concentration diagrams for the radionuclides. Distinctive relationships between the concentrations of these nuclides and the area are demonstrated and discussed. Inferences that are based on the GIS results are also made on some characteristics of the ancient Mapungubwe civilisation.

Keywords

natural radiation, Mapungubwe, radionuclides, GIS software, archaeology

Introduction

The Kingdom of Mapungubwe (1075 – 1220) was a pre-colonial civilization in southern Africa located at the meeting of the Shashe and the Limpopo rivers. The kingdom had gold trading links on the East Coast of Africa and is believed to have been the initial stage in the development of the Kingdom of Zimbabwe in the 13th century. The kingdom originated in a larger area which includes other sites like K2, Schroda and Bambandhlanalo, which are all scattered around Mapungubwe (see Fig. 1). The extent of the most of these settlements is still unknown. The monarchy ultimately convoluted in and around the Mapungubwe hill where the monarch resided. Mapungubwe hill acted as a natural fortress for the monarchy and also displayed the embodied standing in the kingdom. Large quantities of soil were carried up the hill to form a foundation for agriculture and buildings [1]. Burials also took place on the hill and most of the precious archaeological artefacts were consequently discovered in graves. This has led to Mapungubwe becoming one of the most important archaeological finds in present day South Africa. The artefacts that were found dated from approximately 1000 AD to 1300 AD and include materials such as pottery, trade glass beads, Chinese celadon ware, gold ornaments, ceramic figurines, crafted ivory, refined copper and iron [1].

Fig. 1: Google Earth image of Mapungubwe and some other archaeological sites around Mapungubwe.

Mapungubwe is situated on an isolated outcrop of sandstone that is about 31 m high and 320 m long with vertical cliff sides. The sandstone is underlain by mudstone and the mudstone is intruded by dolerite dykes. The sandstone and mudstone are sedimentary rock formations and the dolerite is igneous of origin. Primordial radionuclides materialise in most natural material and these rock formations are no exception. It has been shown that different rock formations contain noticeably different concentrations of primordial radionuclides, with the igneous rock usually having higher concentrations than the sedimentary rock [5]. The soil on and around Mapungubwe originates from the weathering of these rock formation and would therefore also contain unique concentrations of primordial radionuclides.
Primordial radionuclides consist of uranium (238\(^{\text{U}}\)) and thorium (232\(^{\text{Th}}\)) and potassium (40\(^{\text{K}}\)) of which potassium is the most abundant [2]. Natural potassium constitutes about 2.4% of the mass of the Earth and is present at percentage level in clays, feldspars and micas [3]. The natural radionuclide 40\(^{\text{K}}\) has an abundance of 0.0119% of all natural potassium whereas all natural uranium and thorium nuclides are radioactive [4]. Potassium in nature distributes as a mono charged positive ion. These potassium salts are highly soluble and when in solution it is very mobile [2]. Potassium concentrations would generally correlate with height when slopes are investigated. Low lying areas like salt marshes subsequently display high concentrations of potassium [7]. It has also been shown that archaeological sites have unique concentrations of primordial radionuclides and that the radiation fingerprint from these sites vary from that of the surrounding area [6]. These variations stem from the transportation of material in and out of such occupied areas by these early human inhabitants. Mapungubwe and the areas around the hill that were inhabited would therefore most probably also demonstrate unique radiation fingerprints.

This study aims to demonstrate that variations in the primordial radionuclides can be employed to indicate where humans have settled and interacted with the natural morphology. This study was initiated to act as a pilot project to determine if this method can be utilised to make predictions about the extent of the civilisation around Mapungubwe. Quantitative radiation measurements were done on samples that were gathered at Mapungubwe. Concentrations for potassium, uranium and thorium were extracted and spatially interpolated by means of GIS software. Colour overlays were constructed in order to demonstrate the concentration variations of potassium, uranium and thorium. These results were correlated to the natural geographical factors of the area and archaeological facts of the ancient civilisation at Mapungubwe.

**Experimental analysis**

A NaI(Tl) detector (7.62 x 7.62 cm) coupled to a scintiSPEC Multi Channel Analyzer (http://gs.flir.com/) was used to record the laboratory gamma ray spectra. The scintiSPEC Multi Channel Analyzer that is produced by ICX Technologies has a USB connection through which operating voltage is obtained and signal communication takes place. The system settings and spectrum acquisition were controlled by the winTMCA32 software (with 1024 channels), that is also produced by ICX Technologies. The detector was surrounded by 15 cm thick lead shielding which substantially reduced and smoothed the background radiation. Polypropylene pill containers were used both for the standards and sample materials. A volume of 100 ml was adopted and sample masses ranged from 0.138 kg to 0.181 kg. The system efficiency calibration was done by using three reference materials. A uranium and a thorium standard material were obtained from the International Atomic Energy Agency. The third, a potassium calibration standard of extra-pure potassium chloride (99.98%) was obtained from and certified by Dead Sea Works. Energy calibration was performed in the energy range from 0.3 to 2.7 MeV using anthropogenic nuclides and natural soil samples. The measurement procedure described by Rybach [8,9] was adapted for four regions of interest (ROIs) and implemented with some alterations that were suggested by Chiozzi et al. [10] and Bezuidenhout [12].

Seven soil samples were collected at Mapungubwe. The coordinates at each sampling point were taken by means of a Magellan Sport Track GPS and these positions are displayed on the Google Earth image in Fig. 2. Samples 1 and 2 were taken at the same position, but sample 1 was taken at a depth of 3 m in an archeological excavation. The samples were then prepared in pill containers and left for at least four weeks to allow the daughter nuclides to reach secular equilibrium with the parent nuclides [11].

**Fig. 2:** A Google Earth image that indicates the positions where samples were taken at Mapungubwe. Spectra were acquired for each of the samples and count rates were extracted from four regions centred on the four photo peaks of 214\(^{\text{Pb}}\) (351.3 keV), 40\(^{\text{K}}\) (1460.8 keV), 214\(^{\text{Bi}}\) (1764.5 keV) and 208\(^{\text{Tl}}\) (2614.5 keV) corresponding to the 238\(^{\text{U}}\), 40\(^{\text{K}}\), 238\(^{\text{U}}\) and 232\(^{\text{Th}}\) decay series, respectively. The counts in these peaks were used to
extract the concentrations of the three primordial radionuclides. The acquisition of spectra was conducted in a
room with a constant temperature over counting periods larger than 30 000 s. The count rates of the samples
were divided by the sample mass to accommodate differences in the mass of the various samples. The
coordinates of the sample points and the extracted nuclide concentrations are listed in Table 1.

<table>
<thead>
<tr>
<th>Sample nr</th>
<th>Latitude (degrees)</th>
<th>Longitude (degrees)</th>
<th>Potassium concentration</th>
<th>Uranium concentration</th>
<th>Thorium concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>22,2127</td>
<td>29,3867</td>
<td>466,9</td>
<td>14,4</td>
<td>15,3</td>
</tr>
<tr>
<td>Sample 2</td>
<td>22,2127</td>
<td>29,3867</td>
<td>386,3</td>
<td>11,4</td>
<td>15,2</td>
</tr>
<tr>
<td>Sample 3</td>
<td>22,2127</td>
<td>29,3867</td>
<td>377,9</td>
<td>10,4</td>
<td>16,9</td>
</tr>
<tr>
<td>Sample 4</td>
<td>22,2127</td>
<td>29,3867</td>
<td>425,4</td>
<td>6,1</td>
<td>13,6</td>
</tr>
<tr>
<td>Sample 5</td>
<td>22,21182</td>
<td>38,38727</td>
<td>435,5</td>
<td>12,6</td>
<td>18,0</td>
</tr>
<tr>
<td>Sample 6</td>
<td>22,21162</td>
<td>29,38722</td>
<td>384,2</td>
<td>8,7</td>
<td>22,4</td>
</tr>
<tr>
<td>Sample 7</td>
<td>22,21152</td>
<td>29,38792</td>
<td>397,1</td>
<td>4,5</td>
<td>29,7</td>
</tr>
</tbody>
</table>

Table 1: The sample coordinates with the extracted concentrations of potassium, uranium and thorium.
The concentrations are given in Bq/kg.

The sample positions and nuclide concentrations were then imported into Esri software as three different layers,
representing the three nuclides (potassium, uranium and thorium) as Z values. Each one of the layers was then
triangulated with the nuclides concentrations as the Z values. A TIN was created for each nuclide and an elevation
grid was generated to interpolate the concentration values as colour across the study area (see Figs. 3, 4 and 5).
These elevation grids were exported to KML files and imported into Google Earth. The transparency of the KML
overlays was set in Google Earth to such a level that the underlying aerial photograph was still visible.

Discussion

Sample 2 was taken on the edge of an archeological excavation and sample 1 was taken at a depth of 3 m in the
excavation. The thorium concentrations were the same in both samples, but the potassium and uranium
concentrations were substantially higher in the soil horizons where archeological articles were discovered
(see Table 1). Potassium and uranium are usually present as salts in nature and are therefore more soluble
compared to thorium. When humans occupy an area, the salt content of the soil in such an area usually increases,
which subsequently usually leads to higher potassium concentrations. The top soil at the excavation was
introduced after humans inhabited the area and this most probably led to the uranium and potassium
concentrations being lower than in the soil horizons which date from when humans lived in the area.

Mapungubwe is surrounded by vertical cliff sides and access to the hill top is only possible via one route on the
south west side. All the samples were collected on this route during an ascent of the hill. The concentrations of
potassium, uranium and thorium showed distinctive patterns along this transect. An assumption was made that
the relation between concentrations and height would be similar for all the slopes of the hill. The measured
values for the three radionuclides were consequently extrapolated to cover all the slopes of Mapungubwe. These
extrapolated concentrations and the concentrations on top of the hill were mapped and overlaid on Google Earth
images (see Figs. 3, 4 and 5). The vertical cliffs which form the edge of the relatively flat top of the hill are
indicated by a black line diagrams in each of the figures.

High concentrations of potassium were found on the steepest parts of the slope of Mapungubwbe, while low
concentrations were measured in the centre of the summit terrace and on the horizontal area around the hill
(see Fig. 3). The samples taken from the gorge where the hill is ascended showed the highest potassium
concentrations. This may stem from potassium on the soil on the top terrace that is dissolved in rainwater and
then transported from the summit via the chasm. Most of the potassium from the top terrace would eventually
dissolve in rainwater and be transported to below the cliffs. The low concentration of potassium in the centre
and heights point of the top terrace supports this theory of alluvial transportation of potassium.
Fig. 3: A Google Earth image with an overlay that indicates the variations in potassium concentrations on and around Mapungubwe. A black line diagram indicates the cliff edge of the top terrace of the hill.

A high concentration of uranium was found on the horizontal area closest to Mapungubwe, while low concentrations decreased with height as one ascends the hill. The top terrace of the hill demonstrated a large variance in uranium concentrations (see Fig. 4). Uranium is less soluble than potassium and consequently less transportable than potassium. The large variations in the concentrations of uranium on the top terrace therefore indicate that the soil on the terrace comes from different locations. This supports the fact that large amounts of soil were transported up onto Mapungubwe. The soil was probably carried up over a long period of time and therefore collected from different locations and different soil horizons, each with its own radiation signature. The low concentration of uranium on the slope of Mapungubwe may be due to alluvial transportation.

Fig. 4: A Google Earth image with an overlay that indicates the variations in uranium concentrations on and around Mapungubwe. A black line diagram indicates the cliff edge of the top terrace of the hill.

The highest concentrations of thorium were found in one of the samples that was taken on the top terrace of Mapungubwe. It is however important to note that the thorium concentrations of the samples that were taken on the top terrace showed large variations (see Fig. 4). This further supports the fact that large amounts of soil were transported up onto Mapungubwe and that this soil came from different locations. The thorium concentrations were found to be relatively low in the soil around Mapungubwe.

Fig. 5: A Google Earth image with an overlay that indicates the variations in thorium concentrations on and around Mapungubwe. A black line diagram indicates the cliff edge of the top terrace of the hill.

Conclusion
Soil samples were collected at seven points on a transect of Mpungubwe hill and concentrations of the three primordial nuclides were extracted. The extrapolation, interpolation and mapping of the concentrations of these nuclides was done by means of GIS software and the results demonstrated large variations in the concentrations primordial nuclides on and around Mapungubwe. Some of these large variations in nuclide concentrations were shown to be related to archaeological facts. The most prominent of these fluctuations were on the top terrace of Mapungubwe hill. The huge differences in nuclide concentrations supported the fact that soil was artificially introduced to the top terrace and demonstrated the impact of human activities on the Mapungubwe. This study therefore indicated that measurements of primordial radionuclide may be utilised to investigate archaeological sites like Mapungubwe.

The results of the measurements and the interpolated data were consistent with the archaeological facts. Without the use of GIS software it would have been very difficult to arrive at these results and consequent conclusions. The results did not introduce new archaeological information about Mapungubwe but only tested existing theories. This technique may however introduce new archaeological information with further and more extensive sampling of primordial nuclides in the area. More measurements are currently been planned for the Mapungubwe area and some of the other archaeological areas around Mapungubwe. This may prove to be an additional tool that can help to determine the spatial extent of the civilisations around Mapungubwe.

Developments are also underway to mount the detection equipment on a vehicle and to acquire the measurements continuous and in situ.

References


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