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Effect of Sunlight, Temperature and Time on the Physicochemical Properties of Sachet Water in Yola Metropolis, Adamawa State, Nigeria

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ABSTRACT: This study was carried out to determine effect of sunlight, temperature and time on the physicochemical properties of sachet water packaged within Yola Metropolis Nigeria. The physicochemical parameters were analyzed using standard techniques before and after subjecting water samples to the different storage conditions for a period of 42 days. The analysis gave pH, conductivity, total dissolved solids(TDS), chemical oxygen demand (COD), and turbidity values that ranged from (6.0 -7.9), (26.24 - 42.81) µS/cm, (12 -25.08) mg/L, (2.07 - 3.51) mg/L, (11.40 - 48.0) NTU respectively, all within the World Health Organization (WHO) permissible limit except turbidity. The significant changes detected indicated the migration of organic material from the polyethylene material into the water. The samples stored in a water bath at elevated temperatures showed the highest level of change in conductivity, pH, and TDS values, while the water samples exposed to sunlight showed the highest level of change in turbidity and COD values. Wherein, conductivity, TDS, COD, and turbidity values increased, and pH values decreased overtime. However, chloride and nitrate remained mostly constant. The water samples stored at room temperature (25°C - 35°C) experienced the least change in physicochemical properties. Gas Chromatography analysis at week 5, showed the presence of organic materials in the water samples exposed to direct sunlight.

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One of the most important and abundant compound in the ecosystem is water. According to Ritabrata, (2019), water covers over 70% of the world's surface and also 65% of our body is made up of water showing its abundance. Water is also a basic necessity required for daily consumption. In recent times, health professionals emphasize the need to consume two liters of water each day (Robert *et al.*, 2001; Ritabrata, 2019). Reliable supply of clean drinking water is vital for healthy living in any geographical region (Robert *et al*., 2001) yet some regions in developing countries such as Nigeria suffer the lack of this basic amenity due to accessibility and cost. Hence, the inhabitants are forced to adopt other methods to satisfy their water needs. Over the years, Yola Metropolis Adamawa state, like other regions in Nigeria, have adopted the consumption of sachet water above other water types, due to its accessibility and affordability. Sachet water popularly called pure water, is obtained from underground water sources such as boreholes and wells (David *et al*., 2013; Uduma, 2014; Ojekunle and Adeleke, 2017) which is purified and packaged. Polyethylene is a polymer effectively utilized in the packaging of this type of water. Polyethylene is a widely used polymer for food packaging and in this study water packages made of low density polyethylene was investigated (Cantow, 2006). The efficiency of polyethylene material for packaging are

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of growing interest and researchers have been working on the possible effects of leaching from the polyethylene material into the water enclosed in it for consumption. The cause of the contamination could be due to varying storage conditons which include; long term storage, temperature, components of the packaging material or exposure to UV rays (Sablani and Rahman, 2007; Oluwafemi *et al*., 2021). During the processing of polymers, additives are sometimes used to improve the performance of the polymers. These additives include antioxidants, plasticizers, lubricants, light stabilizers, antistatic agents, slip compounds and thermal stabilizers. They are used in different types of polymeric wrapping materials including polyethylene material (Sablani and Rahman 2007; Obisike and Nwachuku, 2016) and can overtime degrade and penetrate the drinking water on exposure to these storage conditions. Given that the migration process of degradation products from the polyethylene material into the contained water is a slow process, the compounds are usually monitored via a periodic analysis of selected water quality properties (Linus *et al*., 2021). Hence, the objective of this paper is to evaluate the effect of sunlight, temperature and time on the physicochemical properties of sachet water in Yola Metropolis, Adamawa State, Nigeria.

MATERIALS AND METHODS

Yola, the capital city of Adamawa State in Northern Nigeria with about 340,000 inhabitants; most of which are middle class or low income earners. The Yola region is mostly hot thereby, making the sachet water business very profitable, and it is also very affordable. The average day time temperature during the fall period is about 39°C - 41°C (Sambo, 2009).

Sample collection and Analytical Procedure: Sachet water samples used in this investigation were obtained directly from a factory located in Yola and labelled (a total of 12 branded sachets water were used). The physicochemical properties analyzed at the petroleum chemistry department of American University of Nigeria include: pH, total dissolved solid (TDS), chloride, nitrate, conductivity and chemical oxygen demand (COD).

The physico-chemical parameters of the sachet water were analyzed immediately after collection and subsequently over a period of 6 weeks (42 days) consecutively. Conductivity, pH, chloride, nitrate, TDS and turbidity were determined with Vernier logger probes.

Sample Preparation: The water samples were subjected to three different storage conditions of which changes that occurred were recorded on weekly basis. The samples stored at room temperature (25°C - 35°C) (X), the samples subjected to elevated temperatures (40°C – 65°C) with 5°C increase weekly (Y) and the samples exposed to sunlight (Z). Four samples each were subjected to room temperature (control), water bath (40ºC – 65ºC) and sunlight exposure. The tests were conducted over 42 days (6 weeks) period with a 7 days interval starting from day zero of exposure.

Determination of physicochemical parameters: Logger Pro and Vernier Computer Interface were used alongside various sensors for the physicochemical determinations. The conductivity, TDS, Turbidity, pH, and Cl^- probes were calibrated using standards. They include Vernier Chloride Ion-Selective Electrode (low standard (10 mg/L $Cl^–$) and high standard (1000 mg/L $Cl^–$), Vernier pH Sensor (pH 4 buffer solution and pH 9 buffer solution), Vernier Conductivity Meter (500 mg/L TDS standard solution and 50 mg/L TDS standard solution). Afterwards, each sample property was analyzed by fully immersing each probe with the sample being gently swirled.

Chemical Oxygen Demand: The COD analysis was carried out to determine the amount of oxygen required to oxidize the organic materials in the samples.

Concentrated sulphuric acid (167mL) was added to a mixture of 4.9g of potassium dichromate and 3.33g of mercuric sulphate; the solution was made up to 1000L by adding distilled water (Clair, 2003). Into each vial, 2.5 mL of distilled water (serving as a blank), and each of the samples were added. Standard potassium dichromate (1.5 mL, 0.25N) and sulfuric acid (3.5 mL, conc.) were added to each vial and capped tightly; this was then placed in a COD digester (150ºC, 2 hours).

After the digestion reaction, ferrous ammonium sulfate (0.1N) was titrated against each of the vial contents. Two drops of ferroin indicator were used under gentle constant stirring, and at the endpoint, the color changed from bluish-green to reddish-brown and the titer values were documented.

The Biochemical oxygen Demand (COD) of the samples were calculated in mg/L in accordance with equation (1) where A = the volume of ferrous ammonium sulfate for blank, B = the volume of ferrous ammonium sulfate for sample, N = Normality of ferrous ammonium sulfate:

$$\text{COD} = \frac{(A-B)*N*8*1000)}{Volume\ of\ sample\ taken} \quad (1)$$

Gas Chromatography (GC): A GC-MS from Agilent technologies with the following specifications of column Agilent 109015-433:3250C max; 30mx 250µmx 0.25µm was used determine chemical compounds present in the water samples.

RESULTS AND DISCUSSION

The results obtained by the analysis of the effect of time, temperature and sunlight on the physicochemical properties of the water sample stored at room temperature (25°C - 35°C) (X), the water sample subjected to elevated temperatures ((40°C – 65°C) with 5°C increase weekly (Y), and the water samples exposed to sunlight (Z) respectively is presented in the Table 1-3.

Effect of Time: Total aerobic heterotrophic bacteria is predicted to grow to levels that may be harmful to human health under prolonged storage of packaged water at favorable environmental conditions (Warburton *et al*.,1992). Therefore, under the 42 days period, several analysis was carried out to examine the changes in the physicochemical properties of sachet water stored at room temperature determining the effect of time. From Table 1, it can be observed that conductivity, turbidity, TDS, and COD increased by 17.0%, 310%, 66.9% and 88.9% to 30.70 µS/cm, 48.0 NTU, 20.03 mg/L, and 3.91 mg/L, respectively. However, the pH of the water samples decreased; from 7.90 (slightly alkaline) to 6.50 (slightly acidic), and the chloride and nitrate values remained mostly constant. A similar trend was reported by Muhamad *et al*., (2011), hence it was evident from the study that regardless of optimum storage conditions, prolonged storage time can induce contamination which can be attributed to total aerobic heterotrophic bacteria growth (Warburton *et al*.,1992).

Table 1: Effect of time on the physicochemical properties of water sample (control) stored at room temperature between 25°C to 35°C **(**X)

Time of exposure	Conductivity (µs)	pH	Turbidity (NTU)	Cl^- (mg/L)	NO_3^- (mg/L)	TDS (mg/L)	COD (mg/L)
0	26. 24	7.90	11.7	Nd	-	12.00	-
week 1	28.01	7.55	16.9	Nd	0.1	13.50	2.07
week 2	29.80	7.06	39.8	Nd	0.1	15.01	2.33
week 3	30.02	6.90	40.0	Nd	0.1	16.32	2.59
week 4	30.40	6.72	42.7	Nd	0.1	18.02	3.00
week 5	30.55	6.61	45.9	Nd	0.2	18.99	3.58
week 6	30.70	6.50	48.0	0.1	0.2	20.03	3.91

Key: 'Nd'- not detected.

Effect of Temperature: Thermal degradation of polymers is molecular deterioration as a result of overheating (Toma *et al*., 2013). This implies that at elevated temperatures, the long chain backbone of the polymer can be broken down and react with another to change the properties of the polymer. Several analysis were carried out under different temperature condition for 42 days to determine the effect of temperature on the physicochemical properties of values of sachet water. A similar trend for conductivity, TDS, chlorides, nitrates, and COD was observed for the elevated temperature exposed samples as was seen in the control samples group presented in Table 1. Conductivity, turbidity, TDS, and COD increased by 63.9%, 18.1%, 69.2% and 81.2% to 45.90 µS/cm, 18.90 NTU, 25.08 mg/L, and 7.620 mg/L, respectively. The pH of the water samples decreased; from 7.60 (slightly alkaline) to 6.00 (slightly acidic), and the chloride and nitrate values remained mostly constant. The changing trend of the physicochemical properties values with increasing temperature can be ascribed to the occurring of thermal degradation. (Lin *et al.,* 2000).

Table 2: Effect of temperature on the physicochemical properties of water sample in water bath (Y).

Temperature C)	Conductivity (µs)	pH	Turbidity (NTU)	Cl^- (mg/L)	NO_3^- (mg/L)	TDS (mg/L)	COD
40.0	28.01	7.60	16.0	Nd	0.1	14.82	-
45.0	30.90	6.90	16.90	Nd	0.1	16.05	4.205
50.0	33.06	6.60	17.20	Nd	0.1	17.90	4.908
55.0	39.90	6.52	17.92	Nd	0.2	19.51	5.692
60.0	40.72	6.20	18.30	0.1	0.2	22.05	6.306
65.0	45.90	6.00	18.90	0.1	0.2	25.08	7.620

Effect of Sunlight Exposure: After 42 days of exposing water samples under natural sunlight, the physicochemical properties of the samples were measured, to determine the effect of sunlight exposure. Table 3 contains the results obtained, which clearly indicates the increasing value of conductivity, turbidity, TDS, and COD by 43.2%, 264%, 77.1% and 79.9% to 42.81 µS/cm, 41.50 NTU, 23.04 mg/L, and 7.745 mg/L, respectively. On the other hand, the pH of the water, which was initially slightly alkaline at 7.90, became slightly acidic at a pH of 6.24 by the end of the exposure period and the chloride and nitrate values remained mostly constant. This trend may be due to two reasons both cited by Onosakponome, (2021), in their work that the leaching of toxic substance and other chemicals into the water was accelerated by ultraviolet rays from the Sun; and the developing of germs and microorganisms from the polyethylene material which enter the water was as a result of the deterioration of the polyethylene material.

Table 3: Effect of sunlight on the physicochemical properties of water sample (Z)

Time of exposure	Conductivity (µs)	pH	Turbidity (NTU)	Cl^- (mg/L)	NO_3^- (mg/L)	TDS (mg/L)	COD
week 1	29.9	7.8	11.4	0.0	0.1	13.01	4.306
week 2	30.6	6.83	12.3	0.0	0.1	14.02	4.557
week 3	32.54	6.62	38.3	0.1	0.1	16.44	5.409
week 4	36.84	6.55	39.8	0.1	0.1	18.09	6.187
week 5	40.05	6.31	40.4	0.1	0.2	20.50	7.234
week 6	42.81	6.24	41.5	0.1	0.2	23.04	7.745

The results highlighted in Table 1-3, were further categorized into the physicochemical analyses including conductivity, total dissolved solids, pH, chlorides, nitrates, and chemical oxygen demand, as well as GC-MS analysis for a more detailed discussion.

Physicochemical Properties Result

pH results The pH values of water sample X, Y, Z, measured on day zero before exposure to any storage condition gave a pH value of 7.9 (slightly alkaline). The pH value of water sample X, Y, Z as seen in Fig 1 ranged from 6.0 – 7.9, and are comparable with the standard limit for drinking water (6.5 – 9.5) by WHO. However, the minimum value slightly falls below the standard indicating acidity. As observed, the pH of the three water samples decreased with prolonged storage under the different storage conditions following the same trend reported by Linus *et al*., (2021). The sunlight exposed samples exhibited the highest decline in pH as reported by Akharame *et al*., (2018) while the pH of the temperature effect group fluctuated the least. This can be attributed to the migration of slightly acidic materials into the water with extended exposure to sunlight (Bach *et al*. 2012).

Conductivity: The conductivity of sachet water, increased over the period of the 6 weeks ranging from (26.24– 30.70 µS/cm), (28.01 – 45.90 µS/cm), (29.90 – 42.81) for water samples X, Y, Z respectively, with all values falling within the WHO standard limit for drinking water. The trend generated was similar to the result obtained by Toma *et al*., (2013). The samples stored in a water bath at elevated temperatures (40°C – 65°C) showed the highest increase in conductivity values from 28.01 to 45.9 µS/cm. The conductivity of the water samples exposed to sunlight were the second highest from 29.90 to 42.81 µS/cm. The samples kept at room temperature which were the control samples maintained a moderately constant conductivity. Conductivity is an important water quality measurement because it gives a good idea of amount of dissolved material in the water.

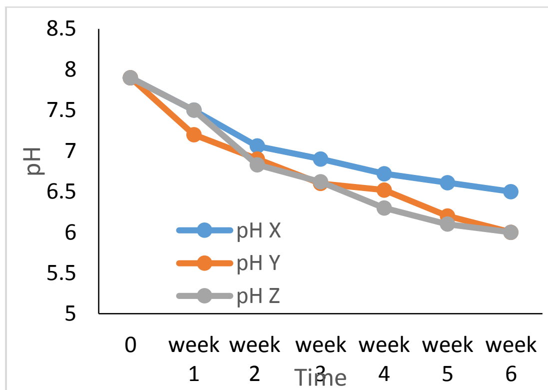

Fig 1: Variation in the measured pH of the three sample groups (X, Y, Z) stored under room temperature, elevated temperature, and sunlight exposure conditions from 0 to 6 weeks

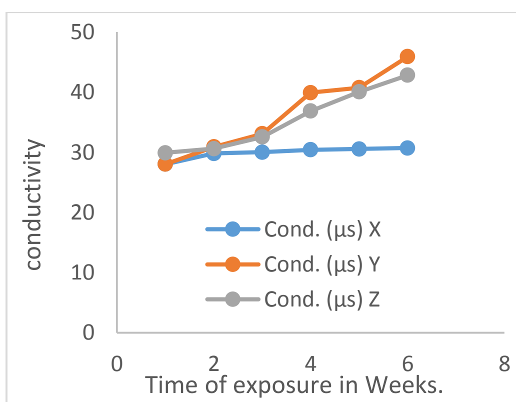

Fig 2: Variation in the measured Conductivity of the three sample groups (X,Y,Z) stored under room temperature, elevated temperature, and sunlight exposure conditions from 0 to 6 weeks.

Total Dissolved Solids (TDS): Total dissolved solids is the term used to describe the inorganic salt and small amount of organic matter present in water like calcium, magnesium, sodium, potassium cation, and addition carbonate, chloride, bicarbonate, sulfate, and nitrate (WHO, Guideline for Drinking-Water Quality 1996). The TDS values for all samples ranged from 12.00 to 25.08mg/L within the WHO limit of 500 mg/L. Fig. 3 shows the total dissolved solids TDS of all the samples. The three samples experienced slight increases in their TDS over the period; with water samples Y having a little higher values than water samples Z. This may indicate that thermal degradation occurred more rapidly in water samples Y due to high temperatures (Lin *et al*., 2000).

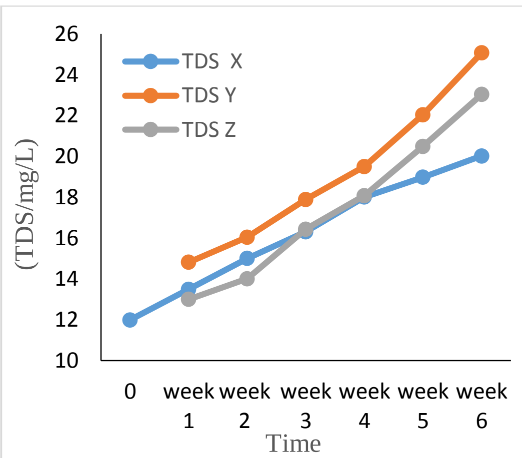

Fig 3: Variation in the measured TDS of the three sample groups (X, Y, Z) stored under room temperature, elevated temperature, and sunlight exposure conditions from 0 to 6 weeks.

Chemical Oxygen Demand (COD): Chemical oxygen demand values indicate the amount of dissolved organic materials in water. Fig 4 shows the variation in COD values of water samples X, Y, Z as a result of the different storage conditions.

The chemical oxygen demand of the water samples was observed to increase overtime agreeing to the trend reported by Muhamad *et al*., (2011).

The sample kept at room temperature X had the least values for COD from from week 1 to week 5 (2.07 to 3.58mg/L) indicating that time had least effect on COD, while the most significant increase in COD values for the same period was observed for both elevated temperature and sunlight exposed samples (4.31 mg/L to 7.23mg/L) which more than doubled by the end of the exposure.

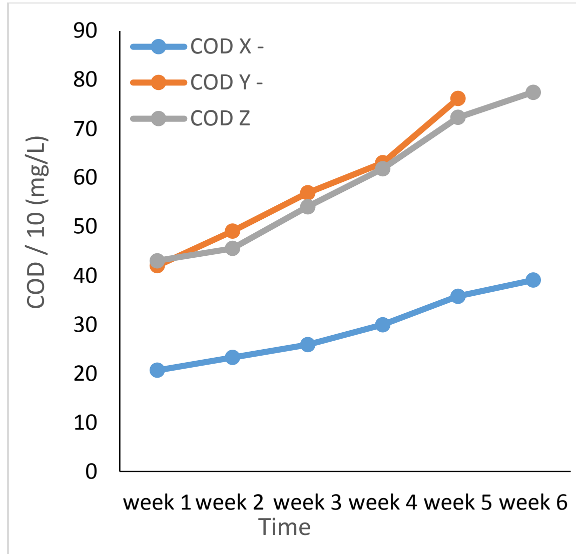

Fig 4: Variation in the measured COD of the three sample groups (X,Y,Z) stored under room temperature, elevated temperature, and sunlight exposure conditions from 0 to 6 weeks.

*Turbidity***:** Turbidity is the phenomenon where by a particular parcel of light beam passing through a fluid medium is avoided from undissolved particles. In this study, turbidity values for all water samples X, Y, Z, ranged from 11.40 to 48.0 NTU greatly exceeding the WHO standard.

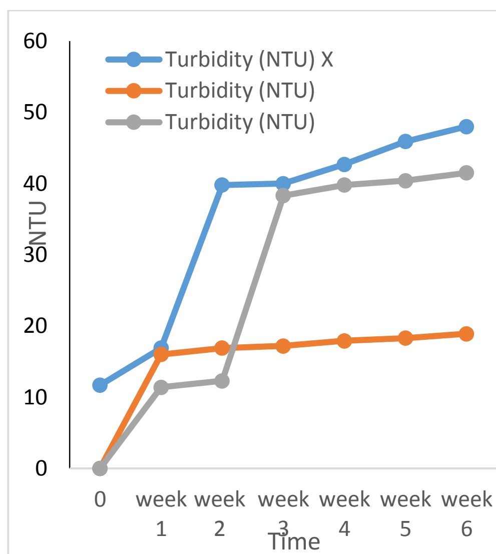

Fig 5: Variation in the measured Turbidity of the three sample groups (X,Y,Z) stored under room temperature, elevated temperature, and sunlight exposure conditions from 0 to 6 weeks.

However in comparison, Hussein e*t al*., (2019) studied the effects of temperature and sunlight exposure on drinking water in a similar hot and sunny climate to northern Nigeria, Kirkuk city, in

North Iraq, and reported turbidity values of water samples from 0.06 to 4.99 NTU all within the WHO standard. The divergence in results, could be attributed to combination of factors including the difference in sunlight intensities, difference in water source and purification process, differences in polymer packaging material, and elusive method errors. However, it indicates that water samples could be unclear.

GC Results: GC analysis of the sachet water contents was done to identify different unknown organic substances that may have possibly migrated from the polymer sachet into the water. After five weeks of exposure, GC analysis was performed on the three sample groups stored in different conditions.

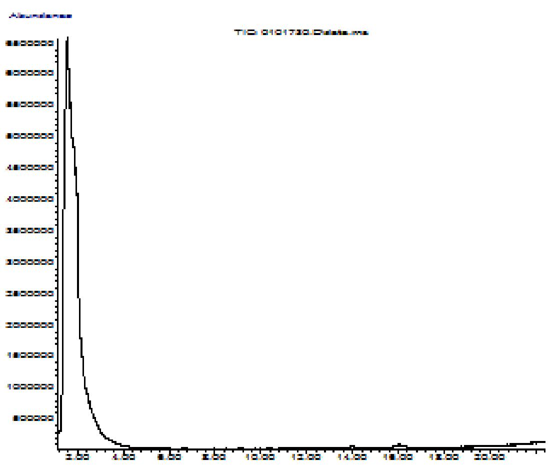

Fig 6: GC analysis of sample X after five weeks of exposure.

Fig 6 shows the total ion chromatogram of the control sample group (water samples X) analyzed to depict the effect of time as a degradation factor in polyethylene. Only one major peak at about 1.7 – 2.9 mins retention time (RT) was observed as expected representing the solvent, with no additional peak, implying no possible leaching. Also, only the solvent peak was observed for the elevated temperature exposed samples (water samples Y) (Fig 7), hence no possible organic compound was detected.

However, the results obtained (Fig 6 and Fig 7) fell below expectations, as additional peaks to account for the organic materials responsible for the increase in the chemical oxygen demand of the control group samples and the elevated temperature exposed samples was not observed. The water sample Z, GC analysis result in Fig 8 showed an additional peak that was detected at a retention time of 7.99 mins. This could probably represent the presence of a trace amount of an organic compound leached into the water. Although similar analysis carried out on sachet water is limited.

The study conducted by Linus *et al*., (2021), could be used in comparison, the results obtained there was similar with the point of difference being the total ion chromatogram of the elevated temperature exposed samples (water samples Y); additional peaks to the hexane peak were observed for the elevated temperature exposed samples at an RT of 26 mins, unlike in this study where only the solvent peak was observed.

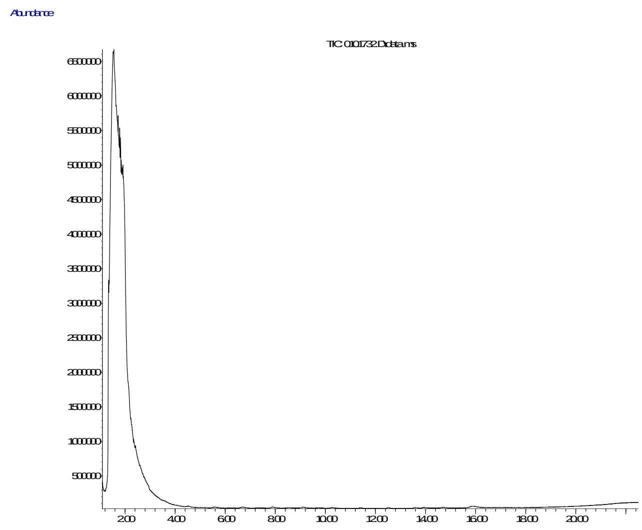

Fig 7: GC-MS Analysis of sample Y after 5weeks of exposure.

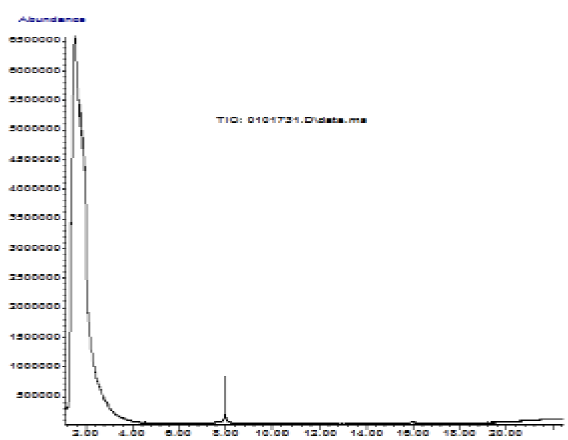

Fig 8: GC Analysis of sample Z after 5 weeks of exposure.

Conclusions: According to the findings in this study, higher temperatures and sunlight exposure significantly affected how quickly organic materials moved from the polyethylene material into the water confined inside, resulting to significant changes in the physiochemical properties. The physicochemical properties of the water samples monitored were still within World Health Organization (WHO) standards for water. Consuming this kind of water, after an extended period of time, however, is detrimental to human health and thus it is important to store sachet water and other polymer packaged beverages in a cool and dry location with a maximum temperature of 30 ºC to avoid contamination.

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