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PARTICULATE MATTER

1. Description of the parameter

"**Particulate matter** (PM), also known as particle pollution, is a complex mixture of extremely small particles and liquid droplets that get into the air." (source: https://www.epa.gov/pm-pollution)

They are mainly emitted into the atmosphere by industrial activities or transportation and can cause environmental damage (eg. acid rains, visibility impairment, depleting the nutrients in soil).

The Particulate Matters pollution can also have negative impacts on humans' health, hence the importance of studying and monitoring their concentration in the air. Among the **health effects** of Particulate Matters pollution we encounter lung problems (asthma, irritation of the airways, coughing, difficulty breathing) and heart diseases when the ultrafine particles get into the bloodstream.

The Particulate Matters have different diameters:
- **PM10**, between 10µm and 2.5µm (coarse particles);
- **PM2.5**, between 2.5µm and 0.1µm (fine particles);
- **PM0.1**, under 0.1µm (ultrafine particles).

Regarding their origin and composition, the Particulate Matters are characterized as follows:
- PM10 includes dust, pollen and mold spores.
- PM2.5 includes combustion particles, organic compounds and metals.
- PM0.1 includes viruses, suspended atmospheric dust and gaseous contaminants.

Coarse particles settle relatively quickly while both fine and ultrafine particles remain in suspension for longer.

2. Standard values for the parameter

"The Clean Air Act, which was last amended in 1990, requires EPA to set **National Ambient Air Quality Standards** for pollutants considered harmful to public health and the environment." (source: https://www.epa.gov/criteria-air-pollutants/naaqs-table)

Thus the Air Quality Standards set by **US Environmental Protection Agency** present the following values for Particulate Matters:
- $35\mu g/m^3$ for PM2.5 particles for an averaging time of 24 hours;
- $12\mu g/m^3$ (Primary standard*) and $15\mu g/m^3$ (Secondary standard**) for PM2.5 particles, over an averaging period of 1 year;
- $150\mu g/m^3$ for PM10 particles based on a 24 hours average.

* ***Primary standards*** provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. (source: epa.gov)
** ***Secondary standards*** provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. (source: epa.gov)

According to the **Air Quality Standards of the European Union**, the concentration of pollutants allowed into the air is as follows (source: EU Environment website):

- $25\mu g/m^3$ for fine particles (PM2.5), over an averaging period of 1 year;
- $50\mu g/m^3$ for PM10 particles on an averaging period of 24 hours;
- $40\mu g/m^3$ for PM10 particles on an averaging period of 1 year.

For PM0.1 particles, there was **no standard value** found.

3. Description of the way the sensor works

The Particulate Matter sensor (**Plantower PMS7003**, in our case) works with various lasers. The laser scatters around. While scattering, it reaches a certain angle and collects solid and liquid particles from the air (eg. dust, smoke and pollen). The data that it collects are the size and volume amount of the particles in the air, using various algorithms.

4. Use of the sensor at the University of Aruba

In order to verify the sensor and to proceed to data collection, measurements were taken at the University of Aruba, on 30th of October, in different places along the Campus:

- interior garden, next to library (**location no.1**);
- designated smoking area near the University Aula and the gazebo (**location no. 2**);
- restrooms (**location no.3**);
- garden area behind classroom D2 (**location no.4**);
- library – bookshelves area (**location no.5**);
- University canteen (**location no.6**);
- front garden (**location no.7**);
- classroom A (**location no.8**).

In each of the locations, an average of 5 to 6 values were measured.

5. Values from measurements at the University of Aruba

Measurement results

The values measured in the different locations at the University of Aruba are shown in the table below. The time period and the average values for the three parameters are also included in the table.

	PM0.1 (µg/m3)	PM2.5 (µg/m3)	PM10 (µg/m3)
Location no.1	6	13	13
12:25-12:26 pm	7	12	15
	7	11	13
	7	9	11
	7	9	9
AVERAGE	**6,8**	**10,8**	**12,2**
Location no.2	6	9	9
12:29-12:31 pm	5	8	9
	4	8	9

	4	7	7
	4	6	8
	5	6	10
	5	6	11
	5	5	10
AVERAGE	**4,8**	**6,875**	**9,125**
Location no.3	5	6	7
12:31-12:33 pm	5	8	10
	6	9	9
	5	8	9
AVERAGE	**5,3**	**7,75**	**8,75**
Location no.4	4	8	9
12:35-12:36 pm	6	9	9
	6	8	8
	7	10	10
	7	9	9
AVERAGE	**6,0**	**8,8**	**9**
Location no.5	6	12	12
12:37-12:38 pm	6	11	11
	5	10	10
	6	9	9
AVERAGE	**5,8**	**10,5**	**10,5**
Location no.6	11	14	14
12:39-12:40 pm	12	15	15
	13	17	17
	13	19	21
AVERAGE	**12,3**	**16,25**	**16,75**
Location no.7	4	5	6
12:40-12:42 pm	4	5	7
	5	6	8
	5	7	10
	5	10	14
	5	8	13
	4	7	12
	5	9	12
	5	8	9
AVERAGE	**4,7**	**7,22**	**10,11**
Location no.8	2	4	4
12:43-12:44 pm	1	3	3
	0	1	1
	1	2	2
	1	3	3
	0	4	4
AVERAGE	**0,8**	**2,83**	**2,83**

Results discussion

The **average values** for the measurements taken at the University of Aruba were **5.79µg/m^3** for PM0.1, **8.88µg/m^3** for PM2.5 and **9.91µg/m^3** for PM10. When comparing them with the standard values set by the European Union (25µg/m^3 for PM2.5 a year and 50µg/m^3 for PM10 on a 24 hours average), the measurements taken at the university are lower. This demonstrates that **the air** of the study area **is of a very good quality**. Even when the results are compared with the US Environmental Protection Agency standards, the outcome stays the same.

Regarding the distribution of the Particulate Matters measurements on locations, in every single case the values recorded for the particles with a smaller size are lower than those that are close to a 10 µm diameter. The **first location** was represented by the interior garden, next to library. The PM values here were a little bit higher than those encountered at the other locations and than the university averages. This could be explained by the density of plants and the lack of natural ventilation. The average for each of the parameters was below the standards set by EU and EPA. The **second location** was the designated smoking area near the University Aula and the area where the gazebo is situated. The measurements were taken when no person was smoking and as a result, the values were low. They were even lower than the averages (in the case of all of the three parameters) because of more natural ventilation and the presence of an Air-Conditioning fan outside of the Aula. **Location no.3** was represented by the restrooms. The Particulate Matters values here were low, below the average values for the entire university. The **fourth location** was represented by the garden area behind classroom D2. Again, the values measured were low. Here the values for PM2.5 and PM10 were the closest to the average measured for the University. The **fifth location** was the bookshelves area from the library. The values measured here were higher compared to the locations from outside. **Location no.6** was the place where the highest values were encountered. Being an indoor place, it lacks strong ventilation. The **seventh location** was the front garden. Here, the measurements were taken close to an Air-Conditioning fan and then 5m away from it, in the garden. The values for the AC were lower (4.5µg/m^3 for PM0.1, 5.75µg/m^3 for PM2.5 and 7.75µg/m^3 for PM10) than those from the garden (4.8µg/m^3 for PM0.1, 8.4µg/m^3 for PM2.5 and 12µg/m^3 for PM10). The **final location** (classroom A) was characterized by the lowest measurements due to the high ventilation. For PM0.1 we even encountered 0µg/m^3 as a value.

From all the locations, the greatest values were found indoor, at the University canteen, while among the outdoor locations, the interior garden presented the highest measurements (**Fig.1**).

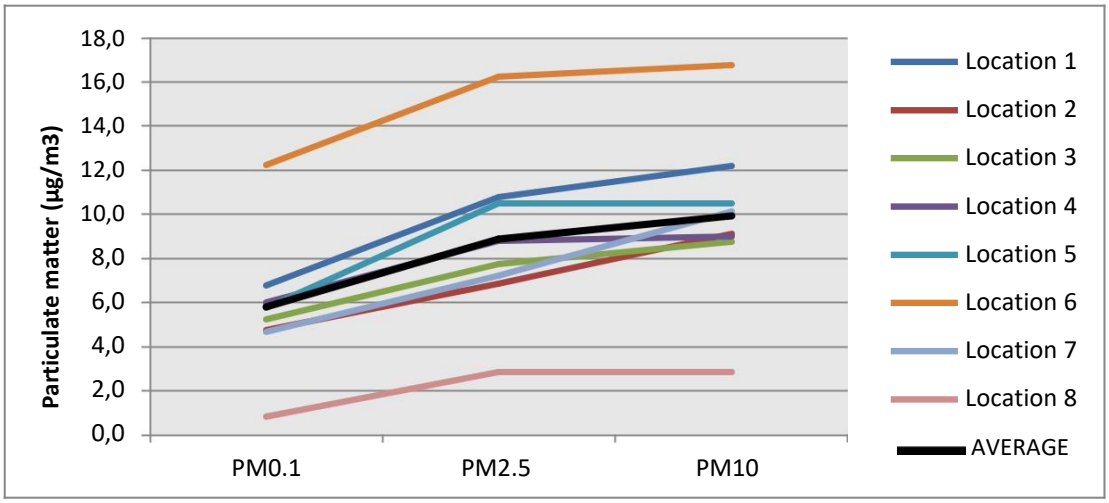


Fig.1 - Average values for the locations at the University of Aruba

6. Results of the measurements taken at the Parkietenbos Dump

The research study was conducted at the Parkietenbos Dump on October 30th, 2017. In order to later identify the points where the Particulate Matter values were measured and thus to ease their visualization by map pinning (**Fig.2**), the geographical coordinates were taken using the Compass application incorporated in iPhone 6.

Fig.2 - Locations at Parkietenbos Dump where the measurements were taken

Because of the rain that poured after approximately half an hour of measurements, the only part of the dump that the values were taken for was the one closer to the ocean (South – South-East). Thus **we lack Particulate Matter measurements for the portion of dump closer to the mangroves** area.

General Observations

It had heavily rained the day before and as a result the ground at the dump was moist. During the first part of the fieldtrip, it was sunny and no clouds. There was little to no breeze (**Location no.1 –** at the entrance of the dump). The wind was blowing from South-West (from the ocean direction), an unusual characteristic as most of the time the trade winds blow from opposite direction (East – North-East). The smell was very intense and it felt like gas and chemical compounds.

There were a lot of broken glass pieces and a lot of soil that is used to keep the trash held together. At the entrance, we also observed a scale used to weigh the cars coming with the trash so when they leave the dump, administration can see how many kilograms of trash people deposited.

Location no.2 was closer to the ocean. Because of the wind blowing towards us, the Particulate Matter values were not so high compared to the other locations (including the entrance). There was little breeze and it was still sunny during the measurements taken here.

Location no.3 was set to a point walking inwards towards the ditch, facing the exit. Here the Particulate Matter values got higher than those taken near the ocean. Meanwhile, it started to get cloudy.

Location no.4 was close to a recently burnt trash. There were sections with smoking coming from the ground. The one that we measured the Particulate Matters for had very high values. The values were the highest if compared to the other locations we took measurements for. It started raining.

The last location (**location no.5**) was uphill from burning boxes. It was raining and windy, and we were far away from the burning boxes to get the expected values for a burning area.

Measurement results

	PM0.1 (µg/m3)	PM2.5 (µg/m3)	PM10 (µg/m3)
Location no.1	18	25	25
11:25-11:32 am	16	19	21
	17	21	21
	17	20	20
	18	23	23
AVERAGE	**17,2**	**21,6**	**22**
Location no.2	10	16	17
11:38-11:43 am	12	21	21
	9	15	15
	10	15	16
AVERAGE	**10,25**	**16,75**	**17,25**
Location no.3	34	48	48
11:45-11:47 am	30	42	46
	30	31	44
	22	34	34
AVERAGE	**29**	**38,75**	**43**
Location no.4	36	64	74
11:48-11:50 am	31	52	60
	27	48	56
	36	60	70
	55	99	114
	66	121	149
AVERAGE	**41,83**	**74,00**	**87,17**
Location no.5	20	32	34
11:58-11:59 am	23	36	41
	24	35	35
	25	35	36
	24	33	34
	24	32	33
AVERAGE	**23,33**	**33,83**	**35,50**

Results discussion

The **average values** for the three parameters are **24.32µg/m^3** for PM0.1, **37µg/m^3** for PM2.5 and **41µg/m^3** for PM10. If comparing them with the values from the University of Aruba, they are way above. Still when compared with the **standard values** set by the European Union, **they are higher**. In the case of PM2.5, 37µg/m^3 is easily surpassing the 25µg/m^3 threshold set for an averaging time of 1 year. The same situation is found for the EPA standard set for an average of 24 hours (35µg/m^3) or for 1 year (15µg/m^3). Nevertheless, in the case of PM10 the average calculated for the measurements taken at the dump is below the standard value set by the European Union (50µg/m^3), as shown in **Fig.3**.

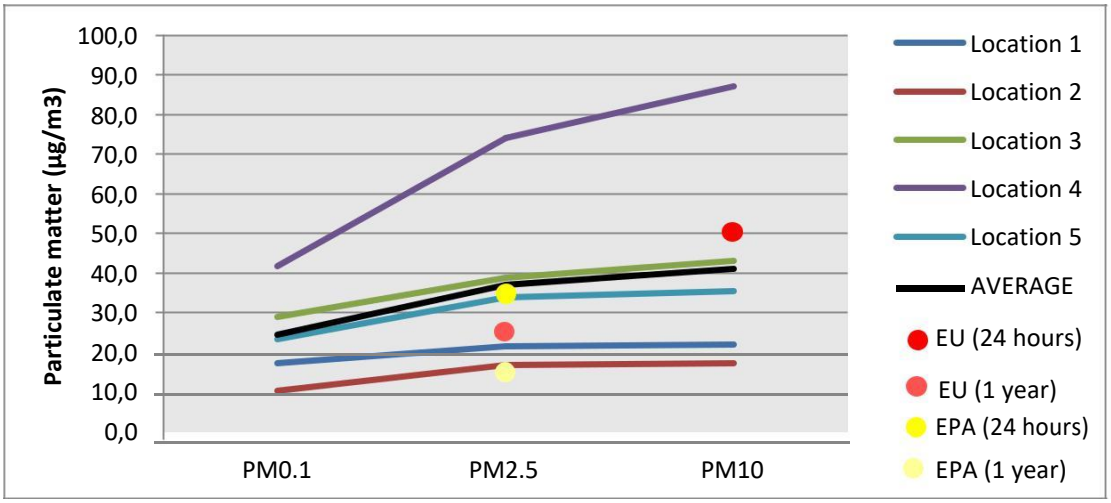


Fig.3 - Average values for the locations at Parkietenbos Dump

The numbers from the different locations at the dump indicate a big diversity of environmental conditions. They also certify the existence of a **polluted air**. For the first location (the entrance), the values are around an average of 20µg/m^3 for all three parameters. In the case of PM2.5, the average value of 21.6µg/m^3 is below the standard set by the European Union, but above the 15µg/m^3 value set by EPA for an average of 1 year. The air quality is thus not the best. Furthermore, the air had a strong smell of smoke and fire in that area.

The second location was characterized by the lowest values mostly because of the presence of the ocean and because of the change in wind direction. Still the average calculated here for PM2.5 (16.75µg/m^3) is higher than the EPA standard. The third location presented values above the average set for the dump, being the second place with the worst air quality. The only standard value not surpassed yet was the EU threshold set for PM10 for an averaging period of 24 hours.

The fourth set of measurements was taken close to some recently burnt trash. Because of the presence of smoke, the air analyzed here presented the highest values and thus the strongest particle pollution. Reaching a level of almost 90µg/m^3 for PM10, breathing on a daily basis the air of this location could cause severe respiratory problems.

The fifth and final location presented values close to the dump average, but still below it. When compared to the entrance and to the areas close to the ocean, location no.5 has a worse quality of the air. For PM2.5, the average for this place was approximately 34µg/m^3 which almost equals the EPA standard set for 24 hours. The average for PM2.5 in this location easily surpasses the standard values calculated by the European Union and EPA, both for 1 year.

7. Conclusion

The Particulate Matter represents particles of different sizes found in the air that enables the scientists to define the particle pollution. The parameters measured are PM0.1, PM2.5 and PM10 according to the diameter of the particles. Assessing the concentration of Particulate Matter in the air is valuable because a too high concentration can produce health problems (e.g. respiratory, cardiovascular).

The first measurements taken with the Plantower PMS7003 sensor were at the University of Aruba. The average values measured here were 5.79μg/m^3 for PM0.1, 8.88μg/m^3 for PM2.5 and 9.91μg/m^3 for PM10. These are below the standard values set both by the European Union and by the US Environmental Protection Agency. This fact certifies a very good air quality among the University of Aruba facilities.

The second set of measurements was taken during a fieldtrip at Parkietenbos Dump. There, the results attested the presence of an increased particle pollution, mainly because of the burning trash. In fact, the highest values for the Particulate Matter were encountered in the areas with recently burnt trash (averages of 41.83μg/m^3 for PM0.1, 74μg/m^3 for PM2.5 and 87.17μg/m^3 for PM10). Because of an unusual direction of the wind during the day of the fieldtrip, the area with the lowest values was the one close to the ocean. The average for the dump (24.32μg/m^3 for PM0.1, 37μg/m^3 for PM2.5 and 41μg/m^3 for PM10) was above the standard values of the European Union and US Environmental Protection Agency, thus certifying the existence of a polluted air for the dump complex.

APPENDIX 1 – Sensor wiring

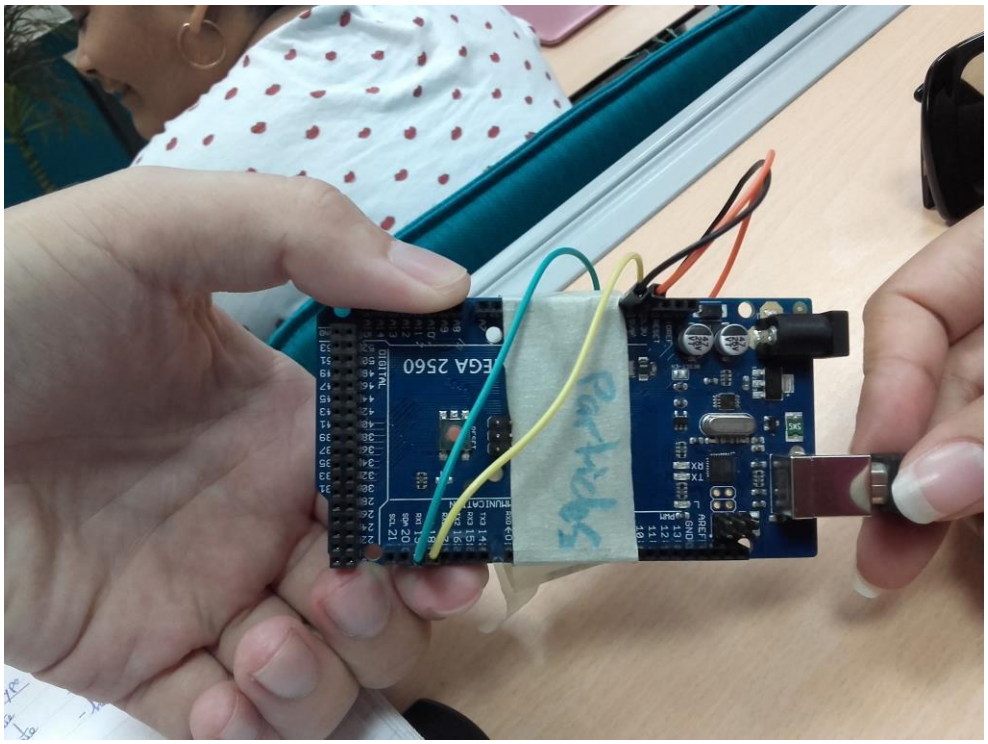


Photo no.1 – Front image of Arduino Mega 2560

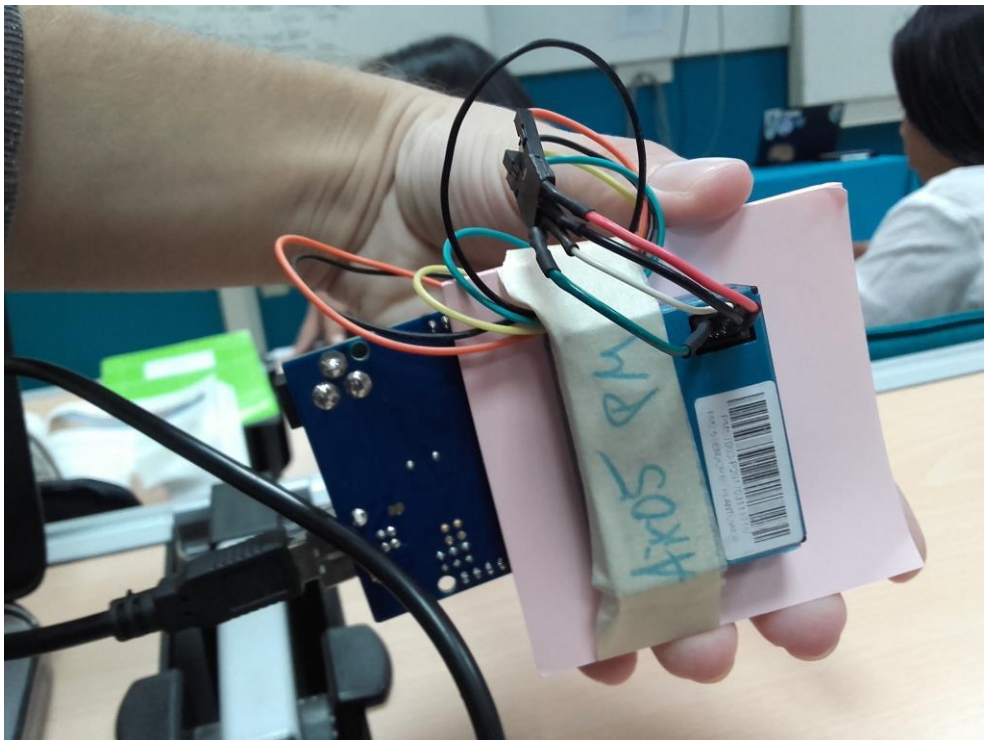


Photo no.2 – Back image of Arduino and the Plantower PMS7003 sensor

APPENDIX 2 – The code used to program the sensor

```
#include <Arduino.h>
#define LENG 31 //0x42 + 31 bytes equal to 32 bytes
unsigned char buf[LENG];

int PM01Value=0;         //define PM1.0 value of the air detector module
int PM2_5Value=0;        //define PM2.5 value of the air detector module
int PM10Value=0;         //define PM10 value of the air detector module


void setup()
{
  Serial.begin(9600);   //use serial0
  Serial.setTimeout(1500); //set the Timeout to 1500ms, longer than the data transmission periodic time of the sensor
}

void loop()
{
  if(Serial.find(0x42)){ //start to read when detect 0x42
    Serial.readBytes(buf,LENG);

    if(buf[0] == 0x4d){
      if(checkValue(buf,LENG)){
        PM01Value=transmitPM01(buf); //count PM1.0 value of the air detector module
        PM2_5Value=transmitPM2_5(buf);//count PM2.5 value of the air detector module
        PM10Value=transmitPM10(buf); //count PM10 value of the air detector module
      }
    }
  }

  static unsigned long OledTimer=millis();
    if (millis() - OledTimer >=5000)
    {
      OledTimer=millis();

      Serial.print("PM1.0: ");
      Serial.print(PM01Value);
      Serial.println(" ug/m3");

      Serial.print("PM2.5: ");
      Serial.print(PM2_5Value);
      Serial.println(" ug/m3");

      Serial.print("PM1 0: ");
```

Changed to 5000ms from an initial value of 1000ms. That translates into 5s – time between measurements.

```
      Serial.print(PM10Value);
      Serial.println(" ug/m3");
      Serial.println();
    }

}
char checkValue(unsigned char *thebuf, char leng)
{
  char receiveflag=0;
  int receiveSum=0;

  for(int i=0; i<(leng-2); i++){
  receiveSum=receiveSum+thebuf[i];
  }
  receiveSum=receiveSum + 0x42;

  if(receiveSum == ((thebuf[leng-2]<<8)+thebuf[leng-1])) //check the serial data
  {
    receiveSum = 0;
    receiveflag = 1;
  }
  return receiveflag;
}

int transmitPM01(unsigned char *thebuf)
{
  int PM01Val;
  PM01Val=((thebuf[3]<<8) + thebuf[4]); //count PM1.0 value of the air detector module
  return PM01Val;
}

//transmit PM Value to PC
int transmitPM2_5(unsigned char *thebuf)
{
  int PM2_5Val;
  PM2_5Val=((thebuf[5]<<8) + thebuf[6]);//count PM2.5 value of the air detector module
  return PM2_5Val;
  }

//transmit PM Value to PC
int transmitPM10(unsigned char *thebuf)
{
  int PM10Val;
  PM10Val=((thebuf[7]<<8) + thebuf[8]); //count PM10 value of the air detector module
  return PM10Val;
}
```

APPENDIX 3 – Photographs taken in different locations during the field trip at Parkietenbos Dump (Source: Group members)

Location no.3 - walking inwards towards the ditch (facing East)

Location no.4 – recently burnt trash

Waste diversity of the dump

Location no.3 - walking inwards towards the ditch (facing North)

Location no.2 – close to the ocean

Location no.1 – dump entrance

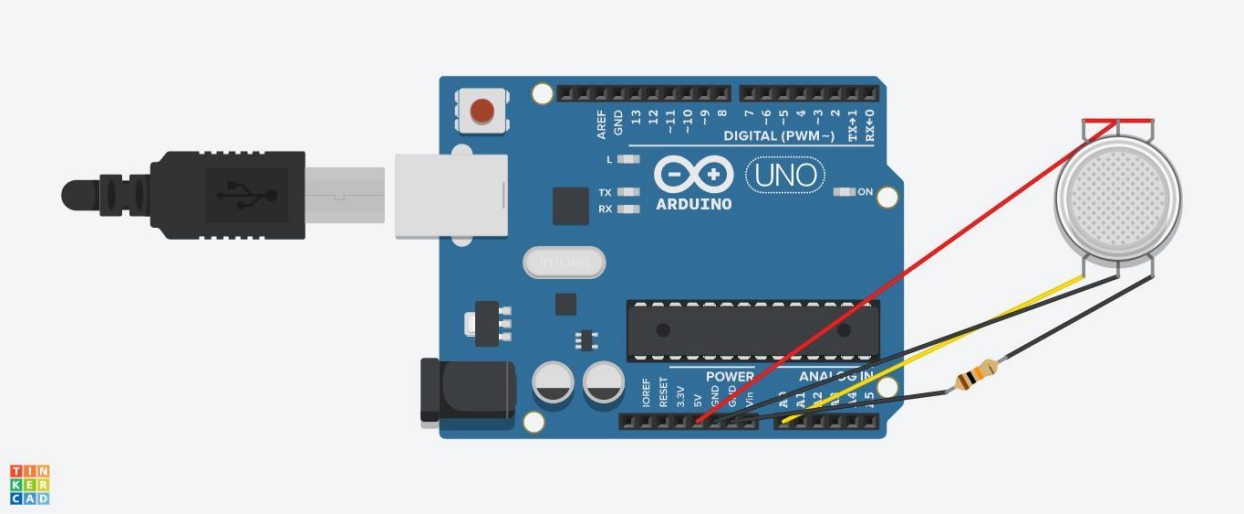
SIMULATION OF THE SENSOR

Sensor used: Gas sensor

Parameter: Propane

The simulation was made for the MQ6 Propane measuring sensor (gas sensor) using the www.tinkercad.com website. This sensor was chosen because the simulator didn't present neither an Arduino Mega 2560 nor a Particulate Metter sensor (in the Components box).

After changing the code and starting the Simulation, Serial Monitor constantly sends the following result: 535.



Link to the Gas Sensor simulation:
https://www.tinkercad.com/things/jznyjmt2YpP

Link to the Gas Sensor simulation (breadboard included):
https://www.tinkercad.com/things/jVkK0xZfplX