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Geonets and Geotextiles as Leachate Containment Materials in Landfills: System Dynamics Modeling Perspective

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Abstract: The effectiveness of geonet, geotextile and their composite as containment materials of landfill leachate has been examined in this paper through the use of system dynamics modeling method. The study area is Oriire Local Government Area of Oyo State, Nigeria. Three materials were studied, which include: GN (geonet), GT (geotextile) and GC (geocomposite). The water absorption, hydraulic conductivity, porosity and thickness were the major properties studied in these liners. Governing equations coded in Visual Basic Computer Programming Language was employed in developing a model. Validation of the model was done with data on the study area. The interrelationship of the properties and the breakthrough times for each material was found through the STELLA 9.1.4 software application. This research showed that the effectiveness of the studied of the order GC < GN < GT. GT is, therefore, recommended for use as landfill liners in the study area.

Key words: System dynamics, geonet, geotextile, liner, Ogbomosoland.

1. Introduction

Geonet and geotextile materials are usually being employed as geocomposite materials in leachate containments during the operation of landfills [1]. The geonet is a high density polyethylene net that is usually placed either above or below the geomembrane liner. This net is used as a collection system for the leachate produced by the solid waste. The second component that makes up the geocomposite liner is a non woven geotextile. This geotextile is bonded to the geonet either on one side or both [2]. The purpose of the geotextile is to prevent any soil from clogging the geonet. This ensures proper collection of the contaminant. The geotextile, when laid over a textured geomembrane, acts as a adherent preventing the geocomposite liner from slipping on the steep slopes of the landfill cell. The geocomposite leads to the final step of the lining system.

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Since this geonet is placed directly on top of the primary liner there is usually a geotextile that is bonded to it to prevent clogging from the cover soil. Most systems that use the textured geomembrane will also use the double bonded geocomposite [3]. A secondary lining system is usually installed because of requirements for leak detection systems. This secondary system is to monitor the primary liner on a regular basis. The secondary system is the same as the primary system consisting of a layer of geomembrane and either geocomposite or geonet.

Leachate is generated when there is excess water passing through stored waste mass dissolving soluble substances. Bottom liners of landfills may contain one or more layers of clay or a synthetic flexible membrane (or a combination of these). As such the common liners include CC (compacted clay) and GC (geo-synthetic clay) [1]. The control of leachate emanating from landfills can be accomplished either by preventing the precipitation from entering the refuse using appropriate covers or through a more realistic approach of containment/barrier and collection system [4].

The principal use of the geonet, geotextile and other liners is to contain the contaminants of solid waste emanating from the landfill after the decomposition of the wastes. Geosynthetic liners have been widely embraced perhaps owing to their moderate costs of procurement, operation and maintenance.

Models and their data have found their applications in various areas of waste management systems and strategies. Some of these include waste collection services [5], infrastructural provision [6], treatment facilities and capacities [7]. Several models are identifiable for waste management but system dynamics model appears to be the latest and comprehensive and is therefore extensively applied [1]. This fact has led to the adoption of system dynamics modeling technique in this paper.

This paper attempts to model the effectiveness of geonet, geotextile and their composite in application as landfill liner containment using the system dynamics method. The selected case study is Oriire LGA (local government area) of Oyo State Nigeria. Oriire LGA has an average population of 150,628 going by NPC (National Population Commission) census [8]. It lies approximately on Longitude 4°18' East, Latitude 8°10' North and situated in the transitional zone between rain forest and savannah region [9].

2. Methodology

2.1 Material

The studied materials were GN (geonet), GT (geotextile) and GC (geocomposite). These materials were all lain at 20° slope angle in the design. The properties studied and employed in data validation as presented in Table 1 on these liners are:

(1) water absorption;

(2) hydraulic conductivity;

(3) porosity;

(4) thickness.

2.2 Governing Equations

The main governing equations are presented below:

(1) Leachate generation equation, as given by Ref. [10] (N cells, i = 1):

$$LQnT\,(n\Delta t) = W4(t) - Wg(t) + \Sigma LQn(\,i,\,(n - i + 1)\Delta t \quad (1)$$

where,

LQ_nT = accumulative amount of leachate generated from the system;

$n\Delta t$ = number of waste cells at the given time;

$W4$ = overall mass of water entering or leaving the dumpsite;

W_g = total water loss due to degradation;

LQ_n = overall leachate quantity generated from a single cell;

n, i = counters;

t = breakthrough time of the liner;

d = thickness of the liner;

α' = effective porosity;

K = coefficient of permeability;

h = Hydraulic head.

(2) The equation for breakthrough time t [11]:

$$t = d^2\alpha' / K(d + h) \quad (2)$$

where,

d = thickness of the liner (m);

α' = effective porosity;

K = coefficient of permeability (m/s).

(3) Liners Leakage rate q_i's equation [11]:

$$q_i = K\left[1 + \frac{y\cos\phi}{d}\right] \quad (3)$$

where,

K = coefficient of permeability (m/s);

d = liner thickness (m);

ϕ = the liner slope (measured in angles);

y = the leachate depth over liner (m).

2.3 Coding, Computer Programming and Simulation

The equations were coded using the Visual Basic Language. The variables constitute the key elements of the model. These variables include water absorption, hydraulic conductivity, porosity, and liner's thickness.

Table 1 Validation data for the geonet, geotextile and geocomposite samples [1, 3, 12].

Material	Water absorption (%)	Hydraulic conductivity (x 10^{-9}) m/s	Porosity	Thickness (m)
Geonet, GN	2.65	1.74	2.58	0.075
Geotextile, GT	2.34	1.50	2.29	0.060
Geocomposite, GC	2.59	2.31	2.52	0.010

Their relationships were formulated mathematically and the system dynamics structures applied in developing the source codes. Once the parameters and the initial values for the state variables (stocks) were specified, the model became definitively determined through the program. The stock flow diagram of the system was designed using STELLA 9.1.4 software and simulation package. The principles of system dynamics were applied to determine the interrelationships of leachate and the GN, GT and GC liners retention ability. These were simulated to predict the results for the next 50 years using year 2006 data as initial values in the stocks of the flow diagram. Causal loops indicating the linkage of leachate generation and variables with the breakthrough time were developed. The STELLA flow diagram of the model is shown in Fig. 1.

2.4 Validation of the Developed Model

To compare the model results with historical data

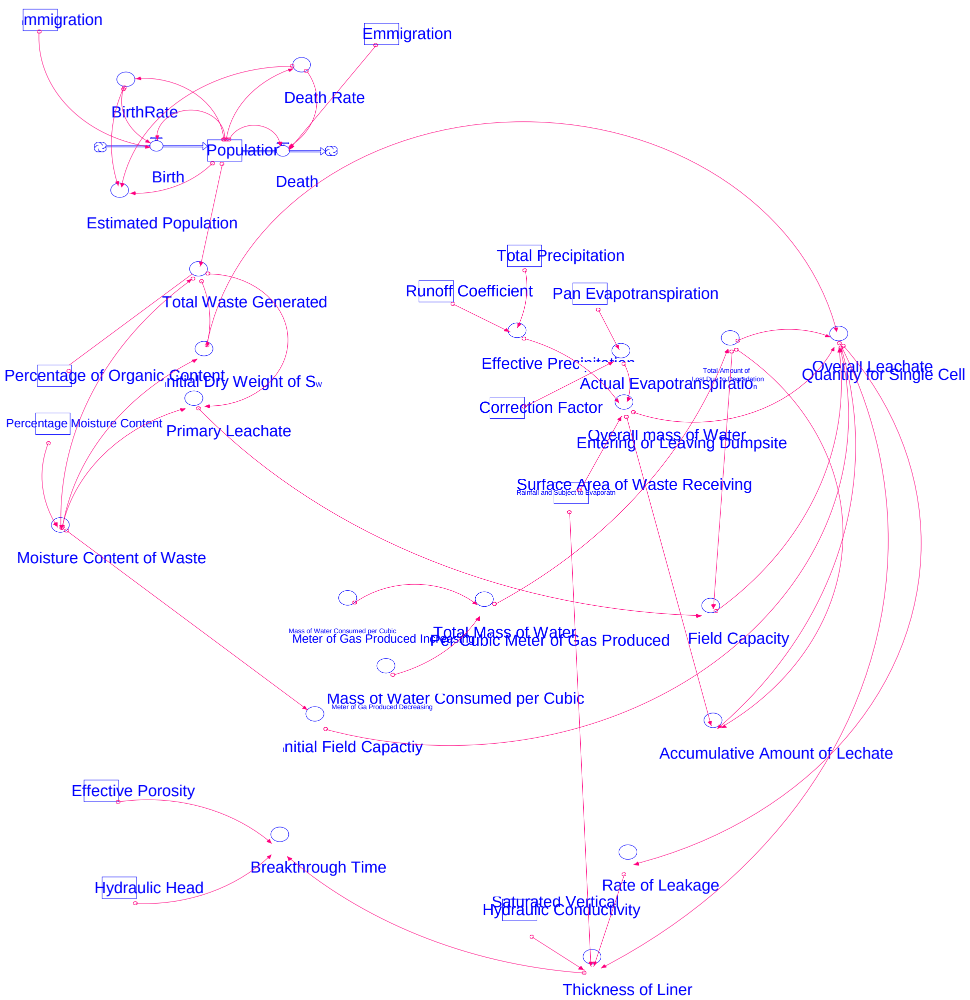

Fig. 1 The Stella flow diagram of the model.

and to check whether the model generates plausible behavior there is need for its validation. The developed model was validated by applying it in the assessment of practical problems of leachate pollution containment with GN, GT and GC in Oriire LGA.

3. Results and Discussions

The results of the simulation for 100 years performance of the studied liners depicting the behavioral patterns one year after the other are as presented in Figs. 2–4.

Fig. 2 shows that the breakthrough time (i.e., the time it would take the modeled quantity of leachate to penetrate the given liner material) for the GN liner is 10,037,250 s or 117 days. The respective durations for GT and GC as depicted in Figs. 3 and 4 are 10,039,523 s (118 days) and 10,033,746 s (116 days). The summary of these results are presented in Table 2.

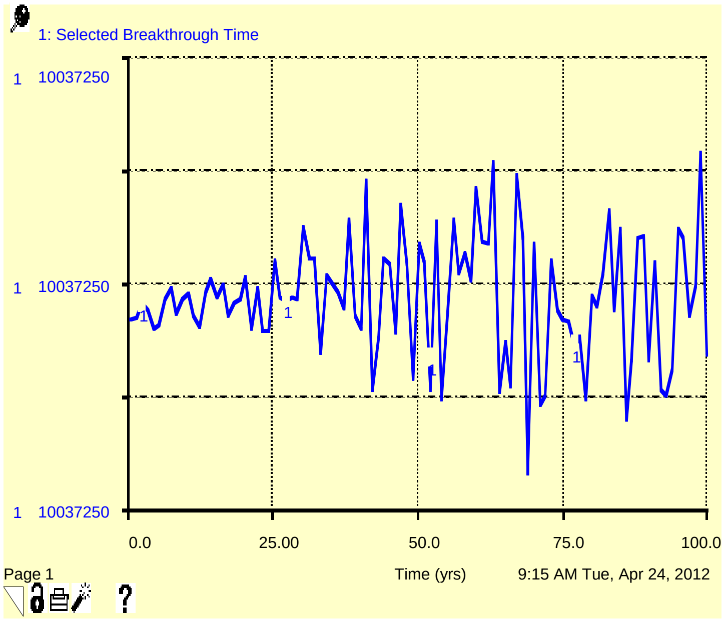

Fig. 2 Breakthrough time graph for GN in Oriire LGA.

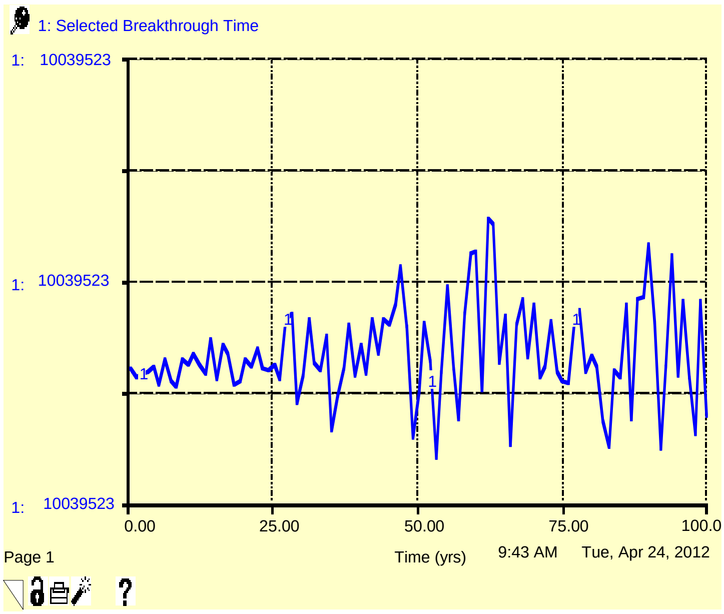

Fig. 3 Breakthrough time graph for GT in Oriire LGA.

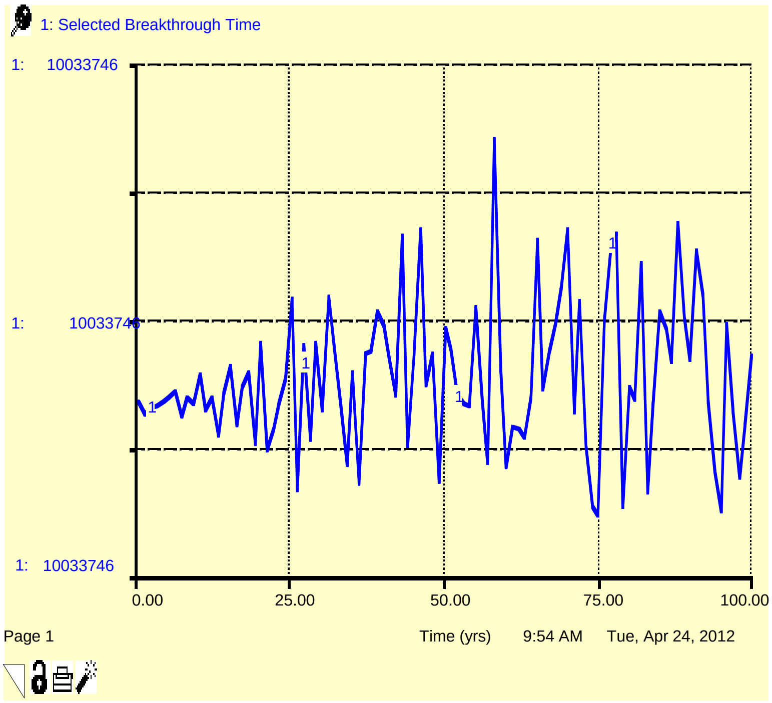

Fig. 4 Breakthrough time graph for GC in Oriire LGA.

Table 2 Breakthrough times of the studied Geomembranes.

Material	Breakthrough time (s)	Breakthrough time (day)
GN	10,037,250	117
GT	10,039,523	118
GC	10,033,746	116

4. Conclusions

This research clearly shows that the effectiveness of the studied geomembrane material liners is of the order GC < GN < GT. The longest breakthrough period discovered for the application of geosynthetic liners in Oriire LGA of Nigeria was 118 days. It is, therefore, recommended that the use of geotextile liners for landfill leachate containment in the study area should be highly encouraged.

The GT, therefore, has the highest retention capability for the leachate volume simulated for 100 years in the study area. This perhaps is linkable to the fact that it has been reported to possess the lowest water absorption rate [3] and as shown in Table 1. The GC, however, recorded the lowest breakthrough period and thus found to be the least capable of the three studied liners.

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