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Study on distribution of radionuclides in soil and pottery samples of archaeological sites of eastern India

Nabanita Naskar[1] · Chandrima Shaha[2] · Ahana Ghosh[3] · Kaushik Gangopadhyay[2]

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Abstract
The present study reports the first data on NORM distribution in soil and pottery samples collected from excavated sites of Erenda (Trench A1) and Bahiri (Trench YB1) located in East Medinipur, West Bengal, India. Collected potteries include grey-wares, red-wares, black-wares and black-red-wares. It was observed that ^{238}U and ^{40}K activities of the pottery samples are higher than that of the soil samples, which might be an indication of their different origin. ^{232}Th activity is uniform along the depth and has similar distribution in both soil and pottery samples of Erenda and Bahiri.

Keywords Naturally occurring radionuclides · Soil and pottery samples · Gamma-ray spectrometry · Archaeological artefact

Introduction

Natural radiation is present everywhere depending on geological and geographical locations. The major contribution towards natural radioactivity in the biotic and abiotic components of the environment comes from ^{238}U, ^{232}Th, the daughter radioisotopes present in these decay series and omnipresent ^{40}K. Altogether, they are termed primordial naturally occurring radioactive materials (NORMs), which have been present in the Earth since its formation. Apart from primordial NORMs, cosmic radiation-induced radioisotopes like ^{14}C, ^{10}Be, etc., are also present in nature. Nuclear techniques like Instrumental Neutron Activation Analysis (INAA) or gamma-ray spectrometry have been rarely used to estimate NORMs in archaeological artefacts. Some of these examples have been discussed here for an understanding of the pottery composition worldwide. Baria et al. [1] reported the concentration of NORMs in seventy ceramic fragments collected from São Paulo II archaeological site using INAA. The reported concentrations of U, Th and K were 2.6 ± 0.5 to 4.4 ± 0.2 mg kg^{-1}, 8.1 ± 0.5 to 14.4 ± 0.9 mg kg^{-1} and 0.3 ± 0.04 to $2.5 \pm 1.3\%$, respectively. Similar work was done by Carvalho et al. [2], where chemical analysis of ancient pottery collected from southwest Amazonia was done by INAA. Vichaidid and Latam [3] conducted a radiometric analysis of pottery samples collected from Thoud-Ta Thoud-Yai excavated site in southern Thailand using NAA and reported 5.6 ± 0.8 mg kg^{-1} ^{238}U, 15.6 ± 1.2 mg kg^{-1} ^{232}Th and BDL ^{40}K. Descantes et al. [4] studied the cultural and site provenance of ceramics gathered from the archaeological sites of Antigua, West Indies using NAA and concluded the local availability of the ceramics. Sanjurjo-Sánchez et al. [5] reported results obtained with ICP-MS, XRF and INAA to conclude similar mineralogical composition of beveled rim bowls collected from the middle Syrian Euphrates sites. Similar studies with INAA were carried out by Prudêncio et al. [6], Dias et al. [7], etc., to understand the chemical composition of Roman amphorae sherds and kilns produced in the regions of Lusitania, Western Portugal. The radioactive isotopic ratios of $^{40}K/^{228}Ac$ and $^{226}Ra/^{208}Tl$ were used as fingerprints to understand the provenance of ancient pottery by Dludosz-Lisiecka et al. [8].

Earlier, from our laboratory, the amount of ^{40}K in archaeological artefacts like glass beads was estimated by gamma-ray spectrometry and could trace back their origin [9]. Eight

✉ Nabanita Naskar
g.nabanitanaskar94@gmail.com

✉ Kaushik Gangopadhyay
k.gongo@gmail.com

1 Diamond Harbour Women's University, South 24 Parganas, Sarisha 743368, India

2 University of Calcutta, 1 Reformatory Street, Kolkata 700027, India

3 Department of Humanities and Social Science, IIT, Gandhinagar, India

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different glass-bead samples from Tamil Nadu, India were analysed. The amount of K varied between 0.26 to 3.27% whereas > 15% K content was observed in two beads each from Arikamedu and Manikollai.

In the present study, an attempt has been made to report the inventory of primitive radionuclides from two different archaeological sites of West Bengal (WB), India; Erenda (21.92°N, 87.58°E) located in East Medinipur district, and Bahiri (20.85°N, 87.79°E) located 22.5 km southeast of Erenda. The objective of this study is to measure the activities of ^{238}U, ^{232}Th and ^{40}K in soil and pottery samples collected from chronological layers of excavated trenches.

Materials and methods

Study area

The archaeological site of Erenda (21°55′4.8″ N and 87°34′42.4″ E) is located on the oblong mound, named Basulir Mandir, adjacent to the market within the village of Erenda in East Medinipur district [10]. Figures 1a and b show the sampling sites of Erenda and the excavated trench A1 at Erenda. The region around the archaeological site is a part of the Belda-Contai upland, which developed as ancient deltas of the Subarnarekha and Kasai rivers [11, 12]. The site is situated at the juncture of the Mid-Holocene Panskura formation and the Late Pleistocene-Early Holocene Sijua formation [13–15]. The entire deposit is divided into two periods—Period I, marked by the BRW, representing the protohistoric early farming culture, and Period II, which was revealed to be in a disturbed condition and possibly belonging to the early historic and early medieval period. The potteries unearthed from the excavation site include black-red-ware, black slipped ware, and a variety of red-ware in various forms of bowls, jars, and storage vessels [16]. Through the AMS method, the protohistoric level was dated to be around 4000–2500 BP or 2000–500 BCE, and the complete occupation level at least continued up to 126 BP or 942–1700 CE [17, 18]. Therefore, the potteries discovered in these trenches might be contemporary to the settlement. The palaeobotanical and organic geochemical study revealed that the archaeological level had a dominance of C4 phytolith morphotypes, along with the presence of fungal spores. The human occupation of the protohistoric level persisted in the warm and humid conditions, and the population perhaps consumed rice, of either wild or domesticated variety. The early inhabitants lived in mud and clay-built huts and perhaps used C4 aquatic grass for the construction of such settlements [19].

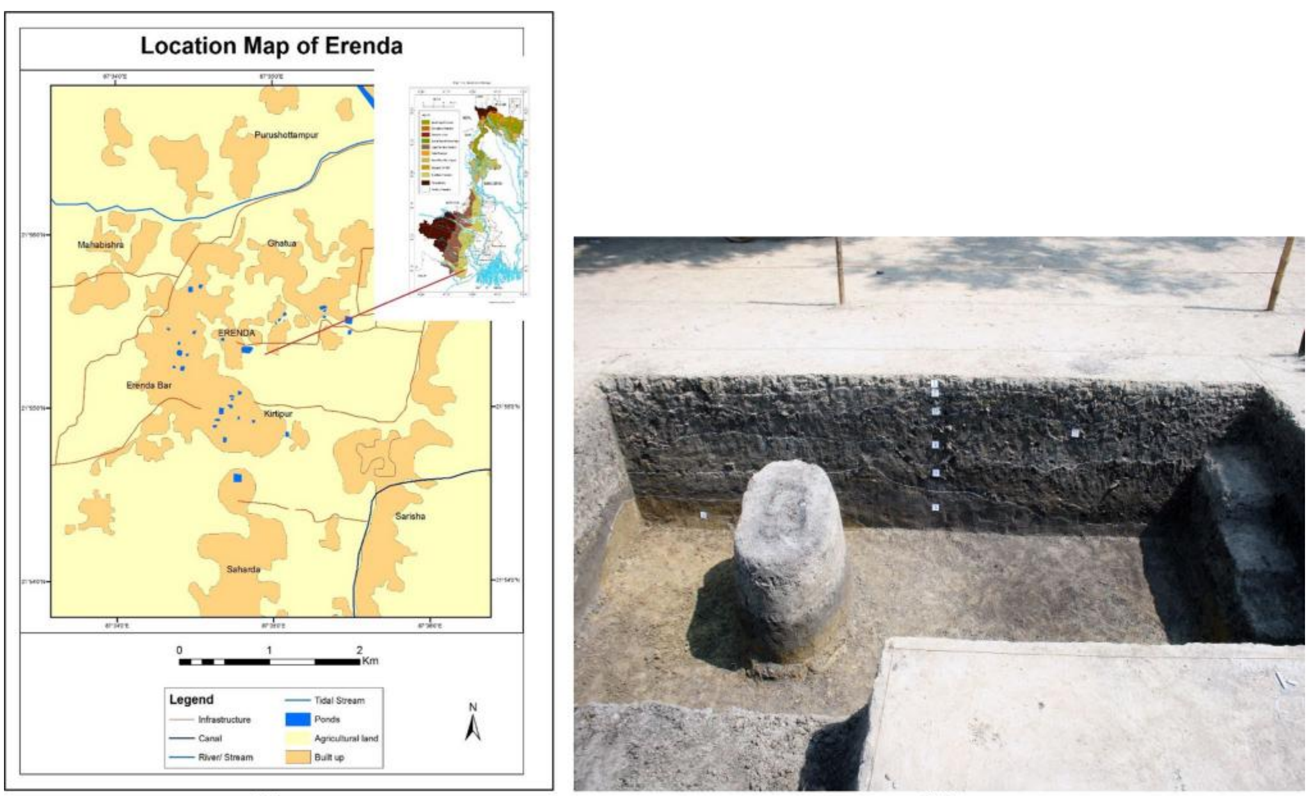


Fig. 1 **a** Map of Erenda and the excavated trench A1 at Erenda, **b** East Medinipur

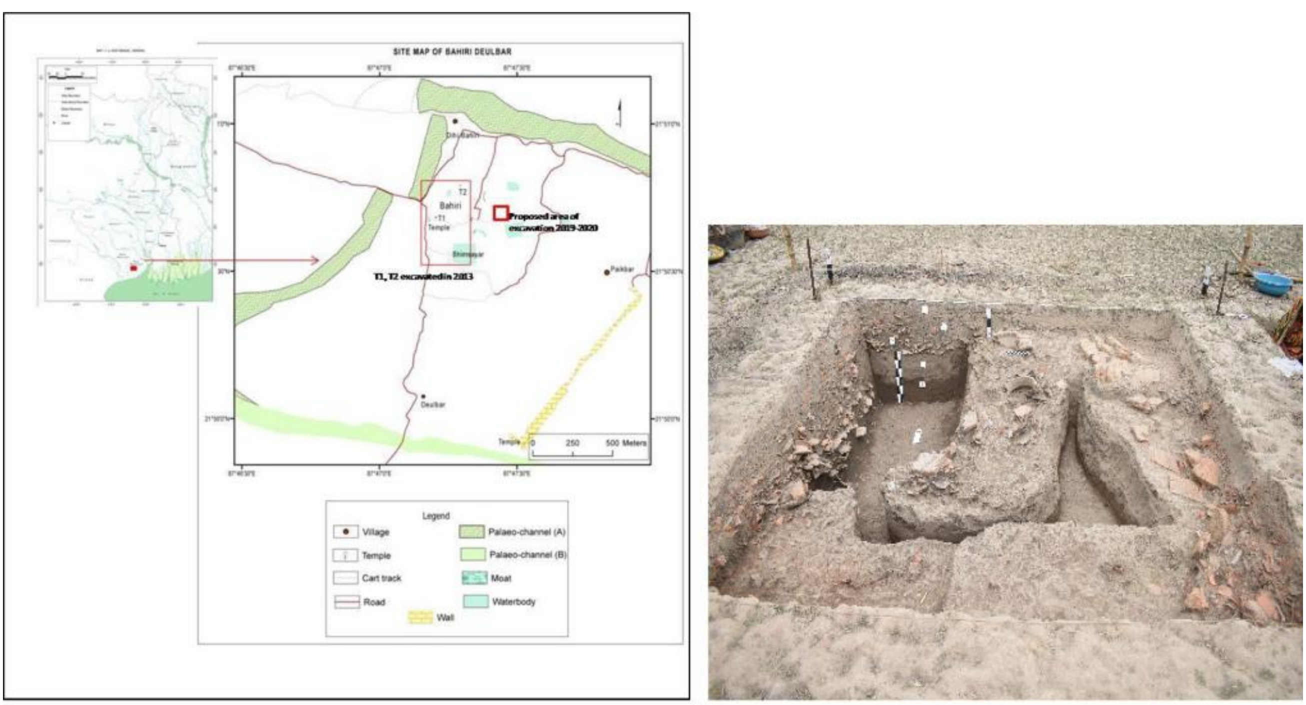
On the other hand, Bahiri (21°50′48″ N and 87°47′20″ E) is situated about 22.53 km southeast of Erenda, in close vicinity of the sea in East Medinipur district. Figures 2a and b show the sampling sites of Bahiri and the excavated trench YB1 at Bahiri. The geological formation of the region has been classified as Kanthi or Contai formation, and it represents the older coastal area with pronounced coastal landforms. The westernmost part of coastal Bengal is filled with a series of dune ridges parallel to the sea which are associated with the mid-late Holocene marine transgressive phase. The site of Bahiri, along with other adjoining sites is located within these sand dune ridges. From the artefacts, such as potsherds and terracotta figurines, the earliest occupation level of the site was identified to be of the early Historic period, being later than Erenda. The excavated potteries include a variety of red-ware, along with grey-ware and black-ware of various forms of bowls, dishes, basins, and large globular vessels. The ceramic assemblage indicates the importance of utilitarian ware which are prevailing throughout the early historic and early medieval levels. The associated artefacts are beads of semi-precious stones, terracotta figurines, and perforated roof tiles [20].

It is noteworthy to mention that both the archaeological sites of Erenda and Bahiri are part of coastal Medinipur. The sediment composition of coastal Medinipur can be divided into two parts: the older alluvium zone of the western section, part of the terminal Pleistocene and the recent alluvium deposit covering the coastal plain. The sites belong to the period of late Pleistocene to early Holocene with the geological Sijua formation [21]. Geologically, this ancient fluvio-marine deltaic region is a relatively recent depositional formation, a composition of primarily silt and clay sedimentation along with sandy materials [21]. The clayey composition includes gravels of siltstone, sandstone and quartz [22]. The transgressive condition of fluvial and marine processes (dominant tidal activities) resulted in the sequential changes of the Subarnarekha delta and the ancient tidal flat [21].

Sample description

Soil samples

The total archaeological deposit at Erenda was 1.65 m. Out of this, 1 m was of the protohistoric period followed by ~ 60 cm deposit of the early historical and early periods. A total of fourteen soil samples were collected from Trench A1 from different levels of the site. Whereas, a 1.2 m total archaeological deposit was excavated from Bahiri, out of which an early historic period was found up to ~ 60 cm depth, preceded by a non-anthropogenic deposit. From different contexts of the site, a total of ten soil samples were collected from Trench YB1. Figures 3a and b represent the sections of Trench A1 (Erenda) and Trench YB1 (Bahiri)



(a) (b)

Fig. 2 **a** Map of Bahiri and the excavated trench YB1 at Bahiri, **b** East Medinipur

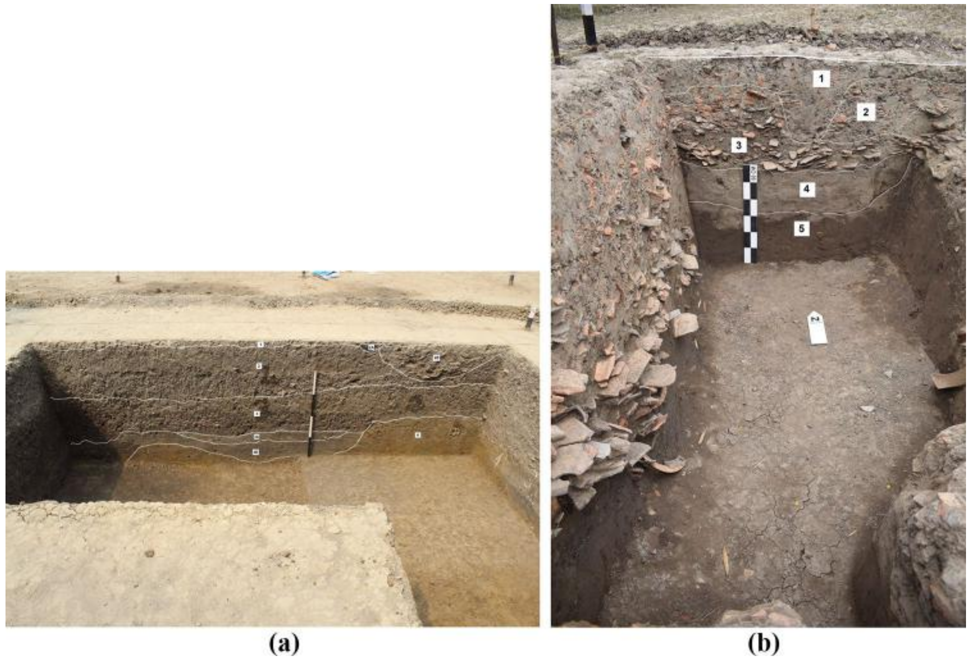


Fig. 3 **a** Sections of Trench A1(Erenda) and **b** Trench YB1 (Bahiri) showing different layers

Table 1 Layer description of Trench A1, Erenda

Layers	Description
1	Surface humus along with loose pot sherds
2	Dark brown silty clay with thickness varying between 39 and 60 cm. Pot sherds belong to the early medieval period. The layer is marked by a pit, noted as 2B
3	Pot sherds of chalcolithic period, characterised by Black and Red Ware between the depth of 34 to 79 cm. Other artefacts found are bone tools, hopscotches, spindle whorls and bone fragments. Notable features include mud floors
4	Olive yellow coloured natural soil (Sijua) with calcium carbonate

showing different layers of the trenches from where the soil samples were collected. Table 1 provides the layer description of Trench A1 of the excavated site, Erenda. Table 2 describes the layer stratigraphy of Trench YB1 of the excavated site, Bahiri.

Pottery samples

Potsherds are common to find during the excavation of the majority of archaeological sites. During the excavations of Erenda and Bahiri, a collection of potsherds of different typologies was unearthed, along with other artefacts, e.g., bricks, tiles, terracotta objects and many more. The intention was to put together a cleaned, ordered and well-documented assemblage for post-fieldwork analysis. Potsherds were collected from all the digs in the case of Erenda and contexts in the case of Bahiri from every trench that was dug in accordance with the objectives of the planned excavations.

The pottery pieces were cleaned of any foreign element from the surface, i.e., soil and other products not part of the original potsherd using water and a soft brush with minimum pressure. Before being tagged and stored in different zip-lock bags according to trench and dig or context number, all the pieces were air-dried thoroughly. The potsherds were marked and stored separately based on

Table 2 Layer description of Trench YB1, Bahiri

Layers	Description
1	Surface humus till 9 cm depth
2	Silty clay layer up to the depth of 41 cm, brownish when wet and grey when dry. Artefacts include rammed pot sherds and building materials along with charcoals and bone fragments
3	Sandy silt deposit with a thickness of 16 cm, composed of the main habitation layer artefacts is large pieces of pot sherds along with bricks
4	Olive green-coloured clay with a thickness of 30 cm. The soil is devoid of anthropogenic activities. Trace of a pit is the north-western segment of the trench
5	Sandy virgin soil with a thickness of 33 cm

their typology and ware variation. Some of the potsherds with special significance were recorded in situ using drawn plans and photographs. Not a single piece of potsherd was marked on the surface using any kind of tools such as ink or markers to avoid hindrance. Rather, paper tags were placed within the bags with proper labelling. All the bags of potsherds were safely transported and kept in the Department of Archaeology, University of Calcutta within storage trunks and boxes.

A total of nine pottery samples were collected from Trench A1 of Erenda for analysis. Of all the selected potsherds, three samples were of grey-ware, one of black-ware, four samples were of black-red-ware, and one of red-ware. On the other hand, the number of pottery samples from Bahiri was nine, of which seven were of grey-ware and two were of red-ware. Figures 4a and b represent the various pottery samples collected from Trench A1 of Erenda and Trench YB1 of Bahiri, respectively.

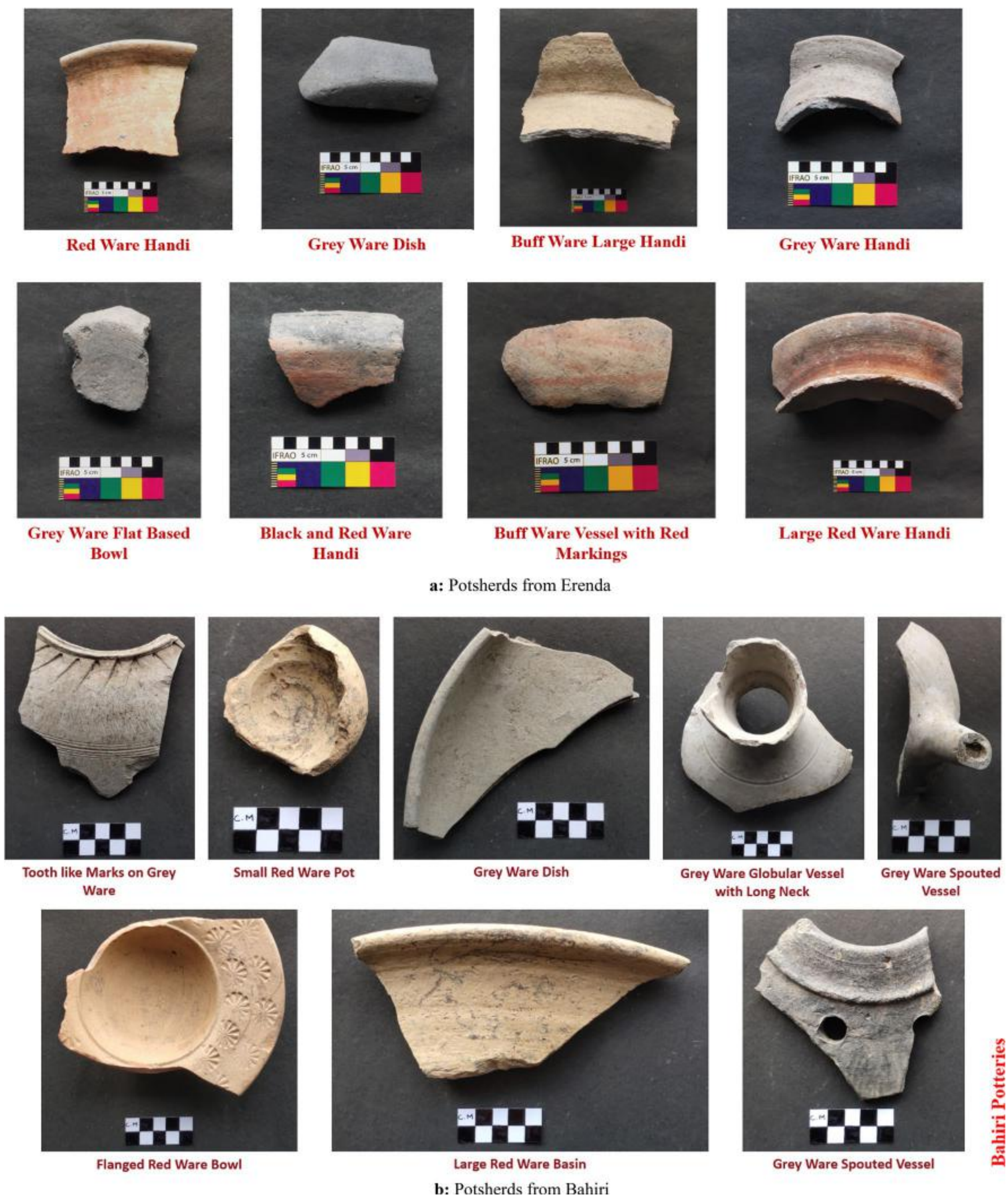


Fig. 4 **a** Potsherds from Erenda **b** Potsherds from Bahiri

Sample and standard preparation

The soil and pottery samples were air-dried till constant weight, i.e., the moisture was driven out completely and pulverized in a grinder to obtain a fine powder. Weighed 50 g of fine-powdered samples, packed in air-tight petri plates (75 mm diameter) and kept for 40 days to attain secular equilibrium.

RGU-1 (Uranium ore) and RGTh-1 (Thorium ore) reference materials (RMs) procured from the International Atomic Energy Agency (IAEA) were used to prepare U and Th standards for the present experiment. RGU and RGTh contain the recommended amount of ~ 4940 Bq kg^{-1} ^{238}U and 3250 Bq kg^{-1} ^{232}Th respectively. From the high-activity RMs, in-house low-activity standards (2.964 Bq ^{238}U and 3.249 Bq ^{232}Th) were prepared by mixing appropriate amounts of RGU and RGTh with silica gel in 75 mm Petri-plates. For the preparation of 2.964 Bq ^{238}U and 3.249 Bq ^{232}Th, 0.6 g RGU and 1 g RGTh were mixed with silica gel, respectively. This was done to ensure a similar sample and standard geometry [23]. Standards were also hermetically sealed and kept as such to establish secular equilibrium. For ^{40}K measurement, an array of KCl standards (10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 Bq activities) were prepared in-house by varying the amount of KCl. For example, to prepare 10 Bq ^{40}K activity, 0.6 g KCl was mixed with silica gel in 75 mm petri plate according to Naskar et al. [24].

Instrumentation and radioactivity measurement

A high-purity Germanium (HPGe) detector having 80% relative efficiency and resolution of 1.65 keV at 1.33 MeV (make: CANBERRA) was used. The detector was shielded inside LS (Laboratory lead shield) series. The detector was connected to the Canberra DSA-LX analyzer, which has an integrated 16 k multichannel analyzer based on digital signal processing. Energy calibration was done using the single point-source standards of ^{152}Eu, ^{137}Cs, and ^{60}Co. All the prepared standards and samples were measured for 60,000 s [23, 25]. All spectra were analysed by Genie-2 k software after being stripped off from respective backgrounds. ^{238}U and ^{232}Th activities in the samples were calculated using the photopeaks of 295.2, 351.9, 609.3 keV for ^{238}U and photopeaks of 338.3, 583.2, 911.2 keV for ^{232}Th [26]. ^{40}K activity was measured from its signature photopeak at 1460.8 keV. Activities of ^{238}U, ^{232}Th and ^{40}K in excavated soil samples were calculated using the comparator method [27, 28]. In the comparator method, the activities were calculated using the formula:

Results and discussion

Activities of NORM in the soil and pottery samples from Trench A1 of Erenda, East Medinipur have been tabulated in Table 3. The activities of ^{238}U, ^{232}Th and ^{40}K ranged between 30.1 ± 1.3 to 44.4 ± 2.9, 51.3 ± 1.6 to 72.7 ± 6.3 and 432.1 ± 8.6 to 503.6 ± 9.4 Bq kg^{-1}, respectively. Measurement of NORM concentration in the pottery samples unfolded an interesting observation. Concentrations of ^{238}U, ^{232}Th and ^{40}K in grey-ware and black-ware samples were similar to that of soil samples (Table 3). The mean activities of ^{238}U, ^{232}Th, ^{40} in Erenda soil samples were recorded as 34.0, 62.2 and 453.9 Bq kg^{-1} and those of grey-ware and black-ware potteries were 37.5, 66.4 and 447.9 Bq kg^{-1}. On the contrary, the NORM concentrations of black-red-ware and red-ware samples were higher than the soil samples, particularly for ^{238}U and ^{40}K. The mean activity of ^{238}U, ^{232}Th and ^{40} of these pottery samples were 43.7, 65.0 and 549.5 Bq kg^{-1}, respectively. The box plots of the activities of ^{238}U, ^{232}Th and ^{40}K in soil and pottery samples from Erenda (Figs. 5a–c) help to visualize the similarities and discrepancies clearly. The box plots show that the activity of ^{238}U and ^{40}K for grey-ware and black-ware pottery samples are almost similar to that of soil samples but the activity of black-red-ware and red-ware samples is higher than the soil samples, which indicates the possibility that the pottery samples are not native. The ^{232}Th activity is rather evenly distributed for both soil and pottery samples from Erenda. ^{238}U and ^{40}K has a variable distribution in black-red-ware and red-ware potteries Erenda sampling site.

The NORM data for the soil and pottery samples collected from Bahiri, East Medinipur has been depicted in Table 4. Activity range of ^{238}U, ^{232}Th and ^{40}K in soil samples was found to be between 22.6 ± 1.3 to 38.8 ± 1.7, 59.7 ± 4.4 to 95.2 ± 6.9 and 448.2 ± 8.9 to 860.4 ± 12.5 Bq kg^{-1}, respectively. For pottery samples (mostly grey ware potteries) collected from the same context of Trench YB1, the activities of ^{238}U, ^{232}Th and ^{40}K varied between 33.6 ± 2.6 to 49.3 ± 1.9, 66.0 ± 8.6 to 82.4 ± 4.7 and 751.9 ± 11.6 to 971.8 ± 13.0, Bq kg^{-1}, respectively. Radioactivity measurement shows that the ^{232}Th activity in soil (mean 77.4 Bq kg^{-1}) and pottery (mean 75.2 Bq kg^{-1}) are similar whereas the ^{238}U and ^{40}K activities were higher for the pottery samples as compared to the soil samples. Figures 6a–c present the box plot distribution of ^{238}U, ^{232}Th and ^{40}K in the soil and pottery samples collected from Bahiri which also indicate that the origin of the pottery in Bahiri might be different from the native soil

$$\frac{Activity\ of\ sample}{Activity\ of\ standard} = \frac{Count\ of\ sample\ under\ particular\ photo\ peak}{Count\ of\ standard\ under\ same\ photo\ peak}$$

Table 3 Activity of ^{238}U, ^{232}Th, ^{40}K in soil and pottery samples from Erenda, East Medinipur, WB

Activity for soil samples in Bq kg^{-1}					Activity for pottery samples (GW and BW) in Bq kg^{-1}				Activity for pottery samples (B&RW and RW) in Bq kg^{-1}			
Sample ID	Depth, cm	^{238}U	^{232}Th	^{40}K	Sample ID	^{238}U	^{232}Th	^{40}K	Sample ID	^{238}U	^{232}Th	^{40}K
A1-II-3	26	35.6 ± 0.9	67.4 ± 3.9	482.2 ± 9.2	A1-II-3 -GW	37.5 ± 1.6	73.2 ± 0.5	480.6 ± 9.4	A1-II-8-B&RW	46.9 ± 0.5	64.7 ± 2.8	521.0 ± 7.5
A1-II-5	36.5	30.2 ± 1.4	51.3 ± 1.6	445.3 ± 8.7	A1-II-5 -GW	39.1 ± 1.0	71.2 ± 3.2	451.9 ± 9.0	A1-III-2-RW	40.6 ± 1.3	55.6 ± 2.2	580.6 ± 15.1
A1-II-6	40.5	32.8 ± 1.2	58.4 ± 3.3	448.7 ± 8.8	A1-II-6 -GW	36.9 ± 2.6	59.4 ± 4.9	337.3 ± 12.0	A1-III-3-B&RW	48.9 ± 0.5	63.0 ± 5.2	655.1 ± 8.7
A1-II-8	50	34.8 ± 2.4	53.7 ± 1.6	432.1 ± 8.6	A1-III-7-BW	36.6 ± 2.2	61.9 ± 7.3	521.9 ± 9.4	A1-III-18-B&RW	40.9 ± 3.5	64.5 ± 3.7	539.9 ± 9.5
A1-III-2	59.5	44.4 ± 2.9	72.7 ± 6.3	470.0 ± 8.9					A1-III-25-B&RW	40.4 ± 3.4	65.3 ± 1.8	501.0 ± 5.2
A1-III-3	62	34.2 ± 1.3	60.6 ± 5.9	456.5 ± 9.2								
A1-III-6	73	33.1 ± 0.5	60.2 ± 4.2	466.5 ± 9.1								
A1-III-7	77	30.1 ± 1.3	58.1 ± 2.0	441.6 ± 8.9								
A1-III-8	81	33.8 ± 1.5	61.4 ± 5.3	447.4 ± 9.0								
A1-III-16	115	32.8 ± 1.5	72.1 ± 3.2	448.2 ± 8.7								
A1-III-18	127.5	33.5 ± 2.6	63.5 ± 2.9	486.5 ± 9.2								
A1-III-20	140	34.1 ± 0.7	67.5 ± 4.7	500.2 ± 9.3								
A1-III-23	154.4	33.7 ± 0.9	59.6 ± 1.7	465.5 ± 8.9								
A1-III-25	163.5	32.9 ± 1.3	63.8 ± 7.0	503.6 ± 9.4								
Range		30.1 ± 1.3 to 44.4 ± 2.9	51.3 ± 1.6 to 72.7 ± 6.3	432.1 ± 8.6 to 503.6 ± 9.4	Range	36.6 ± 2.2 to 39.1 ± 1.0	59.4 ± 4.9 to 73.2 ± 0.5	337.3 ± 12.0 to 521.9 ± 9.4	Range	40.4 ± 3.4 To 48.9 ± 0.5	55.6 ± 2.2 To 65.3 ± 1.8	501.0 ± 5.2 To 655.1 ± 8.7
Mean		34.0	62.2	463.9	Mean	37.5	66.4	447.9		43.7	65.0	549.5
Median		33.6	61.0	461.0	Median	37.2	66.5	466.2		41.4	64.7	530.5

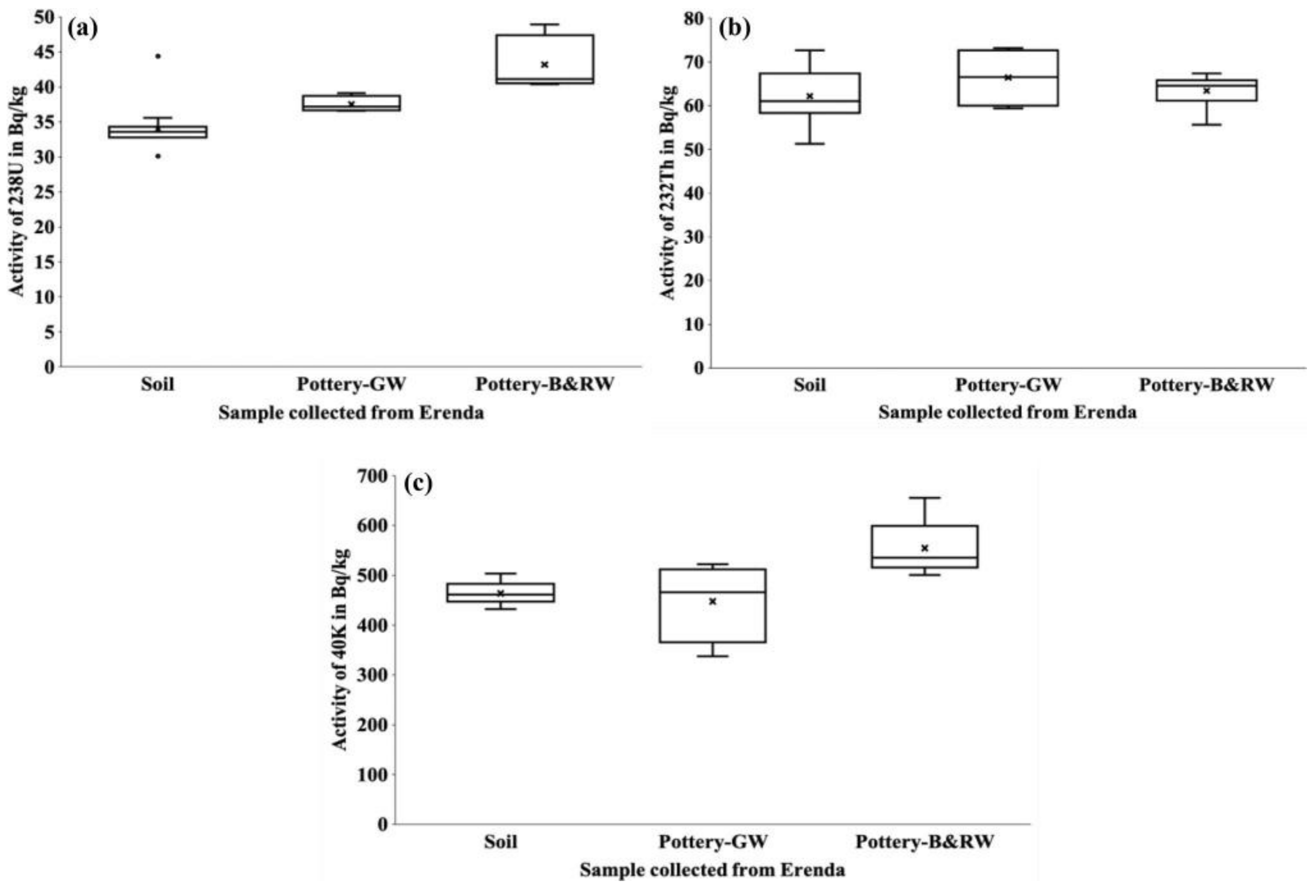


Fig. 5 Box plot of **a** ^{238}U, **b** ^{232}Th and **c** ^{40}K for soil and pottery samples from Erenda

Table 4 Activity of ^{238}U, ^{232}Th, ^{40}K in soil and pottery samples from Bahiri, East Medinipur, WB

Sample ID	Depth, cm	Activity for soil samples in Bq kg^{-1}				Activity for pottery samples in Bq kg^{-1}		
		^{238}U	^{232}Th	^{40}K	Sample ID	^{238}U	^{232}Th	^{40}K
C-11	8	38.8 ± 1.7	91.3 ± 10.3	638.8 ± 10.6	C-11-RW	44.7 ± 2.2	70.3 ± 3.9	751.9 ± 11.6
C-13	17	33.6 ± 2.3	82.4 ± 1.2	653.7 ± 10.5	C-13-GW	48.4 ± 2.1	75.3 ± 1.9	971.8 ± 13.0
C-29	28	36.9 ± 1.9	95.2 ± 6.9	621.4 ± 10.3	C-29-GW	35.9 ± 1.6	66.0 ± 8.6	666.3 ± 13.0
C-31	21	29.2 ± 0.4	69.8 ± 3.0	765.3 ± 11.5	C-36-GW	36.6 ± 2.0	75.1 ± 2.4	885.7 ± 12.6
C-36	32	35.6 ± 1.4	71.1 ± 4.8	860.4 ± 12.5	C-43-GW	42.5 ± 3.5	74.7 ± 11.4	937.1 ± 13.1
C-43	40	22.6 ± 1.3	59.7 ± 4.3	639.9 ± 10.6	C-44-GW	44.5 ± 2.1	77.2 ± 2.6	964.9 ± 12.8
C-44	74	24.9 ± 1.8	63.2 ± 4.1	673.5 ± 10.8	C-53-GW	33.6 ± 2.6	76.7 ± 1.7	871.4 ± 12.3
C-53	102	30.4 ± 0.9	78.3 ± 7.1	448.2 ± 8.9	C-61-GW	37.4 ± 0.7	78.9 ± 2.9	883.5 ± 12.5
C-61	38	32.2 ± 1.9	84.8 ± 7.3	588.1 ± 10.3	C-62-RW	49.3 ± 1.9	82.4 ± 4.7	943.4 ± 12.3
C-62	43	27.6 ± 1.8	78.2 ± 4.9	462.4 ± 8.8				
Range		22.6 ± 1.3 to 38.8 ± 1.7	59.7 ± 4.3 to 95.2 ± 6.9	448.2 ± 8.9 to 860.4 ± 12.5	Range	33.6 ± 2.6 to 49.3 ± 1.9	66.0 ± 8.6 to 82.4 ± 4.7	751.9 ± 11.6 to 971.8 ± 13.0
Mean		31.2	77.4	635.2		41.4	75.2	875.1
Median		31.3	78.3	639.3		42.5	75.3	885.7

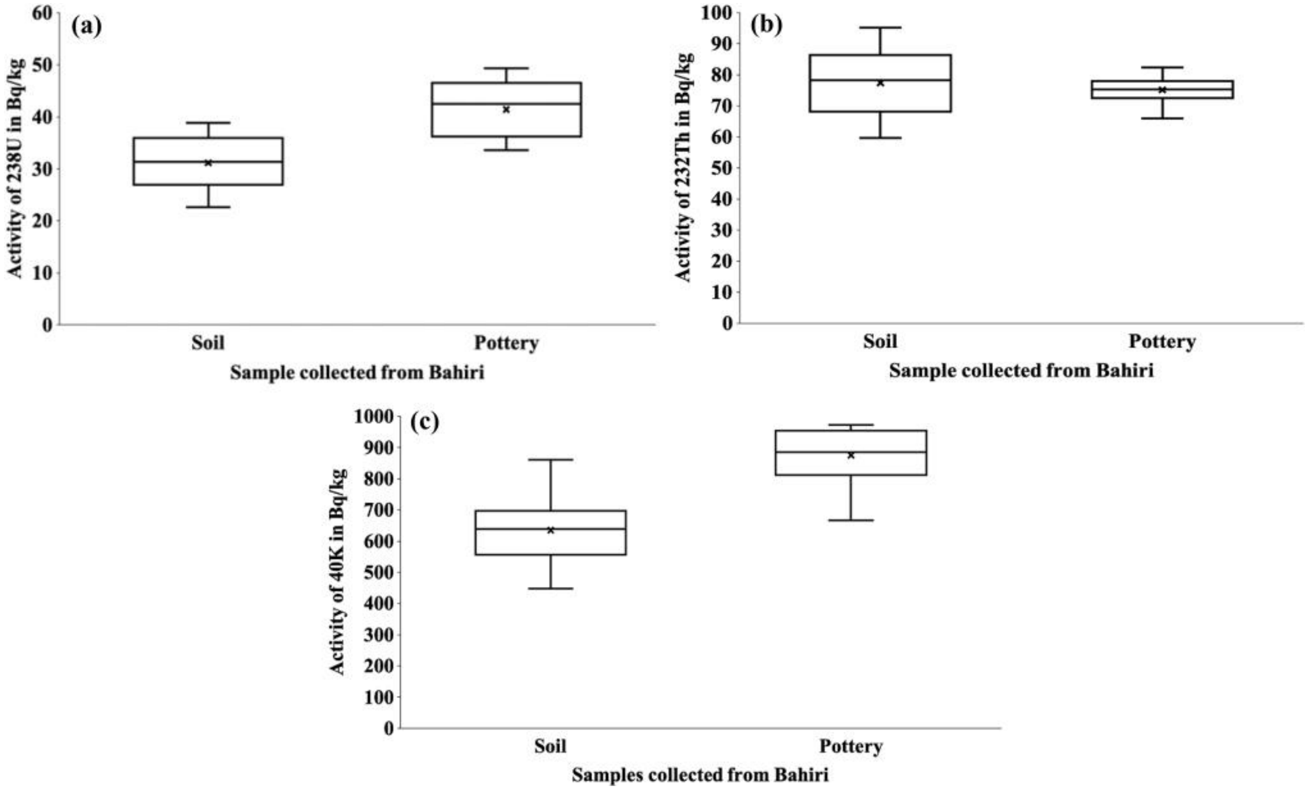


Fig. 6 Box plot of **a** ^{238}U, **b** ^{232}Th and **c** ^{40}K for soil and pottery samples from Bahiri

samples. Further, extensive geochemical analyses would be important to understand their provenance and obtain a firm conclusion.

Another observation is consistently higher ^{40}K activity in both the soil and pottery samples of Bahiri, with respect to that of Erenda samples. Also, overall ^{40}K activity obtained in the soil and pottery samples, both from Erenda and Bahiri is higher than the global average of 420 Bq kg^{-1} [29]. Most of the samples showed ^{238}U activity at par with the global average of 35 Bq kg^{-1}. The ^{232}Th activity was found to be higher than the global average value of 45 Bq kg^{-1} may be because of its insoluble nature and may not have leached out during the time period.

Tamluk, the ancient town, is also a part of East Medinipur, situated between the Rupnarayan and Kasai rivers. A provenance study of the ancient potteries from West Bengal on the basis of elemental oxides and trace elemental composition was carried out by Das et al. [30] using Wavelength Dispersive X-ray fluorescence (WD-XRF). The study included three archaeological sites situated along the east coast of India, Chandraketugarh and Tamluk in West Bengal and Arikamedu in Tamil Nadu. The study reported 3.4–3.7% K_2O in grey-wares (five samples) and 3.5% K_2O in red-ware (one sample), Average Th concentration was 16.8 mg kg^{-1} for grey-wares and 17 mg kg^{-1} in red-ware [30].

In Erenda potteries, Th concentration as calculated from the activity obtained is ~ 16 mg kg^{-1}. Separately, Th content in red-ware (one sample) is 13.7 mg kg^{-1}, grey-ware (three samples) is 16.7 and 15.8 mg kg^{-1} in six black-red-wares samples. Therefore, the present result corroborates with the findings of Das et al. [30]. Potteries collected from Bahiri are mainly grey-wares (seven samples) and two red-wares. Th concentration is 19 mg kg^{-1} in Bahiri soil samples. Th varied between 18.5 mg kg^{-1} in grey-wares and ~ 18.7 mg kg^{-1} in red-wares. From the overall result, it may be said that Th concentration is uniformly present along the eastern basin of West Bengal. Th concentration is comparable in grey-wares for all three eastern ancient sites, Tamluk (16.8 mg kg^{-1}), Erenda (16.7 mg kg^{-1}) and slightly higher in Bahiri (18.5 mg kg^{-1}). For red-wares, Th content is comparable for Tamluk (17 mg kg^{-1}) and Bahiri (18.7 mg kg^{-1}).

Pottery is one of the most commonly studied archaeological artefacts in terms of colour, surface texture, dimension, shape, size, etc., to understand their provenance and trading routes. Geochemical studies provide significant insight into the source of the raw material used during the processing of pottery. Pottery is generally formed from clay, whose primary composition is hydrous aluminium phyllosilicates, with variable amounts of macro-elements. The inventory of naturally occurring radioisotopes in the pottery samples would help to unveil more archaeological facts about the human settlement in these areas. However, extensive geochemical studies are essential prior to a definitive conclusion on the provenance of the pottery.

Conclusion

This study is the first report on natural radiation from two excavated sites in West Bengal, India. The discrimination of the origin of the household materials by measuring NORM activity has rarely been reported and would further open up new archaeological investigations which might be a valuable addition to the trades and exchange of items in ancient times. This study shows the importance of radioactive isotopes, which could be used to characterise archaeological artefacts and soils in future. The basic findings will be important in understanding the palaeo-environment of this area with other supporting analyses in future.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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