Characterization and toxicity effect of leachate from municipality landfill

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Abstract

Leachate from Municipal Solid Waste (MSW) landfill has long known to be an environmental concern worldwide. The composition of landfill leachate may contain metals, ammonia, organics, other toxicants and carcinogens, having major environmental concern, with implications for plant, animal and human health. The pollution of soil, surface and ground water is also some of the major immediate concern related to leachate. This problem is growing at alarming rate in some of the developing countries including Ethiopia, and Adigrat happens to one such fast growing small city Ethiopia. However, in the absence of any significant relevant study for Adigrat City MSW leachate, the present work was undertaken to study the physico-chemical characterization of leachate from the Adigrat MSW leachate and investigate its toxicity effect on pea seed germination (*Pisum sativum*). The characterization was performed on the leachate from Adigrat MSW landfill. Subsequently, the leachate toxicity assessment on pea seed germination was also carried out. The result shows presence of several unacceptable components in the leachate that in some instance was detected at such levels that may pose environmental risk. It was also found that the low pH may add corrosiveness to any contaminated environmental components. Anions (like Cl^-) and heavy metals (like Pb, Zn and Cd) detected in the leachate may also be concern for any possible environmental exposure. Additionally, the pea seed germination experiment suggests existence of such components in the leachate that possibly mask its nutritional property during germination.

1. Introduction

Landfills are the most common means of solid waste disposal in developing countries which may, however, pose serious threat to the quality of environment due to incorrectly secured and improperly operated (Idowan, 2019). The decomposition of solid waste in the landfill, along with rainwater penetration is responsible for formation of a dark liquid with unpleasant odour known as leachate (Przydatek, 2019). The composition of landfill leachate is not simple but it may mainly contains metals, ammonia, organic compounds and other toxicants that could be of great concern for the environment (Pivato and Gaspari, 2006; Gupya and Paulraj, 2016; Han et.al., 2016)

Its quantity and composition is determined by several factors, including waste composition, landfill age and the amount of precipitation (Przydatek, 2019). .

Landfills with effective treatment processes are not toxicological threat (Ančić et.al., 2019). Nowadays there are emerging landfill leachate recovery and treatment studies. Tonni et al. (2021) have recently shown ammonium striping as effective for NH3-N removal from landfill leachate.

Ilaria et al. (2020) have also revealed an improved landfill leachate quality by removing metals and micro pollutants using a pre-treatment tannin-based coagulant for nitrogen recovery using membrane contactor technology. Recent study demonstrated that phytoremediation process removed about 91% of dissolved organic carbon(DOC), 86% of total nitrogen (TN), 90% of NH_4-N and 96% of phosphates from pre-treated landfill leachate (Nair et al., 2019).

However in absence of such measures MSW landfills pollute ground and surface water causing environment problem and risk to human-health (Przydatek, 2019).In addition, landfill morphology percolation rates and diffusive aeration factors may contribute to landfill leachates contamination (Aharoni, I. et.al.,2020). Vahabian et al. (2019) have revealed that MSW leachate contaminated surrounding ground water.

Toxicity is generally determined based on landfill leachate physicochemical properties, with ammonia, chemical oxygen demand (COD) and heavy metals being identified as the major contributors (Thomas et al., 2009). People who consume MSW Leachate contaminated water are at risk of developing adverse health consequences such as cytogenetic abnormalities and DNA damage. Therefore, it is important to monitor toxic potential of MSW landfill leachate Li et al., 2008). (Przydatek (2019) assessed toxicity of landfill leachate by aquatic organsims using Daphnia magna Straus (Cladocera, Crustacea). It has been also analysed on different plant systems such as *Allium cepa*, *Vicia faba*, *Hordeum vulgare* (Sang and Li, 2004). Various studies have also shown that legume crops are very responsive to leachates in terms of growth and seed germination, which can be used to see the impact of such leachate on plants (Kumar et al., 2012). Physicochemical and biological characterstics and toxicity effect of leachate study is therefore necessary to investigate the risk associated with a given landfill (Ančić et al., 2019).

The present study thus aims to utilize the existing understanding on leachate related risks, and on plant responsiveness to leachate, to identify any concern to the rapidly urbanizing Adigrat district where MSW management is evolving fast. Adigrat city in Tigray region of Ethiopia has a landfill that may be generating leachate with possible serious environmental concern. However, there is no information available on the physico-chemical characteristics and toxicity potential of this landfill leachate that may be generated. The present study was, therefore, undertaken to develop some of the first set of data and understanding on the Adigrat MSW landfill leachate and to investigate its impact on pea seed germination; thereby, providing a basis for evaluating relevant mitigation options and its treatment possibilities and reuse in future.

2. Methodology

2.1. Study Area

The study was conducted on the MSW landfill leachate collected from the MSW Landfill' located in, Tigray Region, Ethiopia. The landfill that was started in 2007, has an area of about 4 ha (with the total campus spreading about 7 ha), and is located about 11 Kms from the city centre towards its north. (The city approximately generates about 3600 m^3 of solid waste daily. The town has a formal solid waste collection system, wherein, the waste is collected door-to-door from all establishments including households in trucks. Presently, there is probably no segregation or compaction done before reaching the landfill. A formal manual segregation is performed after the MSW reaches which is subsequently dumped in the landfill. There are a number of existing and emerging technologies that may provide an alternative to the use of a landfill for the disposal of municipality solid waste. These technologies generally fall into the categories of waste incineration, waste handling, and waste conversion. However, the current practice in Adigrat municipality is only waste dumping, simple incineration and partial segregation. There is properly designed 'leachate channels' that carries leachate to a 'collection tank'.

2.2. Sample collection

In the present study leachate samples were collected from the 'channels (C1)' and the 'leachate tank (T1)' of the Adigrat Landfill. Five samples were collected during May-June: two each from leachate 'tank' and 'channel' during May (samples: ST-1 & SC-1); and three each from leachate 'tank', 'channel' and 'drain' during June (ST-2, SC-2 & SD, respectively). The collected samples were sealed in bottles, wrapped in aluminium foil, and transported to laboratory for analysis. The samples were analysed for: physical [true colour, odour, taste, pH, turbidity, total dissolved solids (TDS) and electrical conductivity (EC)]; chemical [biological oxygen demand (BOD), chemical oxygen demand (COD), total hardness, alkalinity, carbonate, bicarbonate, chloride, fluoride, nitrate, nitrate, sulphate, phosphate, sodium, potassium, calcium, magnesium, total iron, manganese, ammonium, chromium, copper, lead, mercury, nickel, zinc, and cadmium]; and biological (E. Coli and Total Coliform) parameters. EC, pH, turbidity, temperature, TDS were measured immediately in the field by water analysis kit (PC-510, Eutech Instruments).

Rest of the parameters were analysed in laboratory (Geology Department Laboratory, Mekelle University, Tigray, Ethiopia) following the standard methods (Pawlowski, 1994)

Metals were analysed by Atomic Absorption Spectrophotometer (AAS; Spectra AA-50B, Varian, England). BOD and COD analysis used Mett-3410, England. Anions were analysed by photometric method (Lambda E7201, Perkin Elmer UV/Vis Spectrophotometer). Alkalinity, CO_3^{2-} and HCO_3^- were analysed by titrimetric method. Total coliform and E. Coli were measured using JKI Colony counter, involving incubation at 37^0C.

2.3. Leachate treated 'Pea-seed germination experiment (PSGE)'

Dry seeds of *Pisum sativum* were collected from Research Centre, College of Agriculture, Adigrat University. Five experimental groups for different concentration of leachate treatment of the seeds T1, T2, T3, T4 & T5 representing 0%, 25%, 50%, 75% and 100% leachate quantities respectively) were setup. Each concentration was setup in triplicate with five seeds each in three different petri dishes to reduce error. The petri dishes were lined with substrate paper and the seeds were placed on the paper moistened with the respective leachate-water mixtures. Thus, a total of 15 different petri dishes with a total of 75 seeds that included three sets for each of the five treatments were setup. The germination was performed under diffused light, in the Environmental Science Laboratory, Department of Environmental Science, Adigrat University. The germination was periodically treated with respective concentrations of leachate to avoid drying of the germination setup. Subsequently, such parameters as 'number of seeds successfully germinated (NSG)', 'number of branches developed (B), number of leaves developed (L), shoot length (SL) and root length (RL) were recorded when significant growth were observed in the seedlings after about two weeks.

The results of leachate characterization and leachate treatment experimented in the following section.

2.4. Statistical Analysis

Results have been generally presented as the ‘mean ± SD’. The statistical difference (0.05) among the control and a series of treated groups has been analysed using one-way analysis of variance (ANOVA). The analysis and data representation has been performed using ‘LibreOffice Cal’ open source software package. ANOVA analysis showed statistically significant difference between various leachate treatments for the various seed germination parameters.

3. Result And Discussion

Leachate is the liquid percolation that drains through the waste in a landfill. Leachate components can be broadly characterized into three major groups’ namely organic matters, inorganic matters and xenobiotic organic compounds, which make bulk of leachate. Besides, some compounds are also found at low concentrations in landfill leachate like arsenate, barium, borate, cobalt, lithium, mercury, selenate and sulphide (Lee et al., 2010). Leachate quality is majorly influenced by the waste composition. It is reported that leaching quality is at its peak after two or three years and decline subsequently (Lee et al., 2010). It has also been reported that leachate from young landfill will show high BOD and COD that decline subsequently to level off after about 10 years (Lee et al., 2010). However, leachate characteristics depend on a variety of factors apart from the waste composition. Age of landfill, temperature to which the waste is exposed, moisture content, oxygen availability and variability in such quantities are some of the important factors that determine the nature and behaviour of leachate in a landfill. Several workers have reported that leachate varies widely depending on waste type and age (Vahabian et al., 2019; Han et al.,2016). Location and climate plays dominant role in waste self-processing and leachate generation in a landfill. Therefore, leachate quality, with similar waste types, may be different in landfills located in varied climatic regions (Naveen et al, 2017). Furthermore operational practices in landfills also influence the leachate quantity and quality. Considering these facts the results of the present study are investigated, and the results of physico-chemical and microbiological characteristics of the Adigrat landfill leachate are presented below.

3.1.1. Landfill leachate characteristics

3.1.1.1. Colour, odour, taste, conductivity and TDS

The sampled leachate colour (‘true colour’ as used in water quality monitoring) was found to be generally higher as compared to the WHO water quality standard during both May and June for the Adigrat landfill leachate. The samples generally showed unacceptable levels of colour, odour and taste (table 1). The pH of leachate ranged 3.27 to 5.12 in the different samples with the maximum acidity observed in the fresh leachate sample (leachate collected before it reaches the leachate channel or the tank, hereafter, referred as ‘fresh leachate’). The pH values show that the the waste in the landfill may have crossed the initial aerobic phase, and as a result of hydrolysis and microbial activity under anaerobic conditions resulted in acidic conditions. Such condition is generally observed in the second phase of landfill stabilization. The pH value is often used to represent the aggressiveness of leachate and biochemical conditions in solid waste (Emenike et al., 2012). pH lower than 7 are usually softer waters and the acidity is due to carbonic, humic, fulvic and other organic acids (Mahapatra et al., 2011), pH above 7 can carry a greater load of dissolved substances (Naveen et al., 2017) and alkaline nature of leachate is an indicator of the mature stage of the dumping site (Naveen et al., 2017). This possibly suggests that the Adigrat landfill has not reached mature stage, which is consistent with the relatively younger landfill age.

The electrical conductivity (EC) values of the leachate were found to vary between 2430-2439 µS/cm in May to 2498-2647 µS/cm in June 2018. Similarly, the total dissolved solids (TDS) were found to be 1733-1737 mg/l in May as compared to 1781-1888 mg/l in June. The TDS values are and order of magnitude lower than those observed in Egypt (Salam and Zuid, 2015), and Nigeria (Aiyesanmi and Imoisi,2011), but relatively comparable to those in India (Naveen et al., 2017) As suggested by Naveen et al. (2017), EC and TDS are influenced by the total amount of dissolved organic and inorganic materials present in the solution, and are used to demonstrate the degree of salinity and mineral contents of leachate (Naveen et al., 2017). Total mineral content further reflects the strength and overall pollutant load of the leachate (Naveen et al., 2017) .The salt content in the leachate is due to the presence of potassium, sodium, chloride, nitrate, sulphate, ammonia and others (discussed further later in section 4.1.1.4). Extremely high values for conductivity are attributable to high levels of cations and anions (Naveen et al., 2017). High TDS may reduce water clarity, which contributes to light limitation resulting in a decrease in photosynthesis and leads to an increase in water temperature (Naveen et al., 2017). This may affect the leachate biota. High TDS also limits the growth and may lead to death of many aquatic organisms (Naveen et al., 2017). A related parameter, turbidity ranged 8.54-12.54 and averaged to 9.7±1.6 NTU, with higher values for fresh leachate.

3.1.1.2. BOD and COD

The BOD ranged 12564-13874 mg/l (13008±535 mg/l) for the various leachate samples (table 1and figure 1). The values were higher during June as compared to that in May. The highest BOD was observed for the fresh leachate. The COD ranged from 25641-27849 mg/l, averaged to 26706±924 mg/l, with the values not showing specific pattern between May and June sampling, but in general both BOD and COD were observed to be higher in the fresh leachate sample. Both BOD and COD values appeared higher than those reported from Nigeria (Aiyesanmi and Imoisi,2011; Ogundiran and Afolabi,2008), Egypt (Salam and Zuid,2015), India (Naveen et al., 2017) and Malaysia (Umar et al., 2010). The BOD to COD ratio ranged 0.45-0.50 that averaged to 0.49±0.02. The ratio was found higher than those reported from India (Naveen et al., 2017), Malaysia (Umar et al., 2010), but lower than those observed in Nigeria (Aiyesanmi and Imoisi, 2011). The ratio is consistent with the pH observations as the values support the existence of acidic condition in the landfill.

3.1.1.3. Hardness and Alkalinity

The total hardness ranged 732-874.5 and averaged to 777±56 mg/l ($CaCO_3$), with the highest value for the fresh leachate (figure1). The values are higher than those observed in Nigeria (Aiyesanmi and Imoisi, 2011) and most closely comparable to that reported for India (Naveen et al., 2017). The alkalinity ranged 350-401 and averaged to 377±22 mg/l ($CaCO_3$), which is found to be lesser by an order of magnitude compared to that observed in India (Naveen et al., 2017) and an order of magnitude higher than that observed in Nigeria (Aiyesanmi and Imoisi, 2011). Both hardness and alkalinity were found to be highest in the fresh leachate.

3.1.1.4. Anions and Cations

The level of inorganic elements present in leachate is dependent principally on the ease of leaching inorganic constituents present in the MSW and the stabilization process in the landfill (Naveen et al, 2017). In this perspective the ion concentrations in the sampled leachate gives important result (figure 2 & 3). The concentration of Chloride (Cl^-) ranged 52.2-67.8 and averaged 59±6 mg/l with the fresh leachate showing highest values (figure 4), which is very low as compared to that observed in Nigeria (Aiyesanmi and Imoisi,2011; Ogundiran and Afolabi,2008), Egypt (Salam and Zuid,2015), India (Naveen et al, 2017) and Malaysia (Umar et al., 2010). Fluoride (F^-) ranged 0.09-0.25 and averaged to 0.15±0.06 mg/l (figure 3); again the highest values recorded for fresh leachate. Nitrate was ranged 26.8-36.5 and averaged to 30.4±3.8 mg/l, whereas, nitrite ranged and averaged to 0.67-0.82 and 0.7±0.06, respectively. The nitrate (NO_3^-) values are close to those observed in India (Naveen et al, 2017) and higher than those observed in Egypt (Salam and Zuid,2015) and Nigeria (Aiyesanmi and Imoisi, 2011). The sulphate (SO_4^{2-}) values ranged 366-383 and averaged to 371±7 mg/l (SO_4^{2-}), which are slightly lower than those observed in Egypt (Salam and Zuid,2015) and much higher than those observed in India (Naveen et al, 2017) and Nigeria (Aiyesanmi and Imoisi, 2011). The phosphate (PO_4^{3-}) values ranged and averaged 0.08-0.25 and 0.14±0.07 mg/l (as PO_4^{3-}), respectively, which is closely comparable to those observed in Egypt (Salam and Zuid,2015). The ammonium concentration (NH_4^{2-}) in the leachate ranged and averaged 2.54-4,12 and 3.2±0.6 mg/l NH_4^{2-}, which is several order of magnitude lower than that observed in Nigeria (Aiyesanmi and Imoisi, 2011), Egypt (Salam and Zuid,2015) and India (Naveen et al, 2017). The cation values of the samples are presented in figure 4. The sodium (Na^+) values ranged and averaged 29-36 and 32±3 mg/l, respectively, which is several order of magnitude lower than that observed in India (Naveen et al, 2017). The potassium (K^+) and Calcium (Ca^{2+}) values are also found to be much lower than those observed in Egypt (Salam and Zuid,2015), Nigeria (Ogundira and Afolabi,2008) and India India (Naveen et al, 2017). The iron (total iron) values ranged and averaged 0.86-1.6 and 1.0±0.3 mg/l that is much lower than those reported from India India (Naveen et al, 2017) and Malaysia (Umar et al., 2010). The magnesium (Mg^{2+}) values ranged between 38-45 mg/l. In general the values have been found to be higher for fresh leachate for the various anions and cations measured.

3.1.1.5. Heavy metals

The lead (Pb) values ranged 0.61-0.81 and averaged 0.70±0.08 mg/l (table 1 and figure 3) that are significantly higher than that reported from Egypt (Salam and Zuid,2015), Nigeria (Ogundira and Afolabi,2008) and India (Naveen et al, 2017), Manganese (Mn) and Chromium (Cr) were not detectable in all the collected leachate samples. Copper (Cu) ranged 0.86-1.03 mg/l, whereas, mercury (Hg) ranged 0.00-0.02 mg/l. Nickel (Ni) ranged 0.03-0.08 mg/l a value closely comparable to those observed at several locations viz. Egypt (Salam and Zuid,2015), Nigeria (Ogundira and Afolabi,2008), India (Naveen et al, 2017). Zinc (Zn) in the the collected samples ranged and averaged 5.6-9.3 and 7.6±1.6 mg/l, respectively, which is much higher than the values reported for Egypt (Salam and Zuid,2015), Nigeria (Ogundira and Afolabi,2008), but relatively closer to that observed in India (Naveen et al, 2017). The Cadmium (Cd) values ranged and averaged 0.03-0.09 and 0.06 0.02 mg/l that is very close to similar observations in Egypt (Salam and Zuid,2015) and India (Naveen et al, 2017), but much higher than that observed in Nigeria (Ogundira and Afolabi,2008). It is important to note that, in general, the values for heavy metals are found to be relatively higher for the fresh leachate.

3.1.1.6. Microbiological characteristics

The *E.Coli* and total coliform values were found to be nil for May leachate samples but ranged 174-201 MPN/100 ml in June samples with the higher limit representing the fresh leachate. The values are within the range 50-8100 MPN/100 ml reported by Umar et al. (2010) for Malayasia.

Table 1 is available in the Supplementary Files.

3.1.1.6. Seed germination under leachate treatment

The experiment on Pea seed germination under different concentrations of landfill leachate treatment showed important results. Out of the 5 seeds (treated in triplicate for each leachate concentrations; 0, 25, 50, 75 & 100%), significant impact of different concentrations was observed on the various morphological parameters representing the germination (table 2 and figures 4,5 & 6). The seed germination, represented by number of successfully germinated seeds (out of 5), showed rise (37%) and best germination rate at 25% leachate concentration (Table 2 and Figure 6) that subsequently lowered and with 100% leachate showing lowest germination rate, even lower than the 100% distilled water treatment, showing that the leachate because of various pollutant helps germination of seed when added in small quantity, but prohibits germination at higher concentration. This probably represent that the pollutant components, possibly organics and mineral nutrients helps seed germination, whereas, at higher leachate concentration the nutritional value of the leachate is dominated/masked by the toxic components of the leachate that prohibits germination, lowers the germination rate below even that observed for the pure distilled water; also possibly causing majority of the seed to die and decompose/degrade.

Result of ANOVA test performed on the germination parameters results i.e 'number of leaves', 'shoot-length' and 'root-length' and 'number of branches'. This showed that the mean values for the four germination parameters showed statistical difference between the different leachate treatment concentrations. These germination parameters showed improvement with the increasing leachate concentration up to 50%, thereafter subsequently lowered with increasing leachate concentrations (Table 2 and Figure 6). The 'number of leaves', 'shoot-length' and 'root-length' as well as the 'number of branches' showed maximum values at 50% leachate concentration and continuously falling values thereby (Table 2, Figure 5 and Figure 6). These possibly suggest that pea seed germination is boosted by addition of smaller amounts of landfill leachate and is adversely affected at its higher concentrations. This suggests that the sampled Adigrat landfill leachate contains certain components that have nutritional value for the pea seed germination, but there exists certain other components or characteristics that forbid pea seed germination. This showed the possible toxic properties that the landfill leachate has that may be detrimental for growth and survival of vegetation that is exposed to such leachate (Olivero et al., 2008). This result shows that the leachate is an environmental concern associated with the landfill of Adigrat town that should be considered seriously.

Table 2: Leachate treated seedling morphological characteristics after germination (in Avg. ± SD)

	T1	T2	T3	T4	T5
Seeds Germinated (Nos.)	2.7±1.5	3.7±0.6	3.0±1.0	3.0±1.0	1.3±0.6
Leaves (Nos.; Avg.)	6.0±5.3	11.1±3.6	14.9±1.2	11.6±1.9	9.8±3.7
Branches (Nos.; Avg.)	1.7±1.1	3.4±0.8	4.3±0.7	3.3±0.7	3.2±1.0
Shoot Length (cm; Avg.)	11.8±9.3	20.8±8.9	28.4±2.3	15.3±5.3	6.9±3.0
Root Length (cm; Avg.)	3.1±2.2	4.2±0.6	4.8±0.4	2.3±0.3	1.7±0.2

4. Conclusion

Physiochemical and biological characteristic of the Adigrat landfill leachate showed that pertinent environmental concerns associated with the leachate components. The results show that there are several unacceptable components detected in the Adigrat landfill leachate and at such levels that can be serious environmental concern. The pH, hardness and alkalinity can have bearing for the soil or water that gets contaminated by the Adigrat landfill leachate, which can subsequently affect the vegetation in the area. The low pH can add corrosiveness to any contaminated environmental components. The anions like Cl^- and heavy metals like Pb, Zn and Cd detected in the leachate can also be concern for any possible environmental exposure. The leachate treated pea seed germination experiment further support existence of such components in the leachate that mask the nutritional property of the leachate during germination; further supporting the concerns related to the leachate characteristics. Therefore, the results support both initial hypothesis of this study in that the contaminants are beyond WHO permissible limit and has toxicity effect on *Pisum sativum*. Hence, appropriate recommendations are listed below. The Adigrat landfill leachate can thus have serious environmental implications which have the potential to aggravate in future as the waste load increases and characteristics changes with the fast growing developmental activities and population in the area. It is therefore important to consider following as part of the solid management and landfill management practice of the Adigrat town, and as part of further study on Adigrat landfill leachate:

1. There should be no leakage in the drain, channels and the tank carrying and storing the leachate.
2. Any overflow of the leachate be avoided.
3. The leachate should be treated properly before discharge into the environment.
4. The leachate characterization should be carried out for longer time periods, possibly covering different seasons and temporal spans.
5. The leachate should also be characterized for xenobiotic organic compounds and those other components that have not be covered in the present study.
6. Dedicated experiment should be conducted to identify the toxic components of the leachate and scale their potential to affect the environment.
7. Technologies, such as, waste to energy, composting, recycling and waste reuse need to be taken in to consideration to improve waste disposal, handling and reusing practices in the Municipality.

Declarations

Declarations

Availability of data and materials

All data generated or analyzed during this study are included in this published article

Competing Interest

The authors declare that they have no conflict of interest.

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Authors' contributions

Each author has made substantial contributions to during proposal development; the acquisition of data, analysis and interpretation of data, draft writing and revising the work**.** Finally all authors read and approved the final manuscript

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Table

Table 1 is available in the Supplementary Files.

Figures

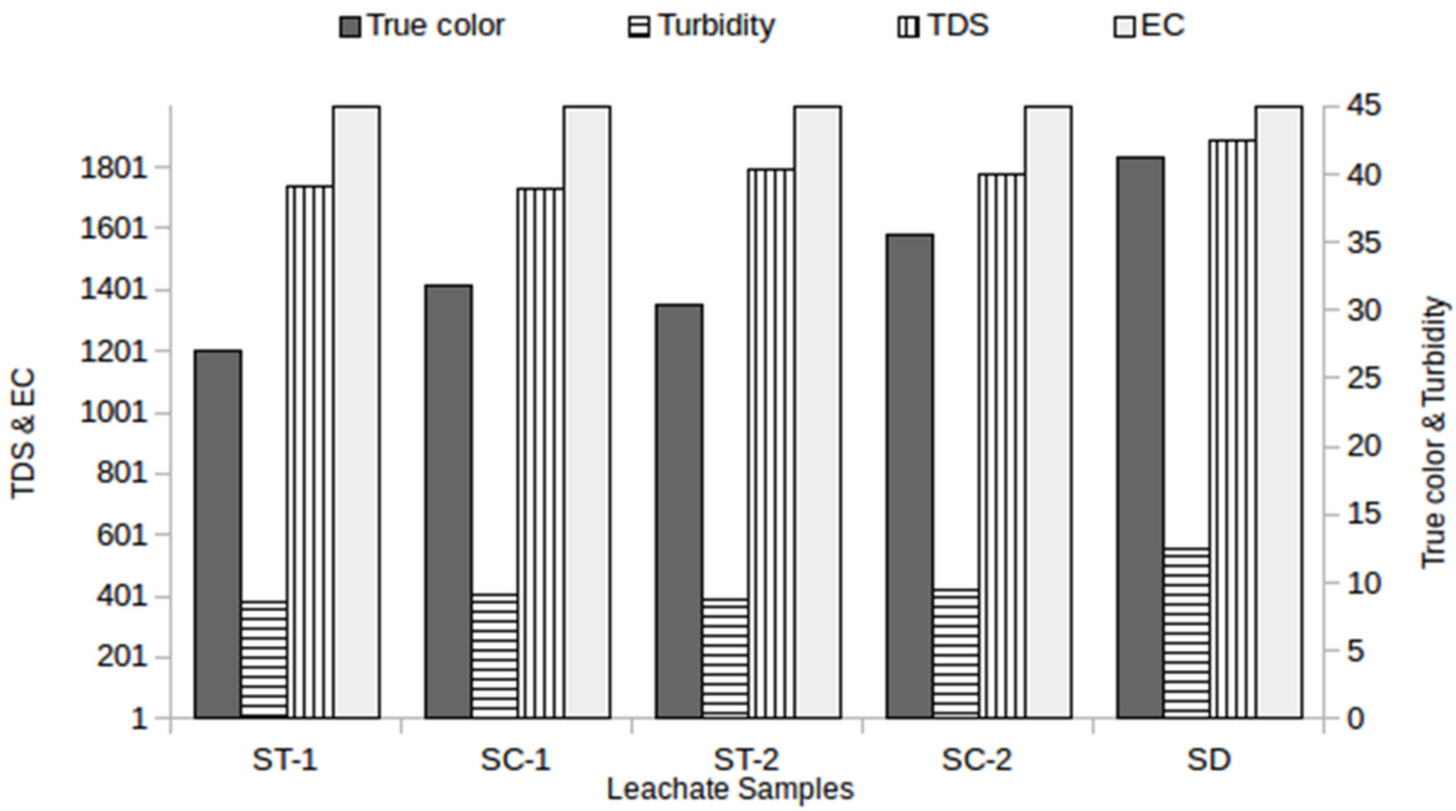

Figure 1

Color (CTU), turbidity (NTU), TDS (mg/l) and EC (mS/cm) of Adigrat landfill leachate for May (ST1 and SC1) and June (ST2, SC2 and SD).

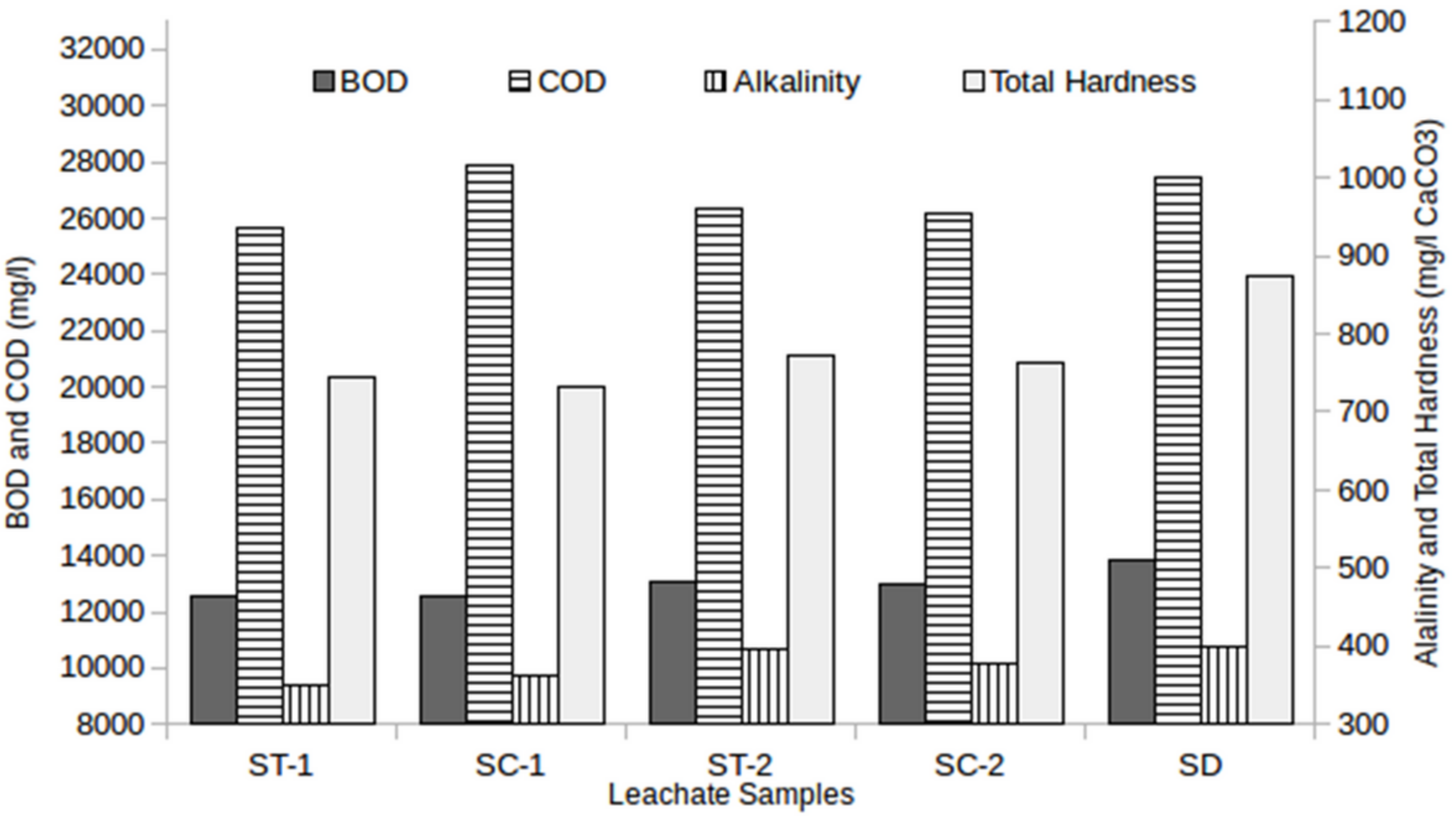

Figure 2

BOD, COD, Alkilinity (as CaCO3) and total hardness (as CaCO3) of Adigrat landfill leachate for May (ST1 and SC1) and June (ST2, SC2 and SD).

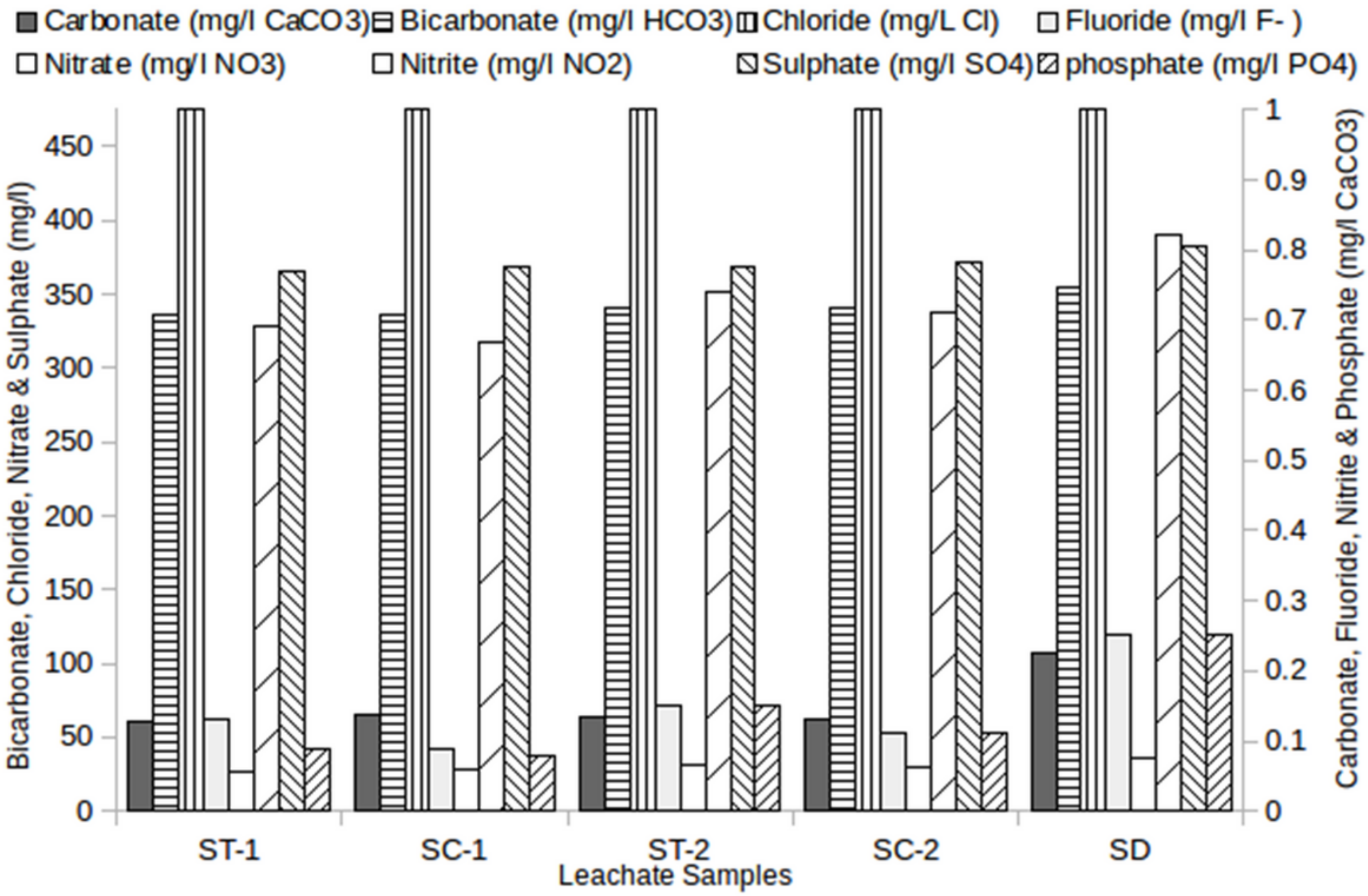

Figure 3

Anion concentrations (mg/l) for Adigrat landfill leachate for May (ST1 and SC1) and June (ST2, SC2 and SD).

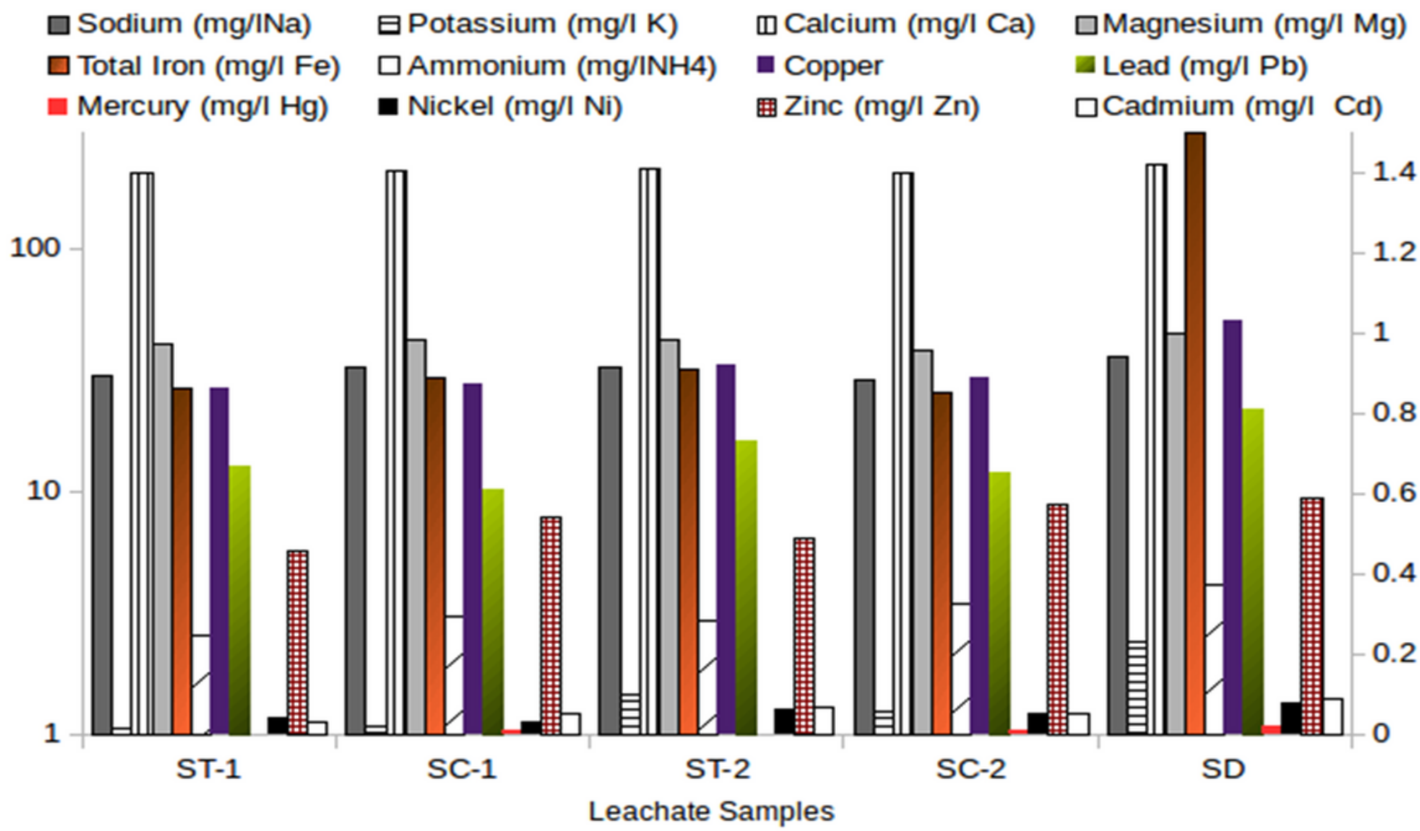

Figure 4

Cation concentrations (mg/l) for Adigrat landfill leachate for May (ST1 and SC1) and June (ST2, SC2 and SD).

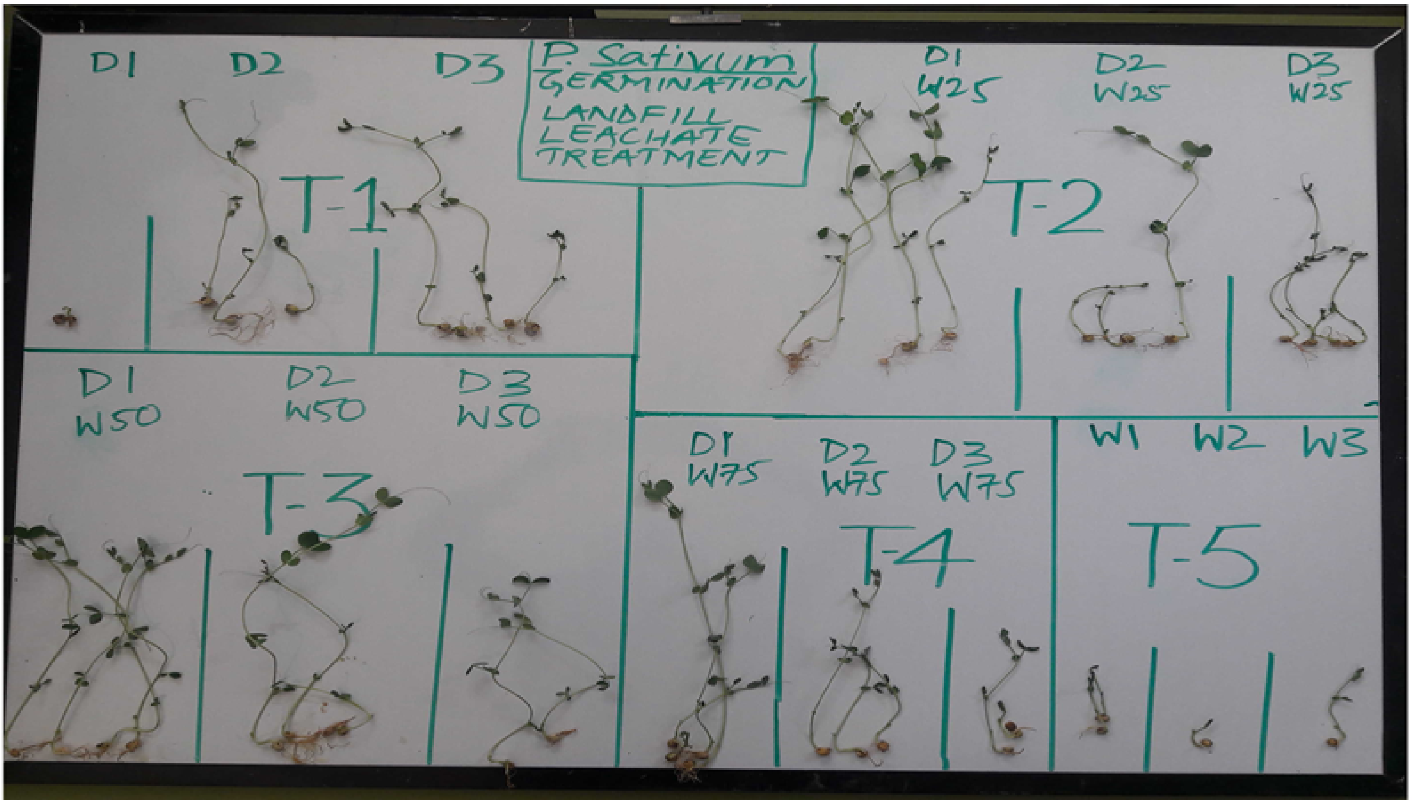

Figure 5

Experimental set-up for comparison of pea seedling morphological characteristics for T1, T2, T3, T4 and T5 treatments. The successfully grown seedlings germinated in triplicate are compared for various parameters.

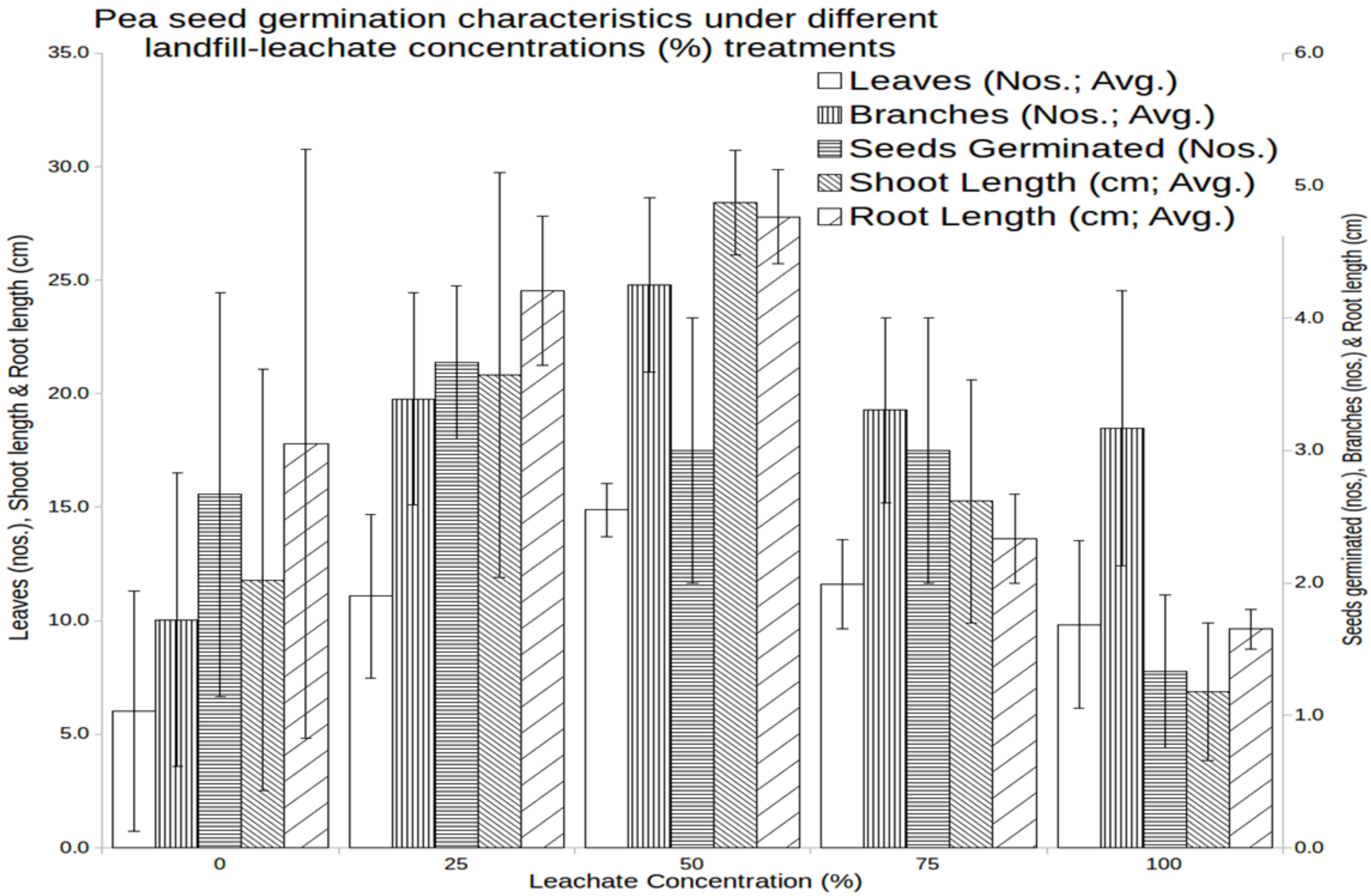

Figure 6

Pea seedling morphological characteristics for 0, 25, 50, 75 & 100 % leachate treatments.

Supplementary Files

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- Table1.png