

Research Paper

An investigation into the Correlation among Municipal Solid Waste Pollution, Fecal Coliform Water Pollution and Water-borne Diseases (Typhoid and Diarrhea) in the Least Developed Countries: The case of Juba – South Sudan

Correlation among municipal solid waste pollution, fecal coliform water pollution and water borne diseases in Juba/south Sudan

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ABSTRACT

This study was carried out to investigate the correlation among municipal solid waste pollution, fecal coliform water pollution and water-borne diseases such as; typhoid and diarrhea in Juba city, South Sudan. Water samples were collected from the river Nile, boreholes and a well and then analyzed for the presence of fecal coliform; also physical parameters such as temperature, pH, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were tested. The results revealed that the river Nile is highly contaminated; with an average range of 15.25 – 102.6 Coliform Forming Unit/100ml (CFU/100ml). The pH and temperature were within the normal range. TDS showed very high values with range of 470 – 1230 mg/L which is far beyond the USEPA and WHO recommended 500 mg/l. The EC was not so high; ranges between 59 μ s - 201 μ s/cm which is slightly above the recommended 160 μ s/cm. The CFU/100ml readings of the boreholes and the well were within the range of 0 – 26 CFU/100ml. Out of the eleven sampled boreholes, six were clean with 0 CFU/100ml which meets the USEPA and WHO recommended value but the other five and the well were contaminated. The TDS and EC

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were extremely high ranging between 4810 – 8230 mg/L and 1032 – 1775 µs/cm respectively. pH and temperature were within normal range. The study also found that there is strong correlation between typhoid and water contaminated with fecal coliform while the reverse is true for diarrhea. The degree of linearity (correlation) between fecal coliform (CFU/100ml) and Typhoid Fever was further confirmed by conducting a test of hypotheses (t-test statistic) at 5% significance level on the correlation coefficients determined. The study concluded that, the poor municipal solid waste management in Juba is posing high risk to the human health and the environment.

Keywords: municipal solid waste, fecal coliform, water pollution, CFU/100ml

1. INTRODUCTION

Management of solid waste is one of the major challenges worldwide and especially municipal solid wastes. In addition to polluting the environment; inadequate collection, recycling or treatment and uncontrolled disposal of waste in dumps pose health risks. This situation is more alarming especially in the cities of developing Countries [1, 2, 3, 4, 5, 6]. The situation is aggravated by lack of public awareness, lack of waste management facilities and corrupt systems of political and environmental governance [1]. Municipal solid waste management continues to be a major challenge for local governments in both urban and rural areas across the world and one of the key issues is their financial constraints [7]. [8] stressed that the “inadequate management of municipal solid waste in most cities of developing countries leads to problems that impair human and animal health and ultimately results into economic, environmental and biological (biodiversity) losses”.

The poor municipal solid waste management in the developing countries can cause adverse impacts on; human health and the environment [9]. Furthermore, [6] emphasized that “the ill managed municipal solid waste in the developing countries contributes to the high morbidity and mortality rates in many cities”. Typically one to two thirds of the municipal solid waste generated is not collected in many cities of the developing countries and the most underdeveloped [10]. As a result, the uncollected wastes, which are often also mixed with human and animal excreta, are dumped indiscriminately beside the streets and in drains, so contributing to stagnant water, breeding of insect and rodent vectors and the spreading of diseases [11,12,13]. Most wastes are disposed of in open dumps, deposited on vacant land or burned by residents in their backyards [6,14]. Insufficient collection and inadequate disposal generate significant pollution problems and risks to human health and the environment [6]. In addition, even the somehow collected waste is often disposed of in uncontrolled dumpsites and/or burnt in the open spaces and consequently this has resulted into the pollution of the water resources and the air [4,5,6].

Water is a prerequisite of life; thus, it is an important component of human survival. Water should be purified for a better life style. It is the basic duty of every individual to conserve water resources. Drinking water quality is affected by the presence of micro-organisms and different soluble salts [15,16]. According to an assessment commissioned by the United Nations, it reported that “4,000 children die each day as a result of diseases caused by ingestion of filthy water and most of them are in Africa and Asia [17]”. The situation in Juba totally and practically is in accordance with those authors’ findings.

This is because Juba is one of the most undeveloped places in the world: although slow to moderate developmental progress is being made in many physical, social, political and economic sectors. It was reported that Juba is perhaps currently among the fastest developing places in the world [19]. More specifically, growth in its population is noticeable. In 2011, Juba’s population was estimated at approximately more than 500,000 people [20].

97 The city is characterized by rapid development, urban sprawl and inadequate services
98 provision. Due to this rapid growth in the population; and with majority of the people settling
99 in urban centers: all forms of waste and associated residual materials have tremendously
100 increased in the City. Unfortunately, there is no proper waste management infrastructure.
101 The lack of the waste management infrastructure is evident in sight of trash deposits
102 everywhere – dumped beside streets, clogging streams, bobbing down into the river Nile,
103 littered around buildings, even strewn across the graves in the municipal cemetery and with
104 plastic trash predominating all over the city. Some locals describe the mounting waste in the
105 city as raindrops from the clouds. The pervasive plastic half-liter, empty water bottles seem
106 to have been sprinkled down from above and lie everywhere – some still new, fat and even
107 sparkling a bit; others already old, squashed and dusty. According to [21], “Juba is inundated
108 not with water, but with millions and millions of empty plastic water bottles”. It seems ironic
109 that plastic bottled water is so prevalent in a city watered by the river Nile.
110

111 In Juba, there is no sanitary landfill available for municipal solid waste disposal: Juba's
112 municipal solid wastes are being dumped indiscriminately on the land and partially outside of
113 the city at the designated open dumping site 16 km away from the city. In Juba, both human
114 and animal excreta can be seen in the municipal solid waste stream. Thus, during the rainy
115 season, all this waste finds its way into the river Nile. Unfortunately, most of the city's
116 population still depends on the direct use of the river Nile water for drinking and all other
117 domestic purposes without any treatment. There has been an increasing number of recorded
118 water-borne diseases' patients at the two main hospitals. Thus, building on this, the authors
119 were motivated to carry out this study which aimed at investigating the correlation among
120 municipal solid waste pollution, fecal coliform water pollution and some of the most common
121 water-borne diseases in Juba such as typhoid and diarrhea.
122

123 **2. MATERIAL AND METHODS**

124
125 This study was carried out in three different phases: the assessment of the municipal solid
126 waste pollution status in Juba city, the water (both surface and underground) samples'
127 analysis and the correlation analysis which involved the collection of a two year statistical
128 data of the incidence of the targeted diseases from the two main hospitals in Juba.
129

130 **2.1. Study Area**

131
132 Juba is the capital city of the Republic of South Sudan (the world's newest country) situated
133 in North East Africa (figure 1 below).
134

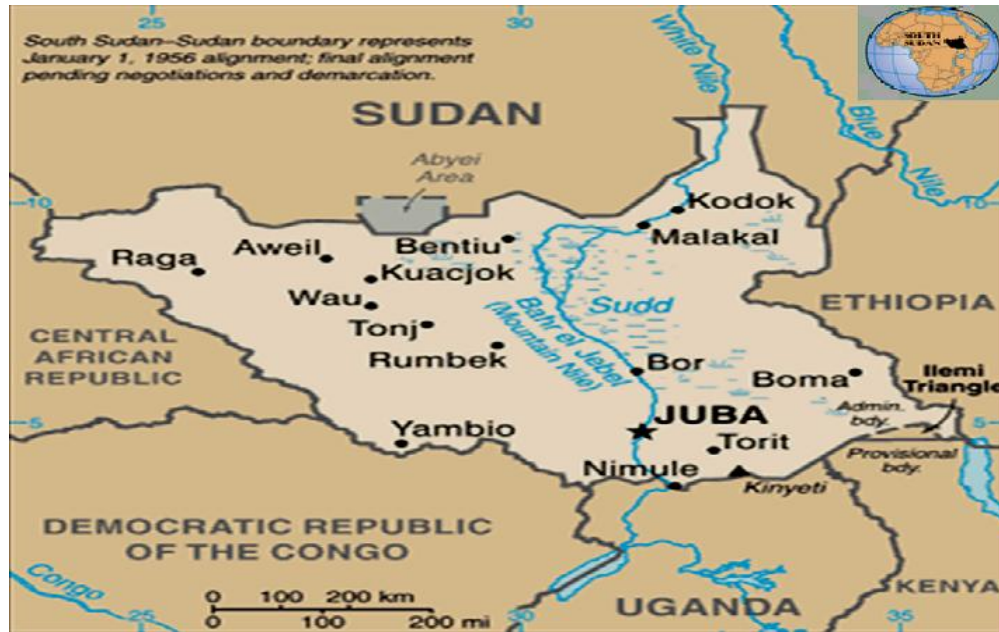


Figure 1: The map of South Sudan showing the location of Juba

Sources: Adopted and modified from: <https://www.cia.gov/library/publications/the-world-factbook/geos/geos/od.html>

The city is located within the southern part of South Sudan in Central Equatoria State. Its geographical coordinates are 4° 51' 0" North and 31° 37' 0" East [18]. It is at the western bank of the river Nile. Juba is a county made up of three districts (*payams*) which include Juba, Kator and Munuki and is directly administered by the city mayor. Juba is situated in the midst of vast expanses of open space, including swamplands and agrarian landscapes. It is estimated to occupy a 12 kilometer area in diameter from the center of town (approximately 11,300 hectares). Greater Juba, including the surrounding rural lands, encompasses roughly 100 kilometers in diameter. Juba has a tropical wet and dry climate and as it lies near the equator, temperatures are high year-round. It has average yearly high temperature of 94.1°F (34.5°C) and an average yearly low temperature of 70.9°F (21.6°C). The most rainfall in South Sudan is between the months of April and October and the average yearly total rainfall is 37.54 inches (953.7 mm).

2.2 Sampling, Sample Collection and Analysis

2.2.1 The municipal solid waste pollution status assessment

This was conducted in order to set a base for the correlation analysis derivation. The assessment was achieved through a household survey to know the amount of waste being generated and its composition in the city. The survey involved a total of 350 houses visited: 150 in Munuki district (*payam*) being the densely populated district of Juba county, 100 in Juba district and also 100 in Kator district.

2.2.2 Water sampling design

This research was carried out during the rainy season (April to September 2012). Water samples were collected from the river Nile, boreholes and a well; all of which are within Juba city. From the river Nile, twelve sampling sites were chosen with the upstream to

downstream pattern and assigned a representing symbol **S** (S1 – S12). S1 was at Rajaf (upstream), S2 at Tokiman, S3 at Lologo, S4 at Juba Bridge, S5 at Juba Port, S6 at Urban Water Corporation (Intake point), S7 at Jebel Nyoka, S8 at Gabat, S9 at Nyaying, S10 at Roton, S11 at Walawalang and S12 at Morlobor Village (downstream). S1 is 7 km from Juba to the South and S12 is 13 km away to the North; these two sites were considered to be the control points. The rest of the sites were within Juba city with a distant interval of about 1.5 km. For the boreholes/well; they were randomly chosen that is: eleven boreholes and each one of them assigned a representing symbol **BH** (BH1 – BH11) and one well with the symbol **W**.

2.2.3 Samples' collection and analysis procedure

The water samples were collected mostly during morning hours of the day under controlled temperature conditions using 1000ml properly labeled screw-capped sterile plastic bottles. Immediately after taking a sample, it has to be put in a portable cooler box containing ice boxes in it so as to maintain the 4°C temperature before reaching the Laboratory as recommended by [22,23]. The samples were then transported to the Central Laboratory for Water Quality (Juba, South Sudan) for analysis at least within a maximum of 6 hours. They were then properly analyzed following quality control procedure for water quality analysis as recommended by [22]. The method used was the "Membrane Filtration Method".

"Membrane filtration method involves filtering several different-sized portions of the sample using filters with a standard diameter and pore size, placing each filter on a selective nutrient medium in a petri plate, incubating the plates at a specified temperature for a specified time period and then counting the colonies that have grown on the filter. This method varies for different bacteria types (variations might include, for example, the nutrient medium type, the incubation temperature and time; and the number and types of incubations, etc. [22]). The medium used was enriched Lauryl Sulphate Broth.

During the six month sampling period, the surface water (river Nile) was sampled for five consecutive months (April – August-2012) with sampling frequency of 4 times per month for each site. This was done in order to obtain a representative value. A total of 240 samples were collected from the river Nile. For the underground water (boreholes/well); the sampling was done only in one month that is September-2012. The total number of samples analyzed was 48. All samples were incubated at the temperature of 44°C for 24 hours as the target was only fecal coliform. Then the number of colonies formed were counted. Some physical parameters were analyzed on site using a pH, EC and TDS meter (Model HI 98129, Manufactured by HANNA). They include Temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS).

Table 1: Fecal coliform (CFU/100ml) standards

Water Use	Desirable Level (CFU/100ml	Permissible Level (CFU/100ml
Drinking	0	0
Swimming	<200	<1000
Boating or fishing	<1000	<5000

Source: (USEPA, 1985; APHA, 1992)

3. RESULTS AND DISCUSSION

3.1 The General Assessment of the Municipal Solid Waste Pollution Status in Juba City

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3.1.1 Municipal solid waste generation and its composition in Juba city

The amount of municipal solid waste generation differs from place to place to a great extent; its production pattern is being influenced by consumption pattern, standard of living, climate, season and cultural practices (UNEP, 2003; Visvanathan and Glawe, 2006). The municipal solid waste generated per-capita (kg/day) in Juba is relatively low when compared to some South Asian countries. Its per-capita ranges between 0.33 to 0.44 kg/person/day unlike that of the South Asian countries which vary in a range from 0.3 to 0.9 kg/person/day (WWF–Pakistan, 2001). Table 2 below shows the household municipal solid waste (kg) generated in Juba city.

Table 2: Household municipal solid waste (in kg) generated/house/day and per capita/day

Payam	Population	MSW(kg)/house/day	MSW(kg)/capita/day
Kator	152,000	2.29	0.33
Juba	113,776	3.3	0.36
Munuki	243,000	3.05	0.44
Total	508,776	8.64	1.13
Average		2.88	0.37

From the table above, it is clear that the highest household municipal solid waste generator was Juba district (*payam*) with a population of about 113,776, generating about 3.3kg/house/day; which is about 0.36kg/capita/day. The second district (*payam*) that generated municipal solid wastes after Juba was Munuki district (*payam*); with a population of about 243,000 people, has a household generation rate of about 3.05 kg/ day and this is about 0.44kg/capita/day. Kator district (*payam*) was the least in waste generation. With a population of about 152,000, it has a household generation rate of 2.29kg/day and is equivalent to 0.33kg as per capita/day. The average household municipal solid waste generation per house was found to be 2.88kg /day which gives 0.33 kg/capita/day in Juba as a whole.

3.1.2 Household municipal solid waste generated (in tons)/payam/month and per year

In this study, it was found out that the three districts (*payams*) of Juba generated quite a huge amount of municipal solid waste as shown in the table 3 below:

Table 3: Shows household municipal solid waste generated (in tons)/payam/month and per year

Districts (Payams)	Tons/Month	Tons /Year
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Munuki district (payam)	1,518 tons/month	18,216 tons/year
Kator district (payam)	633.6 tons/month	7,603.02 tons/year
Juba district (payam)	569.98 tons/month	6,839.77 tons/year

The figure below shows the percentages of the waste generated by the three payams.

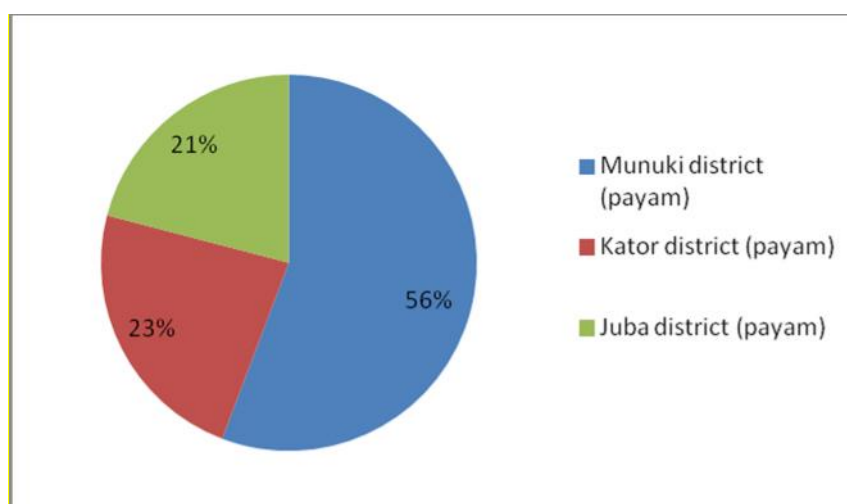


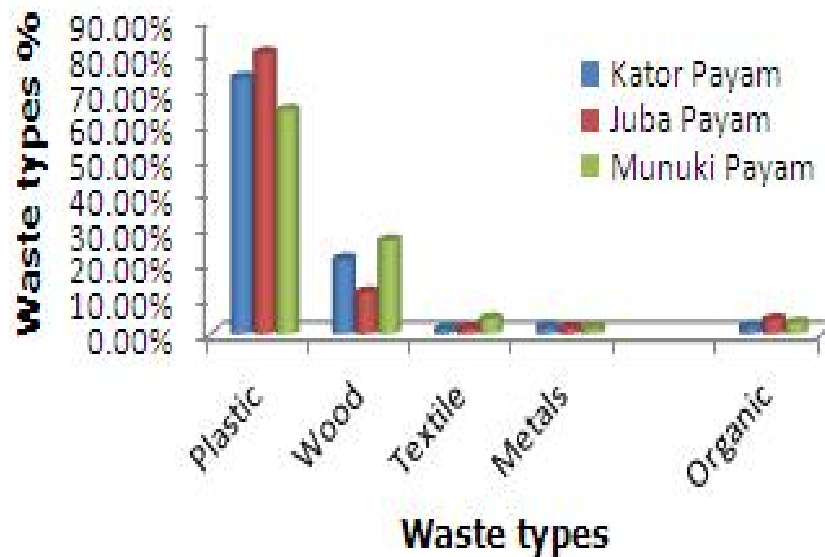
Figure 2: Shows the percentages of municipal solid waste generated in tons/year in Juba

Table 3 and Figure 2 above show clearly how much household municipal solid wastes in tons/payam are being generated in a month and in a year by the three districts (*payams*) of Juba. It is clear that Munuki payam was at the lead with a generation rate of about 1,518 tons/month which is about 18,216 tons/year (equivalent of 56%) followed by Kator payam that produces about 633.6 tons/month that is 7,603.02 tons/year (which is about 23%). Juba payam generates the least household municipal solid waste compared to the other two payams. Its generation rate was about 569.98 tons/month which was about 6,839.77 tons/year (which is equal to 21%). This is because Juba payam is a commercial center hence; it has fewer residents than the other two payams.

Table 4: Types of household municipal solid waste generated by the three payams of Juba.

Type of waste	Kator Payam	Juba Payam	Munuki Payam
Plastic	73.42%	80.65%	64.18%
Wood	21.34%	11.87%	26.73%
Worn out cloth(textile)	1.26%	1.61%	4.48%
Metals	1.93%	1.61%	1.49%
Organic (mostly food waste)	2.00%	4.26%	3.12%

Table 4 above presents the different types of municipal solid wastes being generated in the study area. From the table it is clear that 80.65% of the total household municipal solid waste generated in Juba payam is plastic; 11.87% wood; 1.61% are worn out cloth (textile) and metals respectively and 4.26% organic. Whereas in Kator payam, plastic makes up 73.42%; wood 21.34%; worn out cloth (textile) 1.26%; metals made up 1.93% and organic constitute 2.00%. In Munuki payam, plastic makes up 64.18%; wood 26.73%; worn out cloth is 4.48%; metals make up 1.49% and organic 3.12%. Therefore, considering the averages of the entire household municipal solid waste generated in Juba city; it becomes 72.73% is plastic, 19.9% wood; 2.43% worn out cloth 1.04% is metal and 3.13% is organic. The above table is graphically presented as shown in figure 3 below:



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282
283

Figure 3: Types of household municipal solid waste (%) generated in Juba

284 3.2 The Surface Water: Results of Water Samples' Analysis of the River Nile

285

286 The overall analysis results showed that the average fecal CFU/100ml concentration for all
287 the twelve sampled sites of the river Nile range between 15.25 – 102.6 mpn/100ml at sites
288 S12 and S7 respectively. This fecal coliform count range is above the 0 mpn/100ml for
289 drinking water as the recommended standard by [22, 24, 25, 26, 27]. Unfortunately and
290 regrettably, most of the poor population of Juba city still directly depends on the river Nile's
291 water for drinking and all other domestic needs. The presence of high fecal coliform
292 concentration in the river Nile's water is not only a clear indication of the serious municipal
293 solid waste pollution in Juba but also it signifies the high percentage of both human and
294 animal excreta in the waste stream. This is in accordance with the findings of [11, 13,12] that
295 "in the developing countries, municipal solid waste is often mixed with human and animal
296 excreta". Another major source of this contamination is the illegal direct discharge of
297 untreated sewage into the river Nile from the hotels along it.

298

299 The river water is therefore, contaminated with pathogens which can cause various water-
300 borne diseases. This is in part explained by the high incidence of diseases such as typhoid,
301 diarrhea, hepatitis A and gastro-intestinal infections in the city. Thus, the river water is not fit
302 to be used for domestic purposes, except otherwise if treated: but it can be use in
303 recreational purpose for example, swimming and boating. The sites S1 and S12 to some
304 extent performed their role as control points by showing the low readings. The values of pH

at all the sampling sites ranged from 6.8 to 8.3 and were normal according to the USEPA and WHO recommended values. The temperature for all the sites was also within the normal range. The TDS for all the sites ranges between 470 – 1230 mg/L. Eleven of the sites except site 12 have their range beyond the 500mg/l USEPA and WHO recommended value. This clearly shows that the banks of the river Nile are exposed and lack natural vegetation. The EC ranges between 59µs - 201µs/cm: eight of the sites (S1 – S8) results were all above the WHO 160 µs/cm recommended value and this is due to the fact that there are a lot of human activities around. For example, car washing, swimming, cloths washing, bathing and many others; all these activities could be a good source of chemicals' input into the river. S9, S10, S11 and S12 were below due to the fact that they are having very low human activities and also far from the city centre especially for the case of S12.

Table 5: shows averages of the readings of fecal coliform forming unit (CFU/100ml) and some physical parameters of the sampled sites of the river Nile.

Site	Site's Name	CFU/100	Physical Parameters			
Number		ml	Average	Average	Average	Average
		Average	pH	Temperature	TDS	EC
		Reading		(⁰ C)	(mg/L)	(µs)
S1	Rajab West	33.04	8.3	28	920	185
	(Upstream)					
S2	Tokiman	31.6	8.3	28	910	184
S3	Lologo	38.19	8.3	28	940	187
S4	Juba Bridge	43.95	8.2	28.3	980	189
S5	Juba Port	77.85	7.2	28.1	790	190
S6	Urban Water	97.05	8.2	28	980	201
	Cooperation					
	(Intake Point)					
S7	Jebel Nyoka	102.6	8.4	28.3	1230	229
S8	Hai Gabat	98.6	7.4	28.1	980	205
S9	Nyaying	70.9	7.4	28	860	126
S10	Roton	46.6	7.3	28	780	106
S11	Walawalang	33.6	7.4	28.1	630	98
S12	Molobor	15.25	6.8	28	470	89

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Village
(Downstream
)

3.3 Underground Water Samples' Analysis Results

The results revealed that (table 6 below); the underground water was lightly contaminated compared to the surface water. The results for BH2, BH3, BH4, BH5, BH8 and BH11 indicated that there was no fecal coliform contamination; and this is in accordance with the USEPA and WHO recommendation of 0 CFU/100ml. Thus, the water has the highly desirable level for human consumption. For BH6, the one with the highest concentration; there are three factors suspected of causing the contamination. These include: (i) The borehole is very old; it was drilled in 1986. So there is the probability that the sink pipes (metal) might have started to get corroded, hence, leakage can happen. (ii) There is a row of six pit-latrines (dry toilet system) dug so close to the borehole (just about 10 meters away). These pit-latrines serve a considerable number of people every day; the Juba Pentecostal Church Basic School's pupils and also a big number (those who come to pray) on Sundays. (iii) The borehole is just about 15 meters from the Khor Bou stream which is highly contaminated. For BH7, the main factor contributing to the contamination is the pit-latrines. Hai Neem is a residential area of upper class citizens thus; every house has at least a pit-latrine. Also the oldness of the borehole could be another factor. Results for BH9 and BH10 also showed contamination. The suspected cause is the presence of pit-latrines near them and also their age. For BH1, the contamination could be from underground leakage into the borehole. This is because Juba Nabari is a low lying flat area near Juba International Airport. Thus, when it rains, all the wastes from the upland are washed and get settle down in this low lying land. The pH and temperature for all the sampled boreholes were within the normal range. The TDS and EC analysis results showed extremely high readings which are so far above the USEPA and WHO recommended value. These high values imply that the dissolved salts within are also to their maximum. According to [28], the water molecule (H₂O) is strongly polar and thus, it is a powerful solvent. Groundwater usually adopts the chemistry of the rocks/soil in which it resides. For the well, it is also contaminated with fecal coliform. The cause is due to the fact that it is located at a valley of a creek; so when it is rainy season there is usually stagnation of water around it. This stagnant water when it settles down; can easily get mixed up with the well water thus, causing the contamination.

Table 6: The averages of underground water (boreholes/well) samples' analysis results

Serial	Station Name	CFU/100ml	Physical Parameters			
Number		Average	Average	Average	Average	Average
		Reading	pH	Temperature	TDS	EC
				(⁰ C)	(mg/L)	(μs)
BH1	Esko Company	9	7.5	29	6930	1,661
	Juba - Nabari					

	(Borehole)					
BH2	Juba Nabari (Kolo Road) (Borehole)	0	7.4	29.7	6700	1,405
BH3	Hai Jejira (Munuki) (Borehole)	0	7.3	28.9	5170	1,144
BH4	Hai Nyakuron (Borehole)	0	7.4	29.6	4990	1,092
BH5	El-Sabah Children Hospital – Juba (Borehole)	0	7.3	30.2	6130	1,253
BH6	Pentecostal Church –Juba (Borehole)	26	7.8	29.3	8230	1,775
BH7	Hai Neem (Borehole)	20	7.7	29.5	8050	1,714
BH8	Hia Amarat (House of the Minister of Finance) (Borehole)	0	7.3	28.6	4900	1,135
BH9	Hai Dongoda - Juba (Borehole)	10.5	7.6	28.3	7140	1,637
BH10	Juba Medical Complex (Borehole)	9	7.6	29	6890	1,617
BH11	Munuki Block B (Borehole)	0	7.4	28.8	4810	1,032
W1	Lologo (Well)	17.5	7.7	28.1	7930	1,730

3.4 The Correlation Analysis between Water Pollution and Typhoid Fever Disease

In order to achieve this, the data below were computed using SPSS version 20. These data include: the cumulative averages of the CFU/100 ml concentrations of the river Nile table (7) and a two year statistical data of the incidence of typhoid collected from the two main hospitals in Juba table (8) below:

Table 7: Average CFU/100 ml of the River Nile's concentrations at different sampling sites and months

Location	Months					Cumulative Averages
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	
Rajab West (Upstream)	27.7	28	35	41	33.5	33.04
Tokiman	28.5	30.5	32	36	31	31.6
Lologo	35.45	39	37.5	42.5	36.5	38.19
Juba Bridge	39.75	42.5	46.25	48.25	43	43.95
Juba Port	74.5	78.25	81	79	76.5	77.85
Urban Water Cooperation (Intake Point)	93.24	94.5	98.5	104	95	97.05
Jebel Nyoka	98.25	99.5	105.25	109	101	102.6
Hai Gabat	94.5	97	101	102	98.5	98.6
Nyaying	67.7	69.5	73.5	75	69	70.9
Roton	45	46.5	47.5	48.5	45.5	46.6
Walawalang	33	34	33.5	35	32.5	33.6
Molobor Village (Downstream)	15.25	15.5	16	17.5	14.5	15.25

368 **Table 8: shows the two year statistical data of Typhoid incidence in the two hospitals**
 369 **in Juba**

Year/ Month	2010		2011	
	El-Sabaah Children's Hospital	Juba Teaching Hospital	El-Sabaah Children's Hospital	Juba Teaching Hospital
	Typhoid	Typhoid	Typhoid	Typhoid
Jan.	41	77	74	221
Feb.	36	182	85	249
March	70	213	64	152
April	94	285	75	267
May	179	345	83	218
June	214	390	137	323
July	350	465	181	307
Aug.	327	685	141	275
Sept.	276	553	164	220
Oct.	172	339	107	301
Nov.	146	254	77	123
Dec.	85	177	40	108

370
 371 Linear regression analysis to establish the correlation between Typhoid Fever and
 372 CFU/100ml is clearly shown in figure 4 below:
 373

El-Sabaah Children's Hospital	Juba Teaching Hospital
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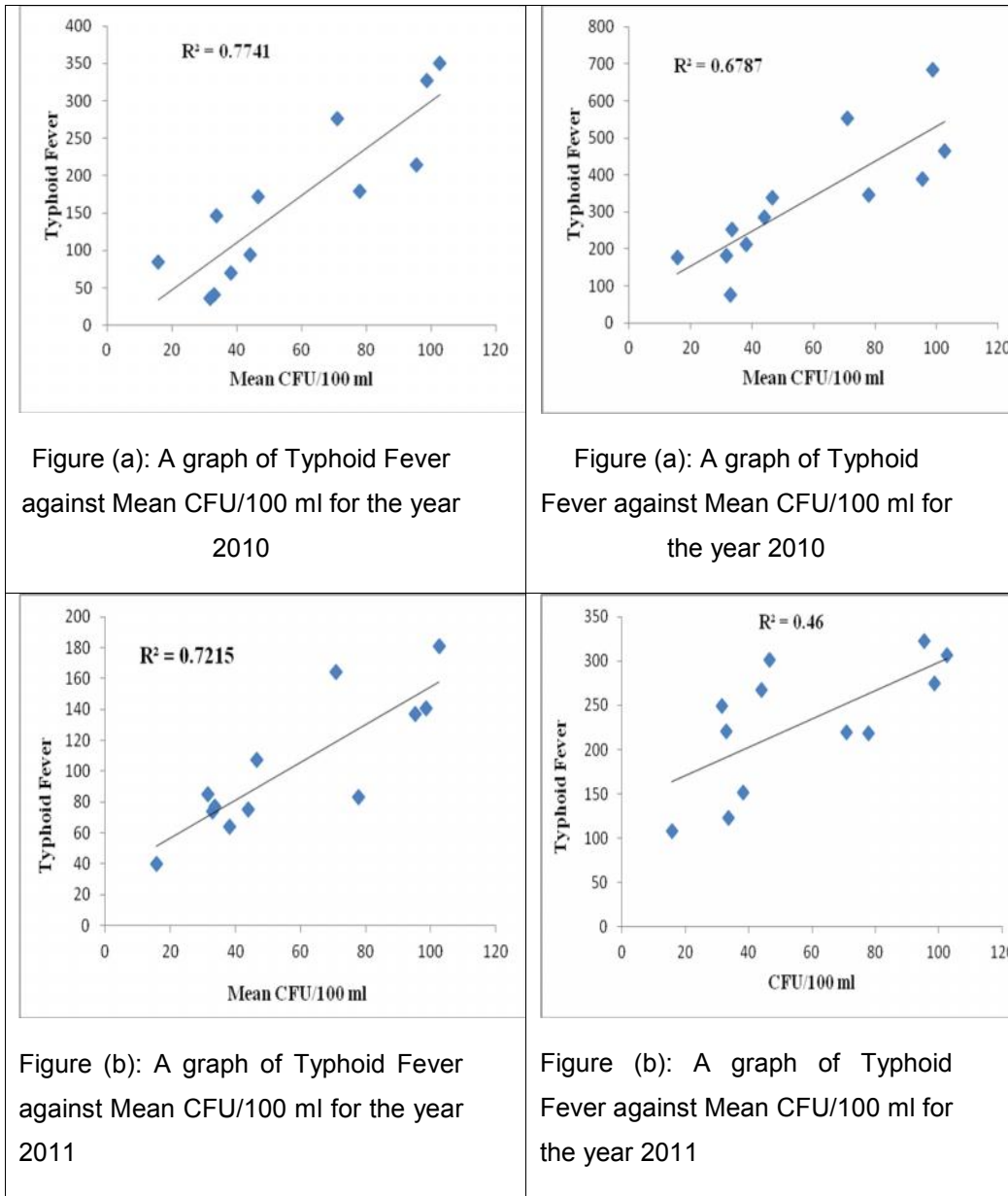


Figure 4: shows the scatter plots between CFU/100 ml and typhoid fever incidence

3.4.1 Correlation analysis (R^2 and r statistics) for typhoid fever

The deterministic model (R^2) and the correlation coefficients (r) between the variables (Typhoid Fever and CFU/100ml) were calculated and the results are shown in tables 9 and 10 below respectively. The values of R^2 (table 6) helps to interpret the relationships existing between variables in terms of variations. That is, from table 6, El Sabbah Children's Hospital and Juba Teaching Hospital in the year 2010 had 0.7741 and 0.6787. These R^2 values indicate the 77.41% and 67.87% of the changes in Typhoid Fever are explained by the change of CFU/100ml. In the year 2011, 72.15% and 46% of the changes in the Typhoid

387 Fever and CFU/100ml could be explained for El Sabbah Children's Hospital and Juba
 388 Teaching Hospital respectively. The closer R^2 is to 1, then there is an indication that the data
 389 points lie close to the least square line. This can be seen in figure 4. With reference to table
 390 9, it can be seen that the R^2 value for El Sabbah Children's hospital in both years are
 391 relatively closer to 1. This means that the linear regression analysis performed to estimate
 392 the R^2 , comparatively, describe the variation in the data well for El Sabbah Children's
 393 hospital than Juba Teaching Hospital.

394
 395 In this study, the correlation coefficient (r) was used as a criterion to determine the strength
 396 and nature of the linear relationship between water polluted with fecal coliform (CFU/100ml)
 397 and waterborne diseases such as typhoid fever. The results (table 10 below) revealed a very
 398 high positive correlation between typhoid fever and water polluted with fecal coliform for both
 399 hospitals in Juba. Comparatively, it was also noticed that the strength of the relationship for
 400 El Sabbah Children's Hospital in both years were stronger than that of Juba Teaching
 401 Hospital's recorded cases. This shows that a stronger relationship exist between Typhoid
 402 and CFU/100ml in El Sabbah Children's Hospital than in Juba Teaching Hospital. The
 403 correlation coefficient values obtained is completely in line with the findings of [29], when he
 404 pointed out that "human and animal excreta waste contains disease-carrying organisms
 405 such as the bacterium *Escherichia coli* and pathogens that cause cholera, typhoid, diarrhea,
 406 dysentery, hepatitis A and cryptosporidiosis". Furthermore, this strong correlation is backed
 407 up with the fact that most of the residents in Juba entirely depend on the water from this
 408 polluted river Nile for drinking and all other domestic use. The high income class usually tries
 409 to avoid typhoid infection through drinking distilled/pure water: and this is why empty plastic
 410 water bottles dominate the waste stream. The middle class tries to do so by purifying the
 411 river water using Chlorine or at times Alum (Aluminium Sulphate) locally know as "Water
 412 Guard" when Chlorine is not at hand. For the case of the latter, it is rather helpless. It only
 413 settles the suspended particles in the water and makes it appear clean but it does not kill the
 414 germs/micro-organisms. While the last class or the disadvantaged group; of course the poor
 415 residents of the city: they depend solely on the direct use of the river water without any kind
 416 of treatment.

417
 418 The principal means of acquiring the *Salmonella typhi* (the bacterium that causes typhoid) is
 419 through ingestion of water contaminated with feces (fecal coliform). Also it can be acquired
 420 through bathing or any form of contact with this contaminated water. In Juba, almost
 421 everybody is exposed to typhoid fever infection because the entire city uses the river water
 422 for bathing and washing. Not only that but also all the restaurants in the city use this very
 423 water for customers to wash their hands before eating and also for washing the dishes.
 424 Therefore, in Juba, whether you drink pure water or not; you still remain at high risk of
 425 typhoid fever infection except if you can avoid it by bathing with boiled water and not eating
 426 in a restaurant.

427

428 **Table 9: Coefficient of determination (R^2) of CFU/100ml verses typhoid fever**

Year	Month	El Sabaah	Juba Teaching
		Children's Hospital	Hospital
		CFU/100 ml vs. Typhoid Fever	CFU/100 ml vs. Typhoid Fever

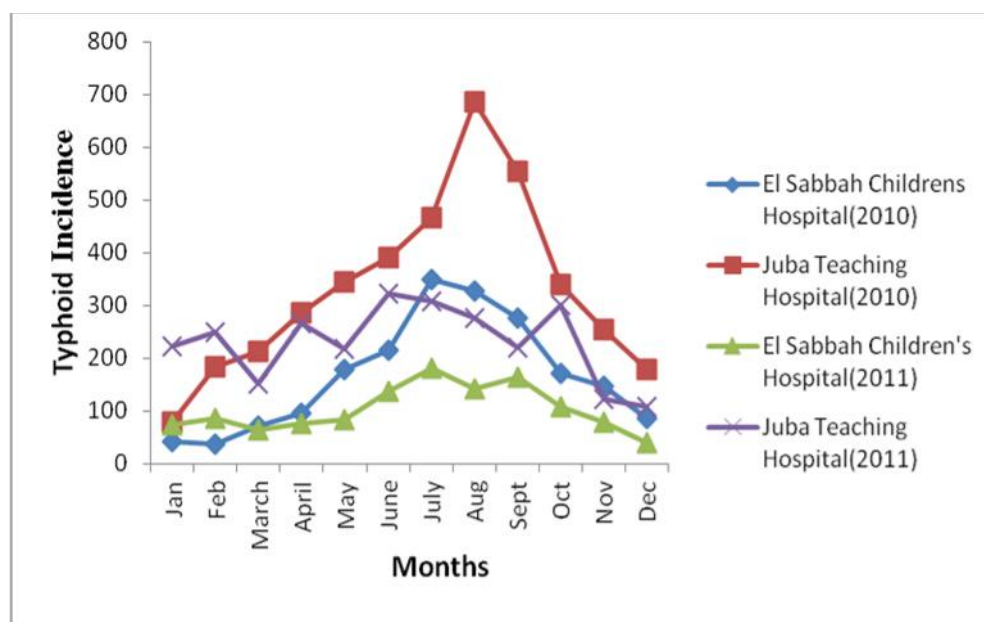
2010	Jan.-Dec.	0.7741	0.6787
2011	Jan.-Dec	0.7215	0.46

Table 10: Correlation coefficient (r) of CFU/100ml verses typhoid fever

Year	Month	El Sabaah	Juba Teaching Hospital
		Children's Hospital	
		CFU/100 ml vs.	CFU/100 ml vs. Typhoid
		Typhoid Fever	Fever
2010	Jan.-Dec.	0.8798	0.8238
2011	Jan.-Dec	0.8494	0.6782

NB: A close observation among tables 8, 9 and 10 showed that there is no match: that is, the R^2 and r values do not correspond to the typhoid fever incidence recorded in the two hospitals. Juba Teaching Hospital has lower R^2 and r values despite the fact that it has the highest recorded typhoid fever incidence: this is due to the fact that; statistically, the coefficient values do not have control over the recorded data.

3.4.2 Trend analysis for typhoid recorded cases at the two main hospitals in Juba



443 **Figure 5: shows the trend of typhoid incidence in the two hospitals**

444

445 From the figure above, it is very clear that Juba Teaching Hospital has the highest incidence
446 rate compared to El-Sabaah Children's Hospital. There are a number of factors behind this
447 high rate: firstly, most patients in Juba Teaching Hospital use the river water for washing and
448 bathing but not for drinking and secondly the lack of proper implementation of the
449 professional ethics by the medical personnel is also a major contributor. For example, most
450 of the nurses are very aggressive and this at times frightens the patients' attendants and this
451 in turn could lead to poor communication between the nurses and the patients' attendants.
452 This will definitely affect the medication monitoring. Thirdly, most of the patients admitted in
453 this hospital are the poor citizens and there are cases whereby they cannot afford buying the
454 medication as the hospital does not provide free medicines. This is so far the worse factor:
455 because the moment the patient fails to buy the medicine, the next stage becomes a
456 terminal case. While for El-Sabaah Children's Hospital's low rate, there are also some
457 factors behind this: firstly, it is a Children hospital; and naturally much care is paid to children
458 than to the adults. Secondly, Unicef (United Nations Children's Fund) is supporting the
459 hospital by providing medicines and nutritional services. This must be appreciated by all
460 good wishers because it is truly contributing so much to the well being of the children in the
461 hospital. Hence, Unicef must be given a credit for what it's doing. Thirdly, the hospital is
462 using very clean water: El-Sabaah borehole in the analysis has zero CFU/100 ml (BH5 in
463 table 6).

464

465 The trend also showed clearly that the peak of typhoid fever incidence is in the month of
466 July; and this is also the time of the year when the rains reach their climax. Also this is the
467 time of the year when the river Nile is highly polluted; because the heavy rains wash any
468 kind of waste in this highly polluted city into the river Nile. With just the naked eyes, one can
469 easily see that the water is really polluted because of the amount of dirt in it. Therefore,
470 logically there is a strong connection between municipal solid waste pollution, water pollution
471 and typhoid incidence. From the trend figure above, it is noticed that there was a gradual
472 and steady increase in the track of typhoid fever incidence from January to June for Juba
473 Teaching Hospital in the year 2010. Then from June to July, there was a very sharp
474 increase: and then from July to December it showed a sharp decrease. This is in line with
475 the rain trend pattern of the year; whereby the rains also start to increase from April to July
476 with the maximum heavy rains between June and September. For El-Sabaah Children's
477 Hospital, the trend track is almost the same. The only difference is that the typhoid fever
478 incidence peaks in June while for Juba Teaching Hospital, it is in July. For the year 2011, the
479 trend track for Juba Teaching Hospital was unstable; mean while El-Sabaah Children's
480 Hospital showed somehow stable increase and decrease pattern. This is because in 2011,
481 there was low precipitation and was marked with very high irregularity of the rainfalls.

482

483 **3.5 Diarrhea Correlation Analysis (R^2 and r statistics for diarrhea)**

484

485 This correlation analysis used the data from table 7 and a two year statistical data of
486 diarrhea incidence from the two main hospitals. Table 11 below presents the diarrhea
487 incidence data:

488

489 **Table 11: shows the statistical data for diarrhea incidence in the two main hospitals in**
490 **Juba**

491

Year/ Month	2010		2011	
	El-Sabaah Children's	Juba Teaching	El-Sabaah Children's	Juba Teaching

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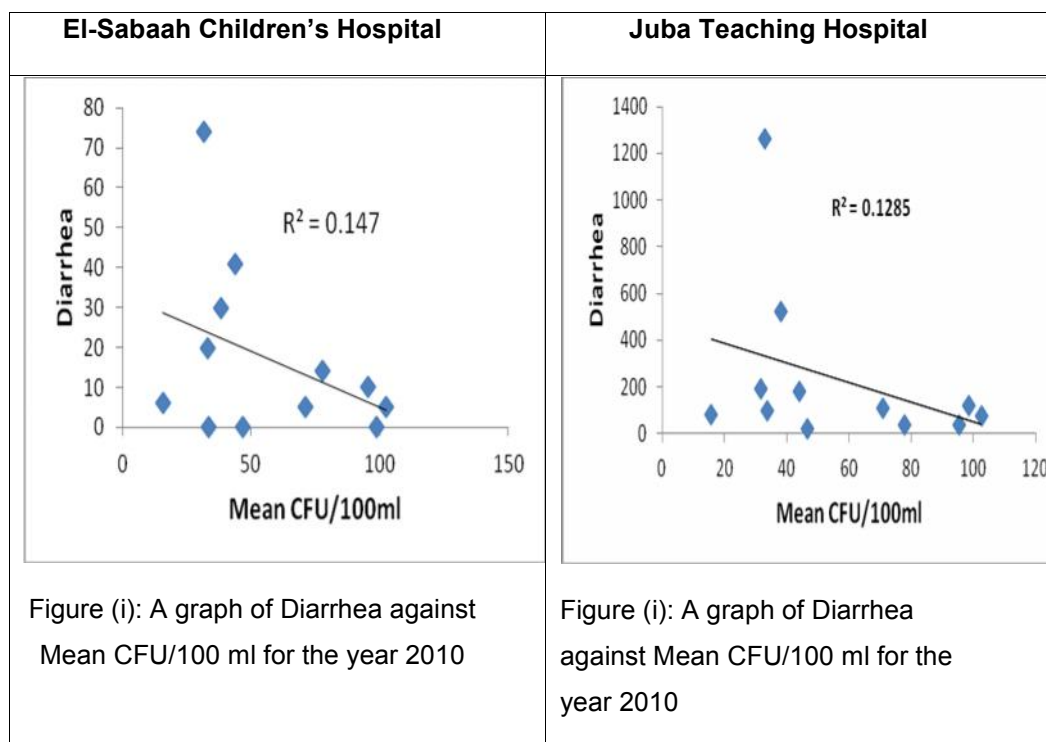
E-mail address: martinkajokare@yahoo.com

	Hospital Diarrhea	Hospital Diarrhea	Hospital Diarrhea	Hospital Diarrhea
Jan.	20	63	21	170
Feb.	74	193	17	89
March	30	523	9	142
April	41	183	31	153
May	14	39	37	115
June	10	36	19	98
July	5	77	61	26
Aug.	0	122	15	106
Sept.	5	108	48	139
Oct.	0	21	33	78
Nov.	0	98	21	107
Dec.	6	81	17	122

492

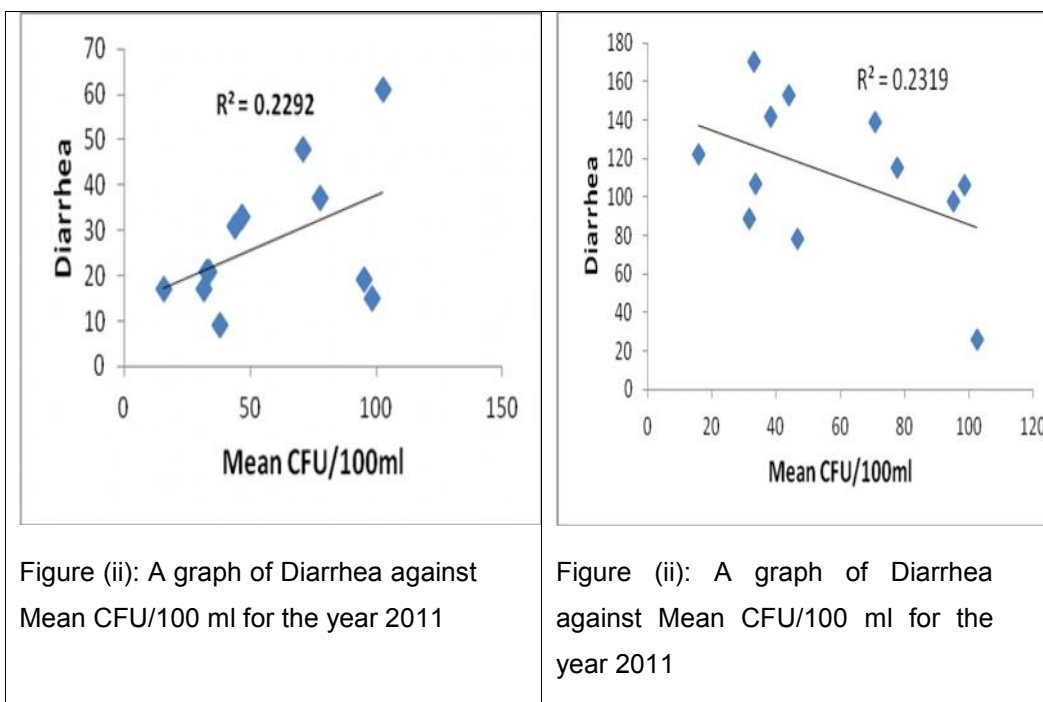
493 The below graphs show the linear regression analysis results for the correlation between
494 diarrhea incidence and CFU/100 ml:

495



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Figure 6: shows the scatter plots between CFU/100 ml and diarrhea

3.5.1 The correlation coefficients for diarrhea incidence

From the graphs above, it can clearly be seen that there is no linear correlation between diarrhea and CFU/100ml. Table 10 below shows that the correlation coefficients for El-Sabaah Children's Hospital are 0.3834 and 0.4787 for the years 2010 and 2011 respectively. For Juba Teaching Hospital, the correlation coefficients are 0.3585 and 0.4815 for the years 2010 and 2011 respectively. These values indicate a weak to moderate correlation. The reason for this weak correlation is that: diarrhea is a water-borne disease that has got no connection with water contaminated with fecal coliform but it is rather a symptom of diseases related to fecal coliform water contamination. For example, a person infected by typhoid, Cholera, Hepatitis A, Salmonellosis, *E coli* infection and many others can have diarrhea. Thus, the weak correlation is in turn an evidence that diarrhea has got no any relationship with water contaminated with fecal coliform.

Table 12: Coefficient of determination (R^2) of CFU/100ml verses diarrhea incidence

Year	Month	El-Sabaah Children's	Juba Teaching
		Hospital	Hospital
		CFU/100 ml vs.	CFU/100 ml vs.
		Diarrhea	Diarrhea

2010	Jan.-Dec.	0.147	0.1285
2011	Jan.-Dec	0.2292	0.2319

Table 13: Correlation coefficient (r) of CFU/100ml verses diarrhea incidence

Year	Month	El-Sabaah Children's	Juba Teaching
		Hospital	Hospital
		CFU/100 ml vs.	CFU/100 ml vs.
		Diarrhea	Diarrhea
2010	Jan.-Dec.	0.3834	0.3585
2011	Jan.-Dec.	0.4787	0.4815

3.5.2 Trend analysis for diarrhea recorded cases at the two main hospitals in Juba

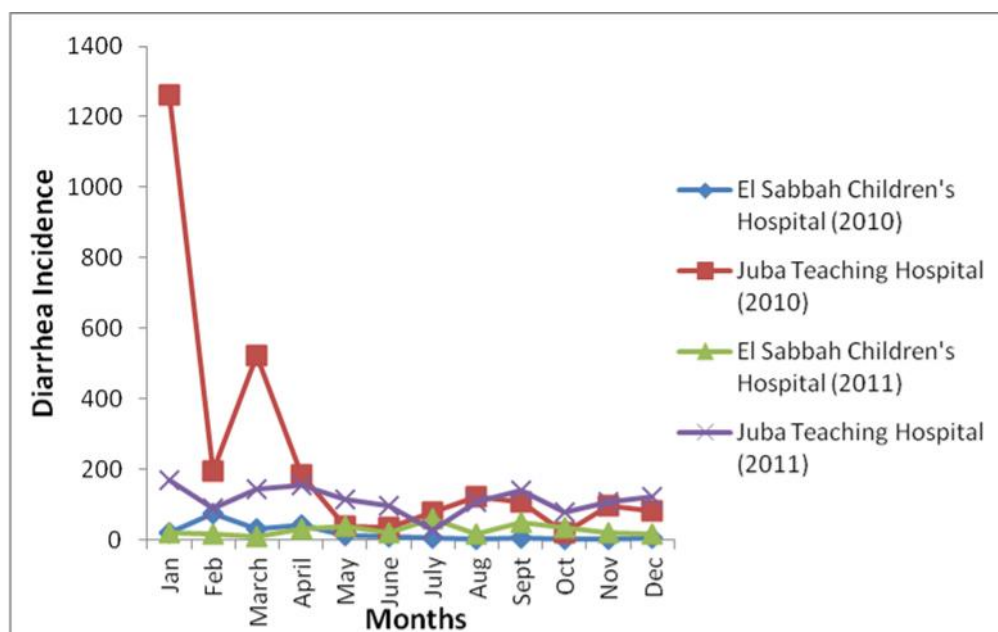


Figure 7: shows the trend of diarrhea incidence in the two hospitals

From figure 7 above, it is clear that the trend of diarrhea does not follow the waste pollution and water pollution pattern. It peaks in January that is in Juba Teaching Hospital; and this is the time of the year where there are no rains. Even with the naked eyes one can see that the river Nile is not polluted; because the water generally appears cleaner than during the rainy season. Juba Teaching Hospital has the highest rate. This is basically due to the fact that adults have many kinds of diseases compared to children. Hence, some of these diseases are the cause of the diarrhea for example, HIV/AIDS patients have continuous diarrhea. Here, also the poor medical care can contribute to some of the diarrheal cases. The situation in El-Sabaah Children's Hospital is somehow very encouraging. The low rate has two main factors contributing to: firstly, children have very few diseases apart from the "six child killer diseases" plus Malaria and Typhoid which no body in Juba can escape. Secondly, the degree of proper care and the clean water they use also play a major role.

For the diarrhea incidence trend track, it showed instability in both years: this is due to the fact that diarrhea incidence has got no connection with the water pollution due to the heavy rains; therefore, it does not follow the rain trend.

3.6 The Correlation Confirmatory Test

To further confirm the degree of linearity (correlation) between fecal coliform (CFU/100ml) and Typhoid Fever, a test of hypotheses (t-test statistic) at 5% significance level was conducted on the correlation coefficients determined.

Testing of hypothesis

Null hypothesis: There is no correlation between Typhoid Fever and water polluted with fecal coliform (CFU/100ml)

$$H_0 : \rho = 0$$

Alternative hypothesis: There is correlation between Typhoid Fever and water polluted with fecal coliform (CFU/100ml)

$$H_1 : \rho \neq 0$$

Significance level: $\alpha = 0.05$

Test statistic:
$$t = r \frac{\sqrt{n-2}}{\sqrt{1-r^2}}$$

Where; r = correlation coefficient (refer to table 10)

n = number of observations = 12

Decision rule: Reject H_0 if $|t| > t_{\alpha/2, n-2}$

Conclusion: If the calculated $|t|$ is greater than $t_{\alpha/2, n-2}$, reject the null hypothesis and vice versa.

From the student t-distribution tables, $t_{(0.025, 10)} = 2.228$.

Table 14: Computed t-test value for correlation coefficient for typhoid and CFU/100ml

Year	Month	El Sabaah Children's Hospital	Juba Teaching Hospital
2010	Jan.-Dec.	5.85364	4.59586
2011	Jan.-Dec.	5.08979	2.91851

From table 14 above, since calculated t exceeds the appropriate critical values $t_{(0.025, 12)} = 2.228$, the conclusion is that the data provides convincing evidence that there is a relationship between typhoid fever and water polluted with fecal coliform (CFU/100ml).

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These results further corroborate the scientific findings quoted in literature that the cause of Typhoid fever can be attributed to water polluted with fecal coliform. Hence, $H_0 : \rho = 0$ is rejected and $H_1 : \rho \neq 0$ is accepted.

Furthermore, the degree of non-linearity between fecal coliform (CFU/100ml) and Diarrhea was confirmed. A test of hypotheses (t statistic) at 5% significance level was also conducted on the correlation coefficients determined.

Testing of hypothesis

Null hypothesis: There is no relationship between Diarrhea and CFU/100ml

$$H_0 : \rho = 0$$

Alternative hypothesis: There is a relationship between Diarrhea and CFU/100ml

$$H_1 : \rho \neq 0$$

Significance level: $\alpha = 0.05$

Test statistic:
$$t = r \frac{\sqrt{n-2}}{\sqrt{1-r^2}}$$

Where; r = correlation coefficient (refer to table 13)

n = number of observations = 12

Decision rule: Reject H_0 if $|t| > t_{\alpha/2, n-2}$

Conclusion: If the calculated $|t|$ is greater than $t_{\alpha/2, n-2}$, reject the null hypothesis and vice versa.

From the student t-distribution tables, $t_{(0.025, 10)} = 2.228$.

Table 15: Computed t-test value for correlation coefficient for diarrhea and CFU/100ml

Year	Month	El Sabaah Children's Hospital	Juba Teaching Hospital
2010	Jan.-Dec.	1.31277	1.21428
2011	Jan.-Dec.	1.7244	1.7376

Judging from the t values obtained (table 15) for the correlation coefficients, it can be concluded that there is no relationship existing between Diarrhea and Fecal Coliform at 95% confidence interval, hence, the alternative hypothesis ($H_1 : \rho \neq 0$) is rejected.

Therefore, the conclusion to be drawn here is that the correlation coefficients values obtained between CFU/100ml and Typhoid are statistically significant where as the opposite can be stated for the Diarrhea and CFU/100ml.

3.7 The Correlation between Municipal Solid Waste Pollution and Water-borne Diseases

There was no statistical correlation analysis done for municipal solid waste in relation to water-borne diseases simply because the correlation between the two is not a direct one. A lot of literature confirms that the relationship is indirect. For example, according to [13,11], "in the developing countries, the uncollected waste, which is often also mixed with human and animal excreta, is dumped indiscriminately beside the streets and in drains, so contributing to water stagnation, breeding of insect and rodent vectors and the spread of diseases".

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Furthermore, even the somehow collected waste is often disposed of in uncontrolled dumpsites and/or burnt in the open spaces and consequently; this can result into the pollution of the water resources and the air [4, 5, 6]. From these two statements, it can be concluded that there is a strong correlation between typhoid and the pervasive municipal solid waste pollution in Juba city. The logical connection is that, this waste contains both human and animal excreta which when it rains, it's washed into the river Nile. The evidence is the high fecal coliform contamination of the river Nile's water confirmed during the water samples' analysis. Also many researchers confirm that the main cause of water-borne diseases is ingestion of water contaminated with feces which in turn contains the fecal coliform. Therefore, the high incidence of typhoid fever in Juba is primarily from the municipal solid waste pollution and coupled with the poor sanitation status in the city.

From the above correlation analysis, there is a clear indication that there is surely a very strong correlation between water polluted with fecal coliform and typhoid fever. There is also very strong logical correlation between municipal solid waste pollution and typhoid fever although not statistically confirmed. Weak to moderate correlation between diarrhea and water pollution was noticed from the statistical analysis. Therefore, there is an urgent need for the government of South Sudan and other developing countries with similar situation to take drastic measures towards municipal solid waste management so as to avoid the loss of innocent lives.

4. CONCLUSION

Generally, the poor municipal solid waste management in most cities of the developing countries has resulted into many problems. The uncontrolled and un-scientific dumping of municipal solid wastes has brought about serious human health problems; contamination of both surface and ground water which is in turn a threat to human health. The analysis results obtained from this study revealed that, the river Nile is highly contaminated with fecal coliform to the extent that it is unfit to be used as drinking water except for other purposes. For the boreholes and the well, the results were somehow good. Out of the eleven boreholes tested, six of them were found to be clean thus; satisfying the USEPA and WHO recommended standard value for drinking water. The other five and the well were found to be contaminated but not as high as the surface water.

The results of this study can be so useful to the general public and the government. It will alert those people who are currently using the contaminated water about the high risk of being infected by water-borne diseases and the related ones if they continue using it especially for drinking. Water-borne diseases such as typhoid, diarrhea, dysentery, hepatitis A and occasionally cholera are currently a serious public health problem in Juba. Therefore, this study will act as a guide for the government to take the necessary measures to tackle the municipal solid waste pollution in the city. Hence, the cities' authorities in the developing countries must heavily invest in municipal solid waste management in order to avoid the high risk to both human health and the environment.

This study confirmed that there is a very strong correlation between typhoid fever and water contaminated with fecal coliform. It also found out that there is a weak correlation between diarrhea and the contaminated water. Thus, it can be concluded that there is a strong correlation between municipal solid waste pollution, water polluted with fecal coliform and typhoid fever in Juba.

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673 **AUTHORS' CONTRIBUTIONS**

674

675 Author MKL designed the study, literature search, collected and analyzed the data, wrote
676 the first draft of the manuscript. Author QS supervised the work. Author YYZ performed
677 the correlation analysis. All authors read and approved the final manuscripts.

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