Assessment of Annual Effective Dose Equivalent and Excess Lifetime Cancer Risk Due to Radionuclide Present in Water obtained from Oloru, Kwara State, Nigeria

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Abstract: *This study was carried out so as to assessed the radiological concentrations in water through the use of a well shielded and well calibrated NaI(Tl) detector. Three primordial radionuclides namely ^{238}U, ^{232}Th and ^{40}K were detected in the samples. The radionuclides concentrations range from 2.85 ± 0.79 Bql^{-1} to 25.80 ± 4.62 Bql^{-1} (11.08 ± 2.61 Bql^{-1}) for ^{238}U, from 0.57 ± 0.06 Bql^{-1} to 7.11 ± 0.66 Bql^{-1}(3.69 ± 0.34 Bql^{-1}) for ^{232}Th and from 1.45 ± 0.14 Bql^{-1} to 31.93 ± 2.42 Bql^{-1}(12.49 ± 1.05 Bql^{-1}) for ^{40}K respectively. The average annual effective dose equivalent and excess lifetime cancer risk obtained across the specified age groups are found to be higher than the recommended values for public exposure. It was therefore imperative that appropriate measures be taken to prevent the populace from adverse radiological health implication on the individual that rely on the water for survival.*

Keywords: Effective Dose, Oloru, Radionuclide concentrations, Water.

1 INTRODUCTION

Water, an essential commodity of life, because of its daily consumption and uses. It serves as solvent that promotes chemical activities, transportation medium for nutrients, hormones, enzymes, minerals, nitrogenous waste and respiration gases as well as several other important functions (Akinloye, 2008). The existence of organic matter would have been impossible if not for water, as water is the most abundant element in protoplasm, the essential material of which plants and animals are composed (Donald, 1968). It was reported that, the Earth's surface is covered with about 70% of water, which is estimated at a volume of approximately 1.4 billion km^3, out of which groundwater occupy about 30%. Water is said to be potable provided it is safe to use for domestic purposes without causing damage to human health (WHO, 2011). In addition, it must be aesthetically pleasing in regards to appearance, taste and odour. It must also be free of harmful concentrations of chemicals, pathogenic microorganisms and radionuclides.

The distribution of radionuclides in water arise from trace amounts of terrestrial radionuclides, most of which are dissolved solids from rocks, soils and mineral deposits.These radionuclides originate from unstable radioactive atoms that contain excess energy and mass. For these atoms to attain stability, the atoms undergo radioactive decay by releasing the excess energy and mass in form of radiation. Radiation is of health concern to humans because it results in changing the basic makeup of atoms in cells, and more specifically the deoxyribonucleic acid (DNA) molecules inside of cells. However, life has evolved in the environment with significant level of radiation. (UNSCEAR, 2000; WNA, 2013).

The pathways relevant to the analysis of radionuclides in the environmental materials are external irradiation, inhalation and ingestion (IAEA, 1991).External irradiation comes from radionuclides that are located outside the body majorly form cosmic rays and terrestrial radionuclides that are found in soil and water. Exposures by inhalation occur when humans inhale radioactive gases that are produced by radioactive materials found in the environment (UNSCEAR, 2000). Exposure by ingestion pathway occur when humans swallow or consume radioactive substances. With the exception of inhalation of radon and its progenies that contribute the highest doses to the population, the uptake of radionuclides by ingestion is much higher than that by inhalation (EPA, 2009).

The presence of radionuclides in drinking water can cause human internal exposure which result from the decay of radionuclides taken into the body through ingestion and inhalation (Gorur and Camgoz, 2014). These radionuclides are then distributed within the body organs according to the metabolism of the element involved (Tchokossa *et al.*, 2012). This study was conducted owing to the inability of Oloru community to access potable and treated pipe-borne water, leaving a large percentage of the community to depend majorly on dug wells that are indirect contact with soil. This was observed when carrying out the National Youth Service Corps (NYSC) in the community and its environment. The study will provide a baseline radiological data as there is no record of such in literature.

2 MATERIALS AND METHODS

2.1 Sampling, Preparation and Analysis

Oloru, is located in Moro local government area of Kwara State, Nigeria. It is situated at the west of central region of Nigeria and bounded by latitudes $8^{0}27^{l}$ N and $8^{0}30^{l}$ N and longitudes $4^{0}36^{l}$ E and $4^{0}9^{l}$ E. The geological formation of the study area consists of rocks, hill and steeps, and lie entirely within the basement rocks of Nigeria (Rahama, 1988). The study area was group into five locations so as to have good representative sampling of the area, keeping in mind the population density, location of residential areas and schools.

A total of twenty-five water samples were collected across the study area. The water samples were collected from dug wells with different depths ranging from 10 m to 36 m, so as to have a detail record of the study area. At each collection, the water samples were collected at the early hours of the day from the dug wells using manual collection method usually employed by the residence. The water samples were then transferred to 2 liter polypropylene containers that had previously been washed with nitric acid (HNO_3) and distilled water. The samples were then acidified with 11M HCl at the rate of 10 ml per liter so as to prevent adsorption of the radionuclides on the container. The samples were packed in a prepared cylindrical polypropylene container, tightly sealed and kept for a period of 28 days which was a sufficient time required to attain a state of secular radioactive equilibrium between radium isotopes and their respective daughters before their gamma spectrometry.

The radionuclide contents of the water samples were determined using a well calibrated and well shielded NaI(Tl) detector, a product of Canberra, USA. The energy and efficiency calibration of detector was carried out using both the point sources and IAEA-385 standard sediment source. The data acquisition was achieved through a Genie 2k software. Prior to the sample measurement, an empty container of the same geometry as the detector was counted for 36000 s so as to determine the background gamma ray distribution. The sealed samples after attaining a state of secular equilibrium were each placed on the detector for analysis. Samples were counted for the same period of time. The gamma energies used for the estimation of radionuclide concentrations were ^{214}Pb with 352.0 keV ^{214}Bi with 609.3 keV for

^{238}U, ^{208}Tl with 583.2 keV and ^{228}Ac with 911.1 keV for ^{232}Th and ^{40}K at 1460.8 keV. The samples activity concentrations A ($Bqkg^{-1}$) were determined using Equation1:

$$A = \frac{C_{net}}{P_\gamma \times \varepsilon \times v \times t} \qquad (1)$$

Where C_{net} is the net peak area, $P\gamma$ is the absolute gamma ray emission probability, ε is the full energy peak efficiency of the detector, t is the counting time, and v is sample volume.

The Minimum Detectable Activity (MDA) for each radionuclide was determined using Equation 2. This is the smallest concentration of radioactivity in a sample that can be detected to a statistical degree level at 95% (Currie, 1968).

$$\text{MDA} = \frac{2.71+4.66(\sigma)}{P\gamma \times \varepsilon \times t \times v} \qquad (2)$$

Where σ is the standard deviation of the background collected during time t over the energy range of interest, Pγ, ε, v and t remain as earlier define.

2.2 Estimation of Radiological Parameters

The annual effective dose equivalent (AEDE) resulting from the ingestion of the radionuclides in the water sample was estimated using Equation 3:

$$AEDE\ (mSvy^{-1}) = \textstyle\sum_i^n (A_i \times W_i \times D_c) \quad (3)$$

Where A_i is the activity concentration (Bql^{-1}) of each of the radionuclide detected in the water, W_i(l/y) is the annual water intake and D_c ($mSvBq^{-1}$) is the dose conversion factor for the particular radionuclide. For this study, different age ranges were considered with the consumption rates. Thedoseconversionfactorsfortheradionuclidesdetectedinthewatersamples, the annual water intake according to the different age groups were obtained from ICRP (2012).

The excess lifetime cancer risk (ELCR) quantifies the probability of developing cancer over a lifetime at a given exposure level from the ingestion of radionuclides. This was determined using Equation 4:

$$ELCR = AEDE \times D_l \times R_f \qquad (4)$$

Where AEDE is in Bql^{-1}, D_l is the average duration of life (70 y), and R_f is the risk factor ($0.05\ Sv^{-1}$) obtain from ICRP (1990).

3 RESULTS AND DISCUSSION

The radionuclide concentrations for the water samples analyzed are as presented in Table 1. The results show that the radionuclides detected in the water samples belong to the natural terrestrial radionuclides headed by ^{238}U, ^{232}Th series and the singly-occurring radionuclide ^{40}K. It was observed that 14 samples had concentrations below detection limit (BDL) for ^{238}U, 6 samples for ^{232}Th and 2 samples for ^{40}K respectively. The values obtained range from 2.85 ± 0.79 Bql^{-1} to 25.80 ± 4.62 Bql^{-1} with a mean value of 11.08 ± 2.61 Bql^{-1} for 238U, from 0.57 ± 0.06 Bql^{-1} to 7.11 ± 0.66 Bql^{-1} with a mean value of 3.69 ± 0.34 Bql^{-1} for ^{232}Th and from 1.45 ± 0.14 Bql^{-1} to 31.93 ± 2.42 Bql^{-1} with a mean of value 12.49 ± 1.05 Bql^{-1} for ^{40}K respectively. The mean activity concentrations obtained for the radionuclides detected are found to be above than the recommended values of 1.0 Bql^{-1}, 0.1 $Bql^{-1}$and 10.0 $Bql^{-1}$for ^{238}U,^{232}Th and ^{40}Krespectively, as the permissible level for drinking water (WHO, 2011). These higher concentrations may be attributed to the direct contact of water with the soil, since the dug wells are not ringed. Therefore, solubility of the soil may have resulted to the higher concentration.

The results obtained for AEDE due to ingestion of radionuclides in the water samples across categories of age are as presented in Table 2. The values of AEDE obtained for the water samples in this work indicate that some of the values are in agreement with the values obtained by Nwankwo (2012) and Nwankwo, (2013) in Kwara State, and these samples values are also in agreement with the results obtained by Ononugbo *et al.*, (2013).

Figure 1 shows the bar chart of the variation of the mean AEDE obtained in the water samples. The chart indicates that children within the range of 0 – 1 years old are more vulnerable to radiological effect due to their weak immune system and rapid cell growth as the mean AEDE obtained for the age range exceeded 1 $mSvy^{-1}$ recommended by ICRP (1990). The ELCR due to the ingestion of radionuclides across categories of age in the water samples is presented in Table 3. The values of ELCR obtained are found to be higher than the mean value of 10^{-4} (EPA, 2012) and in agreement with the results obtained by Ononugbo *et al.*, (2013). The radiological implication of the higher activity concentrations, AEDE and ECLR obtained for the water sampled may poses a significant health hazards to the community populace that rely on these sampled water for survival when the decay products of the radionuclides ^{238}U and ^{232}Th are ingested.

4 CONCLUSION

This study has further assessed the radionuclide contents in water of Oloru community in Kwara State. A previous report on the determination of radionuclide contents in soil of the same area show that the radionuclides detected occurred with regularity in the soil samples and belongs to the natural radionuclide headed by ^{238}U, 235^{Th} and the singly occurring ^{40}K (Akinloye *et al.*, 2018). This was attributed to the direct contact of the water by radionuclides from the soil. The contribution of the radionuclides activity concentrations to the AEDE are higher than the tolerable level of0.1 $mSvy^{-1}$ and 1 $mSvy^{-1}$to the general public for prolonged exposure as recommended by WHO and ICRP for drinking water. Likewise, the contribution of AEDE to ELCR obtained in this report were higher than there commended mean value and this implies that there is the possibility that an individual consuming these water to develop cancer in the future. Therefore, it is imperative the water sources in the study area be given adequate treatment before consumption so as to prevent any adverse health effects.

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Table 1: Radionuclide concentrations in the water sample

Sample Code	^{238}U (Bql^{-1})	^{232}Th (Bql^{-1})	^{40}K (Bql^{-1})
W_1	BDL	2.84 ± 0.27	31.93 ± 2.42
W_2	BDL	4.01 ± 0.35	24.63 ± 2.17
W_3	10.80 ± 2.85	3.44 ± 0.32	12.71 ± 1.09
W_4	BDL	BDL	12.93 ± 1.13
W_5	5.85 ± 1.42	BDL	BDL
W_6	8.67 ± 3.05	BDL	22.85 ± 1.90
W_7	BDL	4.44 ± 0.39	3.73 ± 0.32
W_8	BDL	BDL	1.45 ± 0.14
W_9	2.85 ± 0.79	4.44 ± 0.41	18.95 ± 1.55
W_{10}	BDL	4.88 ± 0.46	13.49 ± 1.21
W_{11}	BDL	5.24 ± 0.49	6.79 ± 0.61
W_{12}	BDL	5.68 ± 0.52	3.51 ± 0.32
W_{13}	5.40 ± 1.09	3.44 ± 0.34	8.47 ± 0.70
W_{14}	16.20± 3.99	5.24 ± 0.47	2.84 ± 0.25
W_{15}	BDL	2.80 ± 0.26	15.49 ± 1.30
W_{16}	6.75 ± 1.53	2.04 ± 0.19	8.64 ± 0.86
W_{17}	22.50 ± 5.24	0.80±0.07	10.75 ± 0.92
W_{18}	25.80 ± 4.62	6.38 ± 0.56	BDL
W_{19}	BDL	2.47 ± 0.23	1.73 ± 0.15
W_{20}	6.90 ± 1.50	BDL	29.09 ± 2.24
W_{21}	BDL	BDL	5.13 ± 0.43
W_{22}	10.20 ± 2.59	0.57 ± 0.06	15.38 ±1.27
W_{23}	BDL	7.11 ± 0.66	19.89 ± 1.55
W_{24}	BDL	0.80 ± 0.08	14.15 ± 1.29
W_{25}	BDL	3.41 ± 0.33	2.79 ± 0.25
Range	**2.85 ± 0.79** **25.80 ± 4.62**	**0.57 ± 0.06** **7.11 ± 0.66**	**1.45 ± 0.14** **31.93 ± 2.42**
Mean	**11.08 ± 2.61**	**3.69 ± 0.34**	**12.49 ± 1.05**

MDA for the radionuclides: 0.068 Bql^{-1} for ^{238}U, 0.047 Bql^{-1} for ^{232}Th Bql^{-1} and 0.17 Bql^{-1} for ^{40}K respectively.

Table 2: Annual effective dose equivalent for the water samples across specified age ranges.

Sample Code	Annual Effective Dose Equivalent (mSvy^{-1})					
	0 - 1 y	**1 - 2 y**	**2 - 7 y**	**7 - 12 y**	**12 - 17 y**	**>17 y**
W$_1$	1.24 ± 0.11	0.68 ± 0.04	0.50 ± 0.04	0.43 ± 0.04	0.57 ± 0.05	0.62 ± 0.06
W$_2$	1.54 ± 0.14	0.39 ± 0.04	0.58 ± 0.05	0.52 ± 0.05	0.71 ± 0.06	0.79 ± 0.07
W$_3$	1.54 ± 0.19	1.51 ± 0.36	0.70 ± 0.11	0.66 ± 0.11	1.01 ± 0.17	0.99 ± 0.15
W$_4$	0.14 ± 0.01	0.14 ± 0.01	0.08 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
W$_5$	0.16 ± 0.04	0.69 ± 0.17	0.14 ± 0.03	0.14 ± 0.03	0.24 ± 0.06	0.19 ± 0.05
W$_6$	0.48 ± 0.11	1.26 ± 0.38	0.35 ± 0.09	0.31 ± 0.08	0.45 ± 0.13	0.20 ± 0.29
W$_7$	1.46 ± 0.13	0.18 ± 0.02	0.49 ± 0.04	0.48 ± 0.04	0.68 ± 0.06	0.76 ± 0.07
W$_8$	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.01 ±0.00	0.01 ± 0.00	0.01 ± 0.00
W$_9$	1.70 ± 0.17	0.68 ± 0.12	0.65 ± 0.07	0.61 ± 0.07	0.87 ± 0.09	0.93 ± 0.10
W$_{10}$	1.70 ± 0.16	0.30 ± 0.03	0.60 ± 0.06	0.56 ± 0.05	0.79 ± 0.08	0.88 ± 0.08
W$_{11}$	1.75 ± 0.16	0.24 ± 0.02	0.59 ± 0.06	0.56 ± 0.05	0.82 ± 0.08	0.91 ± 0.09
W$_{12}$	1.85 ± 0.17	0.22 ± 0.02	0.62 ± 0.06	0.59 ± 0.05	0.87 ± 0.08	0.97 ±0.09
W$_{13}$	1.34 ± 0.15	0.83 ± 0.15	0.54 ± 0.06	0.52 ± 0.06	0.77 ± 0.10	0.79 ± 0.10
W$_{14}$	2.16 ± 0.27	2.09 ± 0.48	0.96 ± 0.15	0.93 ± 0.14	1.45 ± 0.23	1.43 ± 0.21
W$_{15}$	1.06 ± 0.10	0.26 ± 0.02	0.39 ± 0.04	0.34 ± 0.03	0.49 ± 0.05	0.54 ± 0.05
W$_{16}$	0.93 ± 0.11	0.95 ± 0.19	0.43 ± 0.06	0.41 ± 0.06	0.62 ± 0.09	0.60 ± 0.09
W$_{17}$	1.00 ± 0.18	2.78 ± 0.63	0.69 ± 0.14	0.67 ± 0.14	1.07 ± 0.23	0.92 ± 0.19
W$_{18}$	2.76 ± 0.32	3.22 ± 0.56	1.29 ± 0.17	1.26 ± 0.17	1.99 ± 0.27	1.92 ± 0.25
W$_{19}$	0.81 ± 0.08	0.10 ± 0.01	0.27 ± 0.03	0.26 ± 0.02	0.38 ± 0.04	0.42 ± 0.04
W$_{20}$	0.50 ± 0.07	1.13 ± 0.20	0.35 ± 0.05	0.30 ± 0.05	0.41 ± 0.07	0.36 ± 0.06
W$_{21}$	0.05 ± 0.01	0.06 ± 0.01	0.03 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00
W$_{22}$	0.63 ± 0.11	1.34 ± 0.32	0.40 ± 0.07	0.37 ± 0.07	0.57 ± 0.12	0.50 ± 0.10
W$_{23}$	2.48 ± 0.22	0.44 ± 0.04	0.87 ± 0.08	0.81 ± 0.07	1.16 ± 0.11	1.28 ± 0.12
W$_{24}$	0.40 ± 0.04	0.18 ± 0.02	0.17 ± 0.02	0.15 ± 0.01	0.19 ± 0.02	0.20 ±0.02
W$_{25}$	1.12 ± 0.11	0.13 ± 0.01	0.38 ± 0.04	0.36 ± 0.04	0.52 ± 0.05	0.59 ± 0.06
Range	**0.02 ± 0.00**	**0.02 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**	**0.01 ± 0.00**
	2.76 ± 0.32	**3.22 ± 0.56**	**1.29 ± 0.17**	**1.26 ± 0.17**	**1.99 ± 0.27**	**1.92 ± 0.25**
Mean	**1.15 ± 0.13**	**0.79 ± 0.15**	**0.48 ± 0.06**	**0.45 ± 0.06**	**0.67 ± 0.09**	**0.68 ± 0.07**

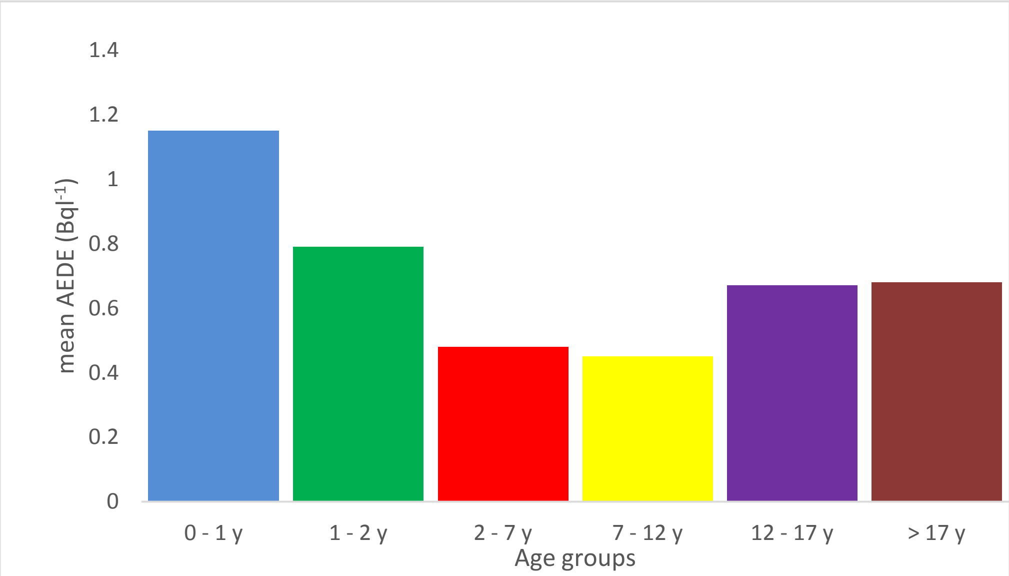

Figure 1: Comparison of AEDE estimated across different age groups

Table 3: Excess Lifetime Cancer Risk of the water samples across specified age range.

Sample Code	Excess Lifetime Cancer Risk (x 10^{-3} per year)					
	0 – 1 y	1 - 2 y	2 – 7 y	7 – 12 y	12 - 17 y	> 17 y
W_1	4.34 ± 0.39	2.38 ± 0.12	1.75 ± 0.15	1.52 ± 0.13	2.00 ± 0.18	2.17 ± 0.20
W_2	5.38 ± 0.47	1.38 ± 0.12	2.02 ± 0.18	1.82 ± 0.16	2.50 ± 0.22	2.75 ± 0. 24
W_3	5.37 ± 0.68	5.29 ± 1.24	2.45 ± 0.38	2.32 ± 0.37	3.53 ± 0.59	3.46 ± 0.53
W_4	0.47 ± 0.04	0.49 ± 0.04	0.28 ± 0.03	0.21 ± 0.02	0.21 ± 0.02	0.21 ± 0.02
W_5	0.57 ± 0.14	2.40 ± 0.58	0.49 ± 0.12	0.49 ± 0.12	0.82 ± 0.20	0.67 ± 0.17
W_6	1.68 ± 0.37	4.42 ± 1.32	1.23 ± 0.30	1.09 ± 0.28	1.59 ± 0.46	0.71 ± 0. 02
W_7	5.11 ± 0.45	0.63 ± 0.06	1.72 ± 0.15	1.64 ± 0.14	2.39 ± 0.21	2.67 ± 0.24
W_8	0.05 ± 0.01	0.06 ± 0.01	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
W_9	5.95 ± 0.59	2.38 ±0.43	2.29 ± 0.25	2.12 ± 0.24	3.04 ± 0.33	3. 24 ± 0.36
W_{10}	5.96 ± 0.56	1.05 ± 0.10	2.09 ± 0.20	1.95 ± 0.18	2.78 ± 0.26	3.08 ± 0.29
W_{11}	6.12 ± 0.57	0.83 ± 0.08	2.08 ± 0.19	1.97±0.19	2.86 ± 0.27	3.19 ± 0.29
W_{12}	6.49 ± 0.60	0.76 ± 0.07	2.17 ± 0.20	2.07 ± 0.19	3.04 ± 0.28	3.39 ± 0.31
W_{13}	4.69 ± 0.52	2.91 ± 0.51	1.90 ± 0.23	1.81 ± 0.22	2.70 ± 0.34	2.78 ± 0.34
W_{14}	7.57 ± 0.93	7.32 ± 1.69	3.35 ± 0.52	3.26 ± 0.50	5.08 ± 0.81	4.99 ± 0.74
W_{15}	3.70 ± 0.34	0.90 ± 0.08	1.37 ± 0.12	1.24 ± 0.11	1.72 ± 0.16	1.89 ± 0.17
W_{16}	3.26 ± 0.40	3.32 ± 0.68	1.51 ± 0.22	1.43 ± 0.21	2.16 ± 0.33	2.11 ± 0.30
W_{17}	3.49 ± 0.63	9.71 ± 2.19	2.42 ± 0.49	2.33 ± 0.48	3.76 ± 0.79	3.23 ± 0.66
W_{18}	9.67 ± 1.11	11.26 ± 1.95	4.51 ± 0.60	4.42 ± 0.59	6.98 ± 0.95	6.72 ± 0.86
W_{19}	2.83 ± 0.26	0.34 ± 0.03	0.95 ± 0.09	0.91 ± 0.07	1.32 ± 0.12	1.48 ± 0.14
W_{20}	1.74 ± 0.23	3.94 ± 0.70	1.22 ± 0.18	1.05 ± 0.16	1.44 ± 0.25	1.25 ± 0.21
W_{21}	0.19 ± 0.02	0.20 ± 0.02	0.11 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
W_{22}	2.20 ± 0.37	4.83 ± 1.12	1.41 ± 0.25	1.30 ± 0.26	1.98 ± 0.42	1.75 ± 0.35
W_{23}	8.69 ± 0.80	1.54 ± 0.13	3.05 ± 0.28	2.84 ± 0.26	4.05 ± 0.37	4.49 ± 0.41
W_{24}	1.41 ± 0.14	0.63 ± 0.06	0.61 ± 0.06	0.51 ± 0.05	0.65 ± 0.06	0.69 ± 0.08
W_{25}	3.92 ± 0.38	0.48 ± 0.05	1.32 ± 0.13	1.26 ± 0.12	1.83 ± 0.18	2.05 ± 0.20
Range	**0.05 ± 0.01**	**0.06 ± 0.01**	**0.03 ± 0.00**	**0.03 ± 0.00**	**0.03 ± 0.00**	**0.03 ± 0.00**
	9.67 ± 1.11	**11.26 ± 1.95**	**4.51 ± 0.60**	**4.42 ± 0.59**	**6.98 ± 0.95**	**6.72 ± 0.87**
Mean	**4.03 ± 0.44**	**2.78 ± 0.28**	**2.09 ± 0.21**	**1.59 ± 0.20**	**2.34 ± 0.31**	**2.39 ± 0.30**