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Assessment of radiological exposures in the vicinity of Gold mining area of Wau-Bulolo in Papua New Guinea

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► ***Original article***

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ABSTRACT

***Background*:** Reports of natural radioactivity measurements from the environmentally sensitive regions of Papua New Guinea are few and far between. Radiological impacts owing to exposure to radionuclides which are naturally occurring from gold-mine regions in the Wau-Bulolo district of Morobe province in Papua New Guinea were appraised. Experimental locations were selected along the Bulolo River and its tributaries. ***Materials and Methods*:** Ambient gamma levels were measured from the locations directly using a digital gamma dosimeter and the resulting indoor and outdoor annual effective doses were estimated. Measurements in the locations along with two control points each were made for the dose assessments. Selected radionuclides other than primordial were assessed in the samples of surface soil collected from sampling sites and control points. Gamma ray spectroscopy was used to estimate the activity levels of radionuclides in the soil samples collected from the sampling and control areas. ***Results*:** Measured gamma dose rates were between 0.13 μSvh^{-1} to 0.2 μSvh^{-1} in the region. The estimated outdoor and indoor effective dose rates resulting from the environmental gamma were observed to vary from 160 μSvy^{-1} to 233 μSvy^{-1} and from 638 μSvy^{-1} to 933 μSvy^{-1} respectively. Radionuclides namely ^{45}Ca, ^{203}Hg, ^{51}Cr, ^{198}Au, ^{140}Ba and ^{59}Fe were found at trace levels. ***Conclusions*:** Presence of selected radionuclides were found in the soil samples along the river flowing through the mining area. All the samples analyzed showed very low activity levels thus having negligible effect on the background radiation level and human health.

INTRODUCTION

The prime sources of natural environmental radiation are emanations from low levels of primordial radionuclides namely Potassium (^{40}K), Uranium (^{238}U), Thorium (^{232}Th) and their progeny present in surface soil. Air, water and vegetation are the main routes of radionuclide intake [1, 2]. There are two principal deposition processes for aerial radionuclides. In wet process airborne radionuclides settle down to the ground by rain, snow and hail. In dry process absorption of gases and particles take place by natural surfaces. These terrestrial sources contribute 82% of human absorbed radiation doses [3]. The level of natural exposure fluctuates around the earth by a factor of nearly 3 to 100 [4]. The sources of these naturally occurring radionuclides can be cosmogenic, primordial or man-made [4, 5]. Radiation dose rate from cosmogenic sources ranges from 0.26 $mSvy^{-1}$ at sea level to 5.2 $mSvy^{-1}$ at an altitude of 6000 m above sea level. The figure is slightly less in equatorial region than in higher latitudes and slightly less indoors than outdoors due to the shielding effect of buildings [6].

The primordial or terrestrial radionuclides mainly ^{40}K, ^{238}U, and ^{232}Th and the progeny of the latter two isotopes constitute the natural gamma ray exposure. Extensive variations in exposure occur for these constituents, particularly in the case of radiation dose due t inhalation from radon and its decay products, which can accrue to relatively higher levels indoors [4,5] than outdoors. Slight quantities of radioactive constituents released to the environment from coal and nuclear power plants, agriculture, mining, fisheries and industrial applications are also sources of radiation exposure to man. The average annual doses globally resulting from man – made sources is at about 17% of the background level from natural radiation sources [4]. The average annual effective dose globally from both natural background and man -made sources per person in the year 2000 was 2.81 $mSvy^{-1}$, from which 2.40 $mSvy^{-1}$ is from naturally occurring radionuclides [4].

Papua New Guinea (PNG) has rocky highlands, intricate geology and has extensive mineral resources owing to the fact that country is located along the collision zone between the oceanic crust of the Pacific Plate to the north and the continental crust of the Australian Plate to the southern part [7]. Many features of the geology and tectonic evolution of PNG is poorly understood, despite the occurrence of several huge deposits of metals and minerals all

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through the country. The mineralized areas are dominated by the presence of copper and gold. PNG also has other resources of significance, which includes cobalt, nickel, molybdenum, chromium, iron and platinum in varying quantities. The mines are spread over different provinces of the country indicating potential prospects of the terrains. Despite rich deposits of minerals and large-scale mining operations in the country there has not been any research and publications on natural environmental radioactivity. Worthy management for protecting the environment needs systematic baseline data with good quality resulting from accurate measurements [8]. This work involves radiation dose assessment of the radiation levels existing as natural background using the state of the art techniques along the Gold mine region of Wau-Bulolo District in Morobe Province of PNG. Most of the environmental radioactive analysis involves assessment of primordial radionuclides. The present study investigates the presence of selected radioactive heavy metals using gamma spectrometry.

MATERIALS AND METHODS

Study area

Figure 1 displays the mapped out Morobe province in Papua New Guinea and the Wau-Bulolo district. The fourteen locations of Wau-Bulolo District where the soil samples were collected for analysis in this work are also depicted in the figure 1. The sampling site extends from 7°0'0" to 7°22'0" South latitude and 146°30'0" to 146°50'0" East Longitude. The study area is along two main rivers, Bulolo and Watut both originating from the Mount Kaindi, a host of three fully developed Gold mining sites. This area has mining sites with high gold potential for both large scale and alluvial mining since 1900 with intense extraction activity. The region currently has approximately 60,000 inhabitants. The area is under the influence of a tropical climate with two seasons, rainy and sunny, interchangeably. It has sandy loam soil characteristics with sedimentary and metamorphic rocks. There have not been any studies on natural radioactivity carried out in this region hitherto.

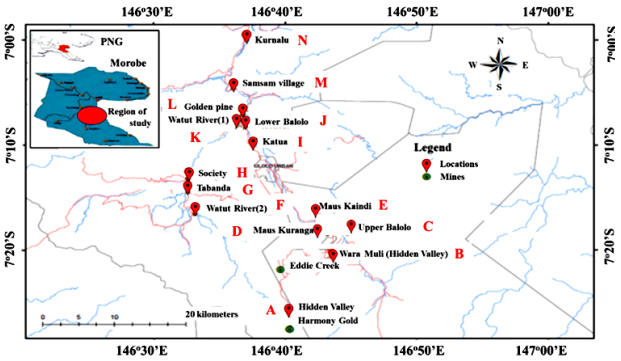

Figure 1. Locations of sample collection and Gold mines in Wau Bulolo.

Sample collection and preparations

Sample collection locations were selected along the river basins of Bulolo and Watut both which originate from the Mount Kaindi. Water from these rivers are being used for the gold mining operations and the used water is flushed out to these rivers. Snippets and grains of gold along with other metals and minerals after mining are flown down the stream of rivers. Owing to this fact, alluvial gold mining in large numbers can be seen at the river banks.

Fourteen locations were earmarked for collection of soil samples using a Global Positioning System (GPS-Garmin, Etrex 30X, USA) with the Lat-Long coordinates. Locations were chosen from the populated areas. From each location samples from the river bed (from the dry regions near to the stream) and two control samples about 15 and 30 meters away were collected. Soil samples were collected following the American Society for Testing and Materials protocols and Standard Practice for Sampling Surface Soil for Radionuclides [9, 10]. The samples were packed in labeled plastics bags to be taken to laboratory for processing and analysis. The soil samples were dried over a period of 5 to 7 days to remove all moisture content under an infrared lamp and were sieved with a 100 mesh sieve. The homogenized samples were filled in a 20 mml sample bottle. Hermetically samples kept in sealed containers were kept for at least a period of 30 days for the radio nuclides progeny to reach equilibrium.

Experimental

During collection of soil samples from the selected sites, measurement of ambient gamma activity and doses were carried at a height of 1.0 m above the ground, using a hand held SOEKS Quantum Professional Geiger Muller (GM) pocket survey meter made in USA. The device is a double GM tube instrument used for precision measurements. The locations of sample collection were demarcated using Garmin eTrex 30x GPS with Digital Compass. The coordinates were later plotted into the map of the sampling area using a Geographic Information System (GIS) Plotter system and are shown in figure 1.

For the radiometric analysis of the soil samples, a NaI(Tl) Gamma Spectrometer having modular design (Berthold, Germany - LB 2045) was used. The system comprises of a microprocessor unit, graphical display screen with touch panel and a power supply unit. The data acquisition is done via the measurement electronics with additional plug in cards, a high voltage unit with preamplifier (BE 0002) and an Analog to Digital Converter (ADC) for spectrum recording (BE0104). For radiometric analysis, sample containers were slotted into a shielded well type chamber of the NaI(Tl) scintillator for counting gamma rays originating from radionuclides in the samples. Details of each sample were fed into the

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system before analysis. Preliminary observations of background radiation and efficiency of the detector were carried out periodically and fed to the system. The period of counting was set at 12 hours. The device stops counting automatically if the statistical error drops to less than 1%. Two windows were used at a time for two different radionuclides whose energy range do not overlap. The detector read out the radionuclide specific activity along with the statistical error.

Determination of radiological parameters

The annual average effective dose rates were estimated using the absorbed dose rates measured by the dosimeter by using the conversion factor of 0.70 $SvGy^{-1}$ and outdoor occupancy factor of 0.2 and indoor occupancy factor of 0.80. Outdoor annual effective dose rates (E_{gO}) and Indoor annual effective dose rates (E_{gI}) were assessed using the equations (1) and (2) respectively.

$$E_{gO}(mSvy^{-1})=D_R(nGyy^{-1}).T(h).K(SvGy^{-1}).G_1\times10^{-6} \quad (1)$$

$$E_{gI}(mSvy^{-1})=D_R(nGyy^{-1}).T(h).K(SvGy^{-1}).G_2\times10^{-6} \quad (2)$$

Where: D_R- Dose rate in nano Gray per hour in air at 1.0 m height

T = hours in one year (8,766)

K = dose conversion factor (0.70 $SvGy^{-1}$)

G_1 = outdoor occupancy factor (0.20) and

G_2 = indoor occupancy factor (0.80).

Based on the gamma spectrometric analysis of soil samples, specific radioactivity of selected radioisotopes were determined and are presented in table 2. Radionuclides were selected according to their radiological relevance, i.e. short half-life of a few days.

For determining the radiological parameters namely, the annual effective dose rates, values of gamma doses measured by the survey meter were used. Several readings were taken at each location and the arithmetic mean values were used for the assessment of radiation doses.

Statistical analysis

Data were analyzed using SPSS 20.0 software. The data determined are presented by mean and standard deviation. We have taken the statistical uncertainties of sample weight, detector efficiency and the like to determine the standard uncertainty using the error propagation law [11]. The background radiation of the detector plays an important role in the detector sensitivity along with other factors as it affects the minimum level of detection of the detector. Background corrections have been incorporated for the better quality of the data. The outdoor and indoor annual effective dose rates were found to have good correlation except of two locations. The level of significance at 95% confidence interval has also been presented for two locations where there is significant difference from the normal trend.

RESULTS

Average values of gamma dose measured at fourteen regions are depicted in table 1. Using the measured doses, annual effective resulting from the exposure to gamma radiation were also determined. The gamma dose has a mean value 0.16±0.02 $nGyh^{-1}$, the average annual outdoor effective dose was found to be 206.18±23.28 μSv and mean annual indoor effective dose was 824.71±93.14 μSv. According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), average effective dose per annum from radiation sources is 0.82 mSv which is about 34% of all the exposures [4]. Majority of the indoor values of gamma dose we estimated are in good agreement with this value. Certain locations have significant deviation from the average value. Levels of significance (*P*-values) for such estimates are also presented in the table 1.

Table 1. Gamma measurements in air and estimated outdoor and indoor annual effective dose.

Location			Gamma dose	Annual Eff. Dose (μSvy^{-1})		*Level of significance*
Code	Latitude	Longitude	$nGyh^{-1}$	Outdoor	Indoor	
A	7′ 12″ S	146′ 41″ E	0.16	196.36	785.43	
B	7′ 20″ S	146′43″ E	0.20	245.45	981.79	*P=0.023*
C	7′ 18″ S	146′ 46″ E	0.16	196.36	785.43	
D	7′ 19″ S	146′ 42″ E	0.16	196.36	785.43	
E	7′ 15″ S	146′ 42″ E	0.19	233.18	932.70	*P= 0.028*
F	7′ 15″ S	146′ 34″ E	0.15	184.09	736.34	
G	7′ 12″ S	146′ 33″E	0.17	208.63	834.52	
H	7′ 11″ S	146′ 33″ E	0.18	220.90	883.61	
I	7′ 10″ S	146′ 38″ E	0.18	220.90	883.61	
J	7′ 08″ S	146′ 37″ E	0.18	220.90	785.43	
K	7′ 08″ S	146′ 37″ E	0.16	196.36	883.61	
L	7′ 07″ S	146′ 37″ E	0.18	220.90	883.61	
M	7′ 05″ S	146′ 38″ E	0.13	159.54	638.16	*P= 0.030*
N	7′01″ S	146′ 39″ E	0.14	171.81	687.26	*P= 0.043*
	Maximum		**0.20**	**245.45**	**981.79**	
	Minimum		**0.13**	**159.54**	**638.16**	
	Mean		**0.16**	**206.18**	**824.71**	
	Standard Deviation		**0.02**	**23.28**	**93.14**	

The average external gamma dose rates in air was 0.16 ± 0.02 $nGyh^{-1}$ with maximum of 0.20 $nGyh^{-1}$ (Location B) and minimum of 0.13 $nGyh^{-1}$ (Location M). Location B has large scale mining activity upstream. Geographically the location where the minimum exposure rate was found (Location M) at further downstream tributary in contrast to maximum measurement with reference to proximity of the excavation site. The four locations (F, K, M and N) having no mine upstream have dose rates equal to or below average. The annual average effective outdoor dose rate was 206.18±23.28 μSv with maximum of 245.45 μSv and minimum of 159.54 μSv.

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The average effective Indoor Dose Rate was 824.71 ± 93.14 μSvy^{-1} with a maximum of 81.79 and minimum 638.16 μSvy^{-1}.

Measured Dose rates were found to reduce gradually as we move away from the sample collection location in river site to the control sites as shown in the figure 2. In all the cases the gamma dose rates were higher for the soil sampling location situated in the river and control sites away from the river were found to have lesser gamma dose rates.

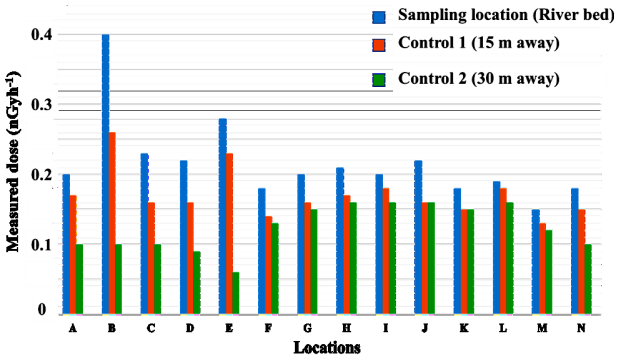

Figure 2. Measured Dose rates in the sample collection locations and the control sites.

Soil samples collected from the location and the control sites were analysed for six radionuclides namely calcium (^{45}Ca), Mercury (^{203}Hg), Chromium (^{51}Cr), Gold (^{198}Au), Barium (^{140}Ba) and Iron (^{59}Fe). Altogether 42 samples form 14 sampling locations were analysed and their results are presented in table 2. Maximum, minimum and mean (with standard deviation) of specific activities are shown.

Table 2. Radionuclides' specific activities in locations and control points.

Radionuclides	Sample			Control 1			Control 2		
	Activity (Bqkg^{-1})			Activity (Bqkg^{-1})			Activity (Bqkg^{-1})		
	Max	Min	Mean ±SD	Max	Min	Mean ±SD	Max	Min	Mean ±SD
Calcium 45	0.34	0.06	0.20± 0.06	0.39	0.11	0.19± 0.09	0.29	0.11	0.18± 0.05
Mercury 203	0.40	0.10	0.18± 0.08	0.18	0.10	0.15± 0.03	0.21	0.08	0.15± 0.04
Chromium 51	0.34	0.07	0.1± 0.07	0.19	0.08	0.13± 0.04	0.21	0.05	0.13± 0.05
Gold 198	0.15	0.03	0.07± 0.03	0.08	0.02	0.05± 0.02	0.08	0.01	0.05± 0.01
Barium 140	0.10	0.03	0.04± 0.02	0.05	0.02	0.02± 0.01	0.10	0.02	0.03± 0.02
Iron 59	0.09	0.02	0.06± 0.02	0.07	0.03	0.05± 0.01	0.08	0.02	0.05± 0.01

DISCUSSION

The investigations were carried out to determine the gamma dose and effective doses in the region of interest and to determine activity levels of certain radionuclides from selected locations in the vicinity of Wau Bulolo gold mine region. As indicated by figure 2, the activity concentrations were found decreasing gradually as we move from the sampling locations to control sites.

There are numerous reports of external gamma dose rate measurements from several parts of the globe. Nevertheless, reports from the mining areas, especially gold mine regions, are scarce. The average absorbed dose rate in air from New Eastern Concession area of Perseus Mining in Ghana was reported as 0.08 ± 0.02 nGy h^{-1} with an average effective dose of 93± 28 μSvy^{-1} [12]. A similar study held in and around a gold mine in Itagunmodi in south west Nigeria reported the annual effective gamma dose rate of 81.3 μSvy^{-1} [13]. Both of these results of dose measurements are only half of that measured at Papua New Guinea. The reason could be the difference in geology in these regions.

Following section discusses the general properties and safe limits of the measured short lived isotopes in the soil samples from the Wau Bulolo region in Papua New Guinea [14]

Presence of all the radionuclides in the soil collected from the study region could be either due to the mining activities in the region or could be the result of fall out. Later argument is more appropriate as the measured specific activities of the radionuclides in the river sites and control sites have no appreciable difference. Nevertheless, detailed and intensive study is needed to confirm the fact [15, 16].

Therefore, the results of this study established that average annual effective dose rate of 206.18 ± 23.28 μSv due to the ambient gamma rays in the outdoor is much less than the 0.5mSv global average. More importantly, the estimated annual average of effective dose in the indoor atmosphere for the region, 824.71±93.14 μSv is in excellent agreement with the global average of 0.82 mSv [4]. Therefore, the estimated external and internal radiation dose in Wau -Bulolo region does not pose any radiation risk from the environmental gamma radiation as the observed exposure rates are below 1mSv for the members of the public as stipulated by International Commission on Radiological Protection (ICRP)-103 [17].

CONCLUSION

The average annual effective dose rate of 206.18 ± 23.28 μSv in the outdoor and 824.71±93.14 μSv in the indoor atmosphere were measured for the region. The results are in excellent agreement with the available reported values from other regions of the world by various agencies. Therefore, there is no risk of any biological effect owing to the exposure to the natural background radiation in the region. Presence of certain short lived Radionulcides found in the soil samples need to be investigated extensively.

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***Author contribution*:** (P.J) design of research, data analyzing and writing editing. (F. P.) Research and writing assistance. (D.K.) data collection, data analyzing and writing manuscript.

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