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Kachok Dumsite Characteristics and Its Future – A Third Kenyan City Perspective

Kabok P Aguko*, Michael O Oloko, Stephen G Agong and John Odiaga Oloo

Jaramogi Oginga Odinga University of Science and Technology, Bondo, Kenya

Abstract

47 Counties inclusive of Kisumu were created as regional administrative units by the Kenyan constitution 2010. The County Government immediately redirected Solid Wastes from other county's townships to be disposed at the existing 2.73 ha Kachok dumpsite. However, the disposal of solid wastes by observation from collection, transportation to dumping has been having challenges. A compelling aim to re-assess the dumpsite arose to determine if it satisfies minimum siting standards, characteristics and potential for the County. Findings show the dump is not properly sited and is at 10% or lower collection rate of the city's wastes since the 1970's, it is full beyond capacity/potential and a nuisance. The rate indicates need for improved planning, regulation and enforcement for the city and the county. The average dump composition in the order of plastics, glasses and organic matter is 34.7, 13.8 and 51.8% and weight per volume that varied by depth/age with an estimated volume of 6853 m³. It has high carbon content (>2%) and heavy metals have not found their way into the groundwater system. Presence of NO_3 though shows groundwater pollution is taking place. Air quality parameters exhibited similar trends with higher concentrations over the dumpsite, reducing outward with the nearby sensitive receptors impacted. The dumpsite should be relocated with caution and use of its organic contents directed to agriculture. The other possible uses such as extraction of energy and recycling of waste contents may need review as dumps depository potential is outlived.

Keywords: Dump site; Characteristics; Potential; Agriculture; View point

Introduction

Solid waste management (SWM) is today undertaken by the City of Kisumu as a delegated responsibility of the County Government of Kisumu (CGK), one of the 47 devolved systems of Governments in the western region of Kenya [1]. The Department of Environment (DOE) carries out the services under sections of; Street Sweeping, Refuse Collection and the Dumpsite Management. Besides, there are Community Based Organizations (CBOs), Non-Governmental Organizations (NGOs) and private companies. Estimates in Kisumu City show that about 35 organizations are involved in sorting at source, collection, transportation, recycling, and creating awareness on SWM. Yet, it is estimated that only about 10% [2] of the SWs are disposed compared to Nairobi at approximately 40% [3,4]. This activity with the advent of CGK, has been expanded to cover wastes generated in other county County townships (Ahero, Maseno and others) while the main disposal site remains the 2.73 ha at Kachok dumpsite from 1970's. This expansion though is insignificant in extent and characteristics, but has not been properly structured and determined.

Today, the planning and regulation of waste management in Kisumu City is limited and cannot be qualified and quantified appropriately. The unplanned dumping site at Kachok was formalized in the1990's when then the Municipal Council posted employees to attempt some control but with lack of regulation. Government of Kenya outlines the environmental requirements for waste disposal in Kenya were not enacted then [5].

The Kachok dumping started in around 1975 due to increased business within the Kisumu town and that the present Kibuye Market was rejected by the locals as a dumping site. The enhanced business started with the advent of the railroad that reached Kisumu (then port Florence) in 1901. In 1903 the township boundaries were gazetted and in the 1930's and 1940's, the city became a leading East African Centre for military, investment and administration. Some 12,000 acres, including water was thus set aside for its development. It was extended to 53 km² that included the populated Peri-urban settlements of Manyatta and Nyalenda in 1976. The town is now the third largest in Kenya after Nairobi and Mombasa. Evidence though show that Kachok Dumpsite was reserved for a sisal factory in the 1960's but later for public use as Government Trust Land. Surprisingly, no major thought for future has been devoted to a dumpsite for Kisumu town and the environs and even for Kisumu County to date. This is common in Kenya for the counties and county major towns today.

The city's population on the other hand has grown over the years. At the present growth rate of 4.74%, Kisumu's population is now estimated at 560,000 people. It is characterized by dependant young people; three quarters of who are under 30 and 43.5 percent are under 15 years old. Today, 50% Peri-urban area houses the highest population density at 10,000 people per km2, the urban areas at 1,500 to 3,000 people and the rural areas at 170 to 680 people per km². It covers an area of 297 km² of land and 120 km² under the Lake Victoria.

As noted in Khamala EM et al. Nairobi population density at approximately 2.2 million is way above Kisumu City [6]. It is the nearest City for comparison of progress and challenges of SWs management, needless to mention the other African and world cities. No area of Kisumu City today is within the high density range of Nairobi (>30,000 people per km²). The Kisumu Peri-urban areas population density is only at 10,000 people per km², which is within the lower range of the Medium density population of Nairobi (5,000 to 29,000 people per

km²). The urban areas are still within the low population density of Nairobi (<5,000 per km²). The question is; at what stage is solid waste management going to be enhanced within Kisumu City and to include Kisumu County. A study was therefore conducted at the dumpsite to determine; the state of the Kachok dumpsite, its material and suitability to minimum standards for Kisumu Town, County and the future. Of great concern, were the volume characteristics of the waste, water flow and water quality, surrounding dynamics, evaluation and way forward.

Materials and Methods

Dumpsite general characteristics

Literature review and observation show that in Kenya and most African countries, solid wastes are disposed of by way of open and controlled dumping at designated and non- designated dumpsites [7-10]. The order in effective control in this case decreases in standards from Cities, towns, townships, village markets and to villages. These can all be observed at the Kachok dumpsite and the Kisumu County.

Dump sites are the most commonly used method for waste disposal in the world [11], Weiss S applies this for Kenya and Kisumu County through observation and records as in Tchobanoglous et al. [12] who states dumpsites are for disposal of solid or semi-solid materials from human and animal activities that are regarded useless, unwanted or hazardous. Visvanathan et al. [13] points out that dumpsites are the easiest option of final disposal in most developing countries–and a matter of transporting the collected waste to the nearest available open space for discharge. Jung et al. [14] notes open dumping to have potential of reducing environmental quality in neighbourhood, poses threat to public health, the environment including scavengers who depend on it for their livelihood. Consequently, the following associated environmental and health hazards and risks which were noted for Kachok by observation and may be experienced continuously [14], in and around many dumpsites in Kachok Waste disposal site [2], and include and not limited to; Unpalatable odour dust emissions, poor aesthetics, environmental nuisances, attraction of vermin, vector and pest, severe health risks to human beings and animal, breeding of disease vectors, flies and rats.

Site physical characteristics

Apart from the characteristics within and immediately around Kachok dumpsite, the key aspects that are considered for the suitability of dumpsite are capacity and the surrounding location. Ravindra et al. points out the location characteristics that should have been looked at in the case of Kachok dumpsite, but were omitted for reasons of time of initiation [15]. These included and not limited to land use and cover, slope, geology, population projections, soils, distance from roads, rivers, residential areas, airports, canals, lakes and of late in Kenya the community participation. These were reviewed against the present status and the larger overview of the surrounding.

The location characteristics for Kachok Dumpsite as is listed in Ravindra et al. were estimated in a GIS environment [15]. It was noted that Geographic information system (GIS) today is a good decision support tool for planning waste management. Kontos et al. helps in analyzing optimal locations for transfer stations; planning routes for transporting wastes from residential, commercial, industrial customers to holding grounds and to landfills; new locations and monitoring the landfills [16,17]. It provides a digital data bank for future monitoring of the site program and reduces time and cost of the site selection. Keir A confirms that initiatives have been taken for example to setup GIS such as ArcInfo and ArcView as key components for managing

this information [18]. Republic of Kenya Emphasizes that the trend is towards desk top GIS which has been significantly increasing [19]. Even, ESRI released ArcInfo NT as a substitute to ArcInfo at a workstation. Similarly, many other GIS software vendors have adopted such for example Small World and GenaSys [7].

Dump compaction - height and volume reduction

The dumpsite characteristics were determined from the surveyed topographic area. Samples were taken at point locations by depth and spread for analysis. The survey was to ascertain topographic area, chemical parameter characteristics, contours, volume of selected sample area (portion) for a compaction test (Figure 1), where use was made of a tractor roller on site.

A reconnaissance (pre-visit) survey was undertaken plus creation of control points for the larger area inclusive of a selected portion. Sport vertical heights were picked at interval of 6 m and 10 m. The co-ordinates and point heights were booked for determination of volume and area in the two cases, before and after compaction. The selected area was for determining the effectiveness of onsite use of the tractor roller in compaction.

The Total Station survey equipment and the TopoCAD (software) were used for picking the boundary of the plot, vertical heights and for plotting the field data (x,y,z). The data were for generation of contours, area of the plot and for determining the volume of dumped materials above the ground surface. The total volume of the dumpsite was therefore estimated from the compacted select sample area (0.77 ha) against the total area (2.73 ha), for assumed density of 450 kg/m3 and measured average height or depth of the dump as 6.5 m.

In order to understand the dumpsite chemical characteristics, the shape and depth were taken into account and four locations (A, B, C, D, E) within the dumpsite were selected as in Figure 2. Samples were collected at the locations at different depths from the top to bottom surface of the dumpsite (at 2 m, 4 m and 6 m) by use of excavator (sample) scoops from the varied depths. A spade and sack were for collecting the samples from the excavator scoops. The samples were weighed by a spring weighing scale (kgs) and sorted out into; Polythene and Plastics (P/P), Glasses and the organic materials. Each of the sorted
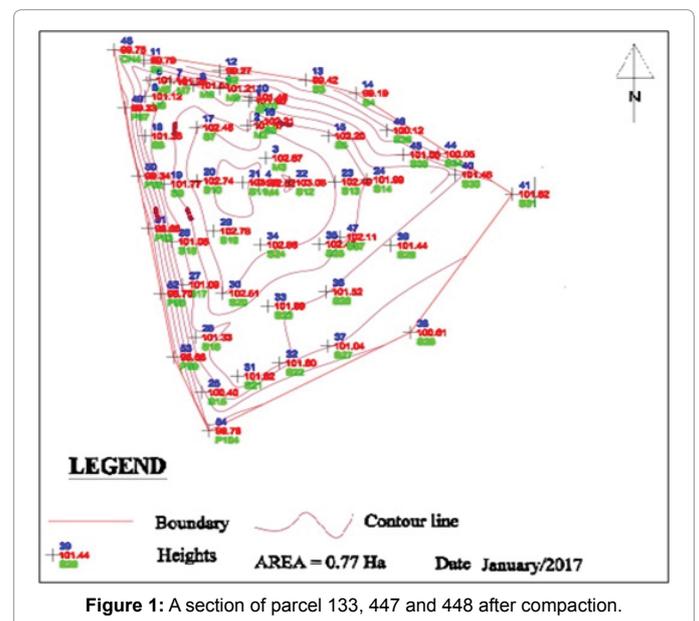

Figure 1: A section of parcel 133, 447 and 448 after compaction.

Figure 2: Sampling positions.

materials was individually weighed.

At the predetermined locations and depths as in Figure 2, samples picked were taken for analysis at KALRO Laboratories in Kisumu town for parameters for which reagents were available. The samples were foremost prepared ready for analysis. The basic chemical characteristics determined were; pH (in water at ratio of 1 sample: 2.5 water); Fe (iron) and Cr (chromium)–in atomic absorption spectrophotometer (AAS) after extraction using concentrated Sulphuric acid (wet digestion); OC (organic carbon) – using Wakley Black method involving extraction by a mixture of dichromate solution, Phosphoric acid and Sulphuric acid and thereafter titration using ferrous Sulphate.

Dynamics and impact of dumpsite to surrounding

Hydrology and leachate flow: The effect of Kachok dumpsite on surface water and groundwater bodies was evaluated from samples taken at various points along the drainage channels as in Figure 3. Water samples were taken from a long road side storm drain, the dumpsite, and the channel that partly drains the swamp east of the dumpsite, a spring at Pembe Tatu Estate with origin from the swamp, irrigation canal below the swamp area, Auji stream and a spring within the swampy area. The tests for parameters were guided by the Republic of Kenya [19] and the Kenya Standards KS 05-459, Part 1:1996. Leachate from the dumpsite periodically flows as surface flow into the ditches to Lake Victoria through Auji stream. Three storm water drains surround the dumpsite (Figure 3). The first flows along its northern edge into the main ditch (MA14 – 05 to MA14 – 07). The second runs past the dumpsite (MA14 – 03 to MA14 – 04 to MA14 – 01). The last is the main drainage ditch (MA14 – 09 to MA14 – 08 to MA14 – 02) that joins Auji stream which ends up in Lake Victoria – Kenya. These are enhanced by the ground and surface water often pumped from underground basement spaces of the neighbouring properties in cases of construction and during maintenance operations.

The Kachok dumpsite originally is a borrow pit (E340° 46' 10", S 00°06' 21") which is eastward along Kisumu – Kericho - Nairobi road, about 3 km from the City Centre (Central Business District). The City is surrounded by Nyamasaria River to the East and Awach River to the west which constitutes the main drain of water flows to Lake Victoria. This system is augmented by Kisat to the west and Auji drainage channels to the east on the inner side of the two major rivers. These rivers are bound in the north eastern side by the Nyang'ori – Nandi hills and Lake Victoria on the south western end. A number
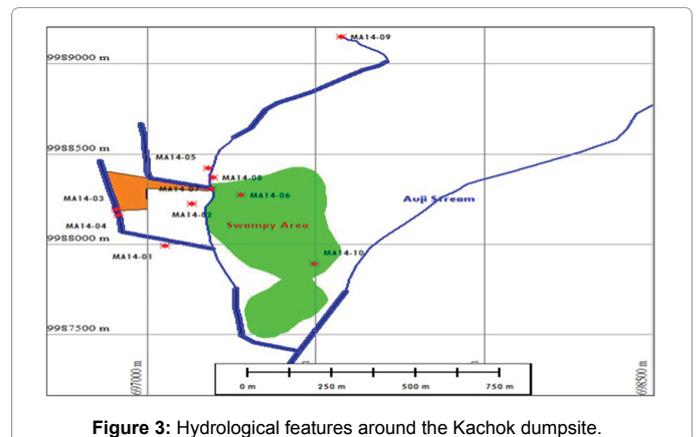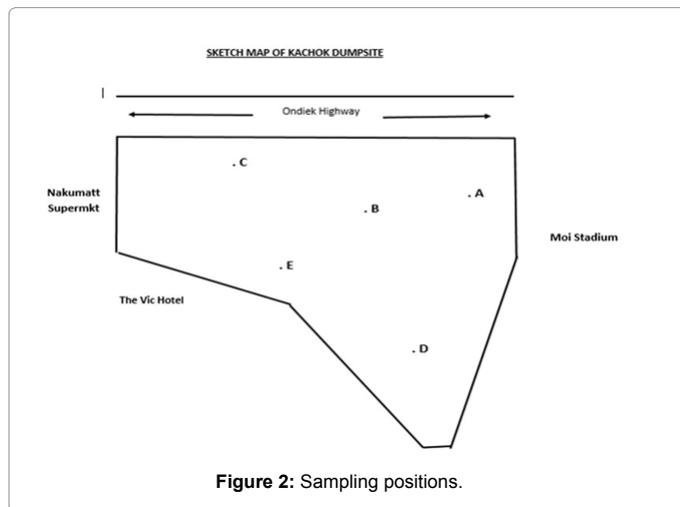

Figure 3: Hydrological features around the Kachok dumpsite.

of constructed drain ditches end up into Auji stream. One such ditch, intimated as perennial in Figure 3, drains the Kachok dumpsite area into an immediate wetland downstream before joining Auji stream.

The flow evaluation was augmented by the K- Conceptual model in a mountain-valley ridge system (Figure 4). According to United Nations Centre for Human Settlements the relative hydraulic conductivity (K) in the valleys in mountainous regions as the case of Kisumu depicts the model in Figure 4. This allows interpretation in the case of Kachok Dumpsite that lies on the peneplain to the Nandi Hills [4]. Figure 4 shows K in the soil/alluvium layer typically in the range of 10^{-4} to 10^{-3} m/s and extends to about 3 m. This diminishes to 10^{-7} to 10^{-5} m/s in the saprolite/weathered bedrock horizon, with further reduction to 10^{-9} to 10^{-6} m/s in bedrock. Groundwater pollution relative to hydraulic conductivity between the various soil horizons (depths) and proximity to the source of pollution hence plays an important role in the Kachok dumpsite risk considerations.

Further, five (5) vertical electrical resistivity soundings tests were undertaken along the Ondiek highway side of the dumpsite to help estimate the thickness and distribution of various soil and lithological horizons. This was done in the direction of MA 14 – 3 to MA14 – 4 as in Figure 4. The soil samples previously taken from the dumpsite were analyzed as sample 1 and the last 4 out of 5 samples were aggregated into one for analysis.

Air quality and noise

The existing background noise levels and air quality were determined in Kachok Waste disposal site from 5 potential noise-sensitive receptors identified from reconnaissance survey and use of a GIS map [2], these were;

- ASP1- Centre of the dumpsite (Old Bus Stage (0° 06' 20.9" S, 34° 46' 12.63" E as point no 1);

- ASP2 - Perimeter fence opposite of Nakumatt City Supper Market (0° 06' 24.33" S, 34° 46' 11.01" E as point no 2);

- ASP3 - River Auji opposite the Kisumu Polytechnic (0° 06' 20.75" S 34° 46' 17.66" E as point no 3);

- ASP4 - Perimeter fence of Makasembo Estate (a residential area, 0° 06' 09.77" S 34° 46' 10.42" E as point no 4);

- ASP5 - approximately 100 meters from the Kisumu Day Secondary School (0° 06' 13.69" S 34° 46' 05.85" E as point no 5).

The five sites (Air sampling points - ASPs) selected were taken as;

Figure 4: K- Conceptual model in a mountain-valley ridge system.
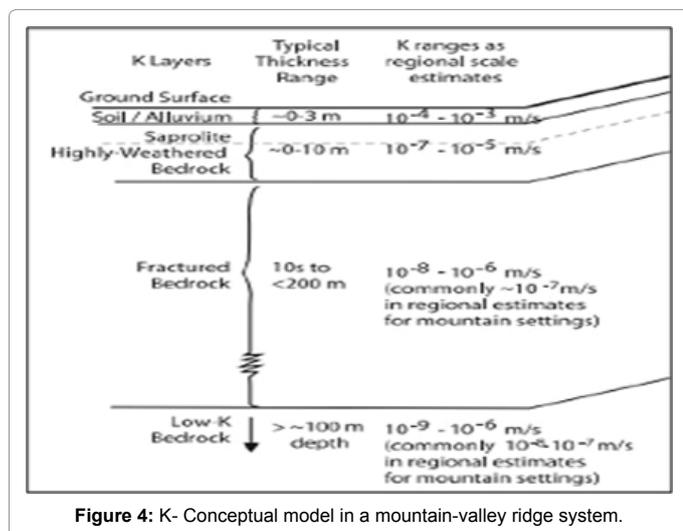
representative areas of the current noise levels around the dumpsite, easily accessible areas under the current conditions, likely to exist after the improvement or any development of the site and were safe for possible night-time measurements and operations.

The environmental noise assessment was undertaken for additional knowledge apart from air quality in August 2017. This was done by a compliant and calibrated Type 1 data-logging Precision Impulse Integrating Sound Level Meter-LAeq. The basis was the international standards for sound level meter specifications (IEC 61672:1999, IEC 61260:1995 and IEC 60651), together with ISO 19961:2003 and ISO 3095:2001. LAeq is based on the A-weighted sound level and defined in energy as opposed to straight numerical terms. However, the L10 measured against the L90 was also used (ISO 1999, 1990). LAeq is widely used as the base for developing a dose-response relationship for community noise annoyance, and especially where noise is relatively steady and broadband. Apart from being related to the level of exceedance of a guideline value, it gives information regarding nature and extent of the noise source. The L90 gives indication of background noise level, L10 represents higher noise levels and together with L50 and L90 they are used for traffic noise impacts.

The measurements were done over a twenty-four-hour period categorized as daytime (07:00-22:00) and night-time (22:00-07:00) for comparison to international guidelines. In each period the continuous A-weighted equivalent sound pressure level (LAeq) of at least 15-minute duration was taken. Abnormal disturbances, such as loud noise generation in close proximity or sudden noise bursts that affect the measurement, were discarded. In addition to the Leq, L5, L50, and L90, the occurring (Lmax) and (Lmin) levels during the measurement period were also recorded. These were appropriate for determination of; noise levels with future operations; background noise when no activities are contributing to the ambient noise levels; nature and the extent of noise.

The air quality sampling was done by the passive diffusive tubes/equipment and absorption cartridges for the gases which were mounted in diffusive bodies and exposed for a period of 7 days. Analyses of the cartridges were undertaken at the SGS laboratory in accordance with standard methodologies (Ion chromatography/GCMS). The laboratory data and sampling duration were used for calculating the gases concentrations. Particulate matter samples (TSP, PM10) were done using High Volume Samplers and concentrations determined gravimetrically. Heavy metal analysis was done using ICP/OES (Cold Vapour Technique).

The wind speeds were measured at the five locations with a portable meter also capable of measuring the wind speed gusts. These baseline assessments were for sampling and analysis of all wind directions and for TSPs, H_2S, PM10, PM2.5, NOx, VOCs, and heavy metals.

Results and Discussion

The collection and disposal of solid waste today in Kisumu town and environs is the responsibility of Kisumu County government through a department assisted by CBOs, NGOs and individuals under various arrangements. It is estimated that 10% [2] of wastes is handled compared to 40% [1], for the capital city of Nairobi. The gap means Kisumu city and the County government need to review and re-direct the SWM intention for future improvement of the system. The key word in this case is proper planning, regulation and enforcement to constantly minimize the gap, Planning need to be for long range to cover every part of the county, which is absent as of now.

Siting of solid waste dump

Kisumu County is concentrating on solid wastes of Kisumu town and are yet to site and give a comprehensive consideration at village markets, townships, and designated towns and even to Kisumu Town itself. The Kachok dumpsite in terms of its suitability then and now is reviewed against parameters according to Ravindra et al. with the numerical weighting factors as indicated from 1 to 10 [15]. The estimates are; Soils (moderately suitable - 3), Distance to Residential area (unsuitable -1), Distance to Airport (highly suitable - 4), Distance from canals (Unsuitable - 1), Distance from lakes (highly suitable -4), Distance from rivers (unsuitable- 1), Distance from roads (Unsuitable 1), land use/land cover – 2), population density (Unsuitable - 1), Geology (moderately suitable – 3), Slope (moderately suitable -3). Adding the weighting factors and determining the suitability characteristics average (24/12 = 2) according to Government of Kenya, the Kachok dumpsite is categorized between Unsuitable to less Unsuitable [5]. The dumpsite therefore was not suitable from the beginning and should be considered for transfer to another location. The above discussion supports that; i) Kachok dumpsite developed under spontaneity ii) the estimate of handling only 10% of the waste means a need for large improvement in collection and dumping iii) that the dumpsite size, population growth and quantity of wastes estimates do not matarch.

A number of factors hence need to be considered in any study aimed at identifying or review of location of a specific dumpsite which come into play within such surroundings and villages thereof. These today in Kenya are viewed with challenges of economic, social and political factors as is appropriate. The problem is aggravated by the open nature of disposing waste (dump), Kachok included and especially in the slum areas of most African cities [20,21]. In Kisumu County, apart from the city there are numerous townships and village markets that experience the problem in the glare of exiting existing laws, our stage of development and lack of plans for execution since 1960 and needs to be done.

Dump compaction (height and volume reduction)

The Kachok Dumpsite at maximum use covers 2.73 hectares confirmed from the topographic survey that included 0.77 ha for the compaction test. The topography of the dump was undulating due to non-uniform treatment of solid wastes as dumping continued. This is in Figure 1 of the topographic map showing concentrated and dispersed contour lines. The average height of the selected area before the survey

was 101.88 m above sea level and 100.89 m after compaction (Table 1). This resulted in an average height reduction of 0.90 m after compaction (a 68.53 m³ reduction of the 0.77 ha portion of the dumpsite). Out of the survey point heights (45) picked, 19, 12,13,4 and 1 respectively differed in range of change of height after compaction as: 0 – 0.5 m, 0.5 – 1 m, 1.1 – 2 m, 2.1- 3 m and above 3 m. This indicated that; the tractor roller used a spread and compaction approach in handling the dump wastes, that areas with higher level of dump compacted more compared to the lower level of fresh dump. The potion surveyed was also used in estimating Kachok Dumpsite Volume as;

Compacted sample area = 0.77 ha (Figure 1), Total area of the dumpsite = 2.73 ha, Compacted volume- 6,853 m³ (Estimated from survey - Table 1)

Overall average dumpsite depth = 6.5 m (estimated from sample digging 3 m above ground level and 3.5 m below ground level)

Dumpsite Vol = $(6,853 \times 2.73)/0.77 \times 6.5 = 157,930$ m³; Assumed Density = 450 kg/m³

Therefore; Weight in tons = $157,930 \times 450 = 71,068,500 = 71,068.5$ tons

Dump main waste types

Table 2 data show samples taken by weight using a spring balance by depth of the dumpsite as in Figure 2 and named A, B, C, D and E. It is concluded from Table 2 that the plastics percentage on average varied from 12.5 to 48.7%, glass from 6.1 to 51.3% and organic matter from 5.3 to 68.8%. The average in order of plastics, glasses and organic matter is; 34.7, 13.8 and 51.8% as is in Table 2. If outliers in Table 2 are ignored within the columns, the percent plastics, glass and organic matter by depth/location was more or less constant within limits.

In addition, a previous study by Kachok Waste disposal site [2] and by observation within Kisumu City, the type of solid waste (Tables 3-5)

delivered to the Kachok dumpsite may be described as mixed municipal waste; basically categorized as domestic, biomedical, industrial, office, supermarket, e - and farm wastes. Out of these; plastics, metals, tins, PET mineral water bottles, glass bottles, paper, e-waste, chicken feed, furniture/wood, polyethylene bags/jute/sacks/polythene bags, food and flimsy plastics materials are often collected for recycling from the Kachok dumpsite.

The Table 5 findings agree with the evaluation of the dump organic matter in Table 2, that it constitute over 50% of the Dump material, though approach to analysis were different.

These are compatible to what is found in many African cities and includes food, yard, wood wastes, paper, plastic, glass, metal and others; ceramics, textiles, leather, rubber, bones, inerts, ashes, coconut husks, bulky wastes, and household goods.

In terms of agriculture, soil is classified as having high carbon content when organic carbon is greater than 4% (Table 3) and should be applied at a rate of 2.5 tons/ha. The Kachok dump material has high carbon content and can be applied to improve soil to benefit crops conditions. The limits to other elements are as in Table 6 suggested by Riley and Department of Petroleum Resources [22,23]. In the Kachok Sample, the elements were either not detected or are within limits.

Looking at the Table 4 compared to Tables 3 and 6 there are variations. The heavy dangerous metals were either not detected or are within limits (for example Chromium (VI) was not detected). Caution is therefore given that tests should be done from time to time before application in agriculture.

Geology, Leachate Flow, and Soils

The physical nature of the Kachok dumpsite is as explained in Table 7 as given in perspective implementation suggestions by Kachok Waste disposal site study and Figure 1, in addition to air and noise levels

Survey Height Points	Comp. Before	Comp. After	Diff. Height	Survey Height Points	Comp. Before	Comp. (After)	Survey Height Points
M1	102.44	101.66	0.78	P100	100.2	100.09	0.11
M2	102.2	101.87	0.33	R2	101.44	100.77	0.67
M3	101.29	100.87	0.42	P17	103.16	102.66	0.5
M4	104.05	102.52	1.53	P16	102.07	100.56	1.51
M5	103.62	101.14	2.48	P15	100.14	99.92	0.22
M6	102.14	101.12	1.02	P13	102.12	101.09	1.03
M7	101.22	100.99	0.23	P124	102.54	101.06	1.48
M8	101.52	101.11	0.41	R27	103.83	102.78	1.05
M9	101.12	100.21	0.91	R18	100.84	100.23	0.61
M10	101.45	100.46	0.99	R17	100.73	100.61	0.12
P2	105.18	102.33	2.85	TR 4	100.87	100.76	0.11
P3	104.77	101.47	3.3	P137	100.77	100.11	0.66
P89	104.8	102.78	2.02	R24	101.67	101.44	0.23
P90	103.97	101.06	2.91	P31	100.49	100.12	0.37
P91	100.72	100.12	0.6	P32	102.12	100.25	1.87
R4	104.24	103.06	1.18	P140	100.99	100.11	0.88
R3	102.7	102.49	0.21	P141	100.44	100.09	0.35
P95	102.74	101.36	1.38	P139	100.68	100.16	0.52
P94	100.53	100.12	0.41	S30	101.12	100.76	0.36
R6	100.57	100.44	0.13	S31	101.24	100.05	1.19
P96	102.19	101.36	0.83	S32	100.76	100	0.76
P97	100.27	100.1	0.17	S33	101.23	100.12	1.11

R9	102.6	101.52	1.08	S34	101.55	101.11	0.44
P102	100.58	100.44	0.14	S35	102.35	101.78	0.57
P103	101.82	100.76	1.06	Avg.	101.88	100.98	0.9
Area	0.77Ha			Volume	6,853 M^3		

Table 1: Determining survey compaction heights.

Site	Depth (m)	G/W (Kg)	P/P (Kg)	Glasses (Kg)	Organic (kg)	Plastic %	Glass %	Organic %
A1	1.8	76	37	5	34	48.7	6.6	44.7
A2	1.8	76	33	39	4	43.4	51.3	5.3
A3	1.8	80	40	7	33	50	8.8	41.3
B1	4	48	6	13	29	12.5	27.1	60.4
B2	4	50	17	4	29	34	8	58
B3	4	48	12	3	33	25	6.3	68.8
C1	2	29	9	5	15	31	17.2	51.7
C2	4	29	9	3	17	31	10.3	58.6
C3	6	28	7	4	17	25	14.3	60.7
D1	2	28	8	4	16	28.6	14.3	57.1
D2	4	30	11	3	16	36.7	10	53.3
D3	6	33	13	2	18	39.4	6.1	54.5
E1	2	32	14	3	15	43.8	9.4	46.9
E2	4	28	12	3	14	42.9	10.7	50
E3	6	32	9	2	21	28.1	6.3	65.6
Avg		43.1	15.8	6.7	20.7	34.7	13.8	51.8

Table 2: Dump characteristics by location/depth.

Sample ID	Depth (m)	pH	Fe,ppm	Cr,ppm	OC, %
R1A1		7.3	756124.6	6136	7
R2A1		7.6	61607	11920	6.4
R3A1	2	7.6	73378	9206	6
R1A2		7.6	57296	11176	7.3
R2A2		7.5	70433	12337	5.7
R3A2	4	7.4	58324	11538	6
R1A3		7.4	61862	12688	6.2
R2A3		7.4	51141	11523	5.2
R3A3	6	7.5	51243	11932	5.2
R1B1		7.3	76877	11154	4.6
R1B1		7.4	61882	18846	4.5
R2B1	2	7.2	71516	14594	4.5
R1B2		7.4	86395	17331	4.5
R2B2		7.2	62346	16175	4
R3B2	4	7.3	68358	20007	4.8
R1B3	6	7.2	87706	17674	2.9
R1D3		7.4	159821	18827	3.1
R2D3		7	81332	19262	3.1
R3D3	6	7.3	65778	22293	4.7
R1E1		7.9	78637	19224	4.6
R2E1		7.7	70768	23115	5
R3E1	2	7.9	78757	23838	4.6
R1E2		7.5	63641	27738	4.6
R2E2		7.6	68213	23454	4.9
R3E2	4	7.7	57003	26189	3.7
R1E3		7.2	73577	30334	3.9
R2E3		7.1	73798	30040	4.1
R3E3	6	7.2	76419	28481	4.7
R2B3		7.3	159821	18827	3.1
R3B3	6	7.2	81332	19262	3.1
R1C1		7.2	65778	22293	4.7
R2C1		7.3	78637	19224	4.6

R3C1	2	7.2	70768	23115	5
R1C2		7.3	78757	23838	4.6
R2C2		7.3	63641	27738	4.6
R3C2	4	7.3	68213	23454	4.9
R1C3		7.2	57003	26189	3.7
R2C3		7.3	73577	30334	3.9
R3C3	6	7.2	73798	30040	4.1
R1D1		7.2	76419	28481	4.7
R2D1		7.3	73396	26906	4.3
R3D1	2	7.2	89155	30842	4.6
R1D2		7.1	77158	29675	4.7
R2D2	4	7.4	83810	30364	4.5

Table 3: Dump chemical parameter content by depth (KALRO).

Parameter- ID/Value	Units	R1D3	R1D3	REE1	R1DB1	R2A3	R1/B2/B3	R3C2	Test Method
Arsenic/As	ppm	ND	ND	ND	ND	ND	ND	ND	AAS
Cadmium/Cd	ppm	ND	ND	ND	ND	ND	ND	ND	AAS
Calcium	ppm	49.73	Nil	2651	Nil	2290.94	Nil	2.66	AAS
Chromium	ppm	ND	2.5	ND	ND	ND	49.4	52.74	AAS
Copper	ppm	151	585	35.2	2.24	6.53	102.92	145.57	AAS
Iron	ppm	4.97	9.38	1256	6.72	176.39	5.11	4.3	AAS
Lead/Pb	ppm	ND	ND	ND	ND	ND	ND	ND	AAS
Mercury/Hg	ppm	ND	ND	ND	ND	ND	ND	ND	AAS
Nickel	ppm	ND	ND	ND	ND	ND	20.58	25.32	AAS
Potassium/P	% m/m	3.2	Nil	3.2	Nil	2.5	Nil	Nil	AAS
Zinc	ppm	621	615	108	590	600.5	471.39	584.4	ASS

Table 4: Kachok dump material parameter analysis (Kenya Bureau of Standards).

Type of Waste	No of Samples	Min%	Max %	Mean % Composition	Remarks
Plastic	20	2.86	15.15	6.5	Consist of water bottles, and any high density plastic materials
Paper	30	5.75	29.24	9	
Polythene	10	2.86	11.49	8	Consist of low density polythene papers like those used in packaging at supermarkets
Organic	20	17.54	60	55.5	Any food waste and degradable material
Bottles /glasses	15	4.47	21.86	6	Contain broken glasses and broken bottles at the site
Bottle tops	6	1.07	3.54	1	Consist of bottle tops of beer bottles and sodas
Clothes	10	2.79	8.77	2	
Inorganic	10	4.48	19.25	10	They are non-biodegradable materials at the site
Medical waste	5	1	1.28	1	Consist of hospital waste and private medical practitioners
Scrape metal	4	0.25	2.36	1	Waste that contain metallic elements that can be recycled
Total				100	

Table 5: Percentage composition of Kachok dumpsite waste.

Element	Unit	Value in O.M	Limits in mg/kg		Test method
			Department of Petroleum Resources [23]	Riley RG et al. [22]	
Arsenic/As	ppm	ND	-	-	AAS
Cadmium/Cd	ppm	ND	380	100	AAS
Calcium	ppm	713.48	-	-	AAS
Chromium	ppm	14.95	240	100	AAS
Copper	ppm	146.92	10	-	AAS
Iron	ppm	208.98	-	-	AAS
Lead/Pb	ppm	ND	210	600	AAS

Mercury/Hg	ppm	ND	530	270	AAS
Nickel	ppm	6.56	720	-	AAS
Potassium/K	%m/m	1.27	-	-	AAS
Zinc	ppm	512.89	-	1500	AAS

Table 6: Permissible element limits in soil for crop growth.

Type of Soil Layer	Description
Surface Layer	Often <1 m thick
Lateritic horizon	Gravel in varying stages of weathering; mixed with decaying solid waste and is generally <5 metres deep.
highly weathered laterite	Layer below is laterite and free of decaying solid wastes; Saturated with mineralized water; forms a shallow aquifer and extends to 10 metres on average. This is the receptor to leachate and immobilizes salts of the groundwater; horizon is generally <5 ohm-m,
Saprolite - weathered layer	Varies in thickness across dumpsite due interplay of physical and chemical processes on the rock. Vary from 1m to at least 10 m thick and is water-bearing to as deep as 30 metres underground
Phonolite bedrock - Unweathered to slightly weathered	Runs on the north-south plane and forms the impermeable layer (aquitard) at the base of the shallow aquifer; porphyritic phonolite from 10 m to 30 m below ground level. The net result is groundwater flows in a south-easterly direction from the dumpsite.

Table 7: Soil layers at Kachok dumpsite.

within and around the dumpsite [2].

Based on the vertical electrical resistivity soundings tests along the Ondiek highway the bedrock returned high resistivity at some locations thus indicating it is unweathered and generally unfractured. It demonstrates that there is no solute/leachate transport taking place in the zone and all seeps remain in situ. Thus, the bedrock zone described in Table 7 had the lowest vulnerability to pollution.

The results of analysis of the soil under the dump site as in Table 8 shows concentration of inorganic toxicants in a descending order, Though parameter concentration of groundwater from proximity of the dumpsite were found to be within permissible limits except Fe and Mn (Table 8). This suggests that most of the toxicants are retained in the soil and do not find way into the groundwater system. It also confirms that the dumping of hazardous materials such as batteries (Zn, Pb) and fluorescent lamps (Zn) have been taking place evidenced by the site samples tested. Test on the Dump material as in Tables 3 and 4 confirms presence of the metals found in the soil of Kachok Waste disposal site as in Table 8, though the magnitude differs [2].

Leachate flow

Overall, there is no widespread occurrence of heavy metals, organic constituents or pesticides in surface water. But later tests in Table 3 indeed indicate high level of organic content of the dumpsite materials.

Underneath the dump wastes, the vertical component of flowing water transports the leachate and the dissolved toxicants to the vadose zone (2 meters thick) into the groundwater zone (2.5 – 3 m). The deeper regional flow however is south-westward in the direction of Lake Victoria, about 25-30 metres below ground level at the bed rock. From KALRO and KBS dump material analyses (Tables 3 and 4) together with Kachok Waste disposal site study [2], (Tables 8 and 9), it is observed that there is;

o   Significant presence of heavy metal toxicants in the soil at the dumpsite.

o   Minimal evidence of heavy metal presence in groundwater at locations beyond the dumpsite.

o   The surface water is affected by organic contaminants and heavy metals as in Table 9.

o   The water flow direction is generally in the west direction

Parameter	Sample 1 (mg/kg)	Sample 2, 3, 4, 5 (mg/kg)
Iron	33212.8	33199.1
Manganese	5510.23	7970.55
Zinc	214.18	447.52
Copper	144.37	118.25
Lead	80.67	43.63
Chromium	22.02	23.42
Nickel	12.26	11.85
Cadmium	10.09	9.62
Arsenic	6.27	9.01
Beryllium	2.56	2.56
Mercury	<0.005	<0.005

Table 8: Values of heavy metal toxicants in soil.

from drain (MA14 -05, 08, 07, 02) to drain (MA14 -05, 08, 07, 02) and to swamp area (MA14 -06 and 10) (Figure 4).

Some of the sample results as in Table 9 show concentrations above permissible levels for some parameters, Total coliforms; *E. coli*; BOD; COD; Nitrates; TDS; Iron; Chromium and Manganese. Thus, NO_3 is generally above the guidelines in all cases except one. BOD is high in one case and above by 50% of guideline in all other cases. COD are high in two cases and also above by 50% of the guidelines in all other cases. TDS is above guideline in 5 out of 10 cases and the rest is about 30% of the guide line. NH4 cases are all significantly below the guideline. As for organisms (Total coliforms and *E. coli*) all the sites showed TNTC except at site 08. Apart from Fe and Mn the rest of metals tested in Table 9 are all below the guideline.

It is noted that; the leachate flow was because of significant secondary permeability of the rock below the horizon (Figure 4) that was conducive to occurrence of shallow groundwater due to highly weathered laterites and fractured rocks that allowed groundwater movement/storage. The colloids formed thus reduce porosity and enhanced formation of a duricrust, caused by immobilized Na+ in the upper soil layer. This process helped in retaining heavy metals within the dumpsite soil and hence movement into groundwater was restricted. The heavy metals thus apparently have not been finding their way into the groundwater system beyond the dumpsite but held within the soil matrix. The presence of NO3 though shows that groundwater pollution is taking place.

Samp.ID	01 – canal	2 well	-03 – storm drain	-04 – storm drain	-05 – well	-06 – spring	-07 – spring	-08 – well	-09 – spring	stream	Avg.	Guide value (mg/l)
	Standard: KS 05-459: Part 1:1996											
NO3	24.6	14.7	22.3	7.4	14	0.04	38.3	47.5	27.9	10.3	20.7	10
BOD	27.7	22.8	39.44	28.75	18.25	28	12.35	18.1	22.9	20.55	23.9	30
COD	49	41	69	54	31	50	21	32	43	39	42.9	50
TDS	1760	567	1645	336	400.4	298.5	2093	1939	354	1734	1,112.70	1500
NH4	0.05	0.08	0.07	0.01	0.08	0.01	0.03	0.03	0.12	0.05	0.053	0.5
Metals	Standard: KS 05 – 459 Part 1: 1969											
Hg	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.001
As	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Cd	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.005
Pb	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.05
Cu	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.1
Cr	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	0.05
Zn	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	5
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Mn	<0.002	1.44	2.74	5.81	0.01	2.89	<0.002	<0.002	1.98	0.01		0.1
Fe	<0.007	2.7	0.02	1.13	0.05	1.8	<0.007	<0.04	0.5	<0.007		0.3
Organisms	Standard KS 05 – 200											
T. coli	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	300	TNTC	TNTC	TNTC	100m/l
E. coli	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	40	TNTC	TNTC	TNTC	Shall be Absent

Table 9: Dump and Surrounding Chemical Parameters.

Air quality

Tables 10 and 11 below show the contributions to ground level concentrations while comparing the United States Environmental protection agency report [24] and WHO report [25] Air Quality Standards for each average period and the pollutant. These are followed by results from the modeling compared to monitoring air quality measuring points assigned by SGS Kenya.

Noise

As in the Kachok Waste disposal site study, all the noise measured complied with the weather conditions specified by ISO code that is; wind speeds and gusts not exceeding 5ms-1and 10ms-1respectively [2]. As observed from the 5 monitoring locations and from the baseline noise environment measurements around the dumpsite, the 3 commercial locations (ASP1- 58dB (A), ASP 2-52.2 dB (A), ASP 3-52.4 dB(A)were graded to be within normal limits. The 2 residential areas (ASP 4 - 57 dB (A), ASP 5 – 58.7 dB (A)) were graded above normal. The results of the grading's were against Kenya's Ambient Noise Regulations as;

- Silent Zone: Daytime: 40 dB(A), Night-time: 35 dB(A).

- Place of Worship: Daytime:40 dB(A), Night-time 45 dB(A).

- Residential; (Indoor) - Daytime 45 dB(A); Night-time: 35 dB(A); (Outdoor)-Daytime: 50 dB(A), Night-time: 35 dB(A).

- Mixed Residential (with commercial and places of entertainment): Daytime: 55 dB(A), Night-time: 35 dB(A).

- Commercial: Daytime: 60 dB(A), Night-time: 35 dB(A).

- World Bank Guidelines (Residential): Daytime: 55 dB (A), Night-time: 45 dB (A); Industrial: Daytime: 70.

The noise contour maps were drawn as in Figure 5; wind speeds were mainly SW bound as is in Figure 6, an example of concentrations is as demonstrated by CH4 in Figure 7.

Conclusion

Solid waste is a term used variably referring to non-liquid waste materials from domestic, trade, commercial, agricultural, industrial and public activities/services [26]. Ibrahim Identified solid wastes as biodegradable, semi-biodegradable and non- biodegradable materials. Aibor MS et al. [27] generalized solid wastes to comprise domestic and estate solid wastes. Tajudeen I [28] described waste as useless, disused or unused materials that if not properly handled, may be dangerous to the health of man. What is regarded as waste by certain group may be a raw material to another group. However, ESRI [29] emphasizes that solid waste management is a global environmental problem that is significant in today's world and as much in Kisumu city and County.

In the African context, rapid urban growth from the 1960s (Kenya included), has added cumulative pressure on the land resources around the cities, townships, market Centre's and an increase in waste generation. This is no exception for the Kachok Dumpsite of Kisumu City in Kenya. Kachok Dumpsite by its availability was a spontaneous occurrence from rapid population growth and increased prosperity of the town in the early mid-1970's which led to increased waste. Tajudeen I [28] notes, there are factors which influence the choice of a method of waste disposal. Siting therefore differs right from an individual

Pollutant (μg/m³)	Averaging Period	Model Results	United States Environmental protection agency [24]	WHO [25]
Particulate Matter (PM10)	1 – hour	282.49	-----	----
	24 – hour	281	150	50
Particulate Matter (PM10)	1 – hour	42.78	----	---
	24 - hour	42.55	35	25
Hydrogen Sulphide (H2S)	1 – hour	0.14	----	10.5
Methane (Ch4)	1 – hour	908.19	8,828x 103	----

Table 10: Discrete receptors; air dispersion model results.

Pollutant (μ/m³)	Particulate Matter (PM10) Value		Particulate Matter (PM 2.5) Value		Hydrogen Sulphide (H₂S) Value		Methane(CH4) Value	
	Measured	Model	Measured	Model	Measured	Model	Measured	Model
ASP 1	226	180.28	56	27.3	0.14	0.089	918	579.59
ASP 2	210	116.21	42	17.6	0.24	0.057	579	373.62
ASP 3	221	111.89	52	16.94	0.21	0.055	904	359.72
ASP 4	148	1.36	31	0.21	0.06	0.001	235	4.36
ASP 5	162	5.02	37	0.76	0.1	0.002	228	16.15

Table 11: Maximum; air dispersion model results.

livelihood at village (community) level to townships, to designated towns and to cities. Control for whatever reasons for example in a neighborhood seems to be a compelling reason for sitting.

A number of factors hence need to be considered in any study aimed at identifying or review of location of a specific dumpsite which come into play within such surroundings and villages thereof. These are not limited to; location of water resources used for public water supply, land agricultural potential, land use, location of archaeological/historically important sites and areas with mineral rights. These today in Kenya are also viewed with challenges of economic, social and political factors as is appropriate. The problem is aggravated by the open nature of disposing waste (dump), Kachok included and especially in the slum areas of most African cities [10,22]. In Kisumu County, apart from the city there are numerous townships and village markets that experience the problem in the glare of existing laws, our stage of development and lack of plans for execution since 1960.

The Kachok Dumpsite is an example of many growing cities in Africa where; "Dumping site may be as simple as from a village individual who sees a lot of space and throws anything to a space the eyes can select and the throw potential can accommodate". Kisumu County needs to correct this right from Kisumu City, Townships, and Market Centre's to Villages. This is happening and is continuing to date. It is confirmed that Kachok dumpsite developed under spontaneity as is many in Africa. It handles an estimate of less than 10% of the waste, meaning there is a need for an enhanced improvement in collection, processing and dumping. The 2.73ha dumpsite size, population growth and quantity of wastes estimates today do not march. The dump characteristics are also not far off that of the Nairobi City save for quantities and should be the first for considerations in any undertaking of attributes comparisons. There is therefore need for long range planning, regulation and enforcement of waste management in Kisumu City and County. These should be adequately qualified and quantified, as there is lack of data in the SWM.

All the nearby sensitive receptors were impacted by the dumpsite that is Kisumu Day Secondary School, Lutheran Church, Moi Stadium and Nakumatt Mega. As observed from the monitoring locations and from the baseline noise environment measurements, 3 commercial locations were graded to be within normal limits and 2 residential areas were graded above normal. All the key air quality parameters assessed
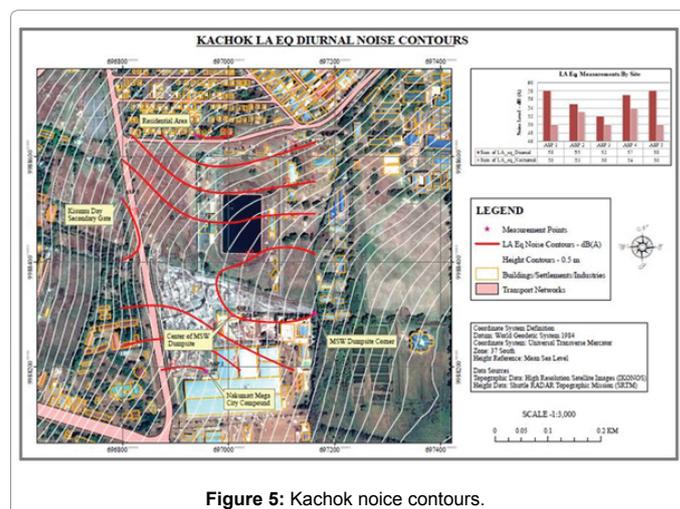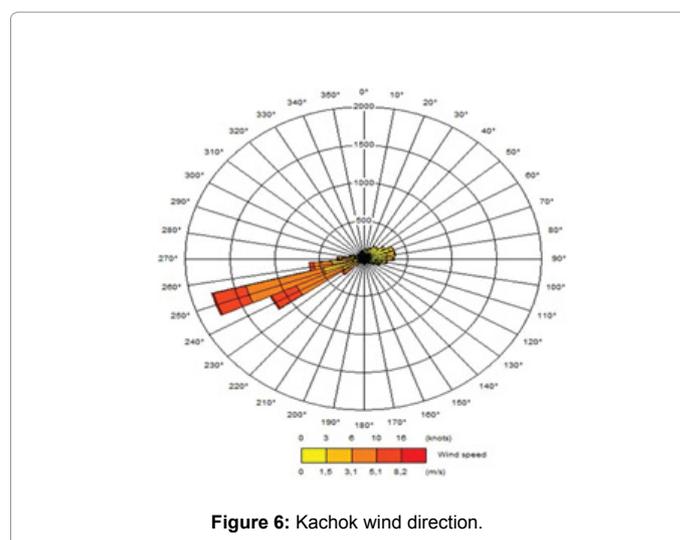

Figure 5: Kachok noice contours.

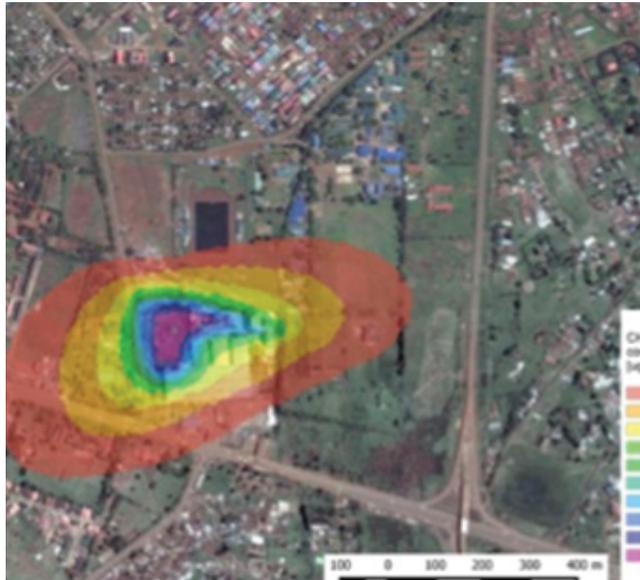**Figure 6:** Kachok wind direction.

Figure 7: Example map for 1-hour concentrations of CH4.

exhibited similar trend with higher concentrations (example as Figure 7) over the dumpsite and gradually reducing outward in all directions. It is clear that the dump site has levels of PM10 and PM2.5 that exceeds both the United States Environmental protection agency and WHO [24,25] maximum guideline limit values. Of the air quality parameters H_2S and PM10 are the most widespread.

Overall, the Kachok location is not suitable and it is where it is due to its availability. There is no widespread occurrence of heavy metals, organic constituents or pesticides in the surrounding surface water. The heavy metals apparently have not been finding their way into the groundwater system beyond the dumpsite however presence of NO_3 shows that groundwater pollution is taking place. Tests of dump material indicates high level of organic content (constitute over 50%) and can be applied to improve soil to benefit crop conditions. Other possible uses may also be enhanced or initiated, such as extraction of energy, recycling of products but based on improved collection systems and dumping procedures.

Acknowledgment

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