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Quantifying of Radioactive Elements in Soil, Water and Plant Samples using Laser Induced Breakdown Spectroscopy (LIBS) Technique

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Abstract:- In this study, the laser-induced breakdown spectroscopy (LIBS) technique was applied to detect radioactive elements on surface soil, plant leaves (Tamarindus indica), and flow water collected from Bala, Mayo-Kebbi Quest, Chad. The survey process indicates that the samples contain radioactive elements U, Fr, Ce, Ac, Cm, Tb, and Pm. The concentrations of the detected elements in samples were determined using the calibration curve method, while the plasma temperatures (T_{exc}) and electron density (N_e) of the detected radioactive elements were calculated from Boltzmann linear plots. Except for uranium, all elements in the soil sample had amounts below the acceptable limit. The concentration of uranium in soil samples ranges from 0.024236 to 0.23439 ppm, with a safety limit of 0.03 ppm. The average plasma temperature T_{exc} for uranium (U) is 700, while the electron density Ne is 500 cm^{-3}.

***Keywords:-** LIBS, Plasma, Radioactive, Tamarindus Indica, Temperature and Electron Density.*

I. INTRODUCTION

Radioactive materials are substances that contain unstable nuclei that spontaneously emit radiation in the form of alpha particles, beta particles, or gamma rays in order to stabilize themselves in process known as radioactive decay [1,2]. These materials can be found naturally or artificially produced in laboratories [3]. Exposure to radiation cause Acute Radiation Syndrome (ARS) (nausea, vomiting, diarrhea, and weakness. Exposure to radiation cause Acute Radiation Syndrome (ARS), it is increasing the risk of developing cancer and genetic Effects (DNA mutations), likewise it can lead to organ damage Also, it can cause cardiovascular disease and cataracts as long-term health effects in addition to radiation burns (similar to thermal burns) These effects depending on the type of radiation, the exposure dose, the time exposure, and the sensitivity of the exposed tissues [4,5].

Laser-induced breakdown spectroscopy (LIBS) involves the collection and processing of the spectral signature resulting from a high-irradiance pulsed laser generated plasma containing an analyte [6-8]. It is also regarded as a sensitive technique that can detect most elements in the range of μg g-1[9]. The purpose of this study is to determine the radioactive elements contained in soil, water, and plant (Tamarindus indica) samples taken in Bala, Mayo-Kebbi Quest, Chad. The presence of these elements can have major biological consequences.

II. METHOD

Samples collection: In present work, a total of three samples of soil, water, and plan leaves (Tamarindus indica) have been collected from Bala, Mayo-Kebbi Quest, Chad (9o, 21'48" N14o54'36" E). The sample of soil was taken from the surface; the plant sample was Tamarindus indica leaves; and the water sample was running water. All samples were used without treatment.

LIBS Setup: The analysis of (surface soil, Plant (Tamarindus indica) and water) samples was carried out using set up depicted schematically in Fig (1).

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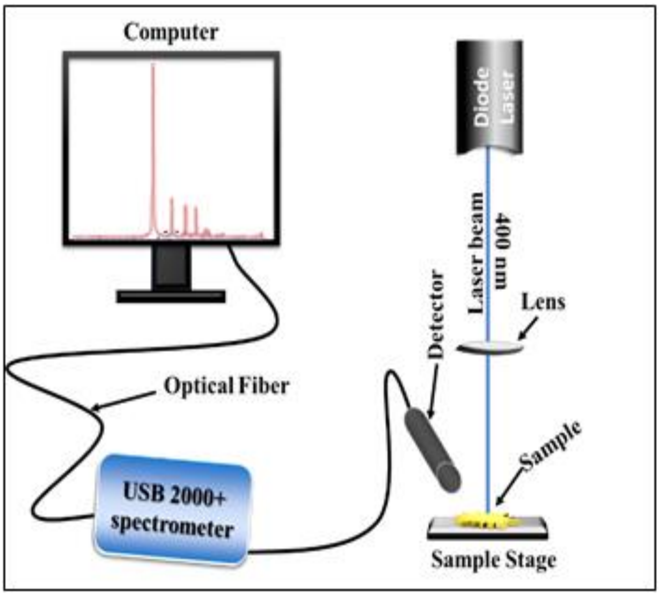

Fig 1 Shows the Experimental Setup for LIBS Evaluation of Soil, Plants, and Water

The LIBS system includes an Ocean Optics LIBS 2000+ spectrometer, a sample container, a diode laser, and OOILIBS software. The 400 nm radiation released at fundamental frequency from the diode laser was used to generate a plasma spark on the target surface. A convex lens (focal length 30 mm) was used for focus the laser beam onto sample. The pulse energy used in these experiments was equal to 100 mJ. The light from the plasma spark is captured via an optical cable equipped with a SMA connection. The USB 2000+ has four spectrometer modules that give high resolution (FWHM 0.1 nm) and a gated CCD detector with 14,336 pixels for simultaneous spectra recording in the 400 nm to 1150 nm wavelength range. The emission is collected at a 45° angle from the incoming laser energy. The data was then captured and used to reconstruct the spectrum [10-13].

III. RESULTS & DISCUSSION

- *After the Samples were Collected, the Experiment was Carried Out, and the Results were Shown as Follows:*

Figure (2) displays the spectrum of three samples (soil, plant, and water). The recorded spectra were analyzed with the aid of the NIST database. The spectra of three samples showed several radioactive elements (U, Fr, Ce, Ac, Cm, Tb, and Pm).

The concentration of the identified elements was calculated using the calibration curve method using the total intensity of a spectral line (I) from an excited atom or ion in plasma during a transition from state j→i. It is given by.

$$I = h\nu_{ij}\ A_{ij}\ N_i \quad (1)$$

Where ν_{ji} is the frequency of the transition from state j→i, A_{ij} the Einstein coefficient for spontaneous emission, N_j the population of the upper-level j and h is the Planks constant [14-16]. The calibration curve for radioactive elements in soil, water, and plant samples is illustrated in figure (3), the concentration of detected elements ranged from 200 ppm for A to 500 ppm for X, as shown in table 1. According to the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO), the results demonstrate that the concentration of all elements, except uranium, on the soil sample is within the permissible range. Uranium concentrations in soil samples ranged from 0.024236 to 0.23439 ppm, while in water and plant samples they were 0.024705 ppm, with a safety limit of 0.03 ppm.

As uranium exceeded the permissible safety limits, it was necessary to know the risk involved. Uranium can cause both radiological and chemical toxicity, and the quantity and duration of exposure influence the health effects, with the kidneys and lungs being the main targets. Workers who have been exposed to uranium have reported some impairment of kidney function. Inhaled insoluble uranium particles, 1–10 µm in size, can cause lung irradiation damage and cancer if exposed to a high enough radiation dosage over time. Even after many weeks, direct dealing with the uranium in metallic form is likely to result in radiation-induced erythema or other short-term consequences [17,18].

Plasma temperatures T_{exc} and electron density N_e of all identified elements were determined using Boltzmann linear plots based on Eq (1). The population density of upper-level Nj is related to ground-level number density (N) by Boltzmann's equation [16].

$$N_j = N_i g_j Q^{-1} exp\left(-\frac{E_j}{KT}\right) \quad (2)$$

- *By Substate the Value of Nj we get:*

$$I = h\nu_{ji} A_{ij} N_i g_j Q^{-1} exp\left(-\frac{E_j}{KT}\right) \quad (3)$$

In the equation above, g_j is the statistical weight, E_j is the energy of upper- level j, Q is the partition function, K is Boltzmann's constant, and T is the plasma's electron temperature.

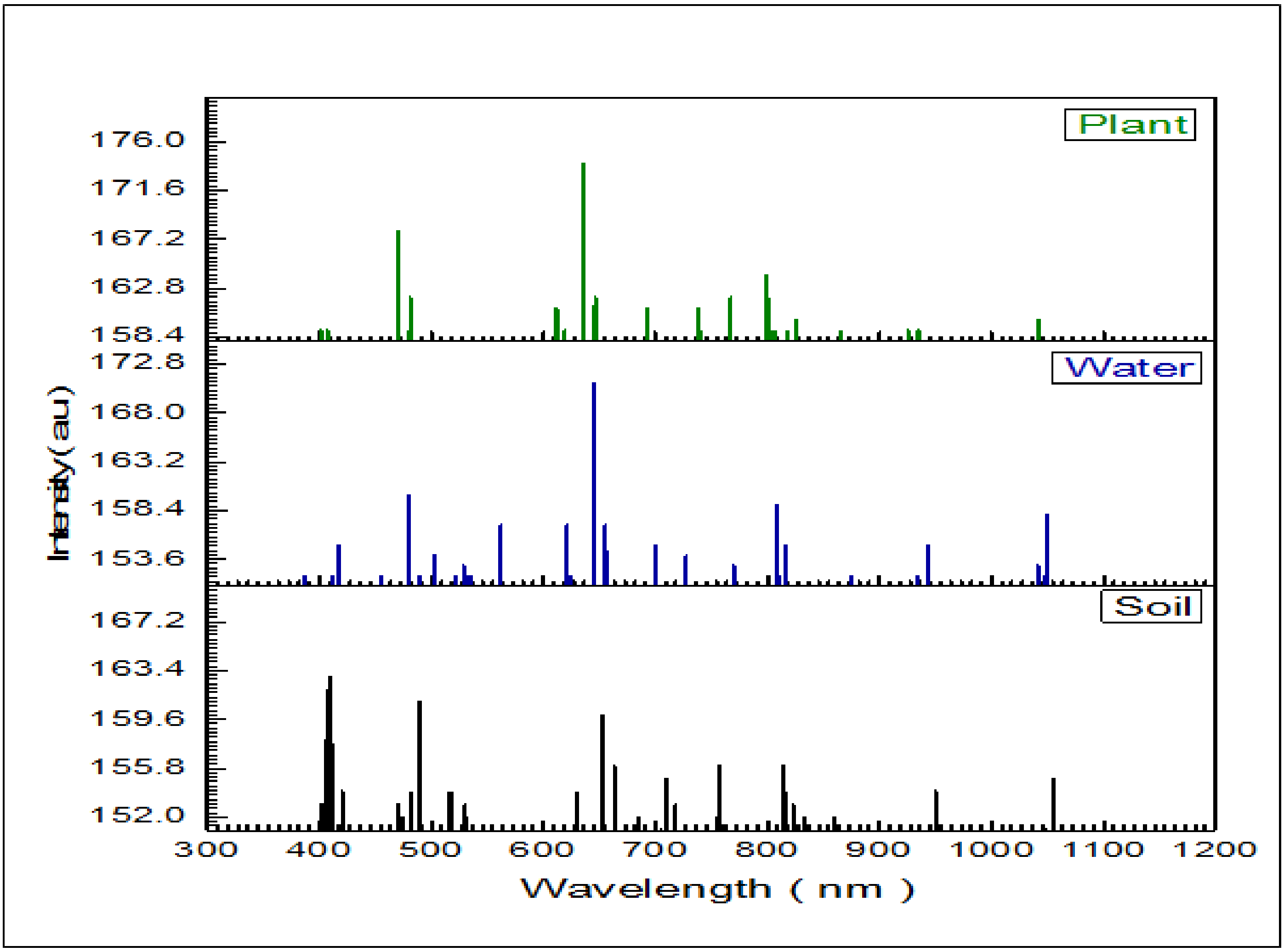

Fig 2 LIBS Spectrum of Soil, Water and Plant Samples Irradiated with100 mJ

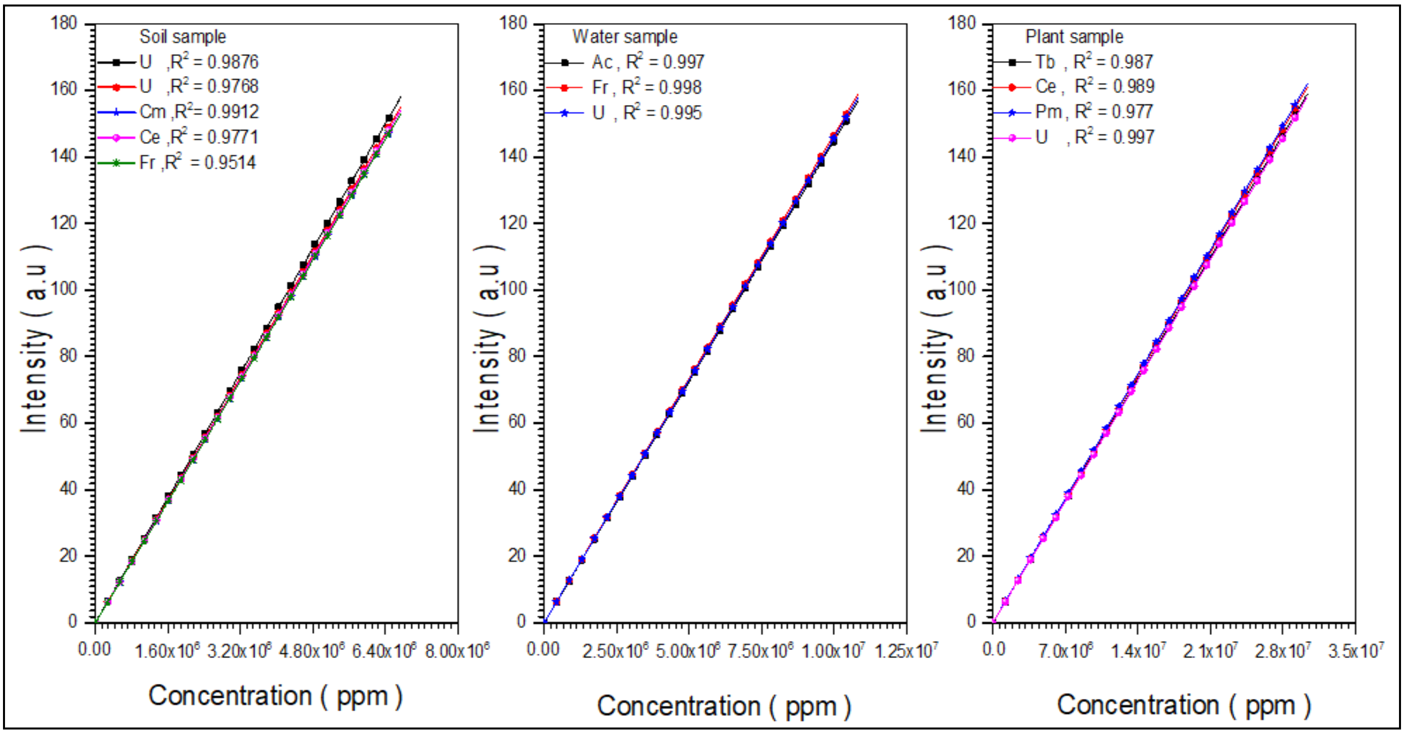

Fig 3 Calibration Curve for Radioactive Elements Detected in Soil, Water and Plant Samples Obtained using Analytic Calibration Function

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Table 1 Analyzed Data of Libs Spectra Soil, Water and Plant Samples Irradiated by 400 Mj

Samples		*Elements*						
		Cm I	*U I*	*Ce I*	*Fr I*	*Ac*	*Tb*	*Pm*
Soil	*λ (nm)*	401.617	405	629.537	717.987			
			1055.493					
	I (a.u)	153	158	154	153			
			155					
	Ak (108)	3.27	0.21	0.55	1.2			
			0.045					
	Ef	25023.578	25348.977	25766.355	13923.998			
			16900.386					
	Ei	00.00	00.00	385401	00.00			
			00.00					
	C (ppm)	2.6845	0.23439	0.17627	0.228858			
			0.024236					
Water	*λ (nm)*		1055.493		816.538	664.369		
	I (a.u)		158		159	157		
	Ak (108)		0.045		1.2	1.2		
	Ef		16900.386		23112.960	17950.71		
	Ei		00.00		00.00	2231.43		
	C (ppm)		0.024771		0.0540956	0.144869		
Plant	*λ (nm)*		1055.805	629.171			426.638	662.680
	I (a.u)		160	161			159	162
	Ak (108)		0.045	0.55			0.81	1.2
	Ef		16900.386	25766.355			25076.265	23345.07
	Ei		00.00	385401			462.120	3919.03
	C (ppm)		0.0247051	0.184176			5.23422	7.445515

The temperature and electron density were evaluated using the Boltzmann plot by plotting ln (I λ/g_jA_{ij}) as a function of energy (E_j/k_B) [19,20], as displayed in figure (4).

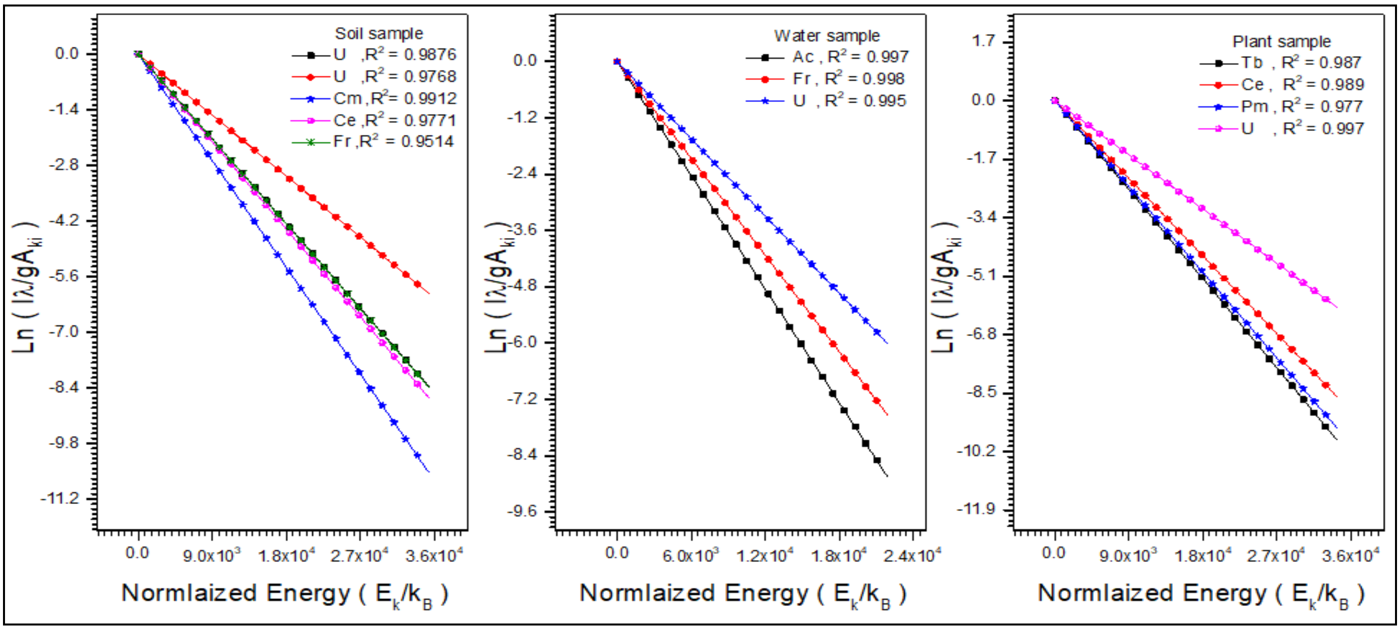

Fig 4 Shows a Typical Linear Boltzmann Plot for Calculating Plasma Temperature for Radioactive Elements Exist on Soil, Water, and Plant Samples

➤ *The Plasma Electronic Density can be Determined using the Following Relation:*

$$ne > 1.6 \times 10^{12} T^{\frac{1}{2}} \times (\Delta E_{ij})^3 \quad (4)$$

Where T is the Plasma Temperature (K) and Eij is the transition energy (eV) [21,22].

Table 1 Plasma Temperature and Electron Density of Radioactive Elements Detected in Soil, Water and Plant Samples Irradiated by 400 Mj

samples		Elements						
		Cm I	U I	Ce I	Fr I	Ac	Tb	Pm
Soil	T_{exc} (K°)	3310	4223 3907	3531	2313			
	N_e (10^{20}cm^{-3})	7.171	9.509 2.607	5.142	0.863			
Water	T_{exc} (K°)		3920		4278	2476		
	N_e (10^{20}cm^{-3})		2.615		7.303	1.329		
Plant	T_{exc} (K°)	3920		3549			3477	2846
	N_e (10^{20}cm^{-3})	2.616		5.168			7.168	2.884

IV. CONCLUSIONS

This paper presents an investigation of surface soil, plant (Tamarindus indica), and flow water taken from Bala, Mayo-Kebbi Quest, Chad, using LIBS technology. The study of the spectra with the aid of NIST revealed seven radioactive elements (Cm, U, Ce, Ac, Fr, Tb, and Pm); the concentrations of identified elements are within the allowed safety level except for uranium, but the cumulative impact must be considered to avoid biological consequences and mutations.

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