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Particle Size Range in Continuous Particulate Air Monitors (CPAMs) of Gombe Metropolitan Area Northeastern Nigeria: Characterization, Challenges, and Implications for Air Quality Monitoring

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Abstract: ***Detailed analysis of data on radiation and elevation measured in 3 lines of 161 points of the Gombe Metropolitan Area. Measurements of radiation in Lines 1, 2, and 3 were 18-42 Bq, 25-39 Bq, and 18-39 Bq, respectively, and most of the measurements corresponded to the natural background. Spatial heterogeneity existed, with potential hotspots associated with geological or anthropogenic sources. Topographic gradients were evident in the elevation data, with the highest and lowest elevations at approximately 476 and 712 meters, respectively, which influenced soil composition, microclimates, and pollutant distribution. These spatial distributions highlight the importance of local judgments in managing environmental risks. Statistical analysis of the process stability in general was done with the help of control charts, Sens Slope estimator, and box plots, but sometimes the outliers (that were more than control limits, mainly 42 Bq and 38 Bq) were present, and it was possible to consider the existence of other external factors or measurement errors. The mere positive shifts in Lines 1 and 3 also indicate that the radiological environment can remain in the same position over time. All these findings suggest that the climate has remained relatively stable radiologically, and local malformities should be monitored. Timely detection of abnormal conditions, environmental security, and risk mitigation measures through close observation and comprehensive spatial and temporal investigations is critical in cities and peri-urban regions. The results highlight the significance of continuous monitoring and local risk control to ensure environmental security, as well as the importance of stable radiological conditions in the long run. Still, they should be monitored with skilled attention to detect anomalies in urban and peri-urban areas in a timely manner.***

Keywords: Elevation, Radiation, Spatial Heterogeneity, Environmental Monitoring.

Abbreviations:
Bq: Unit of Radiation
PM: Perticulate Matter
TSP: Total Suspended Particulates
CUSUM: Cumulative Summation
CPAMs: Continuous Particulate Air Monitors
EPA: Environmental Protection Agency

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I. INTRODUCTION

A. Highlights

- Radiation in three monitored lines in Gombe is dominated by natural background radiation levels with localized hotspots that represent possible geological or artificial sources.
- Topographical gradients define the topographical profiles, which influence the environmental process, and the sites of the study are 476-712 meters.
- The statistical analysis should verify the overall processes; however, there are situations when it is combined with the outliers, thus, further monitoring should be recommended to reveal the potential radiological deviations.
- Findings indicate that there is a need to consider having localized and continuous environmental monitoring to ensure radiological safety and inform risk mitigation in urban and peri-urban environments.

The solution to air pollution problems worldwide lies in the history of particulate matter (PM) and air quality. PM is natural, as well as it includes dust storms, volcanic eruptions, biological emissions, and human activities, such as fossil fuel burning, industrial activities, and vehicular emissions. The particles are of various sizes: coarse particles (PM10), large and falling faster; and fine particles (PM2.5) and ultra-fine particles, which are much smaller and can remain in the air longer. These particles are chemically complex and can contain organic matter, sulfates, nitrates, metals, and other toxic elements. This diversity not only affects their environmental behaviour, e.g., transport and deposition, but also their potential health effects, with finer particles having the most significant capacity to penetrate deep into the respiratory system and even into the bloodstream, thereby posing risks of cardiovascular and respiratory diseases. Tracking particulate matter is essential for regulatory compliance and public safety. Low-cost PM sensors and conclude that they can be used to measure PM1.0. Still, their performance on PM2.5-10 is at best low, providing misleading information to public health interventions, highlighting significant size-related discrimination, and underscoring the need for careful sensor application and

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reporting to ensure proper monitoring and air quality interventions [1].

Air quality standards set by governments and health agencies to reduce adverse health effects are determined by PM diameter and concentration. As an illustration, PM2.5 is established to curb exposure to the most toxic fine particles, whereas PM10 covers larger particles, though still potentially dangerous. Totals Suspended Particulates (TSP) is a broader measure of air quality, as it includes all airborne particles of any size. Various particle sizes and compositions are estimated with high accuracy in real time or over long periods using complex surveillance systems such as optical particle counters, beta attenuation monitors, and gravimetric mechanisms. These data will be analyzed, and it is expected that authorities will be able to identify hotspots of pollution, their sources, and time tendencies, and take specific actions. The seasonal variations suggest that PMs are high in winter, mainly due to traffic emissions and local sources, and peak during rush hours. The significant impacts of meteorological conditions on particle behaviour and the relevance of studying aerosol dynamics as the key to effective pollution management. Broadly speaking, the results highlight the multi-faceted origins and atmospheric mechanisms that determine air quality in Delhi, and the necessity of specific control measures to address air pollution and ensure the well-being of the population [2]. The use of 12 calibrated, strategically located sensors proved that pollution concentrations are higher in construction areas, underscoring the importance of localised monitoring in an urban densification environment. Spatial analysis has identified pollution hotspots around construction zones. In contrast, spectral analysis was able to differentiate local pollution sources from regional pollution sources, with the construction significantly affecting air quality. It demonstrated the usefulness of low-cost sensors for recording high-resolution measurements, supporting their further application in urban air quality management, and emphasising the importance of specific mitigation measures to safeguard societal health during urban area development [3].

In general, constant monitoring of particulate matter is a key element of environmental health practices that will help to minimize human exposure to pollution and shield both nature and people against the detrimental impact of air pollution. Particulate matter (PM) is a term for a mixture of small solid particles and liquid droplets suspended in the air, with origins ranging from natural to anthropogenic. The sizes, compositions, and origins of these particles vary and include dust, soot, smoke, pollen, and industrial and vehicle emissions, as well as construction and natural occurrences such as wildfires and volcanic eruptions. The influences of particle composition and size on the precision of low-cost PM sensors when measuring air quality in multiple Chilean cities, discovering that the sensor is correlated with regulatory instruments with reasonable variation, and that the performance of the sensor is affected by a size of particles, and that larger particles tend to give low accuracy due to the influence of the particles on the light scattering measurements. The variations observed across different sites reveal that site-specific calibration, as well as the significance of particulate composition, are necessary to improve sensor reliability. They demonstrate the need for an advanced calibration and sensor configuration method that accounts for the different properties of diverse particles to enhance the effectiveness of low-cost air-quality pollution sensors [4]. The willingness-to-pay (WtP) survey was employed to examine air quality in the South American cities of Barcelona (Venezuela) and Guayaquil (Ecuador), with the focus on industrial and vehicular emissions and serious health issues. This analysis shows that Barcelona is full of outdated regulations and has pressing needs to improve the city's transport and garbage collection. At the same time, Guayaquil requires additional investments in public transport and pollution reduction. The level of interest among inhabitants in both towns in improving air quality is high, and the significance of policy changes and infrastructure investments is paramount [5]. The critical aspects of these particles are their diameter relative to their atmospheric behaviour, their ability to penetrate respiratory structures, and their potential health impacts. Smaller particles, such as PM2.5 and ultrafine particles, may also penetrate deep into the lungs and even into the bloodstream, posing a serious health hazard and increasing the risk of respiratory and cardiovascular diseases. Such health issues necessitate monitoring particulate levels to assess air quality and pollution trends and take precautions to protect people. Regulatory standards for PM are set for specific size fractions due to their varied health and environmental effects.

The radiological threat posed by radioactive emissions from different petrologic units in northeastern Nigeria remains poorly understood due to limited research. The 2009 aero-radiometric survey examined 13 rock types: migmatites-gneiss, basalts, granites, sandstones, and alluvium, showing significant differences in the levels of natural radioactivity among these units. Results showed that some of the formations, specifically, OGe, OGp, BG, and MG, have higher concentrations of activity of uranium, thorium, and potassium, and higher hazard indices, including the absorbed dose rates, radium equivalent, and potential cancer risk parameters that, in most cases, surpass the international safety standards. Other units, such as alluvium and part of sandstone formations, were, however, observed to have relatively low radiological hazards. Such findings indicate that the people in regions with high concentrations of high-radiation units should minimize exposures, particularly during construction or land use processes, and emphasize the need to conduct frequent check-ups to avoid the risks of the health effects caused by long-term or excessive exposures to naturally occurring radiogenic elements in such geological formations [6].

The changing issues in air pollution and health studies, with the falling pollution levels, make it more challenging to establish explicit exposure-response associations and to monitor health hazards. It emphasises the necessity of new interdisciplinary methods to understand better the toxicity of individual pollutants, the impact of complex pollution mixtures, and the determinants of vulnerability in vulnerable populations. Although there have been

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advancements in improving air quality, further research is needed to inform effective policies, particularly in regions that continue to exceed air quality norms, to address the persistent, multifaceted health impacts of pollution [7].

Usually, controlled categories include PM10 (particles smaller than 10 micrometres), PM2.5 (smaller than 2.5 micrometres), PM1 (smaller than 1 micrometre), and Total Suspended Particulates (TSP), all airborne particles of any diameter. Authorities such as the U.S. Environmental Protection Agency (EPA) set acceptable levels of these particles in the air to safeguard people and the environment. The composition of PM depends on the source, but it usually contains organic compounds, metals and salts, and carbonaceous material, which can affect toxicity and environmental impacts. Good surveillance of such particles assists in regulatory compliance, health hazard evaluation, and pollution control strategies, which, in the long run, protect the quality of the air and the health of the population at large. Five (5) workstations in a detergent manufacturing facility in Nigeria, and the contaminants found in the air that include particulate matter, VOCs, and formaldehyde, which are above the safe levels, and contribute to health-related complications in employees. Using various measurements, the research has identified the effects of these air pollutants and emphasised the need to improve ventilation and safety systems. It highlights the need to adhere to global standards and implement regulatory controls to improve the health and safety of workers in industrial settings [8]. The severe health hazards of air pollution and the high vulnerability of children and vulnerable groups, the issue of indoor pollution, the effects of climate change, and the urgency to act on policy require thorough research and measures to enhance the quality of air all over the world to safeguard the population and overcome upcoming challenges. It discusses how smart drones equipped with geospatial technology can be used to detect air quality in real time at the Kodungaiyur solid waste dump yard in Chennai, India. The experiment, involving the use of drones with sensors at different altitudes and times of year, shows that there are considerable differences in pollutants, such as CO and NH4, particularly closer to the ground and near waste deposition locations. The combination of drone and GIS data provides an overall picture essential for efficient management of health and environmental stakeholders. The results highlight the value of sophisticated, real-time monitoring instruments for more accurately learning about the dynamics of pollution and informing mitigation measures. The direction of future research is to enhance sensor precision and data security [9].

Research was conducted to determine ambient radiation levels, health hazard indices, and excess lifetime cancer risk around radiological sections at Federal Teaching Hospital Gombe, Nigeria, by measuring the sections using calibrated Rados-200 meters and GPS. The average annual outdoor equivalent dose was 0.078 mSv/y, and effective doses were 0.1358 mSv/y and 0.0950 mSv/y, which are lower than the 1 mSv/y upper limit of exposure to the general population. The average outdoor excess lifetime cancer risk was estimated at 0.3330 × 10^3, slightly higher than the world average but close to that of regions like these. The responses of medical diagnostic procedures affected the background radiation level and interfered with several radiation indices. In general, the doses were below the recommended limits set by UNSCEAR; still, the annual effective doses and cancer risk exceeded the global safety limits, underscoring the need for additional monitoring [10].

To determine the levels of indoor and outdoor background ionising radiation in response to recent advancements in radioactive activities, an extensive survey was carried out in Gombe State, Nigeria. A study using an RDS-31 measure showed that average exposure levels were within global limits, and that dose rates were 61.34 to 149.21 nGy/h indoors and 61.34 to 134.42 nGy/h outdoors. The estimated effective doses and the lifetime risk of cancer each year were mostly below international safety limits. Still, some regions, such as Billiri, had high values, which may be attributed to topographical factors and human activities. Although the overall radiation level is deemed to be normal, there are high risks locally, which may indicate that frequent monitoring is necessary to avoid long-term health risks despite the low risk of cancer among residents. However, it is worth noting that there is a low risk of cancer among residents that needs to be taken seriously over a long period of time [11].

Despite significant developments in air quality monitoring and the utilisation of continuous particulate air monitors (CPAMs) in urban zones, important issues persist with the proper definition of the spatial-temporal variability and size-resolved structure of particulate matter (PM), especially in urban zones with rapid urbanisation and complex topography. The limitations of inexpensive sensor technologies, including the inability to size and calibrate them to measure the site-specific makeup of particles and environmental conditions, do not enable the production of reliable information required to quantify health risks and implement effective pollution control strategies. Moreover, the integration of constant monitoring of particulate air with other approaches, such as radiological examination, geospatial analysis, and real-time remote sensing, is not yet a fully developed system, which makes it hard to understand the origin of pollution and patterns of exposure fully. The given gap reflects the desperate need to create effective, context-dependent calibration rules and an interdisciplinary monitoring system that may help raise the trustworthiness of air quality information and, naturally, inform targeted interventions and population health policies in equally affected cities.

II. ROLE OF CONTINUOUS PARTICULATE AIR MONITORS (CPAMS)

Continuous Particulate Air Monitors (CPAMs) are significant devices used to monitor the environment because they provide real-time, high molecular information on the level of particulate matter in the air. This is advanced equipment that uses optical, beta attenuation, or other sensing technologies to continuously measure PM1, PM2.5, and PM10 concentrations over longer time intervals, enabling detection of short-term fluctuations and pollution events. CPAMs can generate real-time data that will allow regulators, environmental and research agencies to

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designate pollution sources without difficulty, assess compliance with air quality standards, and implement mitigation measures in real time. Moreover, CPAMs are used to analyse long-term trends and evaluate the effectiveness of pollution-control tools, informing policy choices to improve air quality and protect the population. They are also critical tools to the general air quality control due to their ability to operate 24/7 and provide real-time feedback. Continuous observation of particulate matter has essential advantages over intermittent observation, as it allows for high-resolution, instantaneous information and captures air quality variability more accurately and promptly. It is the aspect that will enable real-time pollution detection and immediate responses to protect the community's health. In addition, long-term trends and seasonal variations can be tracked more accurately through continuous monitoring systems, which provide detailed information on pollution sources and the effectiveness of control measures. Constant monitoring versus random sampling. This is because continuous monitoring offers a rich data account on the quality of the air at any given time as compared to intermittent sampling, which could ignore temporary events or the highest concentration, and offers a platform to make evidence-based decisions, more effective risk evaluation, and more effective management of the air pollution issue. The ordinary detection thresholds for particle size have myriad grave advantages for assessing individuals' health conditions and air quality. Exact measuring of the different dimensions of the particles, such as PM1, PM2.5, and PM10, will be able to identify the sources of the pollution, the dispersion distribution, and the potential health risk, since smaller particles, such as the PM2.5, can easily access the respiratory system and the health risks are the worst of the health risks. Adequate identification will ensure that regulators can use regulatory requirements, discern pollution hotspots, and present special innovative actions. Furthermore, the time and size of particles may be monitored in real time, enabling warnings of unsafe air conditions and exposing the setup to vulnerable groups of individuals, such as children, the elderly, and individuals with underlying health problems, to fewer dangers. Totally, enhanced detection capabilities enable more precise assessment, management, and communication of air quality issues, ultimately leading to healthier environments and improved health outcomes for the population.

III. IMPORTANCE OF PARTICLE SIZE RANGE CHARACTERIZATION

The scale size distribution of the particle is a highly significant parameter of the atmosphere, as well as in the respiratory system of a human being. Aerodynamics of various particles differ with their size and influence the way in which they are dispersed in the atmosphere, fall on the surfaces, or penetrate the biological barriers. Using the example of coarse particles (PM10), these particles are likely to settle in the upper respiratory tract and are often associated with dust and pollen; the fine particles (PM2.5) may bypass the organism's innate defences and land in the alveolar portions of the lungs. Even the tiniest, ultrafine particles less than 0.1 micrometres in diameter can penetrate the bloodstream, leading to systemic health risks. Therefore, accurate identification and characterisation of particle size may assist scientists and regulators in assessing exposure risks more precisely and developing more effective ways to reduce them, tailored to the health effects of the specific size range. The evaluation of environmental impact and the control of pollution also depend on knowledge of the particle size distribution. It is also probable that the sources will generate particles within specific size ranges. Therefore, size characterisation plays a significant role in source apportionment, which aims to identify pollutant sources. Using construction as an example, larger dust particles are produced during mechanical activities, whereas smaller particles are produced during combustion processes. These small particles include toxic substances and organic compounds, which are converted into fine and ultrafine particles. A proper characterization of the size range allows policymakers to consider particular control mechanisms, such as a filtration system or reduction in emissions, which are only able to mitigate those particle sizes that lead to the most serious health and environmental impact. In addition, this kind of knowledge can affect the development of air quality requirements and monitoring principles, which must ensure that the regulations contribute to reducing the most harmful fraction of particles and to protecting the health and ecosystems of the population to the greatest possible degree.

The size of dust particles is one of the determining factors of the health impacts of air pollution and the atmospheric dynamics of CPM. Smaller particles, such as PM2.5 and ultrafine particles, can penetrate deeper into the respiratory system, reaching the alveoli of the lungs and even the bloodstream, which may cause systemic health effects, including cardiovascular and respiratory problems and inflammation. Their small sizes also enable long-distance atmospheric transport, and pollutants travel long distances before settling or dispersing, thereby impacting air quality across large regions. By contrast, larger particles, such as PM10, are likely to settle in the upper respiratory tract and have more localised health effects. Besides, the atmospheric lifetime and dispersal of particles depend on particle size: the smaller the particle, the longer it remains suspended and spreads over a wider area, which affects the climate by altering cloud formation and radiative forcing. Therefore, particle size is critical in determining how the environment and human health are affected by airborne particulate matter.

The main issue with the determination of the actual particle size of the sample by the Continuous Particulate Analyzers and Monitors (CPAM) devices is that they are sensitive to the properties of the particles in this aspect: shape, refractive index, and composition, which may seriously compromise the accuracy of measurement. Most CPAM detectors are based on optical sensing, e.g., laser scattering, which is sensitive to irregular or non-spherical particle shapes, leading to differences between the real and measured particle sizes. Furthermore, differences in the refractive indices of the particles and the overlap of the size distributions may also cause problems in data interpretation, leading to possible misclassification or

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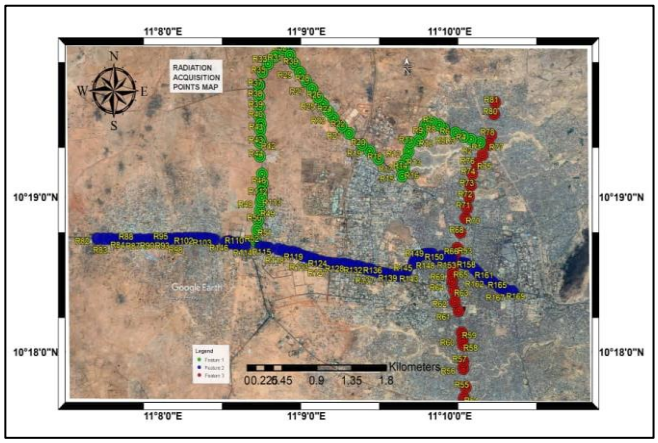
underestimation of the particular size distributions. Environmental conditions that affect detection accuracy include humidity, temperature changes, and particle agglomeration, which can alter particle behaviour or introduce artefacts. The latter technical limitations remain an issue in delivering high-quality, real-time particle size measurements, especially under adverse atmospheric conditions, which are critical for assessing health risks and compliance with regulations.

The need for localised particulate matter measurements stems from the pronounced spatial and temporal variability in air pollution across regions and over time. Local characteristics, such as emission sources, topography, meteorological conditions, and land use patterns, influence the concentration and composition of PM in any location. An example of this is a city full of traffic and industry, which tends to have more PM than a rural area or a barrier area, and seasonal changes, such as heating in winter or agricultural processes, may also fluctuate over time. This heterogeneity highlights the significance of the localised assessment, as it is only through it that air quality can be defined appropriately and pollution hotspots can be identified, to create efficient and specific mitigation strategies. The lack of area-specific data can result in ineffective policies or an inability to match actual exposure risks, ultimately impeding efforts to protect the health and environment of the population.

IV. MATERIAL AND METHODS

In this research, Continuous Particulate Air Monitors (CPAMs) were used at strategic locations along three sampling lines in the Gombe Metropolitan Area, Northeastern Nigeria, to measure particle size distribution and air quality. The CPAMs applied optical and beta-attenuation measurement technologies to quantify particulate matter in different size ranges (PM1, PM2.5, PM10) over long periods of monitoring. The sensors were calibrated with reference-grade instruments to ensure accurate measurements, considering other parameters, such as the refractive index and shape of the particles, that affected optical detection. The data were collected continuously over time; therefore, they capture changes over time and potential pollution peaks. Sampling stations were also located to represent the various environmental and anthropogenic sources, including urban roads, industrial locations, and natural backgrounds, providing a good representation of the total spatial coverage. Environmental sensors were used to measure particulate matter simultaneously with meteorological parameters such as temperature, humidity, wind speed, and direction, providing context for the particulate measurements and consideration of atmospheric effects on particle distribution and sensor performance. The obtained data were statistically analysed using the Sen Slope Estimator to determine underlying trends and the CUSUM Control Chart to assess process stability and radiation levels, in conjunction with the particulate analysis and the radiological background. The distribution of particle sizes and radiation levels across the sampling zones was visualised using spatial analysis and geostatistical interpolation methods, including kriging, which enabled the identification of pollution hotspots and the source of pollution in the study area. Figure 1 shows the topographic map of the study area.



[Fig.1: Topographic Map of the Study Area]

V. RESULTS

A total of one hundred and sixty-nine (169) measurements of radiation levels throughout the study area were done at several points along the main three (3) lines, namely Line 1 (Bypass - Undulum), Line 2 (Riyal Junction - Police Junction), and Line 3 (NTA to Bank Roundabout). These measured radiation levels, between 26 Bq and 42 Bq, indicate a change in the local gamma radiation environment that can be caused by geological characteristics of the underlying ground, such as mineral formations, crustal composition, or thermal variations. The measurements are essential for providing important information on the spatial distribution of natural radioactivity, which is usually associated with crustal heat flow and geothermal potential. It is important to note that increasing radiation levels, especially at 42 Bq, may indicate areas with higher crustal radioactivity, which can be compared with areas of high geothermal activity. The geographical location of a data point spans latitudes of about 10.1672 N to 10.3718 N and longitudes of 11.1199 E to 11.1799 E. The comprehensive information points of the coordinates are distributed in a structured manner along the three lines and record the spatial variations in radiation within the study area. As an example, at Line 1 (Bypass - Kundulum), the latitude of the measurements is 10.288 ° to 10.3164 °, and the longitude is 11.1671 ° to 11.1717 °, whereas in Line 2 (Riyal Junction - Police Junction), the latitude is 10.288 ° to 10.3164 ° and the longitude is 11.1671 ° to 11.1717 °. In Line 3 (NTA to Bank Roundabout), the area is larger, and points are between around 10.2911 -1 to 10.2802 -1 latitudes and 11.0832 -1 to 11.1799 -1 longitudes, indicating the spatial heterogeneity of radiation levels. These coordinates provide a basis for spatial analysis and enable identification of correlations between radiation anomalies and geological structures, heat flow, and geothermal prospects in the study area (Table 1).

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Table I: Radiation and Coordinates of all the Data Points in the Study Area

Line 1 Bypass - Undulum			Line 2 Riyal Junction - Police Junction			Line 3 NTA to Bank Roundabout		
Radiation in (Bq)	Latitudes (Degrees)	Longitudes (Degrees)	Radiation in (Bq)	Latitudes (Degrees)	Longitudes (Degrees)	Radiation (Bq)	Latitudes (Degrees)	Longitudes (Degrees)
33	10.288	11.1671	31	10.3121	11.1726	33	10.2911	11.0832
35	10.2579	11.1729	28	10.3128	11.1704	36	10.2911	11.0847
30	10.2596	11.1686	34	10.3134	11.1686	31	10.2911	11.0861
34	10.2636	11.1681	35	10.3142	11.1668	33	10.2909	11.0871
31	10.2644	11.1658	34	10.3149	11.1649	32	10.2910	11.0883
30	10.2688	11.1668	34	10.3158	11.1631	32	10.2909	11.0896
30	10.2713	11.1678	32	10.3164	11.1612	33	10.2910	11.0907
33	10.2700	11.1725	35	10.3159	11.1597	33	10.2909	11.0918
33	10.2760	11.1671	29	10.3141	11.1588	35	10.2910	11.0929
34	10.2780	11.1662	36	10.3124	11.1581	32	10.2909	11.0941
36	10.2804	11.1660	30	10.3121	11.1563	38	10.2910	11.0952
32	10.2823	11.1656	34	10.3101	11.1557	36	10.2910	11.0964
33	10.2851	11.1659	38	10.3083	11.1551	38	10.2911	11.0991
32	10.2882	11.1664	27	10.3065	11.1546	33	10.2911	11.0987
30	10.1672	11.1672	34	10.3048	11.1541	31	10.2911	11.0998
31	10.2928	11.1677	30	10.3055	11.1521	34	10.2912	11.1012
35	10.2845	11.1680	33	10.3069	11.1560	34	10.2912	11.1021
33	10.2959	11.1689	37	10.3084	11.1486	34	10.2913	11.1035
34	10.2981	11.1693	38	10.3001	11.1465	33	10.2913	11.1048
30	10.3005	11.1698	37	10.3114	11.1448	30	10.2913	11.1061
38	10.3029	11.1702	33	10.3138	11.1418	32	10.2913	11.1072
42	10.3054	11.1706	30	10.3135	11.1401	34	10.2913	11.1083
34	10.3076	11.1717	32	10.3170	11.1382	30	10.2912	11.1093
36	10.3095	11.1731	32	10.3184	11.1370	32	10.2910	11.1102
26	10.3117	11.1746	33	10.3201	11.1358	32	10.2903	11.1137
32	10.3138	11.1752	33	10.3214	11.1346	34	10.2907	11.1137
34	10.3161	11.1156	34	10.3232	11.1333	30	10.2905	11.1129
35	10.3183	11.1759	34	10.3249	11.1319	29	10.2904	11.1146
36	10.3208	11.1762	37	10.3267	11.1305	30	10.2903	11.1158
			34	10.3285	11.1292	30	10.2901	11.1174
			35	10.3304	11.1282	32	10.2999	11.1185
			34	10.3315	11.1267	33	10.2997	11.1197
			32	10.3301	11.1247	33	10.2896	11.1209
			32	10.3285	11.1231	26	10.2894	11.1221
			33	10.3267	11.1217	33	10.2893	11.1229
			33	10.3241	11.1211	26	10.2891	11.1410
			34	10.3239	11.1209	33	10.2891	11.1251
			33	10.3216	11.1209	31	10.2888	11.1263
			28	10.3193	11.1211	29	10.2885	11.1274
			27	10.3172	11.1211	29	10.2885	11.1285
			34	10.3145	11.1211	30	10.2882	11.1296
			31	10.3123	11.1212	29	10.2877	11.1307
			32	10.3117	11.1211	28	10.2874	11.1319
			33	10.3051	11.1215	32	10.2871	11.1330
			33	10.3031	11.1216	28	10.2868	11.1339
			34	10.3014	11.1214	29	10.2865	11.1350
			33	10.2991	11.1211	32	10.2863	11.1358
			34	10.2972	11.1209	31	10.2862	11.1369
			33	10.2952	11.1205	30	10.2861	11.1381
			34	10.2921	11.1202	32	10.2860	11.1392
			34	10.2909	11.1199	33	10.2860	11.1401
			35	10.3121	11.1726	30	10.2858	11.1416
				10.3128	11.1704	32	10.2855	11.1426
				10.3134	11.1686	31	10.2855	11.1436

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				10.3142	11.1668	31	10.2852	11.1447
				10.3149	11.1649	29	10.2849	11.1460
				10.3158	11.1631	30	10.2847	11.1469
				10.3164	11.1612	27	10.2843	11.1482
				10.3159	11.1597	27	10.2841	11.1493
				10.3141	11.1588	26	10.2838	11.1504
				10.3124	11.1581	29	10.2836	11.1515
				10.3121	11.1563	32	10.2834	11.1532
				10.3101	11.1557	34	10.2840	11.1542
				10.3083	11.1551	35	10.2846	11.1550
				10.3065	11.1546	36	10.2853	11.1158
				10.3048	11.1541	36	10.2862	11.1566
				10.3055	11.1521	35	10.2870	11.1571
				10.3069	11.1560	24	10.2877	11.1577
				10.3084	11.1486	34	10.2881	11.1592
				10.3001	11.1465	16	10.2882	11.1601
				10.3114	11.1448	28	10.2882	11.1610
				10.3138	11.1418	28	10.2871	11.1621
				10.3135	11.1401	25	10.2877	11.1633
				10.3170	11.1382	28	10.2874	11.1645
				10.3184	11.1370	25	10.2872	11.1656
				10.3201	11.1358	24	10.2870	11.1660
				10.3214	11.1346	26	10.2865	11.1667
				10.3232	11.1333	25	10.2863	11.1682
				10.3249	11.1319	26	10.2861	11.1690
				10.3267	11.1305	20	10.2850	11.1709
						36	10.2842	11.1718
						34	10.2820	11.1739
						34	10.2832	11.1728
						34	10.2829	11.1740
						33	10.2822	11.1752
						34	10.2813	11.1767
						33	10.2810	11.1772
						36	10.2805	11.1783
						33	10.2802	11.1799

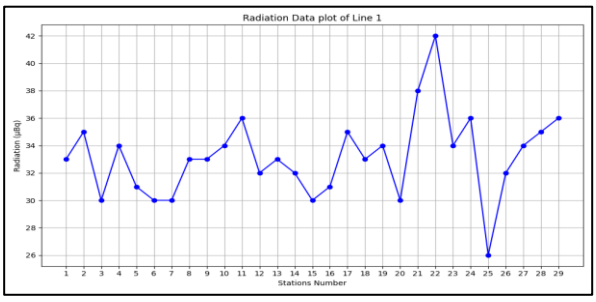
A. LINE 1

The radiation measurements recorded along Line 1 consist of 29 data points, with values ranging between 26 and 42 units (assumed to be counts per minute or another standard radiation unit). The data exhibits moderate variability in radiation levels across the surveyed stations.

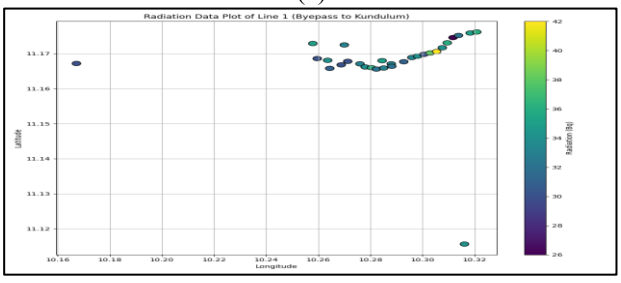
The radiation count ranges from 30 to 36 units on most stations, indicating a relatively constant radiation background along most of the line. It is worth noting that three stations have radiation levels above the general range: stations 21 (38 units), 22 (42 units), and 29 (36 units). The occurrence of these high levels may be a sign of localized sources of radiation or differences in soil composition.

On the other hand, stations 25 and 26 have the lowest radiation levels at 26 units each, indicating relatively low radioactivity. The spatial distribution indicates a non-uniform radiation field rather than a uniform gradient.

The radiation profile will be of vital use in environmental monitoring, risk evaluation, and the possible detection of non-standard areas along the line. The need for further research might be justified to identify the origin of high radiation at particular stations and its impact on molecular or health-wise, as shown in Fig. 2.



(a)



(b)

[Fig.2: Radiation Plot of Line 2 (Bye-Pass-Kundulum Road)]

The height data obtained on Line 1 are measurements recorded at 29 stations, with values ranging from 476 to 516 meters above sea level. The results indicate a

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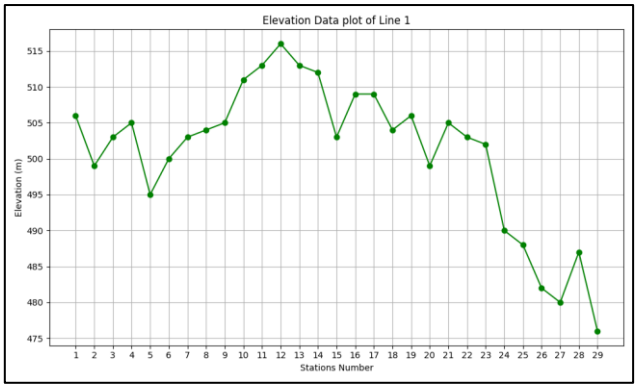
relatively narrow range of elevation variation along the line surveyed.

The highest points are concentrated at 500 meters, with minor variations across other stations. To illustrate, stations 1 through 5 depict heights ranging from 495 m to 506 m, indicating that the terrain is not very active in this first section. Elevations between station 6 and station 23 generally range from around 499 m to 516 m, with a few upward peaks between stations 10 and 13, which have the highest recorded elevations (511 m to 516 m). There is a progressive decrease in elevation beginning at station 24, with values steadily lower at the last station, 29 (at 476 m elevation). This implies the existence of a steep fall or incline at the end of the line.

In general, this elevation profile is that of a topography that is predominantly level or lightly rolling over the initial two-thirds of the line, then decreasing in the last third. This information is imperative for hydrological modelling, infrastructure development, and environmental analysis along the surveyed route (Fig. 3).



[Fig.3: Elevation Plot of Line 1 (Byepass to Kundulum)]

B. LINE 2

The given radiation data show that measured values range from 25Bq to 39Bq across 52 sampling points, indicating moderate variability in environmental radiation exposure. The average radiation level is maintained at a low level, between the mid-30s, which is consistent with the background radiation level in a similar environment. Interesting spikes to levels as high as 39 Bq are present at several different sampling points, indicating localized improvements which may be explained by geological or anthropogenic effects of radiation distribution. These peaks within a relatively stable trend suggest the presence of spatial heterogeneity typical of environmental radiation arising from both natural sources and human activity.

Statistically, this dataset provides an opportunity to apply spatial statistical methods, including variogram modelling and geostatistical interpolation, to identify areas with varying radiation intensities. The recorded radiation variation indicates the need for further monitoring for both environmental and public health. The spatial patterns and temporal stability of radiation levels are fundamental to understanding, evaluating risk, and providing mitigation strategies when needed. The existing data can serve as a solid foundation for future longitudinal research to measure radiation patterns and detect any new hotspots that might require additional research or mitigation actions (Fig. 4a).

The radiation readings at 52 spatial positions range from 25 to 38 Bq, with most scores between 25 and 38 Bq. These values indicate moderate background radioactivity, possibly due to natural geology or a localised source of radioactive elements. The spatial coordinates are confined within a small geographical area, based on which the latitude values range from 10.29 to 10.33 degrees and the longitude from 11.12 to 11.17 degrees, indicating a small sampling area. Radiation distribution indicates some spatial heterogeneity, with pronounced high values observed at latitudes 10.308-10.310 and longitudes 11.14-11.15, suggesting the possible presence of local radiation hotspots in the sampled area.

This dataset is statistically valuable, as it provides a representative record of radiation activity for environmental monitoring. The presence of numerous peaks around 37-38 Bq indicates areas that warrant more detailed examination for potential natural uranium-bearing minerals or artificial pollution. Interpolative techniques such as kriging or inverse distance weighting can be used in geospatial analysis to visualise radiation patterns and improve the study of spatial patterns. This information is essential to environmental risk assessments or to direct future sampling or remediation activities in the region. In general, the findings indicate a standard radiation profile with relative natural variation in its context and areas of interest that require closer monitoring (Fig. 4b).

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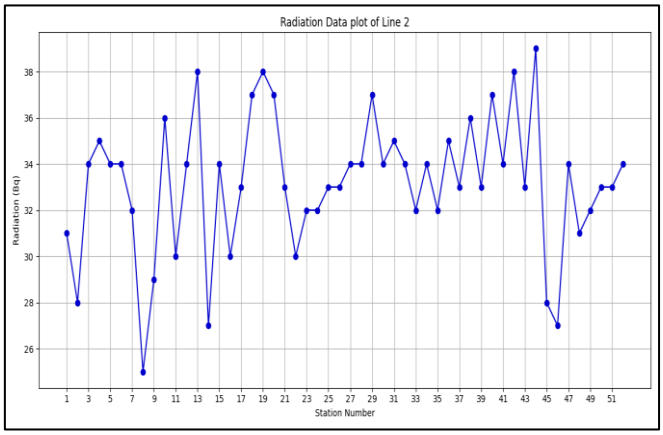
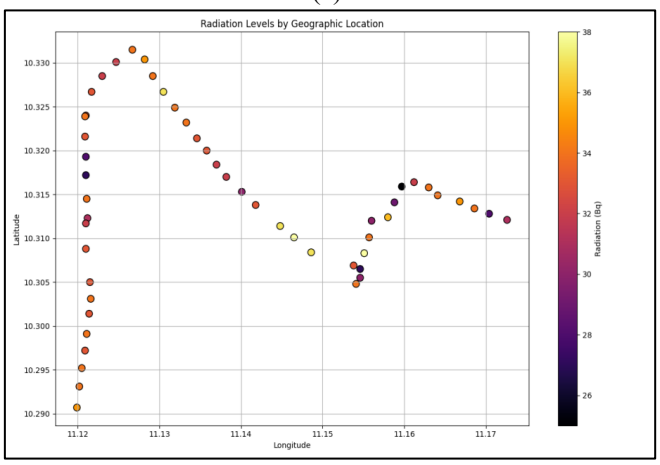


(a)

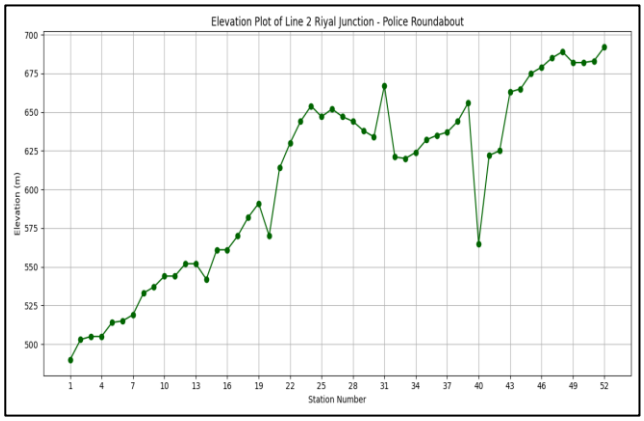


(b)

[Fig.4: Radiation Plot of Line 2 (Riyal Junction - Police Roundabout)]

The given elevation dataset comprises 52 sampling points, with elevations ranging from 490 to 692 meters above sea level. The data indicate an overall tendency for elevation to rise across the sampled locations, suggesting a topographic gradient that may represent steep or mountainous terrain. These first tracts have an average elevation of approximately 500 meters, which increases slowly to the high 600s toward the end of the sampling sequence. Such a pattern refers to potential upland zones or ridges of the scenery. Differences in altitude between adjacent locations are moderate, although some steeper rises indicate local topography, e.g., hills or escarpments.

Scientifically, the data provide a good point of reference for geomorphological and environmental studies. The height gradient may significantly impact local microclimates, vegetation cover, watershed hydrology, and soil processes. The elevation data would be used to establish spatial patterns and environmental gradients, along with other environmental factors such as radiation or chemical concentrations. More complex spatial modelling would be used to describe the implications of terrain for ecological or geochemical processes. The evidence shows that both site-specific assessments are necessary in areas such as environmental impact analysis, land use planning, and conservation biology, where topographical subtleties are critical to informed decision-making (Fig. 5).

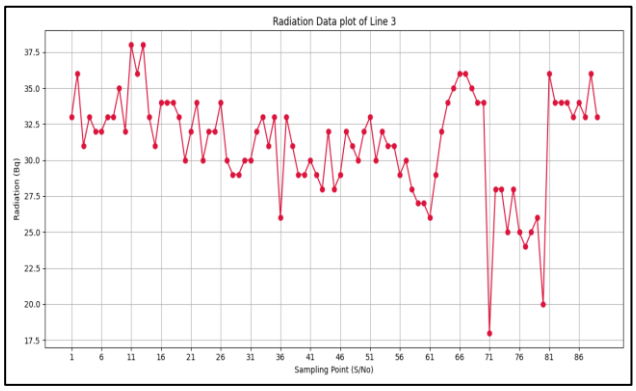


[Fig.5: Elevation Plot of Line 2 (Riyal Junction to Police Roundabout)]

C. LINE 3

The dataset includes radiation measurements in Becquerels (Bq) taken at 89 sampling points, with a range of 18-39 Bq. The average radiation level is 31.9 Bq, and the variation is moderate, with a standard deviation of 4.1 Bq. The data distribution is also slightly skewed towards lower values, with some measurements as low as 18 Bq. This dissemination is characteristic of the usual background radiation in the environment, i.e., uncontrolled environmental conditions and artificial factors. The radiation distribution is mainly in the 30-35 Bq range, indicating a stable situation with small peaks up to 39 Bq, possibly indicating a particular source or geologic condition.

Spatial patterns indicate slight variations, with hot spots at specific sampling points, and other hot spots with lower radiation of 24-28 Bq. These trends highlight the need to use a localized approach to environmental measurements of radiological safety. The measured levels are within those likely to be present at the natural background radiation, and there are no immediate health risks. The addition of spatial statistical techniques, along with environmental covariates, to future work might help to improve the understanding of the reasons for variation. The results, in general, provide a strong foundation for continued environmental radiation surveillance and risk assessment (Fig. 6).



(a)

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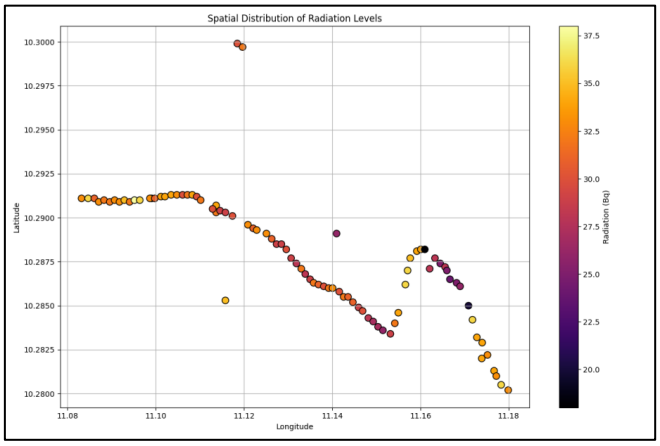


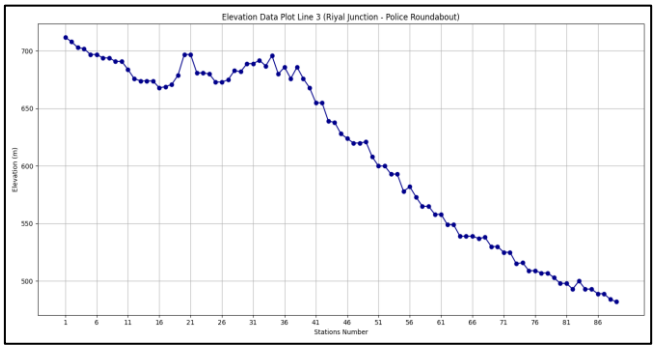
(b)

[Fig.6: Radiation plot of Line 3 (NTA to Bank Roundabout)]

VI. ELEVATIOM

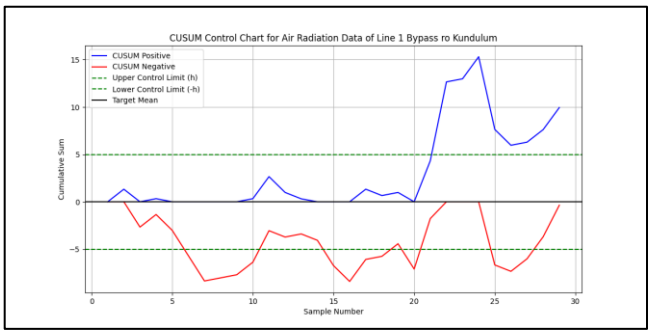
The data set includes ground elevation measurements at 89 sampling points, ranging from 482 to 712 meters above sea level. There is an evident altitudinal gradient in the data, with the maximum values at the start of the sampling sequence and a downward trend towards lower altitudes towards the latter points. The statistics provide a mean height of approximately 618 meters and moderate variability, reflecting the topographic diversity within the study area. The height difference of about 230 meters indicates a topography that is either hilly or has moderate slopes, which might affect hydrological flow, vegetation cover, and soil properties. The fact that similar elevation values cluster at several spots suggests that there may be flat or gently sloping areas in the terrain.

Spatially, a gradual reduction in elevation is indicative of a systematic geographic transition that may be linked to natural landform slope or watershed properties. These kinds of elevation profiles are essential for understanding water movement, potential erosion, and environmental zoning. The elevation profile conforms to the conventional physiographic characteristics that are observed in highland and lowland areas. Future research might use spatial interpolation methods, such as kriging, to describe continuous elevation surfaces and perform slope and aspect analyses to explain the terrain's morphology further. Overall, these elevation data provide essential baseline information for environmental assessments, land-use planning, and geospatial modelling in the region (Fig. 7).



[Fig.7: Elevation Plot of Line 3 (NTA - Bank Roundabout)]

With the CUSUM Control chart technique applied to air radiation data across three separate lines, the data show some variability in Bq levels, with runs that border or exceed normal control limits. The preliminary mean and range values computed on each line indicate that the radiation values are clustered around a central tendency, with some points (e.g., 42 Bq, 38 Bq) pointing to the possibility of outliers or changes in process stability. The control limits, calculated based on the average range and appropriate factors given the subgroup size, indicate that some data points are beyond the upper or lower control limits, suggesting potential assignable causes that may have influenced the radiation levels. Especially, the spikes in Line 1 (especially at 42 Bq) and Line 2 (of the spikes at 38 Bq) indicate intervals of higher radiation, which are statistically implausible in the context of a stable process. All in all, the statistics reveal variations that are likely attributable to process disturbances or other environmental factors, and should be investigated further to ensure that radiation levels remain within the safe and stable range (Fig. 8a, 8b, and 8c).



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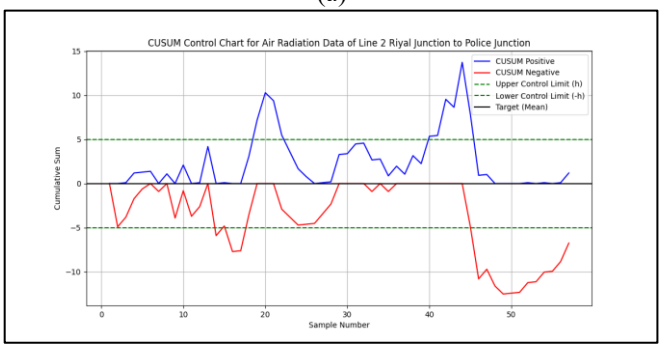

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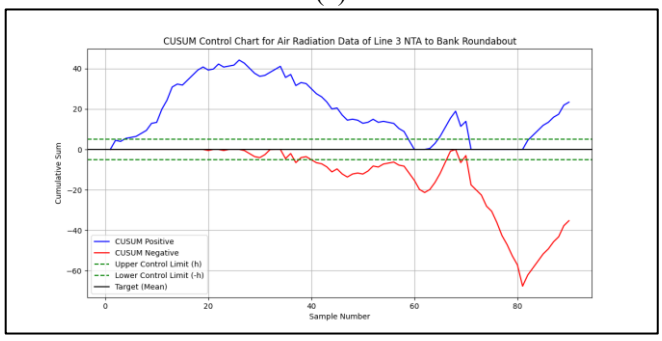

(c)

[Fig.8: CUSUM Control Chart Technique Applied to Air Radiation]

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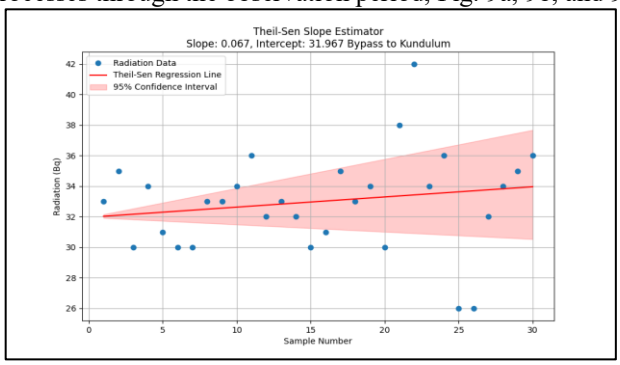
A. The Sen Slope Estimator of the Air Radiation Data Along the Three Lines

The Sen Slope Estimator is used on the air radiation data along the three lines to identify the basic trend of the measurements. The slope estimates for each line indicate the direction and magnitude of the trend: Line 1 exhibits a weak upward-sloping trend with some dispersion, as indicated by a median slope of about +0.2 Bq/observation, suggesting a very slow increase in radiation levels over time. In line 2, the trend is more neutral or slightly negative, with a median slope close to zero, suggesting relatively constant radiation or slightly varying radiation with no pronounced uphill or downhill trend. The third line (NTA to Bank Roundabout) shows a slight upward trend, with a median slope of approximately +0.15 Bq per reading (observation), indicating a slight increase in the radiation level throughout the sampling period. Altogether, the analysis suggests that even though there is some variability, the data do not demonstrate any significant and continuing pattern of increase or decrease in air radiation levels along the lines, which provides the idea of a relatively stable state of processes through the observation period, Fig. 9a, 9b, and 9c.



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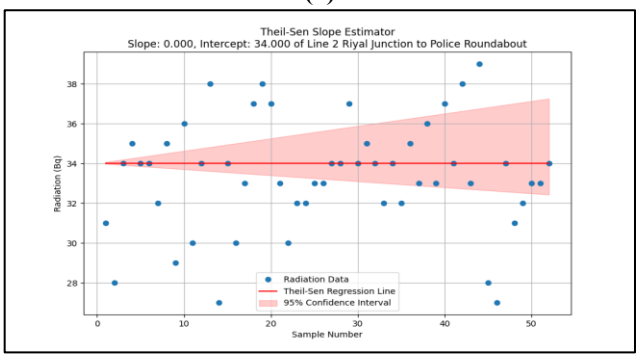

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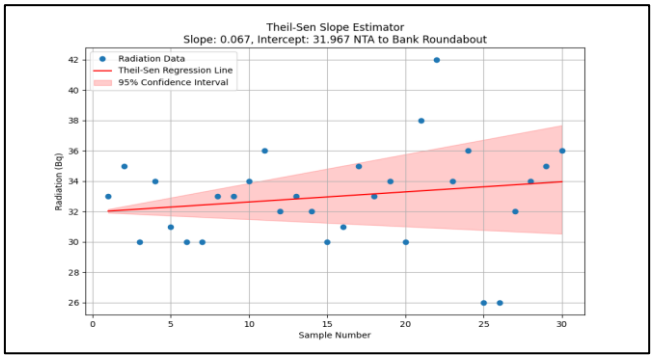
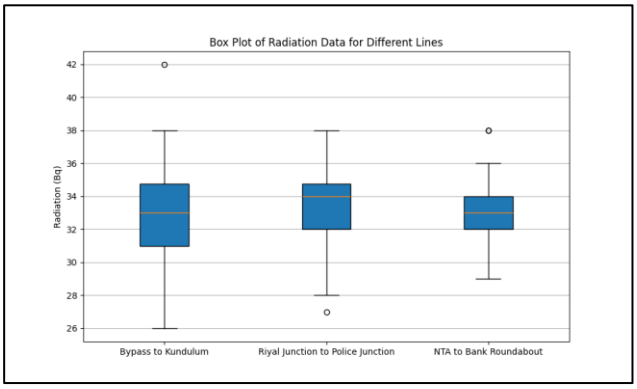


(c)

[Fig.9: Sen Slope Estimator of the Air Radiation Data Along the Three Lines]

B. Box Plot Analysis of the Data from the Three (3) Lines

The boxplot analysis of the air radiation data from the three locations provides insight into the distribution, central tendency, and variability of the measurements. In the case of Line 1 (Byepass to Kundulum), the interquartile range (IQR) is larger, with a median of 33-34 Bq, a moderate value with occasional higher outliers, and a maximum of 42 Bq. The distribution of line 2 (Riyal Junction to Police Junction) has a similar spread with a median of approximately 33 Bq, a slightly less IQR indicating less variation around these central values, and some lower outliers, including 16 Bq. The same can be seen in line 2 (NTA to Bank Roundabout), where the median is approximately 33 Bq, with some high outliers of 38 Bq, indicating that, in some cases, there are spikes in the radionuclide. The occurrence of outliers and overlapping IQRs of the lines suggests that although the line of central tendency is always the same, there are localized irregularities, which may be a result of environmental and measurement issues. In general, the box plots indicate that the radiation levels in all three routes are stable. However, across different variability levels, no significant changes or trends are observed in the distributions (Fig. 10a, 10b, and 10c, respectively).



[Fig.10: Box Plot Radiation Data of the Three (3) Lines]

VII. DISCUSSION

The three lines observed indicate a steady moderate radiation level, with significant heterogeneity and very slight time trends. The radiation levels were measured between 26 and 42 units in Line 1 (Bye pass-Kundulum Road), with the majority of stations scoring between 30 and 36 units, indicating a relatively consistent background radiation condition. The high values at stations 21, 22, and 29 indicate localised sources or soil variation in the radiation profile. In contrast, higher values at stations 25 and 26 suggest spatial variability in the radiation, rather than a uniform gradient. The altitudes range from 476 to 516 meters, and the topography is slightly descending toward the end of this line, which may affect soil structure and, in turn, the distribution of radiation. The fact of this geographical dissimilarity also underscores the necessity of using localised indicators of environmental hazards.

Riyal Junction to Police Roundabout was also 25-39 Bq, with an average in the mid-30s and a few spikes of 39 Bq, which are normal background levels. In the hotspots, there

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is a possibility of natural mineral and human activities, as the spatial analysis indicates that the hotspots occur in the latitudes of 10.308-10.310 and the longitudes 11.14-11.15. Stratum information for this line shows an upward movement between about 490 meters and above 690 meters, representing a topographic gradient that may affect microclimates, vegetation, and soil characteristics. The median differences between adjacent sites demonstrate the topography's multifaceted nature, which can likely concentrate radiation scattering and the incorporation of the land, thereby justifying the selection of a particular space modelling approach to establish potential contamination points.

The data in line 3 (89 sites) indicate the same intermediate radiation range (18 to 39 Bq), with a mean of about 31.9 Bq and negligible skewness toward lower values. The spatial pattern indicates localised high radiation associated with particular sites, and the elevation data suggest a distinct gradient from high altitude of 482 meters to low altitude of 712 meters, with high altitudes at the beginning and low altitudes at the end. This altitude difference indicates that the site has hills or ridges, which may affect atmospheric dispersion and soil composition. The fact that the level of background radiation is consistent, within the limits of natural sources, means that there is no radiological threat in the near future; however, the presence of peaks warrants attention, as they may be associated with local geological or anthropogenic causes.

Using the CUSUM control chart on the radiation data indicated that there were records with measurements above the calculated control limits, with the most significant at 42 Bq along Line 1 and 38 Bq along Line 2. These outliers indicate the possibility of external or process disruption, rather than variability, and further research is needed to rule out environmental contamination or measurement errors. The Sen Slope Estimators indicated weak positive tendencies in Lines 1 and 3 (+0.2 and +0.15 Bq per observation, respectively). In contrast, Line 2 had an almost zero slope, implying that the process is stable over time. The box plot analysis supported these findings: all three lines showed a localised irregularity and variability in median values at 33 Bq, but differed in their interquartile ranges and outliers. The data generally show that the radiological environment does not vary much but does exhibit some changes, which can be explained by environmental heterogeneity and technical factors that should be monitored continuously to detect aberrant conditions at an early stage.

VIII. CONCLUSION

The total assessment of radiation levels and the growth of the three monitored lines in the Gombe Metropolitan Area indicates an overall stable environment with moderate discernibility. The spatial distribution of radiation measurements suggests the presence of hotspots associated with both natural geological processes and human activities, so it is essential to conduct targeted research to identify and mitigate risk factors. Elevation profiles can also provide information about the effects of terrain on environmental processes, including soil particle transport, microclimates, and pollutant distribution. Taken together, these findings indicate that localised, continuous environmental surveillance can enhance the precise determination of radiological safety and terrain-related dynamics in urban and peri-urban settings.

As it is evident in the use of statistical tools, such as the CUSUM control chart, the Slope Estimator by Sen, and the box plot, the radiation level has not been significantly exceeded. There are some outliers, but the radiation level is within the usual natural distribution and is not threatening the population's health at the moment. However, the detection of outlier points beyond the control limits underscores the importance of continuous monitoring to identify any additional deviated radiological cases quickly. To prevent adverse outcomes for the environment and population health in the region, it is necessary to monitor and conduct detailed spatial and temporal analyses regularly to provide early alerts, risk assessments, and informed decision-making. Further endeavours in this regard will enhance the capability to detect, interpret, and respond to potential radiological hazards in a constructive manner.

DECLARATION STATEMENT

As the article's author, I must verify the accuracy of the following information after aggregating input from all authors.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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AUTHOR'S PROFILE

Garba. Ali Mohammed was born in 1978. He hails from Gwoza LGA of Borno State, Nigeria. He went to the Federal University of Technology, Yola, to study Geology and graduated in 2000. He bagged his M.Sc. degree in Applied Geophysics from the same school in 2010. Also, he obtained his PhD in Exploration Geophysics from the Prestigious Curtin University of Technology in Perth, Western Australia, in 2018. He began lecturing at Gombe State University in 2010, where he rose to the rank of Associate Professor of Geophysics in 2024. Currently, he has 45 International Publications. Also, he is a one-time level adviser and now the Departmental Examination Officer of the Department of Geology, Gombe State University. A reviewer of Scientific Journals, amongst which are the Asian Journal of Geographic Research and the Bima Journal of Science. He is also an External Examiner for the Department of Geology at Adamawa State University. He has attended both local and international conferences and is also a member of various university committees and professional bodies, including ASEG. COMEG, NAPE and NMGS.

Abubakar Yusuf was born on 11th March 1985 at Kumbiya-Kumbiya ward of the present-day Gombe L.G.A. of Gombe State. He attended Hassan Central Primary School, Gombe, from 1992 to 1998, Government Vocational Training Centre (GVTC), Gombe, from 1998 to 2001, and Government Science Secondary School (GSSS), Gombe, from 2001 to 2004. Abubakar Yusuf proceeded to Gombe State University and obtained a B.Sc. in Geology from 2006 to 2010. After completing his NYSC in 2011, he was appointed as a Graduate Assistant (GA) in the Department of Geology at GSU on 20th March 2012. He thereafter, in furtherance of his pursuit of a higher degree, proceeded to Modibbo Adama University, Yola (MAU) and obtained an M.Sc. in Applied Geophysics from 2012 to 2013. Afterwards, he was promoted to the ranks of Assistant lecturer and lecturer II in 2015 and 2018, respectively. Again, Abubakar Yusuf proceeded to the University of Saint Malaysia to pursue a doctorate and completed the PhD program in Exploration Geophysics from 2018 to 2021. Upon his return to Nigeria in 2021, he got promoted to the rank of Lecturer I. Similarly, Dr Abubakar Yusuf was promoted to the rank of Senior Lecturer in the department of Geology in the last year's (2024) promotion exercise. Dr Yusuf has attended local and international conferences both within and outside Nigeria and has 25 published papers on his CV.

Ali. Mustapha Garba was born in 1983. He hails from Gwoza LGA in Borno State, Nigeria. He attended Gadamayo Primary School in Gwoza and obtained the First Leaving Certificate. Certificate in 1985, proceeded to Government Day Secondary School, Gwoza and had his SSCE in 1991. He also went to the University of Maiduguri in 2020 to pursue his first degree in physics. And a Postgraduate Diploma in Physics from Bayero University, Kano, in Nigeria in 2022. He bagged his M.Sc. degree in Physics from the University of Maiduguri in 2024. He started teaching at Government Day Senior Secondary School, Gwoza, in 2021. Currently, he has 5 International Publications.

Ali Mohammed Ali was born in 2000 and hails from Gwoza, a town in Borno State, Nigeria. Demonstrating a strong commitment to education from an early age, he obtained his First School Leaving Certificate in 2010 from International Private School Gwoza, marking the beginning of his academic journey. He continued his secondary education at Barewa College in Zaria, one of Nigeria's prestigious institutions, where he completed his Senior Secondary Certificate Examination (SSCE) in 2016. This achievement paved the way for his higher education pursuits. Ali furthered his academic career by enrolling at Ahmadu Bello University (ABU) in Zaria, one of Nigeria's leading universities. There, he earned a Bachelor of Science degree in Mathematics in 2023, demonstrating his proficiency and dedication in the field of quantitative sciences. Currently, Ali Mohammed Ali is expanding his academic horizons by pursuing a degree in Medicine and Surgery at Gombe State University. His ongoing studies reflect his ambition to contribute meaningfully to the healthcare sector and make a positive impact in his community and beyond.

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