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Analysis of Natural Radioactivity and Radiological Hazards in Soil Samples from The Western Ghats, India

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ABSTRACT: This study took soil samples from the Agumbe region in the Western Ghats of Karnataka, India, and studied its natural radioactivity. To evaluate the native radiation levels in this ecologically delicate region, high-resolution gamma spectrometry was used to determine the activity concentrations of naturally occurring radionuclides Ra-226, Th-232, and K-40. We chose Agumbe because of its varied heights and rainfall patterns, in addition to its tropical climate and abundant biodiversity. The gamma spectrometry analysis of soil samples taken from uphill, downhill, and mid-hill sites showed that the radioactive concentrations varied across the various topographies. Ra-226, Th-232, and K-40 concentrations were generally within the global norms, with minor differences explained by regional topographical and geological factors. Environmental monitoring programs and radiological health evaluations can benefit from the study's findings regarding the region's radioactive baseline. Additionally, future research on radiation exposure in environmentally sensitive regions can use this information to support environmentally conscious management practices.

1. INTRODUCTION

One of the most significant aspects of background radiation is natural radioactivity, which is derived from radionuclides that occur in nature and include Ra-226, Th-232, and K-40. The vast majority of the radiation dose that humans are exposed to comes from the soil and water, and these radionuclides are a significant contributor to the overall radiation dose that they receive. For the purpose of environmental radiological research, soil samples are frequently utilized since they are able to provide a definitive estimation of the natural radiation levels in a particular area.

The Western Ghats of India, particularly the Agumbe region, offer a unique environment for conducting research on natural radioactivity phenomena due to their diverse ecosystems, heavy rainfall, and variable altitudes. Agumbe is home to tropical rainforests. These rainforests receive a substantial amount of rainfall, which can create conditions that could potentially alter the mobility and deposition of radionuclides in the soil over time. When it comes to evaluating possible dangers to both human health and the environment, it is essential to have a thorough understanding of the natural radioactivity concentration in such a region. This is especially true in light of the growing number of human activities that are taking place in ecologically highly sensitive areas.

A. Radium-226 in the Environment

Radium-226 (^{226}Ra) is a widely distributed element that can be found in the crust of the Earth. It is a member of the primordial uranium decay series. Because of very long geological times, ^{226}Ra is usually found in balance with its parent isotope, Thorium-230 (^{230}Th), in unaltered rocks. Nevertheless, biological activity, hydrology, and weathering are examples of environmental processes that have the potential to upset this equilibrium, particularly during the process of soil formation. In surface soils, these activities often cause leaching, which reduces the amounts of mobile radionuclides like Uranium-238 (^{238}U) and ^{226}Ra compared to ^{230}Th.

There is a substantial amount of variation in the activity of Ra in soil, which is dependent on the kind of soil and the geological environment. Vinogradov (1959) reported Ra activities in a variety of soils from the Soviet Union. The range of these activities was from 18.5 Bq/kg in gray desert soil to 126 Bq/kg in light brown desert soil. Studies conducted in Italy (Bortoli & Gaglione, 1972), the United States of America (Myrick et al., 1983), and India (Mishra & Sadashivan, 1971; Siddappa et al., 1991; Iyengar et al., 1978) have demonstrated a diverse range of ^{226}Ra activity. The activity levels range from as low as 0.32 Bq/kg in coastal Karnataka to as high as 37,000 Bq/kg in Ramsar, Iran (Khademi et al., 1978).

According to the findings of additional research conducted in India, the soil samples collected from Kalpakkam mines varied from 9 to 25 Bq/kg, but the soil samples collected from Jadugoda and Udaisagar mines ranged from 0.74 to 59 Bq/kg (Kamath et al., 1964). In Bombay, Rao et al. (1983) found values between 8.51 and 33.7 Bq/kg, and Ramachandran et al. (1990) found Ra activity levels between 6.7 and 15.2 Bq/kg in areas located 100 to 200 kilometers from thermal power plants.

B. Thorium-232 in the Environment

Another naturally occurring radionuclide, Thorium-232 (^{232}Th), significantly contributes to the radiation present on the earth's surface. Compared to uranium, it is found in igneous rocks in nearly four times the amount, although it has a lower specific activity (2.97 Bq/g) than uranium does (8.92 Bq/g), which means that their overall radiological impact is equivalent. With a half-life of 1.4×10^{10} years, ^{232}Th decays to ^{228}Ra ($T_{1/2}$ = 5.76 years), which is a beta emitter of environmental significance. This decay process is characterized by a long half-life. The daughters of Ra have a short lifespan, which causes them to impact the short-term radioactivity in the environment.

C. Potassium-40 in the Environment

The most important naturally occurring radionuclide that occurs singly is potassium-40 (^{40}K), which has a half-life of 1.3×10^{9} years. In rocks, soil, and living things, it is extensively dispersed and makes up around 0.012% of the total potassium. Potassium, and by extension K, is an important element that is evenly present in the environment and exhibits minimal change due to environmental influences. Every kilogram of soil typically contains 2.36 mg of K. About 90:1 is the weight ratio of potassium to rubidium in soil. Many investigations have measured ^{40}K in different ambient samples, such as those by Kamath et al. (1964), Pinkerton et al. (1964), Lalit and Shukla (1981), and Laxmi et al. (1990). The activity of ^{40}K in soil varies from 100 to 700 Bq/kg, with a global mean of roughly 370 Bq/kg, according to UNSCEAR (1982). This study's main goal was to ascertain the activity concentrations of Ra-226, Th-232, and K-40 in soil samples that were taken from Agumbe at various elevations. This study also looks at the effects of geological and environmental conditions on the distribution of these radionuclides, including vegetation, rainfall, and altitude. The findings of this study add to an expanding database of environmental radiation levels in India and offer information that may help with future environmental conservation and radiation safety initiatives.

2. MATERIALS AND METHODS

A. Study Area

Agumbe, a small community in Karnataka, India's Western Ghats, served as the study's location. Numerous plant and animal species can be found in the Western Ghats, which are renowned for their great ecological value. High rainfall, particularly during the monsoon season, is a defining feature of the region's climate and may have an impact on radionuclide distribution through leaching and erosion processes. Granite and gneiss formations, which make up the majority of the area's geology, are known to contain naturally occurring radioactive elements in various amounts.

Three different Agumbe localities were used to get the soil samples:
1) Uphill (higher elevation): This region is thought to have comparatively unspoiled soil with possible differences in natural radioactivity. It is often characterized by deep forest cover and little human influence.
2) Mid-hill (moderate elevation): This site offers a representative combination of environmental elements because it is situated at an intermediate altitude and is impacted by both the forest ecosystem and human settlements.
3) Downhill (lower elevation): More human activity, such as agricultural operations, occurs in the lower region, which may change the natural distribution of radionuclides because of fertilization, runoff, and soil erosion.

Agumbe is a perfect research region for examining the connection between environmental factors and radionuclide concentration because of the variations in topography and land use throughout these locations.

B. Sample Collection

A standardized procedure was followed to gather soil samples from every site. Ten soil samples were taken from each of the three sites, for a total of thirty samples. Since this depth is usually utilized in environmental radiological investigations to collect the radionuclides most intimately connected with the soil, samples were gathered from a depth of around 20 cm. To prevent any loss of volatile components during transportation to the lab, each sample was put in a sealed container.
Following air drying, the materials were ground into a fine powder to ensure homogeneity for gamma spectrometry measurement. To homogenize the sample size and exclude bigger particles, the dried samples were sieved. The analysis was guaranteed to be representative of the soil's radioactive concentrations thanks to this preparation procedure.

C. Gamma Spectrometry

Gamma spectrometry determined the activity concentrations of Ra-226, Th-232, and K-40 in the soil samples. Because of its reputation for precisely detecting gamma radiation from radioactive isotopes, a high-purity germanium (HPGe) detector system was employed. We examined each sample for a whole day to ensure

sufficient counting statistics. To account for geometric considerations and system efficiency, the gamma spectrometer was calibrated using established reference sources.
We detected and analyzed the main gamma peaks linked to Th-232 (2614 keV), Ra-226 (186 keV), and K-40 (1460 keV). We applied known calibration factors and decay adjustments to each radionuclide to determine the activity concentrations. The number of disintegrations per kilogram of soil per second, or Bq/kg, was used to report the results.

In a photoelectric event, the photon's full energy is absorbed by an atom's bound electron and manifests as the ejected electron's kinetic energy. As the energy of the photon decreases, the cross section of the photoelectric process rapidly increases and is proportional to Z^5. The photoelectric cross section expression is provided by

$$\sigma_{ph} = \frac{Constant \times Z^5}{E_T^{3.5}} ----(2.1)$$

Where Z is the atomic number of the absorber, E_T is energy of the incident gamma photon (Kapoor and Ramamurthy, 1986).

In Compton scattering the photon is scattered by free electron. The electron K.E. lies between zero and a large fraction of the photon energy. The cross section for Compton scattering is given by

$$\sigma_c = \frac{\pi r_0^2 Z}{2E_T}\left[\ln 4\,E_T + \frac{1}{2}\right] ----(2.2)$$

Where Z is the atomic number of the absorber, E_T is energy of the incident gamma photon; r_0 is the classical electron radius (Kapoor and Ramamurthy, 1986)

The phenomenon of pair production becomes predominant when the incident photon energy exceeds twice the rest mass energy of an electron (1.02 MeV). In this interaction, the incident photon is completely absorbed and an electron-positron pair is created. The cross section for the pair production is given by

$$\sigma_{pp} = Z^2\sigma_0\left[\frac{28}{9}\ln\frac{2E_T}{m_0C^2} - \frac{218}{27}\right] ----(2.3)$$

Where Z is the atomic number of the absorber, E_T is energy of the incident gamma photon, and

$$\sigma_0 = \frac{1}{137}\left[\frac{e^2}{m_0C^2}\right]^2 ----(2.4)$$

Where e is charge on an electron; m_o is the rest mass of electron. C is the velocity of light (Kapoor and Ramamurthy, 1986).

The energy of the incident gamma ray determines the energy of the electrons created when gamma rays interact with material. Any gamma ray detector's job is to transform incoming gamma radiation into electronic pulses that may be used for analysis or counting with the help of auxiliary electronics. As a result, a gamma ray detector must serve two different purposes: first, it must act as a conversion medium where incident gamma rays have a reasonable chance of interacting and producing one or more fast electrons; second, it must serve as a traditional secondary electron detector. These fundamental characteristics hold true regardless of the type of detector—whether it is HPGe, NaI (Tl), or another kind. When gamma ray photons interact with the crystal medium in a NaI (Tl) detector, photoelectrons are released, producing an electrical pulse. Electron-hole pairs are formed in semiconductor detectors, and the electronic pulse is produced by these charge carriers. The energy of the incoming gamma ray photon is related to the size of the electrical pulse in both cases, so we can find out the energy of the gamma photon by looking closely at how tall both pulses are.
Prior to analysis, the detector's output pulses must be amplified using linear amplifiers and preamplifiers. A multi-channel analyzer is used to count and differentiate the amplified pulses. The entire apparatus then makes up a gamma ray spectrometer, a very practical nuclear device for gamma ray detection and analysis. This study used a high-resolution HPGe spectrometer for gamma spectrometry analysis of environmental materials.

D. Details of HPGe spectrometer used in the present study

In the current study, soil samples were analyzed using gamma spectrometry using high-resolution HPGe gamma-ray spectrometry equipment. Fig. 1 displays the block schematic for the HPGe spectrometer setup. The HPGe detector (Model GR 4021, Canberra, USA) is a closed-end coaxial detector. Its measurements are 52 mm in length

and 61 mm in diameter. The detector's Full Width at Half Maximum (FWHM) is 0.83 keV at 122 keV and 2.01 keV at 1332 keV. Compared to a 3″x3″ NaI (Tl) crystal measured at a source-detector distance of 25 cm, the detector's relative efficiency is 40%. For the ^{60}Co source, the ratio of peak height to Compton plateau height is 59:1. The detector's working voltage is -3500V.

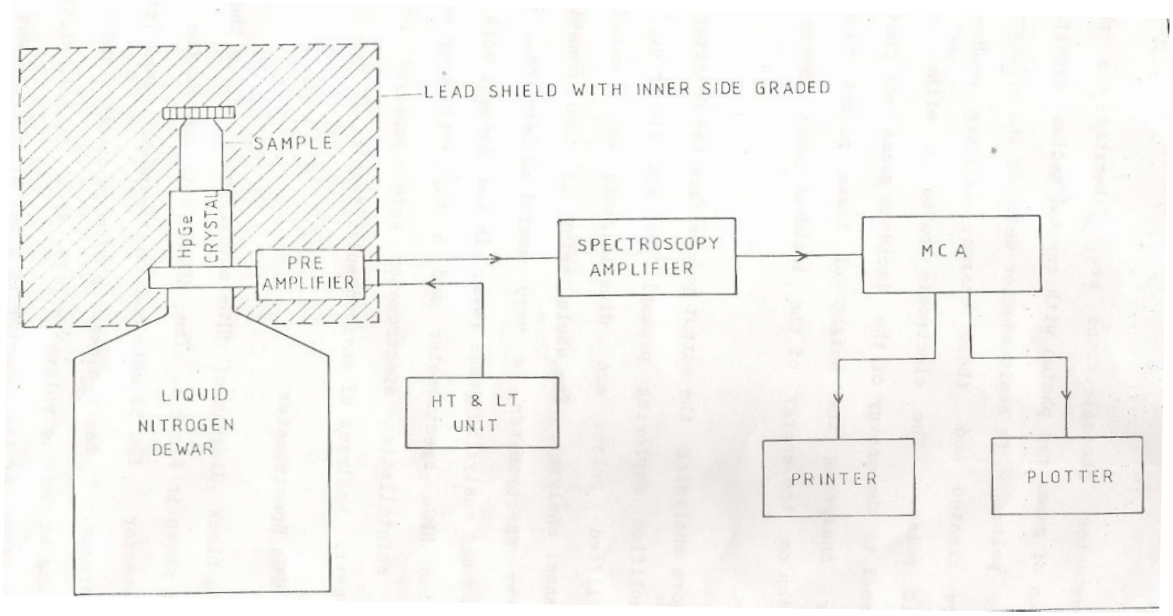

Figure 1: Block diagram of HPGe spectrometer

A 7500 SL/RDC/ULB cryostat is used to install the detector. A cryostat is made up of a Dewar for the liquid nitrogen cryogen and a vacuum that holds the detection element. The setup utilized a 4-inch-long remote detector chamber with ultra-low background cryostat hardware and a vertical slimline dipstick cryostat featuring a 3-inch-diameter end cap. A holder that is thermally coupled to a copper cold finger but electrically disconnected holds the detector element in place. Heat is transferred from the detector assembly to the liquid nitrogen reservoir via the cold finger. To prevent low-energy photons from being attenuated, the detector holders and the outer vacuum jacket or end cap are thin. The holder is usually 1 mm thick and composed of metal. The detector element face is 5 mm away from the detector assembly, so avoid pushing the end cap against it.

The pre-amplifier is used to enhance the detector's output pulses. An integrated 2002CSL FET-cooled charge-sensitive preamplifier is a feature of the HPGe detector GR4021. The preamplifier's primary function, in addition to amplification, is to transform the detection system's weak (high impedance) pulses into strong (low impedance) pulses that may be carried via a cable to the spectroscopic amplifier.

The preamplifier supplies the signal to a computer-controlled Digital Signal Analyzer (DSA-1000) in Canberra, USA. The DSA-1000 is a small device that includes a 16 K Multi Channel Analyzer (MCA), an Analog to Digital Converter (ADC), a High Voltage Supply (0-5000 V), and an amplifier. We use spectroscopy amplifiers to linearly amplify and shape signals from preamplifiers for pulse height analysis. This DSA-1000 incorporates a Canberra spectroscopic amplifier that processes and amplifies the signals from the preamplifier. It contains a gated active baseline restorer. The amplifier is perfect for the HPGe detector because of its excellent DC stability, extremely low noise, large gain range, and variety of shaping time constants. The amplifier's greatest signal-to-noise ratio, least sensitivity of output amplitude to changes in detector rise time, and enhanced pulse symmetry are all advantages. By working on the trailing edge of the unipolar pulse shape, the improved pulse symmetry shortens the time the pulse stays active for a set shaping-time constant. This enables a quicker return to the baseline. Better energy resolution, count rate, and overall performance are the outcomes. We use one differentiator and two active filter integrators to produce unipolar shaping. For better overload and count-rate performance, the DSA-1000 allows the user to trim pole/zero to match the preamplifier's fall-time constant and reduce undershoot after the first differentiator.

The DSA-1000 can produce both unipolar and bipolar outputs simultaneously. A baseline restorer built into the unipolar output keeps the baseline at reference ground while sampling the output signal. By applying the unipolar output signal to a corrected DC level of ± 5 mV DC, the baseline restorer makes the unipolar output look DC coupled. The automated features of the gated DC restorer, which control the restorer threshold and restorer rate, ensure optimal low and high count rate performance.

The performance details of the spectroscopy amplifier are given below:

Gain range	: Continuously adjustable from x 2.24 to x 2438
Operating temperature	: 0 to 50^0c
Gain drift	: ≤ 35 ppm/^{0}c after 15 minutes of operation
Zero drift	: ≤ 3 ppm/^{0}c after 15 minutes of operation
Integral non-linearity	: ≤ ± 0.025% of full scale over the top of 99% of selected range
Differential Non-linearity	: ≤ ±1% over the top of 99% of the range including the effects from integral non-linearity
Overload recovery	: Recover to within 1% of full scale output from x 1000 overload in 2.5 non-overlapped pulse widths, at full gain.
Spectrum broadening	: The FWHM of ^{60}Co 1.33 MeV gamma peak for an incoming count rate of 2 kcps to 100 kcps will typically change less than 6% for 2.8 μs rise / fulltime 0.8 μs flat top and proper p/z matching.
Time Resolution	: 0.01 sec live and true time 0.02s
Regulation	: ≤ 5% variation in output voltage.
Power requirements	: +24V at 40mA max - 24 V at 20mA max + 12V at 80mA max - 12 V at 30mA max.

The Digital Spectrum Analyzer 16k Multi Channel Analyzer (MCA) in the DSA-1000, which connects to a PC, is used to study and handle the signals from the Canberra spectroscopic amplifier. This MCA is one of the most advanced systems, as it can analyze background and sample spectra simultaneously. The CPU in this system performs all of the tasks, including data processing, computing, display production, and system timing. The MCA has built-in preamplifier/amplifier, data processing, pulse height analysis, and I/O modes, as well as the ability to operate a computer and acquire data simultaneously. MAESTRO, a sophisticated Windows-based program, controls the MCA's operations. A sophisticated analog-to-digital converter (ADC) is integrated into the MCA. Highly accurate data transformation and classification can be produced by the ADC. Amplitude-modulated signals, such as those seen when measuring quick, random events, can be processed with outstanding resolution using the MCA. The ADC's full-scale input is 5 V, and it has a digital offset option. It has ZERO control to shift the spectrum and suppress undesired pulses, as well as adjustable lower and upper level discriminators. An arbitrary time interval, ranging from 10 ms to 1 second per channel, is used to define each channel in the MCA. The scalar device counts pulses at rates of up to 10 million counts per second, either at fixed or random intervals during each time period. 700 ns is the maximum dead time between channels. Each channel's elapsed, real, and live times; total counts; and total counts less background counts are automatically calculated and displayed by the system. The Region of Interest option is a highly helpful tool for accurate spectral data analysis in the MCA. Additionally, the MCA offered the option to take the spectrum output and two-point energy calibration. We used a fast printer to capture the output. Figure 2 displays a complete view of the HPGe gamma spectrometer setup used in this experiment.

Figure 2: HPGe spectrometer used in the present study

Various radioactive standards were used to calibrate the spectrometer. The International Atomic Energy Agency in Vienna provided the uranium, thorium, and potassium standards. RG-U, RG-Th, and RG-K stand for uranium, thorium, and potassium, respectively. In terms of uranium and thorium standards, ^{238}U and ^{232}Th are in balance with their daughters. We prepared the standards using 300 ml top hat containers. To prevent the loss of gaseous daughters made from uranium and thorium, containers were meticulously vacuum-sealed.

The following relation was used to determine the detector's effectiveness for various gamma lines of different radionuclides (IAEA/RCA, 1989).

$$E(\%) = N \times \frac{100}{C} \times \frac{100}{a} - - - -(2.5)$$

Where
E is the efficiency of the system for that particular gamma energy
N is the background subtracted count per second under the photo peak
C is the activity of the standard (Bq) and
a is the percentage abundance of the gamma ray.

The variation of detector efficiency with energy is shown in Fig 3. The Minimum Detectable Activity (MDA) of a radionuclide is then determined by using the following relation (IAEA/RCA, 1989):

$$MDA = CL \times \frac{B^{1/2}}{T} \times \frac{100}{E} \times \frac{100}{a} \times \frac{1000}{W} Bq\ kg^{-1} - - - -(2.6)$$

Where
CL is the confidence level
B is the background counts in the peak region
T is the counting time in seconds
E is efficiency of the detector for that particular energy
a is the percentage abundance of the gamma ray
W is the weight of the sample in grams.

This Minimum detectable activity at 95% confidence level for 11 hours of counting time and 140 g sample weight were found to be 2.71 Bq kg^{-1} for 40K, 0.41 Bq kg^{-1} for ^{226} Ra, 0.22 Bq kg^{-1} for ^{232}Th.

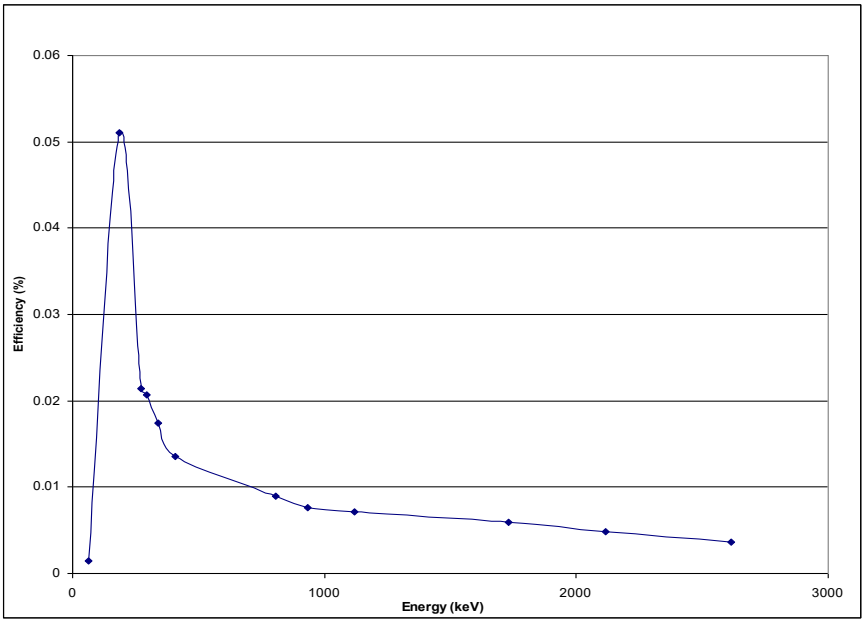

Figure 3: Dual efficiency calibration curve

3. EXPERIMENTAL METHODS

The activity of different radionuclides present in environmental samples is usually low. The low level activities of some of the radionuclides can be determined by direct methods using gamma spectrometer described in the previous case.

A. Sample collection

Environmental samples were collected from different sampling station of Agumbe. Altogether twenty two sampling stations were collected for the present study. The sampling stations are divided into three regions, uphill stations, along the hill and downhill stations. Ten samples from uphill stations, two samples along the hill and ten samples from the downhill stations were selected for the present study. The sample collection stations are shown in fig 4.

Figure 4: Map indicating the sampling stations

B. Soil sampling

For the purpose of evaluating natural radioactivity deposition, soil has to be collected from an undisturbed area on level ground and open terrain. An area of 1 sq. mt. was to be marked, and all the soil up to 5 cm depth was collected by digging with a small pickaxe. Wherever there is grass growth in the soil surface, the top layer of the soil is cut and removed. We thoroughly mixed the soil, collected about 2 kg of sample in polythene bags, and labeled it.

C. Sample processing

Every sample that was gathered was processed in accordance with standard practice. The soil sample was cleared of extraneous items such as plant debris, roots, gravel, stone fragments, etc. To achieve a consistent dry weight, the sample was dried for an adequate amount of time at 1100^{o} C in an electric oven. To allow the ^{222}Rn and ^{220}Rn daughter products to reach radioactive equilibrium with ^{226}Ra and ^{228}Th, respectively, the sample was crushed into a fine powder and sieved through 70 mesh to obtain particle sizes less than 250 microns. The fine powder was then moved to an airtight plastic container (6.5 cm diameter x 7.5 cm height) and stored for a month. Since ^{226}Ra is approximated through ^{214}Bi (1760 keV) and ^{228}Th through ^{208}Tl (2614 keV), this stage is required.

D. Gamma active radio nuclides in soil samples

The concentrations of gamma active radionuclides in soil were determined by gamma spectrometry method employing a HPGe spectrometer. A brief account of different methods of quantification of these gamma active radionuclides is given below.

a. Potassium-40 activity

Since ^{40}K emits a distinctive 1461 keV gamma radiation and the environmental samples do not include any competing gamma rays that would interfere with its detection, gamma spectrometry is a handy way to measure the activity content of 40K in environmental samples. Myrick et al.(1983); Delaune et al.(1986); Chung-Keung-Man et al.(1987); McAulay and Moran (1988); Megumi et al.(1988); Pan Ziqiang et al.(1988); Leung et al.(1990); Ramachandran et al.(1990); Amaral et al.(1992); Fernandez-Aldecoa et al.(1992); Steinhausler and Lettner(1992); Florou and Kritidis(1992); Baeza et al.(1992); Menon et al.(1992); Ibrahiem et al.(1993); Rekhakutty et al.(1993); Radakrishna et al.(1993); Narayana et al. (1995); Katsanevakis et al. (1996); Pavlovic et al. (1996); Krizman et al. (1996); Djuric et al. (1996); Anagnostakis et al. (1996); Shenber (1997) and Bellia et al.

(1997) have employed gamma spectrometric method for the measurement of 40K activity in environmental samples. A high-resolution HPGe gamma-ray spectrometer was used in this investigation to assess the ^{40}K activity in soil samples. Section D of materials and methods provides the specifics of the spectrometer configuration used for the current studies. A 300 cc plastic container was used to collect the soil sample, which was then counted for 40,000 seconds. We recorded the integral counts at the ^{40}K photo peak, located at 1461 keV. We then used the following expression (1AEA/RCA; 1989) to calculate activity A.

$$A = S \pm SD \times \frac{100}{E} \times \frac{100}{a} \times \frac{1000}{W} Bq\ kg^{-1} - - - -(3.1)$$

Where
S is the Compton corrected background subtracted counts per second under the photo peak,
SD is the standard deviation,

$$SD = \pm \sqrt{\frac{C}{T_1^2} + \frac{B}{T_2^2}} - - - -(3.2)$$

Where C= total counts from the sample, B= background counts,
T_1= sample counting time, T_2 =background counting time
E is the photo peak efficiency (%) of the detector (determined using ^{40}K standard as described in section D)
a is the abundance of the characteristic gamma ray (EML Manual, 1983) and
W is the weight of the sample taken for analysis

b. Radium-226 activity

One of the significant and popular techniques for estimating ^{226}Ra in environmental samples is gamma spectrometry. Despite possessing two useful gamma emissions, ^{226}Ra remains challenging to confirm, exhibits low gamma emission abundances, and encounters interference from other naturally occurring radionuclides. Specifically, the primary gamma emission of ^{235}U occurs at 185 keV, within the approximately 1 keV primary gamma emission of ^{226}Ra. Because ^{235}U has much lower amounts of gamma emissions, it's either very hard or impossible to make adjustments for interference.

On the other hand, the ^{226}Ra decay products ^{214}Pb and ^{214}Bi exhibit a large number of interference-free gamma emissions that are reasonably simple to verify. All intermediate daughter nuclides have short lives (seconds/minutes), while ^{222}Rn ($T_{1/2}$=3.825 days) is short-lived compared to ^{226}Ra (1600 years). With gamma energies of 609 keV and 1764 keV, the ^{214}Bi is a gamma-active radionuclide that is unaffected by other gammas. Thus, if ^{226}Ra and its daughter can be brought into balance, ^{226}Ra's activity can be readily monitored using gamma spectrometry and its daughter, ^{214}Bi.

Holtzman (1966); Mishra and Sadasivan (1971); Powers et al. (1980); Lalith and Shukla (1982); Holm et al. (1982); Rao et al. (1983); Myrick et al. (1983); McAulay and Moran (1988); Megumi et al. (1988); Bettencourt et al. (1988b); Pan Ziqianget al. (1988); Leung et al. (1990); Ramachandran et al. (1990); Sutherland and de Jong (1990); Steinhausler and Lettner (1992); Fernandez-Aldecoaet al. (1992); Quindoset al. (1992); Florou and Kritidis (1992); McAulay and Marsh (1992); Baezaet al. (1992); Amaral et al. (1992); Rekhakuttyet al. (1993); Anagnostakiset al. (1996); Djuric et al. (1996); Katsanevakiset al. (1996); Paviovicet al. (1996); Krizmanet al. (1996); Shenber (1997) and Belliaet al. (1997) have used gamma spectrometry for the determination of ^{226}Ra in various environmental matrices employing either HPGe or Ge(Li) or Nal(Tl) detector.

The gamma spectrometry method was chosen for this study to measure the amount of ^{226}Ra in soil samples because it is easy to use, accurate, flexible, and can detect small amounts of ^{226}Ra in environmental materials. A 300 ml plastic container was used to collect the sample, which was then properly sealed and stored for a month to give ^{222}Rn time to balance with its offspring. The next step involved counting the sample for 40,000 seconds. After finding out how much gamma radiation was present from ^{214}Bi (43.30%) and checking the efficiency (section D), the amount of ^{226}Ra was then calculated from the 609 keV peak of its daughter ^{214}Bi using equation (3.1).

c. *Thorium-232 activity*

A straightforward and non-destructive technique for figuring out the amount of ^{232}Th in environmental samples is gamma spectrometry. Gamma spectrometry has been used to measure the ^{232}Th activity in environmental samples by several authors, including Mishra and Sadasivan (1971); McAulay and Moran (1988); PanZiqianget al. (1988); Megumi et al. (1988); Sutherland and de Jong (1990); Leung et al. (1990); Steinhausler and Lettner (1992); Quindoset al. (1992); Amaral et al. (1992); Florou and Kritidis (1992); Fernandez-Aldecoaet al. (1992); Baezaet al. (1992); Radhakrishna et al. (1993); Ibrahiemet al. (1993); Rekhakuttyet al. (1993); Pavlovic et al. (1996); Krizmanet al. (1996); Djuric et al. (1996); Anagnostakiset al. (1996); Katsanevakiset al. (1996); Belliaet al. (1997); and Shenber (1997). Once ^{232}Th and its short-lived daughters have achieved secular equilibrium, the activity of ^{232}Th is ascertained from the gamma line of its daughters.

In the current experiment, the content of ^{232}Th in soil samples was determined using the gamma spectrometry method with an HPGe spectrometer due to its accuracy, ease of use, and convenience. The samples were counted using a method identical to that of ^{226}Ra. Using equation (3.1), which shows that the gamma abundance of ^{208}Tl for the 583 keV and 2614 keV lines is 30% and 36%, respectively, the activity of ^{232}Th was calculated from the 583 keV and 2614 keV gamma lines of its daughter ^{208}Tl.

4. RESULT AND DISCUSSION

The distribution of radionuclides and natural background radiation levels in Agumbe and the adjacent areas has been thoroughly studied using the gamma spectrometer previously mentioned and the already defined methodology. This section presents the findings from various investigations. Values given for various environments are compared with the current work's results and discussed. The final section provides a summary of the conclusions reached.

A. Radium-226 activity in soil samples

Table 1 displays the findings of the ^{226}Ra activity measurement. Figure 4 displays a typical gamma ray spectrum that was acquired for a soil sample. The data clearly show that ^{226}Ra activity has a mean value of 29.8 Bq kg^{-1} and fluctuates between 14.9 and 66.7 Bq kg^{-1}. Uphill station soil activity ranges from 19.3 to 51.6 Bq kg^{-1}, with a mean value of 31.1 Bq kg^{-1}, while downhill station soil activity ranges from 14.9 to 66.7 Bq kg^{-1}, with a mean value of 28.4 Bq kg^{-1}. The distribution of ^{226}Ra appears to be uniform throughout the hill region, as indicated by the roughly uniform mean values for uphill sampling points along the hill and downhill stations.

Table I. The results of ^{226}Ra activity in soil samples of Agumbe region

Sampling Stations	**^{226}Ra activity (Bqkg^{-1})**
Uphill stations	
Agumbe (1)	19.3±0.8
Agumbe (2)	21.9±1.2
Agumbe (3)	24.4±1.1
Agumbe (4)	29.3±1.0
Agumbe (5)	26.9±0.9
Agumbe (6)	32.4±1.3
Agumbe (7)	35.7±1.4
Agumbe (8)	34.3±1.2
Agumbe (9)	35.4±1.3
Shringeri (10)	51.6±1.4
Range	**19.3 - 51.6**
Mean	**31.1**
Sampling stations along the hill	
Agumbe (11)	30.6±1.1
Agumbe (12)	30.8±1.1
Range	**30.6 - 30.8**
Mean	**30.7**
Downhill stations	
Agumbe (13)	14.9±0.8
Agumbe (14)	29.0±1.2
Agumbe (15)	29.7±1.0
Agumbe (16)	32.5±1.1
Agumbe (17)	33.4±1.1
Someshwara (18)	16.1±0.7
Hebri (19)	19.3±0.8
Santhekatte (20)	25.9±1.0
Karje (21)	16.2±0.9
Brahmavar (22)	66.7±1.4
Range	**14.9 - 66.7**
Mean	**28.4**
Overall Range	**14.9 - 66.7**
Overall Mean	**29.8**
Overall Median	**29.5**
Overall S.D	**11.7**

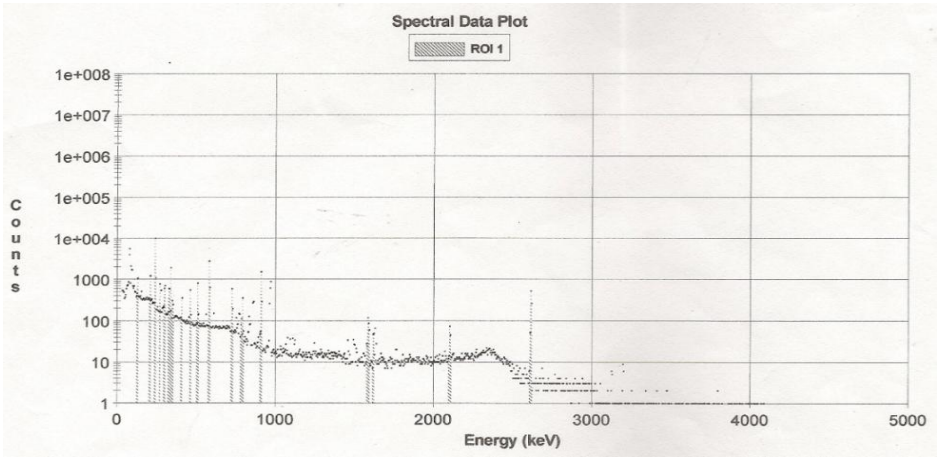

Figure 5: Typical gamma ray spectrum of soil samples

B. Comparison of ^{226}Ra activity with other regions

Table II compares the ^{226}Ra results for soil samples from the current investigation with the values from the literature for different environments. Figure 5 shows a graphic illustration of the comparison. Using a gamma spectrometer, Mishra and Sadasivam (1971) analyzed a large number of soil samples from various locations in India and found that the ^{226}Ra activity ranged from 2.59 to 26.3 Bq kg^{-1}, with a mean value of 14.7 Bq kg^{-1}. The observed ^{226}Ra activity in soil samples from India's west coast is nearly the same. It should be mentioned that samples taken from nearby areas of some of the sites included in the current investigation were included in the study published by Karunakara et al. (2001). The current study's findings are in good agreement with the values reported in the literature for the Indian environment. The fact that the ^{226}Ra activity differs by area is also evident from the table and image.

Table II. Comparison of ^{226}Ra activity in soil

Activity (Bqkg^{-1})			
Present work	**Literature Values**	**Region**	**Reference**
14.9 – 66.7 (29.83)	8.2-68.4 (30.6)	West coast of India	Karunakara*et al.* (2001)
	9.25	Kalpakkam	Iyengar *et al.* (1980)
	7.8-1520	All India	Kamath *et al.* (1996)
	2.59-26.3	All India	Mishra and Sadasivan (1971)
	5.18-33.7	Bombay	Rao *et al.* (1983)
	3.1-15.9	Mangalore	Siddappa *et al.* (1994)
	1-238(25)	Greece	Anagnostakis*et al.* (1996)
	13-165 (46)	Spain	Baeza*et al.* (1992)
	57-71	Italy	Bellia*et al.* (1997)
	26.5	Italy	Bortoli and Gaglione (1972)
	210-1208	Italy	Delaune*et al.* (1986)
	21-80 (53)	Greece	Florou and Kritidis (1992)
	7.3-104.0	Canary Islands	Femandez-Aldecoa*et al.* (1992)
	29.6-104	USA	George and Berslin (1980)
	740-3700	Ramsar, Iran	Khademi and Alemi (1980)
	31-51.8	Poland	Klement(1964)
	29.4-37.4	Yugoslavia	Kljaic*et al.* (1982)
	5.55-38.9	Japan	Kodaira*et al.*(1980)
	49-126	Finland	Markkanen and Arvela (1992)
	20.3-711	Spain	Martinez-Aguirre and Garcia-Leon(1997)
	5-130	Japan	Megumi *et al.* (1988)
	6-292 (46.1)	Ireland	McAulay and Marsh (1992)
	8.5-154.6	USA	*Myric et al.* (1983)
	18.2-79.7	China	Pan Ziqiang*et al.* (1988)
	2.96-140.6	World range	Russel and Smith (1966)
	41	New Jersey	Shellbell and Miller (1996)
	8.7-12.8	Tripoli	Shenber(1997)
	2.96-55.5	UK	Smith *et al.* (1964)
	45-48	Namibia	Steinhaulser and Lettner (1992)
	3.7-141	Czechoslovakia	Vinogradov (1959)

Values given in the parenthesis are mean/median values

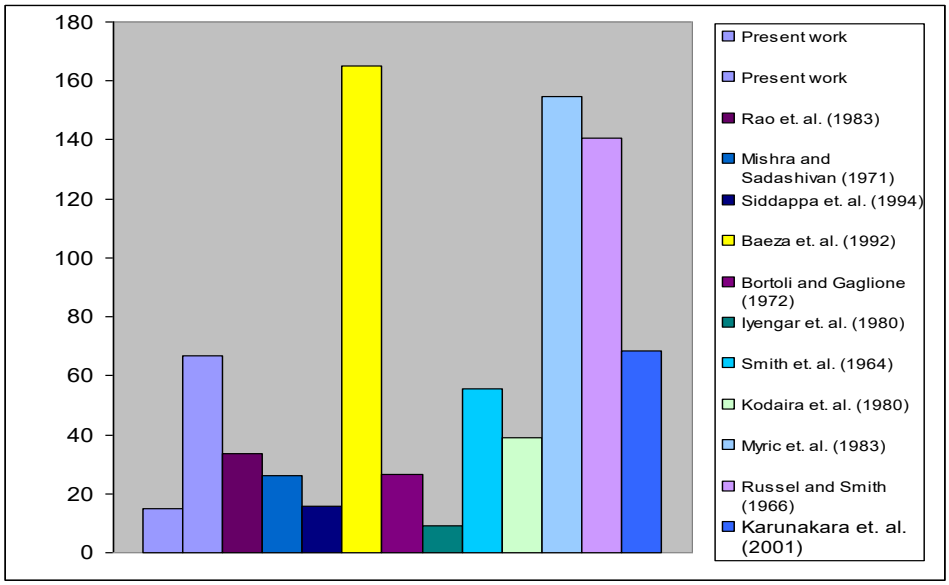

Figure 6: Comparison of ^{226}Ra activity in soil samples

C. Thorium – 232 activity in soil samples

Table III displays the ^{232}Th activity results that were collected for this experiment. The table shows that the activity has a mean value of 33.5 Bq kg^{-1} and ranges from 21.9 to 52.1 Bq kg^{-1}. With a mean value of 29.4 Bq kg^{-1}, the uphill station activity ranges between 21.9 and 40.4 Bq kg^{-1} when taking into account the full region covered under consideration. With a mean value of 36.6 Bq kg^{-1}, the downhill station activity fluctuates between 22.2 and 52.1 Bq kg^{-1}. Compared to the uphill and downhill stations, the samples taken along the hill had greater activity.

D. Comparison of Thorium-232 activity with other regions

The findings from this study regarding various soil samples from the Agumbe region are juxtaposed with the literature values documented for other areas, as illustrated in Table IV and Figure 6. Kamath et al. (1996) conducted an analysis of numerous soil samples from various locations across India and reported that the activity of ^{232}Th varied within the range of 17.5 to 158.3 Bq kg^{-1}. UNSCEAR (1982) reported ^{232}Th activity for numerous soil samples from various regions across the globe. The reported ^{232}Th activity ranges from 7 to 50 Bq kg^{-1}, with a mean value of 25 Bq kg^{-1}, which aligns with the activity observed in the current study for the Agumbe region. The table indicates that the activity of ^{232}Th in soil samples from the Agumbe region is lower than that observed along the west coast of India.

Table III. The results of ^{232}Th activity in soil samples of Agumbe region

Sampling Stations	**^{232}Th activity (Bqkg^{-1})**
Uphill stations	
Agumbe (1)	23.4±1.1
Agumbe (2)	21.9±1.5
Agumbe (3)	23.1±1.4
Agumbe (4)	40.4±1.4
Agumbe (5)	30.8±1.1
Agumbe (6)	29.0±1.5
Agumbe (7)	31.9±1.6
Agumbe (8)	26.9±1.4
Agumbe (9)	29.9±1.5
Shringeri (10)	36.6±1.5
Range	**21.9 - 40.4**
Mean	**29.4**
Sampling stations along the hill	
Agumbe (11)	38.8±1.5
Agumbe (12)	38.1±1.5
Range	**38.1 - 38.8**
Mean	**38.4**

Down hill station	
Agumbe (13)	22.2±1.0
Agumbe (14)	40.3±1.7
Agumbe (15)	42.6±1.4
Agumbe (16)	43.3±1.6
Agumbe (17)	40.7±1.4
Someshwara (18)	24.2±1.0
Hebri (19)	23.4±1.1
Santhekatte (20)	31.4±1.3
Karje (21)	45.9±1.5
Brahmavar (22)	52.1±1.5
Range	**22.2 - 52.1**
Mean	**36.6**
Overall Range	**21.9 - 52.1**
Overall Mean	**33.5**
Overall Median	**31.7**
Overall S.D	**8.8**

Table IV. Comparison of ^{232}Th activity in soil

Activity (Bq kg^{-1})			
Present	**Literature**	**Region**	**Reference**
work	values		
21.9-52.1 (33.49)	5.9-77.2 (38.2)	West coast of India	Karunakara et al., (2001)
	17.5-158.3	All India	Kamath *et al.* (1996)
	18.31	All India Av.	Mishra &Sadasivan (1971)
	10260	Kanyakumari	Rekhakutty*et al.* (1993)
	950	Chamundi Hills	Rekhakutty*et al.* (1993)
	5.7	Andaman	Rekhakutty*et al.* (1993)
	7.4-21.5	Bombay	Rao *et al.* (1983)
	68.8-132.46	Nandadevi	Rao *et al.* (1983)
	12.0-37.1	Mangalore	Siddappa *et al.* (1994)
	1-193 (21)	Greece	Anagnostakis*et al.* (1996)
	7-204 (49)	Spain	Baeza*et al.* (1992)
	73-87	Italy	Bellia*et al.* (1997)
	34	Louisiana	Delaune*et al.* (1986)
	25-43	Serbia	Djuric *et al.* (1996)
	11.6-110.5	Canary Islands	Fernandez-Aldecoa*et al.* (1992)
	16-85(71)	Greece	Florou and Kritidis (1992)
	2.5-95.6	Nile delta	Ibrahiem*et al.* (1993)
	13.2-84.4	Spain	Martinez-Aguirre and Garcia-Leon (1997)
	3-60 (26)	Ireland	McAulay and Moran (1988)
	5-185	Japan	Megumi *et al.* (1988)
	4-130(32)	USA	Myric*et al.* (1983)
	23.3-224	China	Pan Ziqiang*et al.* (1988)
	82	New Jersey	Shellbell and Miller (1996)
	7.6-9.7	Tripoli	Shenber(1997)
	3-38	Namibia	Steinhaulser and Lettner (1992)
	29.6-31.2	Canada	Sutherland & Jong (1990)
	22	USSR	Vinogradov (1959)
	7-50(25)	World range	UNSCEAR(1982)

Values given in the parenthesis are mean/median values

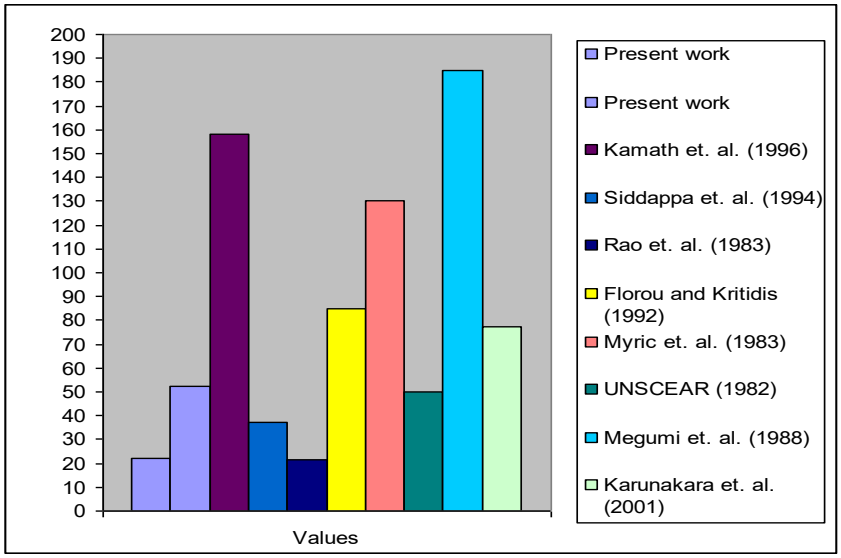

Figure 7: Comparison of ^{232}Th activity in Soil Samples

E. Potassium – 40 activity in soil samples

Potassium-40 is a significant primordial radionuclide found in nearly all environmental matrices. The current investigation involved measuring the activity of ^{40}K in soil samples using the gamma spectrometry method detailed in chapter 3.

The findings from the ^{40}K activity conducted in this study are detailed in Table V. The table indicates that the activity ranges from 84.0 to 562.3 Bq kg^{-1}, with an average value of 162.6 Bq kg^{-1}. The activity in soil samples from the uphill station ranges from 84 to 445.1 Bq kg^{-1}, with an average value of 153.2 Bq kg^{-1}. The activity at the downhill station ranges from 85.6 to 562.3 Bq kg^{-1}, with an average value of 179.7 Bq kg^{-1}. The samples gathered from the hill exhibited marginally lower activity in comparison to those from both the uphill and downhill locations.

Table V. The results of ^{40}K activity in soil samples of Agumbe region

Sampling Stations	**^{40}K activity (Bqkg^{-1})**
Uphill stations	
Agumbe (1)	94.3±5.4
Agumbe (2)	84.0±6.9
Agumbe (3)	94.3±6.3
Agumbe (4)	134.3±6.4
Agumbe (5)	130.9±5.9
Agumbe (6)	132.9±7.8
Agumbe (7)	146.8±8.1
Agumbe (8)	135.0±7.2
Agumbe (9)	134.6±7.7
Shringeri (10)	445.1±13.
Range	**84 - 445.1**
Mean	**153.2**
Sampling stations along the hill	
Agumbe (11)	127.3±6.8
Agumbe (12)	121.0±6.6
Range	**121.0 – 127.3**
Mean	**124.1**
Downhill stations	
Agumbe (13)	137.0±6.4
Agumbe (14)	149.0±8.2
Agumbe (15)	134.9±6.5
Agumbe (16)	140.3±7.3
Agumbe (17)	129.4±6.4
Someshwara (18)	85.6±4.9
Hebri (19)	94.3±5.4

Santhekatte (20)	204.8±7.9
Karje (21)	562.3±14.7
Brahmavar (22)	160.1±6.8
Range	**85.6 – 562.3**
Mean	**179.7**
Overall Range	**84 – 562.3**
Overall Mean	**162.6**
Overall Median	**134.4**

F. Comparison of ^{40}K activity with other regions

The results from this study on soil samples from the Agumbe region are compared with values found in other studies, as shown in Table VI and Figure 7. Karunakara et al. (2001) conducted an analysis of a substantial number of samples from the west coast of India, reporting that the 40K activity ranged from 14.6 to 344.9 Bq kg^{-1}, with a mean value of 152.2 Bq kg^{-1}. The findings align with the results from the current study regarding soil samples from the Agumbe region, and they are lower than the activity observed in soil samples from various other regions both within the country and internationally. The value obtained in this study aligns with the range reported by UNSCEAR (1988) for the global distribution of ^{40}K.

Table VI. Comparison of ^{40}K activity in soil

Activity (Bqkg^{-1})			
Present work	Literature values	Region	Reference
84.0-562.3 (162.64)	14.6-344.9 (152.2)	West coast of India	Karunakara et al., (2001)
	43.0-766	All India	Kamath et al. (1996)
	24-146	Kudankulam	Lakshmi et al. (1990)
	103-1362	Kerala	Lalit and Shukla (1982)
	34.78-245	Bombay	Lalit and Shukla (1982)
	37-572	Bombay	Rao et al. (1983)
	561-876	Bombay	Rao et al. (1983)
	46.4-327.6	Mangalore	Siddappa et al. (1994)
	12-1570	Greece	Anagnostakiset al. (1996)
	48-1586	Spain	Baezaet al. (1992)
	580-760	Italy	Bellia et al. (1997)
	398	Louisiana	Delauneet al (1986)
	348-441	Serbia	Djuric et al. (1996)
	430-730	Russia	Drichko et al. (1977)
	141.6-1489	Canary' Islands	Fernandez-Aidecoaet al. (1992)
	337-1380	Greece	Florou and Kritidis (1992)
	29-653	Nile delta	Ibrahiemet al. (1993)
	670-1000	Finland	Klemolaet al. (1991)
	289-703	Spain	Martinez-Aguirre and
			Garcia-Leon(1997)
	40-800	Ireland	McAulay and Moran (1988)
	440	World average	McAulay and Moran (1988)
	281-891	China	Pan Ziqianget al. (1988)
	930	New Jersey	Shellbell and Miller (1996)
	42-1100	Namibia	Steinhaulser and Lettner (1992)
	265-282	Tripoli	Shenber(l997)
	100-700	World range	UNSCEAR(1988)

Values given in the parenthesis is the median values

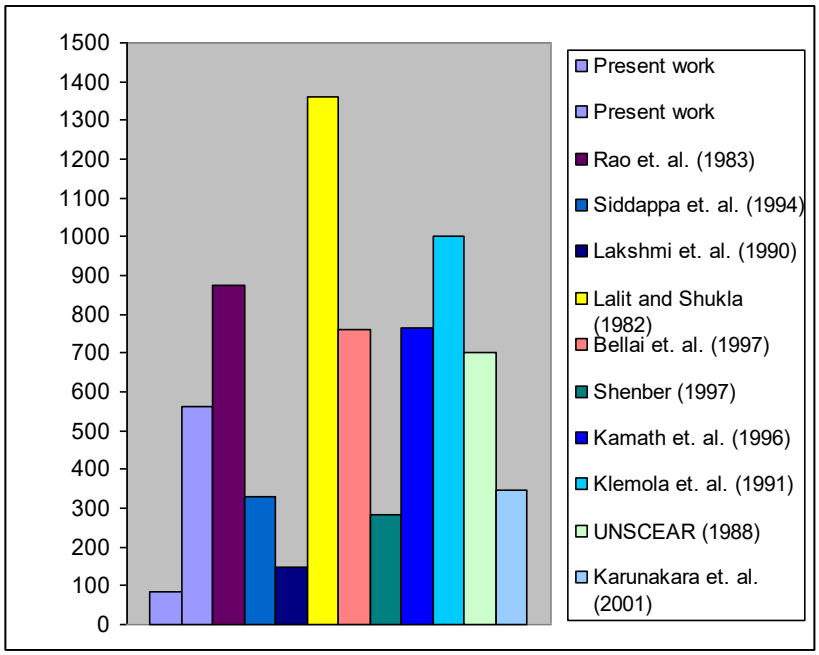

Figure 8: Comparison of 40k activity in soil samples

5. CONCLUSIONS

This study looks closely at natural radioactivity in soil samples from Agumbe, focusing on the levels of Ra-226, Th-232, and K-40 at different heights and land types. The results show that the levels of Ra-226 and K-40 are similar to those found in the western coastal areas of India, indicating that these radionuclides are spread out evenly in the region. Interestingly, Th-232 levels were found to be higher in soil samples from the hillside compared to those from higher and lower areas, indicating that local geological factors might affect the differences in radionuclide levels. Although Agumbe is recognized for having the highest rainfall in Karnataka, the concentrations of primordial radionuclides measured are comparable to those found in other regions of the state and the nation. This calls into question certain prevailing beliefs regarding the potential impact of high precipitation on soil radioactivity levels. The results provide essential information for the national database regarding natural background radiation and emphasize the necessity of ongoing monitoring in ecologically sensitive areas. To get clearer results, future studies should cover a larger area and longer time period, looking at seasonal changes and doing more detailed geological studies to better understand how radionuclides behave in places with a lot of rain.

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