Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/19372
DOI URL: http://dx.doi.org/10.21474/IJAR01/19372

RESEARCH ARTICLE

THE CONCENTRATION OF NATURAL RADIATION SOURCES (NRS), MAINLY ^{238}U, ^{232}Th, and ^{40}K, IN BUILDING MATERIALS (SAND, CLAY BRICKS, AND CONCRETE BLOCKS) USED ALONG KANGUNDO ROAD, NAIROBI KENYA

Amosi Nyongesa Chilai[1], Dr. Nadir O. Hashim[1] and Dr. Felix Wanjala Omonya[2]

1. Kenyatta University, Kenya.
2. International Atomic Energy Agency (IAEA), Austria.

……………………………………………………………………………………………………....

Manuscript Info

Manuscript History
Received: 25 June 2024
Final Accepted: 27 July 2024
Published: August 2024

Abstract

This research aimed at assessing the concentration of Natural Radiation Sources (NRS), mainly ^{238}U, ^{232}Th, and ^{40}K, in building materials (sand, clay bricks, and concrete blocks) used along Kangundo Road in Nairobi City County. Human exposure to ionising radiation is largely due to Natural Radiation Sources (NRS). These radioactive elements with long half-lives are found in the Earth's lithosphere and in construction materials with radiation levels varying due to their geology. A purposive random sampling method was deployed in this work to collect samples of building materials for analysis. The radioactivity concentration levels in the sampled building materials were determined using a NaI (TI) spectrometer at Kenyatta University laboratory. The activity concentration of ^{40}K varied from 151 ± 8 to 2392 ± 120 Bq/kg, ^{238}U varied from 27 ± 2 to 412 ± 21 Bq/kg and ^{232}Th ranged from 54 ± 3 to 612 ± 31Bq/kg. More than 70 per cent of the samples analysed had activity concentration surpassing the world permissible limits of 420 Bq/kg, 33 Bq/kg, 45 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. The study therefore recommended that assessment of radioactivity concentration for samples with high radioactivity values.

……………………………………………………………………………………………………....

Introduction:-

Human exposure to natural background radiation arising from natural radioactivity has been a constant aspect of human life (Mohan & Chopra, 2022). Natural radioactivity originates from the presence of radioactive elements with long half-lives in the Earth's lithosphere and has been present since the formation of the universe. These radioactive elements, notably ^{238}U, ^{232}Th, and ^{40}K, are universally found in various geological materials, including gravels, granites, sand, and gypsum, which are commonly used as construction materials (Mohan &Chopra, 2022).

The rapid urbanisation and construction boom along Kangundo Road, Nairobi City County, Kenya, raised concerns about the potential use of building materials with high levels of radiation. While construction is essential for urban development, the indiscriminate use of such materials can lead to significant environmental and health impact. The use of building materials with high levels of radiation may contribute to environmental degradation, including soil and water contamination due to increased exposure to ionising radiation. Such contamination can lead to long-term consequences on the local ecosystem.

Corresponding Author:- Amosi Nyongesa Chilai
Address:- Kenyatta University, Kenya.

Literature Review:-

Assessments in regards to natural radioactivity have been done although not much on building materials in Africa. Oborah (2022) did assessment of radioactivity concentration and radiation hazards index for building materials used in Babadogoestate, Nairobi City County, Kenya, the levels were within the accepted standards. Hashim (2000) measured the magnitude of radionuclide ^{238}U, ^{232}Th as well as ^{40}K from sediments samples in Mombasa, Kenya. The results also showed that that the levels of radionuclides were within the acceptable standards. Radioactivity for surface soil in the proposed titanium mines in Kenya has been reported (Osoro, 2007), the assessment indicated that the surface soils in the area around the proposed mines contained low levels of natural radionuclide. In Kenya, another study in Kakamega County, Songa (2021) utilised gamma spectroscopy to determine the specific activity levels of ^{226}Ra, ^{232}Th, and ^{40}K in marram as building materials.

The mean value for absorbed dose rate, analysed from soil samples collected in Mrima hills, Kenya (Osoro, 2007) was found to be about seven times the world safety ceiling figures. Regionally in Tanzania, studies conducted at Kyerwa District at the Tin mines revealed ^{226}Ra activity concentrations were high in waste rock (Gurisha *et al*.,2020). Felix O Wanjala (2019) did assess the human exposure to background radiation in Ortum-Kenya, His results showed that the average activity concentration in soil was higher than the world average values. The average ADRA in air at 1 m above the ground was found to be 112±29.6nGyh^{-1}. The soil and rocks in Ortum were recommended for use because the activity concentration of the terrestrial radionuclides was lower than the recommended world threshold values.

Internationally, Viresh *et al*. (1999) measured the natural radioactivity from Indian building materials as well as their by-products. The results showed activity levels less than the ceiling estimated and suggested acceptable radiation dose attributed from building materials. The activity concentrations in building materials available in Turkey (Mavi&Akkurt, 2010) ranged between 158.8 Bqkg^{-1}and 188.8 Bqkg^{-1}. Another study in Turkey using gamma ray spectroscopy showed the concentration levels of ^{238}U,^{232}Th and ^{40}K for randomly selected building materials ranging between 3.5 Bqkg^{-1} and 114.1 Bqkg^{-1}, 1.6 Bqkg^{-1} and 20.7 Bqkg^{-1} ,201.4 Bqkg^{-1} and 49228.8 Bqkg^{-1} respectively (Mavi&Akurt, 2010).

In Cyprus, having applied the dose criterion by WHO (2012) as superficial materials, it was reported that 25 samples met exception figure of 0.3mSv/y, while only one exceeded the limit. Stoulos *et al*. (2003) investigated gamma ray radiation at the same time dose rate from commercially used natural tiling rocks. The result showed the activity for ^{232}Th ranging from 1 – 906 Bq/kg, ^{238}U from 1-588 Bq/kg and ^{40}K from 50-1606 Bq/kg. In Cuba province, Flores *et al*. (2008) assessed activity concentration for 40 samples commonly used as raw materials and building products. Gamma ray spectrometry was used the average figures for concentration were within range of 9 Bqkg^{-1} to 857 Bqkg^{-1} in ^{40}K, 6 Bqkg^{-1} to 57 Bqkg^{-1} in ^{226}Ra and 1.2 Bqkg^{-1} to 22 Bqkg^{-1} in ^{232}Th. From Iran, employing gamma ray spectroscopy, Simin *et al*. (2011) assessed natural radioactivity in building materials. The results of the study showed that cement had maximum value of ^{232}Th concentration at 28.9 Bq/kg and lowest value in gypsum at 2.2 Bq/kg. The study showed that the cement samples had maximum values of 39.6 Bq/kg for ^{226}Ra while that of ^{232}Th concentrations was 28.9 Bq/kg. While the lowest values were 8.1 Bq/kg for ^{226}Ra and 2.2 Bq/kg for ^{232}Th in gypsum samples. In the same work dose rate value was 53.7 nGyy^{-1} while hazard index value was below the recommended levels.

Materials and Methods: -

NaI (T1) Gamma-ray Spectrometer

For the assessment of radiation levels in the building materials, the use of a 76 mm × 76 mm sodium iodide thallium NaI(TI)) gamma-ray detector was deployed, Figure 1. The choice of the detector was based on its proven effectiveness in accurately measuring gamma radiation. The resulting pulse of charge, which corresponds to the energy of the incoming gamma photons, was then collected and recorded by the Multichannel analyser (MCA). The data collected was then displayed as a spectrum on a computer screen. The instrument was essential for the goal of quantifying the radiation levels in the building materials, allowing for analysis and understanding of the potential environmental and health risks.

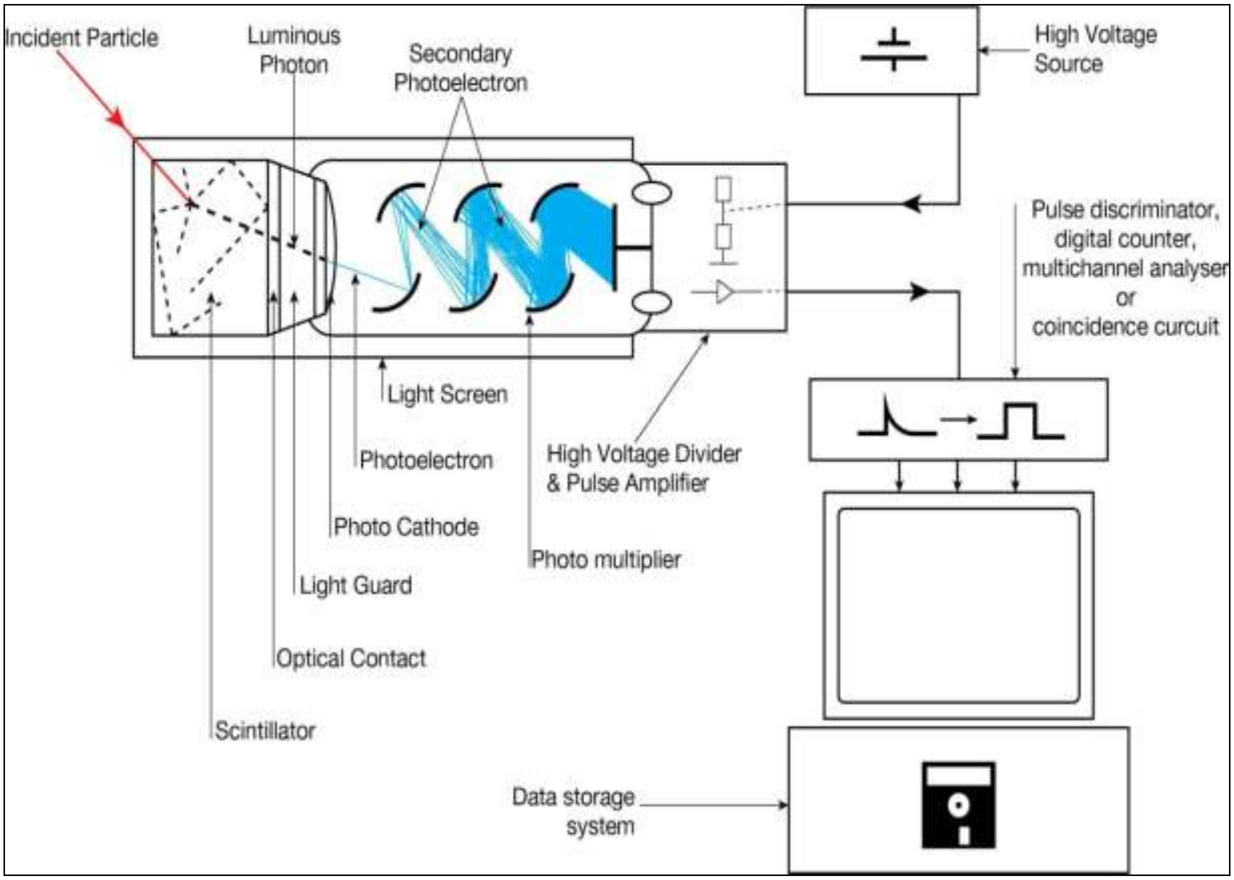

Figure 1:- Gamma-ray Spectrometry using NaI (Tl) Detector (IAEA, 2011).

Calibration in NaI (T1) Spectrometry

The analysis of the building material samples is a pivotal aspect of this study. The goal was to quantify the gamma-ray concentrations of radionuclides present in the building materials accurately. To achieve this, the identification of regions of interest (ROIs) within the gamma-ray spectra was done. In the spectra, the focus was on regions that correspond to the energy levels of the known photopeaks of specific radionuclides. Specifically, the target was the photopeaks at approximately 1460 keV (from potassium^{-40} or ^{40}K), 1765 keV (from bismuth-214 or ^{214}Bi), and 2615 keV (from thallium-208 or ^{208}TI). These ROIs are crucial for the assessment of radionuclide concentrations, as each peak corresponds to a specific radionuclide. A counting time of 30,000 seconds for each sample on the calibrated NaI (Tl) spectrometer was considered. The resulting spectra was recorded and stored as text files for later analysis.

The peak positions were then used to deduce the Energy-Channel relationship. As used in second order polynomial in the form of Equation (1), the photon energy is represented as a function of channel number (Ibrahim &Awadallah, 2009).

$$E = Y_0 + C_1 + C_2 B^2 \quad \text{……} (1)$$

For this case, B represents channel number, while Y_0, C1 as well as C_2 are constants and the fitted values are 13.867±0.693, 3.513±0.176 and 0.001±00005. In Figure 2 the energy calibration curve and the fit parameters was tabulated from Table 1. Therefore, polynomial was generated by least square fit of the calibration, and here E is photon energy and B is the channel number.

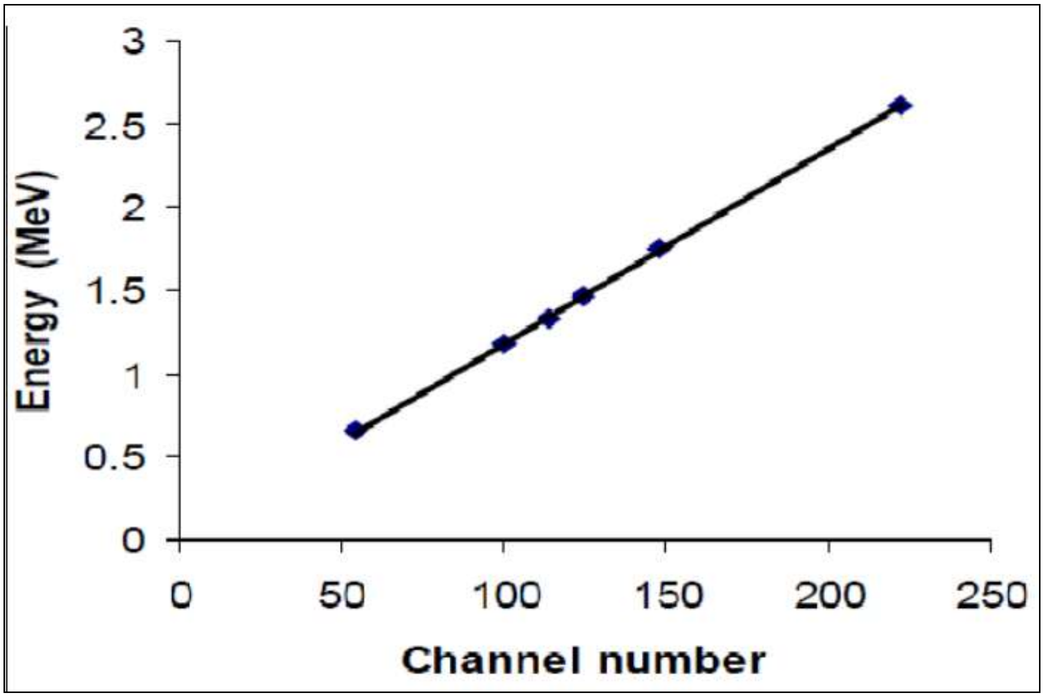

Figure 2:- Energy-channel Calibration Curve for the NaI (Tl) Detector.

Table 1:- The Polynomial Regression for the Energy Calibration of Na (Tl) Detector.

Constant	Fitted value
C_2	0.00109±0.00005
C_1	3.51288±0.176
Y_0	13.86667±0.693

Measurement of Background

The background radiation levels estimation was done using plastic container with distilled water of about 400 ± 10g.The analysis of background radiation was done for a period of 30,000 seconds then the result subtracted from each of the recorded spectrum for all the samples of building materials that were analysed in the research study.

Water has high concentration of ions mainly from the soil. Examples of these ions are sodium, calcium, iron, copper sulfates, carbonates, and nitrates (Alam *et al*., 2012). Water devoid of these ions is said to be deionised. Deionised water was used for background counting because it does not contain radionuclide particles and therefore any counts registered during its' running is said to be from the detector's surrounding environment.

NaI (Tl) Detector Energy Resolution

If a detector can distinguish two close lying photo peaks, it is termed as the energy resolution. Energy resolution of a detector can be expressed in terms of the full width at half maximum (FWHM), as in Equation (2)(Khandoker, 2015).The determination was done Gaussian fitting of photo peak of Cs-137 as shown in Figure 3.

$$Energy\ Resolution = \frac{FWHM}{E} \times 100\% \quad \ldots\ldots (2)$$

Equation (3) was used for the Gaussian curve

$$y = y_0 + \frac{A}{w\sqrt{\frac{\pi}{2}}} e^{\frac{(x-x_c)^2}{w^2}} \quad \ldots\ldots (3)$$

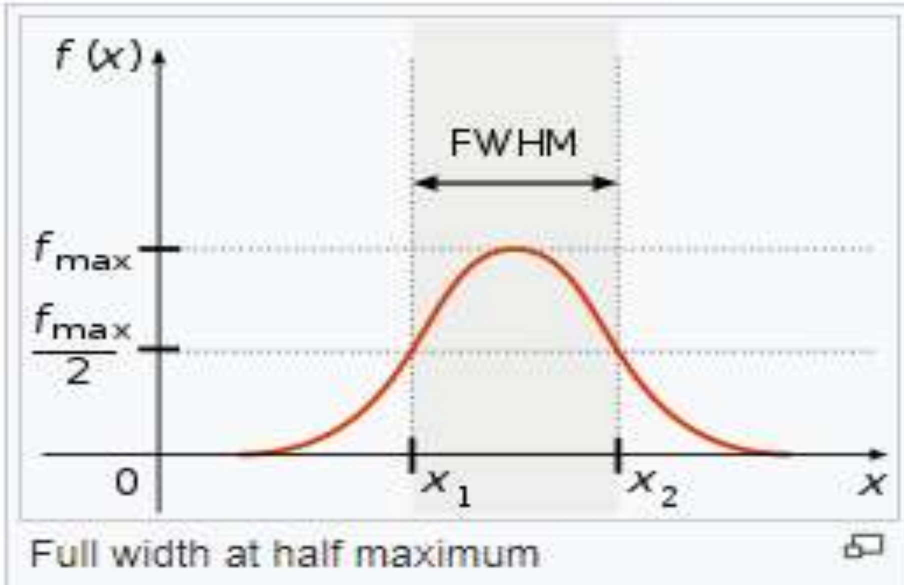

Figure 3:- Full Energy Peak for 137-Cs Measured in my Research Work.

Detector Efficiency

Detector efficiency is defined as the probability that a discharged gamma ray will interact with the detector crystal and cause a given count (Reguigui, 2006). NaI(TI) detector functions by scintillation mechanism. Unlike semiconductor gamma ray detectors, NaI (TI) detector does not suffer long dead times. Since the gamma source was placed on the detector, the distance between the sample and the detector was 0 cm which meant that with the 0.01 per cent dead time of the detector, the detection efficiency was very high. This was verified by comparing the live time and dead times of the detector at the end of each counting run. Therefore, the gamma detector used greatly reduced the chances of missing an emittedphoton. From this work, the efficiency for the standard radionuclides were determined from Equation 4.

$$\eta = \frac{N}{A \times T \times \rho \times M} \qquad (4)$$

Where N is the net count rate, T is the live time; $\rho$is the radionuclide's emission probability, M is mass in kilograms for the standard sample and A the activity concentration of the standard sample.

Table 2:- Detectors' Efficiency and Intensity for the Standard Radionuclides used in this Work.

Nuclide	Energy(KeV)	Intensity	Emission probability	Mass (Kg)	Efficiency	Activity (Bq/Kg)
^{232}Th	238	26.4667	0.4316	0.4	0.079951	1932
^{238}U	351	19.5907	0.3534	0.4	0.046952	2950
^{40}K	1460	8.757	0.1066	0.4	0.021031	9262

Samples Analysis

The analysis of the building material samples was a pivotal aspect of our study. The goal was to quantify the gamma-ray concentrations of radionuclides present in these materials accurately. In order to achieve this, the identification of regions of interest (ROIs) within the gamma-ray spectra was done. In the spectra, the focus was on regions that correspond to the energy levels of the known photopeaks of specific radionuclides. Specifically, the targets were considered as the photopeaks at approximately 1460 keV (from potassium^{-40} or ^{40}K), 1765 keV (from bismuth-214 or ^{214}Bi), and 2615 keV (from thallium-208 or ^{208}TI). These ROIs are crucial for the assessment of radionuclide concentrations, as each peak corresponds to a specific radionuclide. A counting time of 30,000 seconds for each sample on the calibrated NaI (Tl) spectrometer was considered. The resulting spectra was recorded and stored as text files for later analysis.

Procedure for sample analysis was as follows;
1. Every sample was counted for 30,000 seconds on the calibrated Na (Tl) spectrometer and its spectrum recorded and stored in the text files of a PC based MCA.
2. Background count was subtracted from all the sample counts in order to get net count.
3. Radioactivity concentration for all samples was then calculated as described in section that follows.

Figure 4: Regions of Interest in the Spectrum taken for One of the Samples.

Radioactivity Concentration Levels

The activity concentration (A) for each radionuclide in $Bqkg^{-1}$ was calculated using the equation (Beretka& Mathew, 1985).

$$A = \frac{N}{\varepsilon \times T \times I \times M} \quad \ldots\ldots (5)$$

Where A represents the activity concentration in $BqKg^{-1}$, N is the net peak area after subtraction of background of the γ-ray line at energy E, ε is the detector efficiency, T is the counting time in seconds, *I* is the gamma intensity of the specific photopeak and M is the mass of the sample in kilograms. The calculation method allows for accurately quantify the concentration of radionuclides in the building materials, which is essential for assessing potential health and environmental risks.

Results and Findings:-

Radioactivity Concentration

The study assessed the radioactivity concentration levels for the natural Radiotion Sources due for building materials used in along Kangundo road, Nairobi City County. NaI (Tl) detector came in handy for the research work. Activity concentrations for the selected building materials samples were calculated.

Radioactivity Concentration of Building Materials from Kangundo

The building materials used for construction in Kangundo estate are known to come from various regions or Counties surrounding Nairobi County. The sand used is mainly from Machakos County (UN-HABITAT, 2009). The presence of phosphate and granite rocks which undergo the process of weathering as a result of change of weather pattern in Machakos County enhances the formation of sand in this region with elevated levels of radioactive materials (Rotich, 2015). Change in weather in these regions neighboring Nairobi County, such as Kiambu, Machakos and Kajiado causes the weathering of rocks that forms traces of radionuclides to be deposited in river banks and later collected with the sand for building. In addition, the weathered particles form surface soil which is used in the manufacturing of clay bricks.

The calculated values of the radioactivity concentrations in radionuclides for ^{40}K, ^{238}U, and ^{232}Th were presented on Table 3. Mean value of radioactivity concentration in radionuclides ^{40}K was higher than that for ^{238}U and ^{232}Th, as a result of potassium being the major contributor of the naturally occurring radionuclide. The measured radioactivity concentration for ^{40}K varied from 117.7±6Bqkg^{-1} to 2392.3±120Bqkg^{-1} giving a mean value of 859.7±43Bqkg^{-1}. Concentration level for ^{238}U varied from 24.2±1Bqkg^{-1} to 411.9±21Bqkg^{-1} producing a mean value of 78.1±4Bqkg^{-1} and that of ^{232}Th had minimum of value of 54.5±3Bq/kg with the maximum value being 611.9±31Bq/kg and generating the mean value of 159.7±8Bq/kg.

Table 3:- Activity Concentration Levels for the Natural Radionuclides ^{40}K, ^{238}U and ^{232}Th.

SAMPLING SITE	LATITUDES	LONGITUDES	U238 Bq/kg	K40Bq/kg	Th232Bq/kg	SAMPLE TYPE	SAMPLE ORIGIN
K1	36^0,65.1972’	01^0 ,10.758’	290.8±15	390.9±20	135.9±7	SAND	EMBU
K2	36^0,17.655’	01^0 ,55.324’	315±16	602.8±30	163.1±8	SAND	MACHAKOS
K3	36^0,57.677’	01^0 ,20.963’	411.9±21	744.1±37	611.9±31	SAND	KITUI
K4	36^0,57.00’	01^0 ,20.963’	290.7±15	2081.5±104	95.2±5	CONCRETE	KAJIADO
K5	36^0,54.390’	01^0 ,15.351’	33.9±2	117.7±6	163.1±9	CONCRETE	MULOLONGO
K6	36^0,57.343’	01^0 ,16.890’	29.1±1	1059.6±53	210.7±11	SAND	KITUI
K7	36^0,55.369’	01^0 ,15.437’	29.01±1	1554.1±78	163.1±8	CONCRETE	MULOLONGO
K8	36^0,55.00’	01^0 ,15.430’	50.9±3	1723.6±86	149.5±7	CONCRETE	MULOLONGO
K9	36^0,38.913’	01^0 ,15.751’	26.7±1	2392.3±120	135.9±7	SAND	MAI MAHIU
K10	36^0,58.606’	01^0 ,15.367’	31.5±2	904.2±45	244.7±12	SAND	NAROK
K11	36^0,59.517’	01^0 ,13.192’	36.3±2	1690.1±84	149.5±7	BRICK	KAJIADO
K12	36^0,00.370’	01^0 ,16.854’	98.9±5	296.7±15	115.5±6	SAND	MAI MAHIU
K13	36^0,58.940’	01^0 ,14.765’	36.3±2	527.4±26	203.9±10	SAND	KITUI
K14	36^0,58.827’	01^0 ,15.706’	31.5±2	1770.7±89	101.9±5	SAND	MACHAKOS
K15	36^0,59.215’	01^0 ,15.885’	24.23±1	339.1±17	163.1±8	SAND	NJIRU
K16	36^0,58.2531’	01^0 ,18.465’	38.8±2	904.1±45	197.1±10	CONCRETE	KAJIADO
K17	37^0,01.565’	01^0 ,14.349’	36.34±2	296.7±15	115.5±6	SAND	MAI MAHIU
K18	37^0,00.566’	11 ,16.833’	33.92±2	343.8±17	54.5±3	SAND	MWALA
K19	37^0,01.291’	01^0 ,16.553’	33.92±2	353.2±18	115.5±6	SAND	MASINGA
K20	37^0,02.206’	01^0 ,16.992’	43.6±2	395.6±20	210.7±11	SAND	KATANI
K21	37^0,02.890’	01^0 ,17.064’	43.6±2	1813.1±91	210.7±11	CONCRETE	THIKA
K22	37^0,03.484’	01^0 ,17.168’	33.9±2	470.9±24	81.6±4	CONCRETE	LONDIANI
K23	37^0,03.919’	01^0 ,17.256’	48.5±3	150.7±8	108.8±5	BRICK	LONDIANI
K24	37^0,04.146’	01^0 ,16.917’	55.7±3	772.3±39	61.2±3	BRICK	LONDIANI

K25	37^0,04.612’	01^0 ,16.937’	43.6±2	508.6±25	176.7±9	BRICK	MULOLONGO
K26	37^0,06.364’	01^0 ,17.115’	48.46±2	932.4±46	81.6±4	BRICK	THIKA
K27	37^0,06.898’	01^0 ,17.088’	41.2±2	857.1±43	101.9±5	BRICK	RUIRU
K28	37^0,07.088’	01^0 ,17.161’	31.5±2	555.7±28	122.3±6	BRICK	THIKA
K29	37^0,07.327’	01^0 ,16.564’	36.3±2	550.98±28	190.3±10	BRICK	MACHAKOS
K30	37^0,08.307’	01^0 ,16.638’	36.3±2	692.3±34	156.3±8	BRICK	RUIRU
MEAN			**78.1±4**	**859.7±43**	**159.7±8**		

From Table 3, maximum concentration level for ^{40}K, ^{238}U and ^{232}Th in the selected samples of building materials used on Kangundo road were 2392.3 ± 120 Bqkg^{-1}, 411.9 ± 21 Bqkg^{-1} and 611.9 ± 31 Bqkg^{-1} respectively, the minimum radioactivity concentration for radionuclides were recorded as 117.7 ± 6 Bqkg^{-1}, 24.2 ± 1 Bqkg^{-1} and 54.5 ± 3 Bqkg^{-1}.

Table 4:- The mean activity Concentration of Radionuclide in Building Materials Compared to the World Acceptable Limit.

Radionuclide	Study area average values (Bqkg^{-1})	Acceptable Safety Limit (Bqkg^{-1}) (UNSCEAR,2000)
^{40}K	859.7 ± 43	420
^{238}U	78.1 ± 4	33
^{232}Th	159.7 ± 8	45

From Table 4, the average radioactivity concentrations for the radionuclides were above world average values of 420 Bqkg^{-1}, 33 Bqkg^{-1} and 45 Bqkg^{-1} for ^{40}K, ^{238}U and ^{232}Th respectively (UNSCEAR, 2000).

The Figure 5 shows the activity distribution in a graph form for ^{238}U, ^{232}Th and ^{40}K for the sample sites along Kangundo road for the study area. As in Table 3 and Figure 5, the highest radioactivity concentration values for ^{238}U, ^{232}Th and ^{40}K were found in areas marked K_4, K_8, K_9 and K_{21}. The radioactivity concentration values of ^{40}K were high in all the samples studied as compared to other radionuclides and the activity concentration values for ^{238}U were higher than the world average values value of 33 Bq/kg for some samples collected from along Kangundo road. Same for the radioactivity concentration values in ^{232}Th were higher from most of these samples which were above the world weighted mean of 45 Bq/kg (UNSCEAR, 2000). The high level of radioactivity concentration from almost all the sample collected along Kangundo road were due to their origin e.g. Kitui which have concentration of igneous rocks indicated in Table 3.

Conclusion and Recommendation:-

Conclusion:-

In conclusion,this study aimed at assessing the natural radioactivity levels for the Natural Radiation Sources in building materials; sand, clay bricks, and concrete blocks used along Kangundo road in Nairobi City County, Kenya using NaI(T1) detector. The reason for assessing the natural radioactivity levels as a prerequisite to estimate the radiological parameters is for the purpose of determining the ionising radiation health effects due to human exposure to gamma radiation. The analysed data was compared to the world average values and the standard acceptable limits. The activity concentration of ^{40}K varied from 151 ± 8 to 2392 ± 120 Bq/kg, ^{238}U varied from 27 ± 2 to 412 ± 21 Bq/kg and ^{232}Th ranged from 54 ± 3 to 612 ± 31 Bq/kg. More than 70 per cent of the samples had activity concentration above the world average values of 420 Bq/kg, 33 Bq/kg, 45 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively.

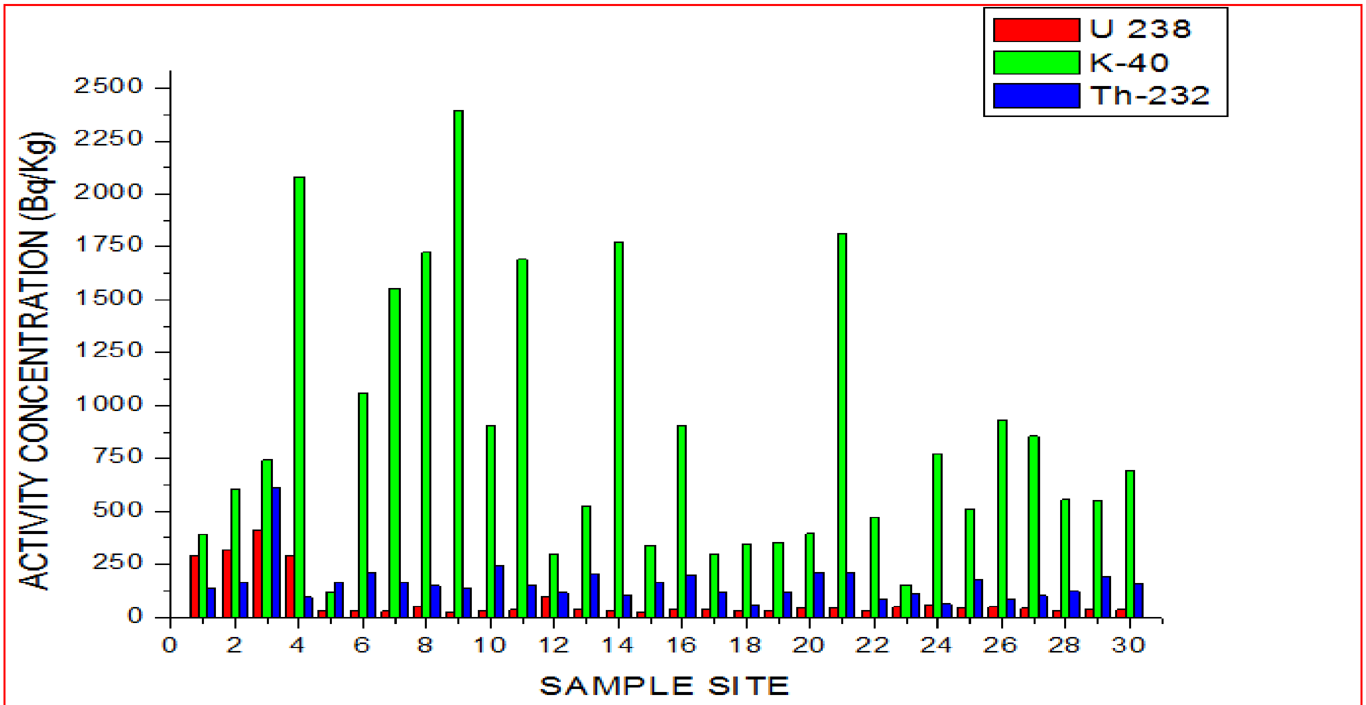

Figure 6:- Concentration Levels of ^{238}U, ^{232}Th and ^{40}K in the Samples.

Reommendation:-
It is therefore recommended that further assessment of radioactivity concentration for samples with high values of Activity be undertaken.

References:-

1. Alam, M., Rais, S., & Aslam, M. (2012). Hydrochemical investigation and quality assessment of ground water in rural areas of Delhi, India. Environmental Earth Sciences, 66, 97-110.
2. Beretka, J., & Mathew, P. J. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Physics, 48(1), 87-95.
3. Felix, K. Wanjala (2019). Human exposure to background radiation in Ortum, Kenya. Journal of Radiation Protection Dosimetry (2020, Vol. 188, No. 1, pp. 98–108.
4. Flores, O. B., Estrada, A. M., Sua'rez, R. R., Zerquera, J. T., &Pe'rez, A. H (2008). Natural radionuclide content in building materials and gamma dose rate in dwelling in Cuba, Journal of Environmental Radioactivity, 99-12, 1834-1837.
5. Gurisha, M. S., Makoba, A. A., Kiyengo, H. E., & Rao, P. V. (2024). Determination of Natural Radioactivity Levels and Radiation Hazards from the Soil of Tin Mining in Kyerwa District, Tanzania. Physical Science International Journal, 28(4), 119-129.
6. Hashim, N. O. (2000). The Levels of Radionuclides and Trace in Selected Kenyan Coastal System. M Sc. Thesis, Kenyatta University.
7. Ibrahim, F. A., &Awadallah, I. M. (2009). Soil radioactivity levels and radiation hazard assessment in the highlands of Northern Jordan., Radiation Measurement,44(1), 102-110.
8. International Atomic Energy Agency. (2005). Analytical Tecniques in Uranium exploration and Ore prossing. Technical report, International Atomic Energy Agency, 341, 81-99, IAEA.
9. Khandoker, A. (2015). Assessment of Natural Radioactivity levels and potential Radiological Risks of common building materials used in Banglandesh dwellings. Paperity Open Science Aggregate. http://www.paperity.org
10. Mann, W., &Gartinkil, S. (1966). Radioactivity and its Measurement. Van Nostrand-Reinhold.
11. Mavi, B., &Akkurt, I. (2010). Natural radioactivity and radiation hazards in some building materials used in Isparta, Turkey. Radiation Physics and Chemistry, 79, 933-937.

12. Mohan, S., & Chopra, V. (2022). Chapter 18 Biological Effects of Radiation. In Woodhead Publishing Series in Electronic and Optical Materials, Radiation Dosimetry Phosphors. Woodhead Publishing. PP 485-508, ISBN 9780323854719. https://doi.org/10.1016/B978-0-323-85471-9.00006-3.
13. Oborah, K. A. (2022). Assessment of Radioactivity Concentration and Radiation Hazards Index for Building Materials Used in Babadogo Estate, Nairobi City County, Kenya. Masters Thesis.
14. Osoro, M. K. (2007). Levels of Natural Radionuclides in Surface Soils around Titanum Mines at Kenyan Coast. MSc (physics) Thesis, Kenyatta University.
15. Reguigui, N. (2006). Gamma ray spectrometry. Practical Information, 21.
16. Rotich, C. K. (2015). Gamma Spectroscopic Analysis of Soil and Green Tea Leaves of Kericho County. MSc (Physics) Thesis, Kenyatta University.
17. Simin, M., Reza, F., &Sedigheh, S. (2011). Natural Radioactivity in Building Materials in Iran. Nukleonik,56(4), 363-368.
18. Songa, K. L. (2021). Analysis of Natural Radioactivity Levels and Radiation Hazards Due to Murram Quarried in Kakamega County, Kenya.http://inis.iaea.org/search/search.aspx?orig_q=RN:52108798
19. Stoulos, S., Manolopoulou, M., &Papastetanou, C. (2003). Assessment of natural radiation exposure and radon exhalation from building materials in Greece. Journal of Environmental Radioactivity,69, 225-240.
20. United Nations Centre for Human Settlements. (2009). The Management of secondary cities in sub-Sahara Africa: traditional and Modern Intuitional Arrangements. UN-HABITAT, 42-83.
21. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000). Sources and Effects of Atomic Radiations, Report of United Nations Scientific on effects of Atomic Radiations to the General assembly.
22. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (1988). Sources and Effects of Atomic Radiations. Report of United Nations Scientific on effects of Atomic Radiations to the General assembly. United Nations.
23. Viresh, K., Ramachinran, T. V, &Rasandra, P. (1999). Natural radioactivity of Indian building materials and by-products. Applied Radiation and Isotopes,51, 93-96.
24. WHO(2012).WorldHealthOrganization,IonisingRadiationinourEnvironment,online.www.who.int/ionising_radiation/env/en