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Assessment and Mitigation Measures for Water Pollution Risks in Khartoum State

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Abstract: Deficiency of sanitation systems and contaminated surface-runoff in urban and rural communities cause serious environmental problems by deteriorating water quality of surface and ground water. The aim of this study is to evaluate the degree of water pollution (surface and ground) in Khartoum State, to determine the symptoms of the environmental problems and to suggest some solutions. The study included analysis of 24 surface water samples, in two seasons, from the River Nile, the Blue Nile, and the White Nile. High values of biochemical oxygen demand (251 mg/l, 210 mg/l) in two locations indicate that there are pollution problems, values of chemical oxygen demand, and biological tests emphasized the occurrence of pollution loads. Questionnaires analysis, which has been distributed as part of this study, showed that the use of septic tanks with soakaway wells (shallow wells receiving septic tank effluents) forms about 21% of sanitation systems in Khartoum, 73% of Khartoum population use pit-latrines, about 1.5% only served by sewerage system, and the rest percentage use other poor sanitation system. Samples were collected from nine soakaway wells receiving septic tanks effluents. Average values of ammonia concentration about 27 mg/l indicate that the quality of ground water aquifers may be threatened by chemical pollution load. As ammonia will be oxidized to nitrate through time as effluents seep through cracks and fissures of soil strata to deep aquifers. To improve the situation of sanitation systems, some Mitigation measures such as adopting ventilated improved pit latrines, erecting small bore sewers and extending the coverage of conventional gravity sewers have been suggested. Upgrading the systems by 50%, 25% and 25%, respectively, will improve the environment in Khartoum state. A total cost estimate of abort 1518 million US$ is required for upgrading sanitation systems in Khartoum state within three phases in a plan extending to 2030.

Keywords: Sanitation Systems; Khartoum state; Pit Latrines; Septic Tanks; Pollution Water Risk; Soakaway Well; Mitigation Measures.

1. INTRODUCTION

The preamble to the constitution of the world health organization (WHO) state that: "the enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being." However, the fast growing population in the third world countries and the limited economic resources in many of these countries led to the dramatic expansion of the urban centres and consequently the use of simple sanitation systems (dry on-site system and wet on-site system). The use of conventional sewerage system is very limited and in most cases the available system is overloaded together with deficiency in operation and maintenance practices. Increase of urbanization in these countries has overloaded the environment, creating pollution problems to surface water and groundwater due to inadequate design and implementation of dry on-site sanitation system (pit-latrines) and wet on-site sanitation systems (septic tanks and aqua-privies). The rate of infection by waterborne diseases in urban communities of developing countries is high. Chemical pollution of groundwater is even more hazardous to health due to accumulation of certain elements which had serious effects on health.

Khartoum state is of an area mounting to 22,000 square kilometres located between longitudes 31.5 – 34.45 degree east, and latitudes 15.8 – 16.45 degree north (Fig. 1). The climate is semi desert, the means of maximum temperature is 41.1^{o}C and means of minimum temperature is 22.7^{o}C. The average of rainfall rate is about 150 mm [1]. For nearly two centuries people from different ethnic groups have moved to Khartoum. Greater Khartoum encompasses three different cities. Khartoum served as the colonial administrative centre during Ottoman and Anglo-Egyptian rule and is now the seat

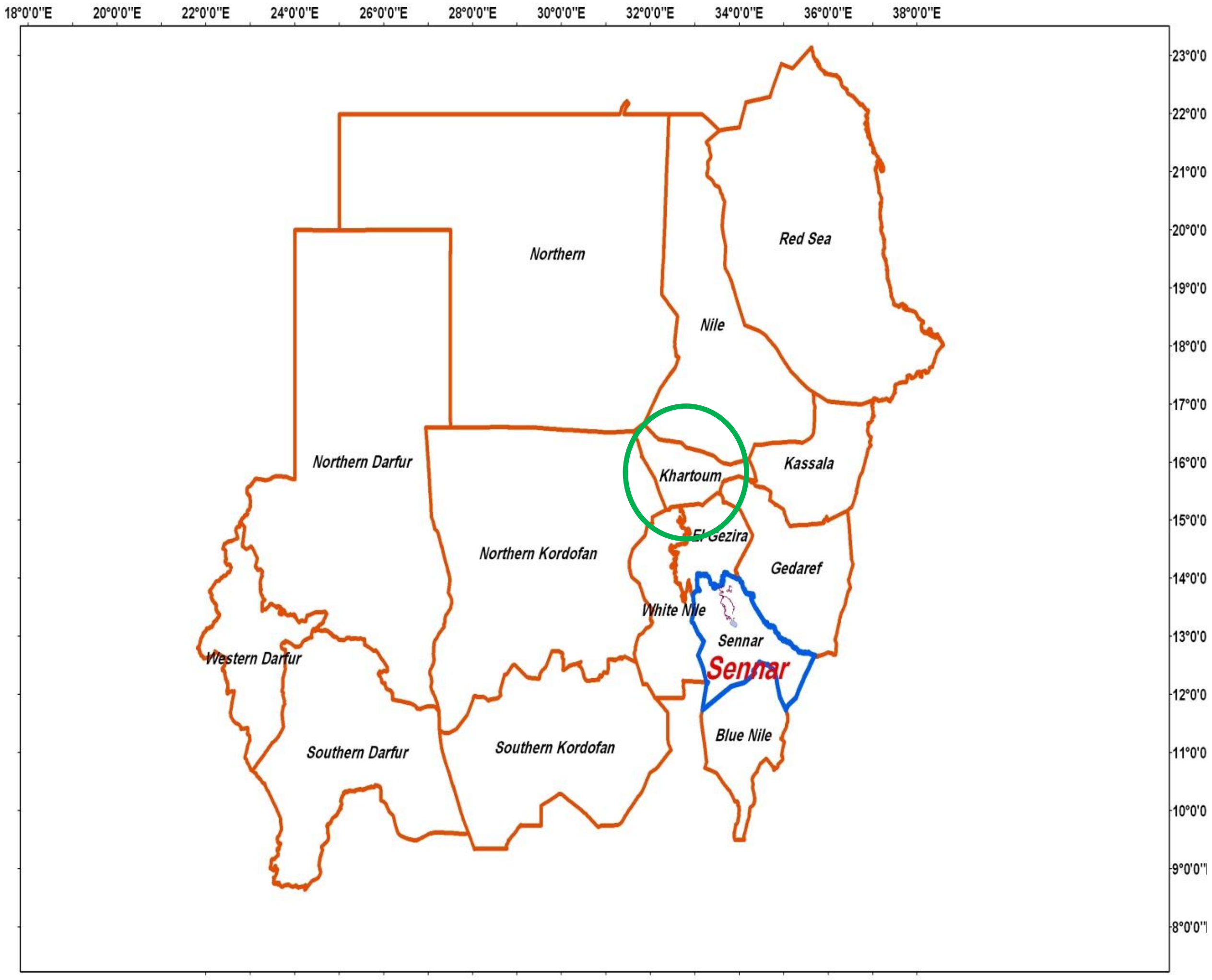

Fig. 1. Khartoum state (study area) [1]

of the government. Omdurman, a more traditional Sudanese town, has mudbrick houses and inner courtyards. The third urban region, Khartoum North, is the newest settlement where, industrial development has taken place.

In the capital, modern industry mingles with traditional settlement. Edible oils factories stand with small factories churning out everything from dried fruits to footwear, textiles, and cosmetics. Steel silos and wheat processing plants tower over small family-run bakeries. Perhaps as many as seven or eight million people, including some million displaced by the war, currently live in greater Khartoum most have come in search of employment opportunities [2].

A multiple indicator cluster survey (2000) which was carried out by the federal Ministry of health, UNICEF, and central bureau of statistic figures that 85.5% of Khartoum state population is urban and 12.5% is rural. Infant Mortality rate is 70, less than 5 years old mortality rate is 100.The Percentage of children of primary school age attending primary school is 69%. More than two thirds of children who enter the first grade of primary school eventually reach grade five. 67% of households (HH) are rich, 15% are poor and 18% are intermediate [3].

This study aims to identify the environmental effects of sanitation systems on urban communities in a developing country (Sudan) and to outline mitigation measures for the effects. Specific objectives were

- To assess sanitation systems in Khartoum state,
- To identify pollution risks on surface and ground water,
- To obtain basic relevant information by questionnaire survey,
- To outline mitigation measures to minimize risk of pollution from sanitation systems,
- To provide a plan for implementing the outcome of the study with cost estimates.

2. MATERIALS AND METHODS

Field work in this study includes three activities: Surface water samples, soakaway wells samples, and Questionnaire. All samples were analyzed in sanitary laboratory of the

University of Khartoum; the data collected by the survey were processed by the help of the computer programs (SPSS and Excel).

2.1 Water Sampling:

Locations of surface water samples were selected according to previous information on the environment along the three rivers; Main Nile, White Nile, and Blue Nile (see Fig. 2 and Table 1). From each location two samples were collected, one in June 2006, and the other in January 2007. For soakaway wells sampling, three random samples were collected from different locations in every town (Khartoum, Khartoum north, and Omdurman) to represent the districts in the study area where wet on-site disposal systems (septic tanks and disposal wells) are used . Table 2 shows locations of septic tank effluent sampling

2.2 Method of Water Samples Analysis

Standard methods of tests are used (Table 3). For surface water all of the above tests were carried out, and for soakaway wells samples, only the first four tests were conducted.

Table 1. Locations of surface water samples

River Nile		Blue Nile		White Nile	
R1	National assembly	B1	Aljreeef (east)	W1	Alkalkla algoba
R2	Almurada	B2	Hilat kuku	W2	Alshajra
R3	TV corp.	B3	Friendship palace	W3	Alfithab
R4	Madenat ElNeel	B4	Almogran	W4	Military Hospital

Table 2. Locations of septic tank effluent sampling

Khartoum town		Khartoum North Town		Omdurman Town	
K1	Burri	N1	Shambat	O1	Almurada
K2	Almujhdeen	N2	Aldrushab	O2	almuhandseen
K3	Alkalakla	N3	Al alafun	O3	Umbada

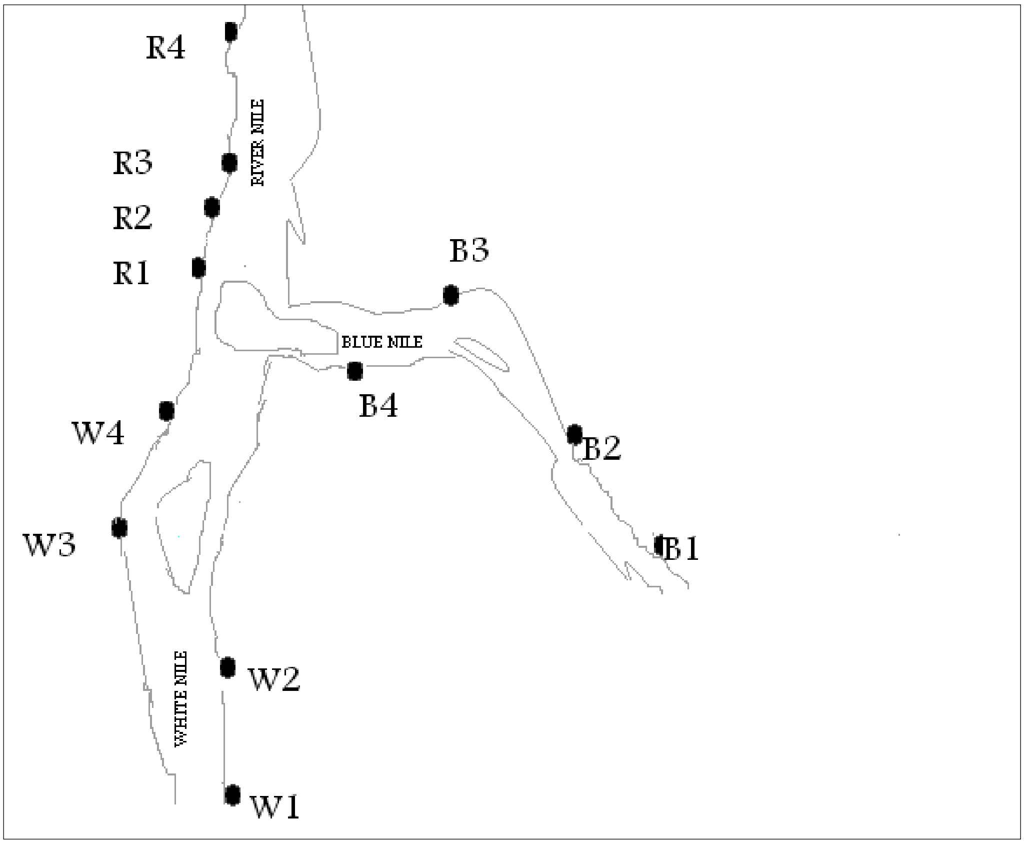

Fig. 2. Sampling locations in River Nile and its tributaries (2006)

Table 3. Methods of samples analyses

Test	Method
BOD	Digital track/ traditional method
COD	dichromate reflux method
Ammonia	Ion specific meter/ titration method
Nitrate	Reagent (color change)
pH	pH meter (direct reading)
TDS	TDS meter (direct reading)
Total coliform	Pour-plate method
Fecal coliform	Pour-plate method

3. RESULTS AND DISCUSSION

3.1 Quality of Surface Water

Samples from 12 locations were selected along Blue Nile, White Nile, and the Main Nile. The collected sampled were analyzed for the following water quality parameters. Results obtained were analyzed and discussed as follows:

3.1.1 Biochemical Oxygen Demand $(BOD)_5$

High values of BOD_5 were detected in two locations: W2 (alshajra), and W4 (Military Hospital). Egyptian Nile pollution protection law (law 48/1982) specified standard value for ambient water [4], that BOD_5 should not exceed 6 mg/l. According to this standard, BOD_5 obtained by this study indicate that there is an organic pollution loads at some locations. As shown in Fig. 3 BOD_5 values were excessively high in two location along the White Nile W4 (Military Hospital) and W2 (Alshajara). At R2 (Almorada) and B4 (Almogran) BOD_5 values were relatively high than the standard value of 6 mg/l.

3.1.2 Chemical Oxygen Demand

According to the Egyptian Nile pollution protection law COD must not exceed 10 mg/l [4]. The results presented in Fig. 4 show that 23 out of 24 samples were above the standard value. The relationship between COD/BOD values indicates the presence of nonbiodegradable organic compounds.

3.1.3 Nitrogen

Ammonia nitrogen: High values of ammonia were obtained at location studied during the hot season (June) compared with that at the cold season (January) (see Fig. 5). Natural ammonia level in surface and ground water is usually below 0.2 mg/l [5]. The presence of ammonia is at concentration above 0.2 mg/l, which is an indication of fresh sewage disposal in water body.

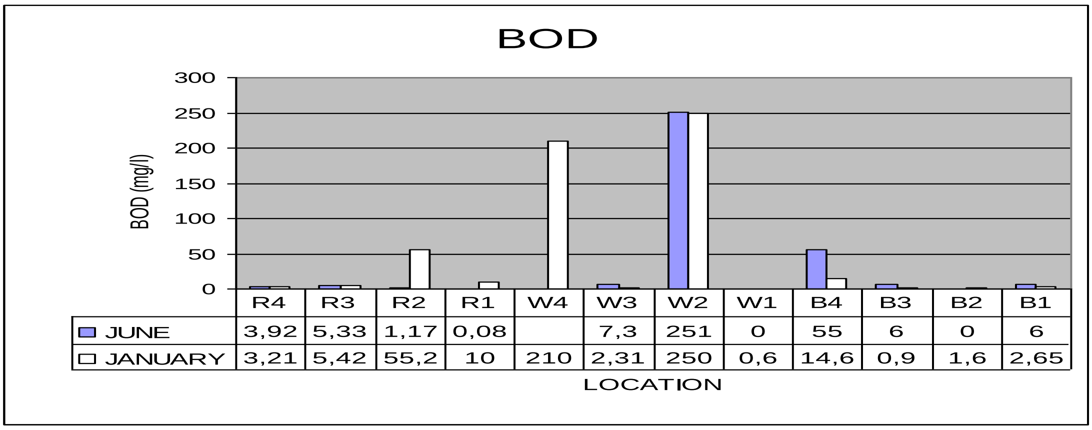

Fig. 3. Biochemical Oxygen Demand of surface water

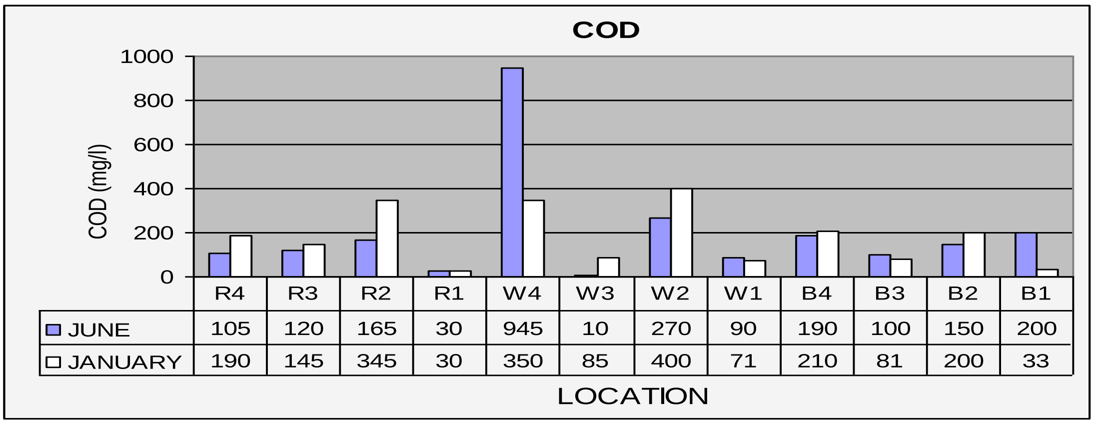

Fig. 4. Chemical Oxygen Demands of surface water samples

3.1.4 pH

There is no wide difference between pH values of samples. All values of pH are in the range of 7.9 to 9.2 (see Fig. 6).

3.1.5 Total Dissolved Solid (TDS)

TDS concentrations are acceptable up to 500 mg/l, according to Egyptian Nile pollution protection law [4]. TDS of all samples were found to be within the permissible limits (see Fig. 7).

3.1.6 Biological Tests

As there is no specified standard value for fecal coliform (FC) counts for the ambient water quality of the Nile River, therefore, the value given by the WHO (1989) as a guideline for use of water for unrestricted irrigation (1000 fecal coliform/100ml) has been taken as a guide for the evaluation of the water quality in this study.

The results of the microbiological examination indicated the existence of a great variation in the spatial distribution of the fecal coliforms counts, (10 samples out of 24 are over standard value). Fecal coliform values are very high at R3 (TV Corp) and W1 (Alkalakla). The total coliform values were high at R4, R2, W1 and B3, at Nile town, Almorada, Alkalakla and Friendship palace respectively. The presence of fecal and coliforms at levels higher than (WHO) guidelines is an indication of pollution of water in the areas investigated

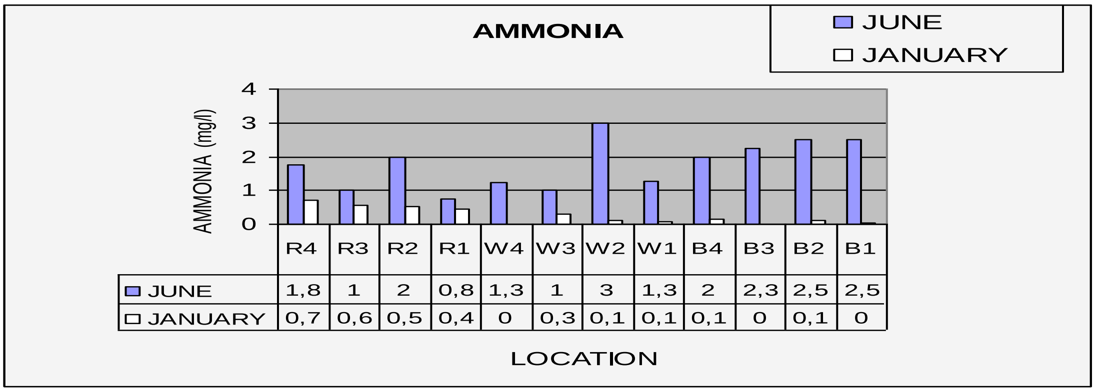

Fig. 5. Ammonia of surface water samples

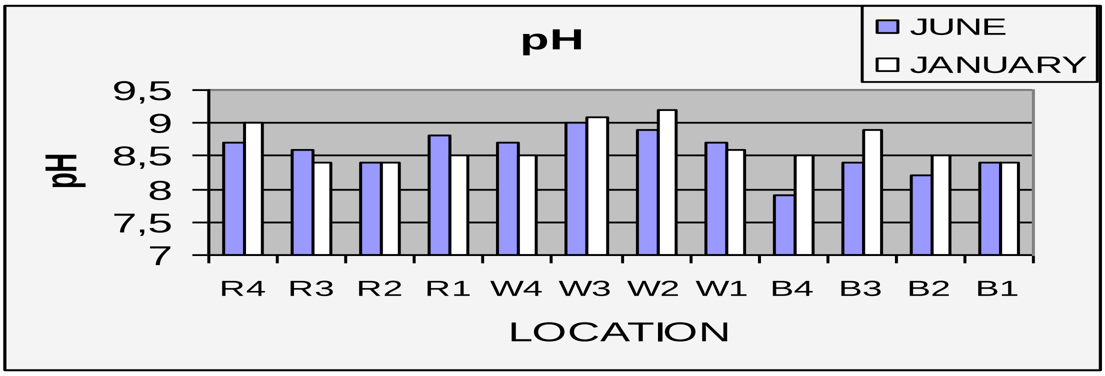

Fig. 6. pH values of surface water samples

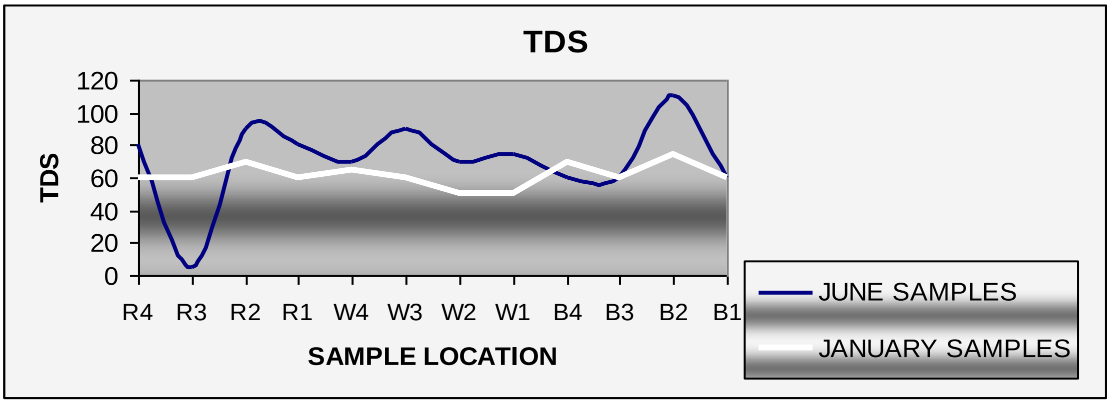

Fig. 7. Total dissolved solid (TDS) of surface water samples

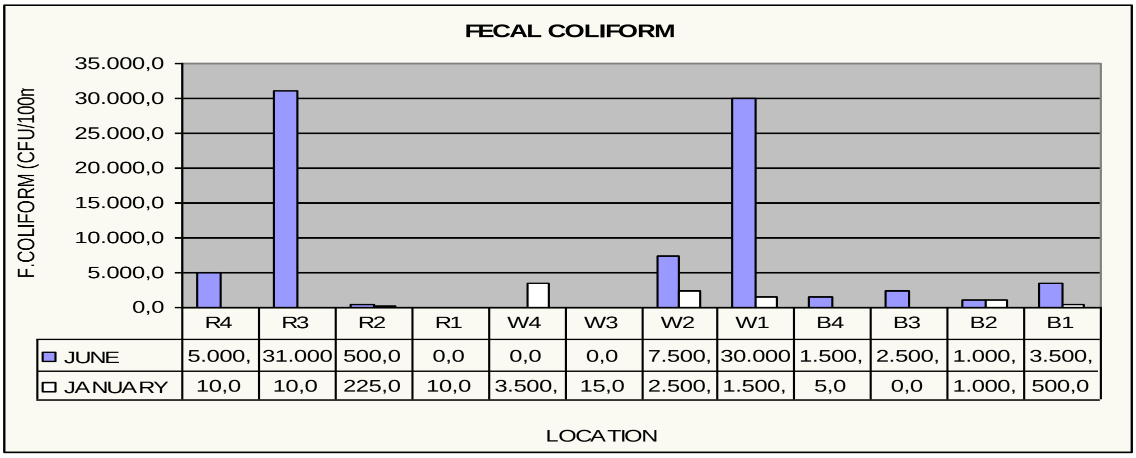

Fig. 8. Fecal colifrom of surface water samples

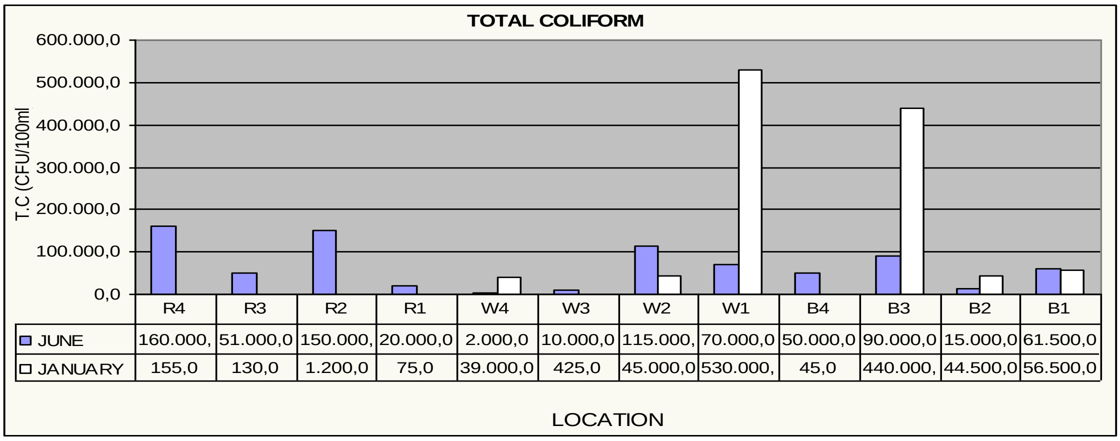

Fig. 9. Total colifrom of surface water samples

3.2 Qualities of Soakaway Wells

Effluent from wet on-site systems (mainly septic tanks) are disposed off into shallow ground water aquifers (soakaway wells) at depths vary from about 10 to 40 m in the study area of greater Khartoum. Samples collected from soakaway wells at location shown on Table 1 are analysed for three parameters BOD_5, COD and ammonia nitrogen. Results are presented in the following bar charts (see Fig. 10-12)

3.2.1 Biochemical Oxygen Demand

The average BOD of these samples was 274.4 mg/l

3.2.2 Chemical Oxygen Demand

Average value of COD was 352.2 mg/l

3.2.3 Ammonia Nitrogen

Presence of ammonia in high concentrations with absence of nitrate indicates that pollution is fresh [6]. Ammonia oxidised with time to nitrite NO_2 and finally to nitrate NO_3. Excess concentration of NO3 (greater than 25 mg/l) is an indication of chemical polluton to ground water aquifers.

The above soakaway wells samples results emphasize that using wells to dispose septic tank effluents forms direct injection of pollutants into ground water, which is very risky to groundwater resources. International Hydrological Program (IHP) and the National committee of the Sudanese national commission for education, science & culture, carried out a comprehensive study for the vulnerability of groundwater resources of Sudan to pollution risks in 2000. The research revealed that the vertical migration of the contaminants is probable particularly in Khartoum and to a lesser extent in Khartoum North. In Omdurman area the situation is better and the vertical migration is relatively less. In term of distances, the maximum vertical depths to which the contaminant would migrate in 20 years with concentration higher than the allowable are as follows: Khartoum 220 meters, Khartoum North 200-220 meters, and Omdurman 150-200 meters [7] . Migration of contaminants means that if there is a production borehole for fresh water within the indicated distances. This means that the ground water obtained from this well for drinking water would be subjected to high risk of chemical pollution.

3.3 Analysis of the Questionnaires

Information obtained from the questionnaire survey gave the following results for the different sanitation systems in Khartoum state:

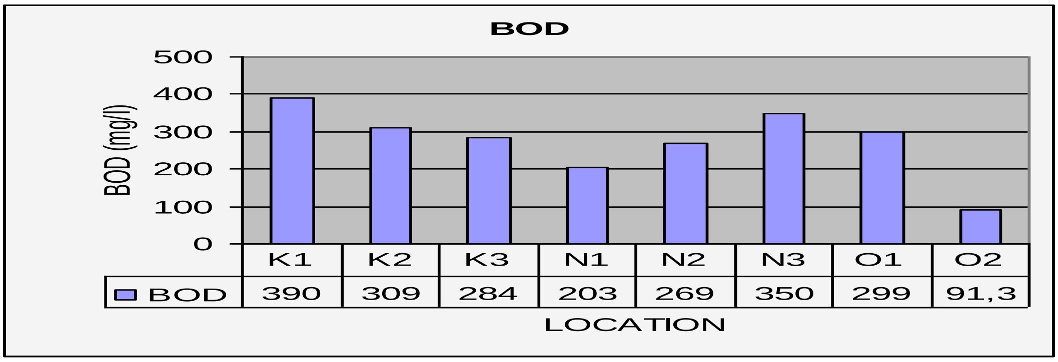

Fig. 10. Biochemical Oxygen Demand of sokaway wells samples

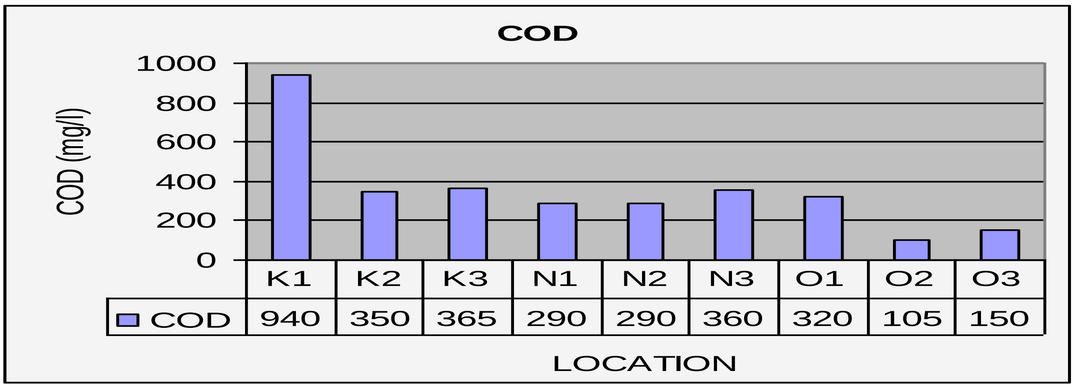

Fig. 11. Chemical Oxygen Demands of sokaway wells

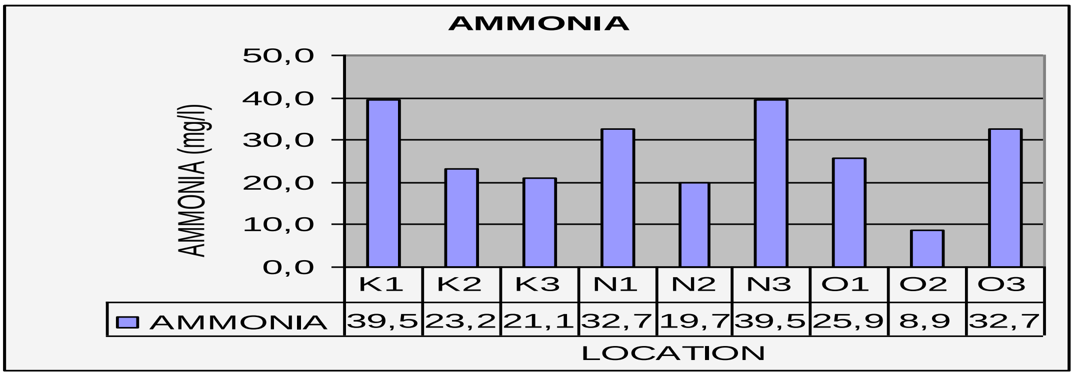

Fig. 12. Ammonia of sokaway wells samples

Nearly every sanitation study will require a household survey to collect quantitative information on questions such as the percentage of households who used different sanitation systems and other related information. From Fig. 13, the percentage of households using pit-latrines are 73.4 %, using septic tanks and soakaway wells is 21.4%, households served by sewer network is 1.4% and others are3.8%. Others include open defecation (1.2%), neighbour (1.2%), mantling (0.4%), just septic tank (0.8%), and septic tank with soakaway (0.2%). In some cases pit latrine is dug until is reached water table, the percentage of these cases is illustrated in Fig. 14.

Two types of problems are encountered by households using sewer network and septic tanks: overflow and repetition of cleaning of the septic tanks within short period of time. The percentage of each problem is illustrated in Fig. 15.

Questionnaire respondents who rejected sewer network system are (39.6%). They attributed their rejection to the current situation of existing sewer network where frequent flooding manholes cause bad smell; deterioration of roads and buildings; and breading of mosquitoes and other insects.

4. Environmental impact and Mitigation Measures of Sanitation Systems and Surface Runoff

4.1 Environmental Impact

The results of the study indicate that there are pollution indicators in surface water (Blue Nile, White Nile, and the River Nile). The use of onsite sanitation systems (dry on-site and wet on-site system) also contributes significantly to health problems of residents in Khartoum state. More than 50% of the diseases occurring in Khartoum state are due to

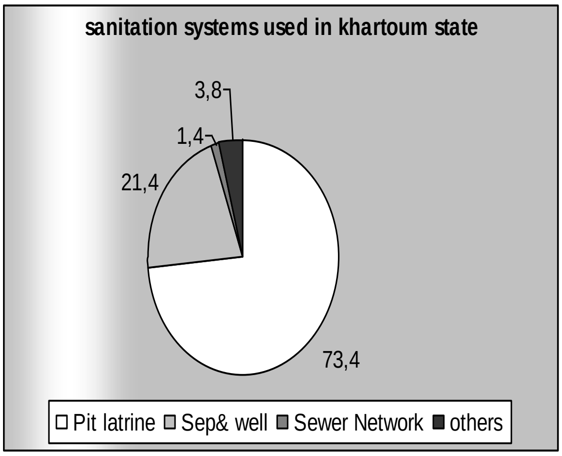

Fig. 13. Sanitation systems used in Khartoum State

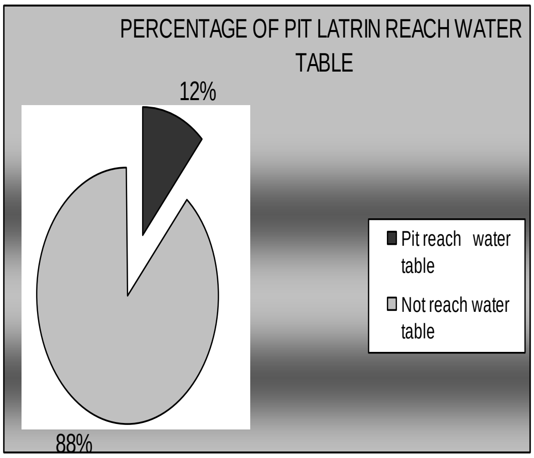

Fig. 14. Percentage of pit Latrine reach water

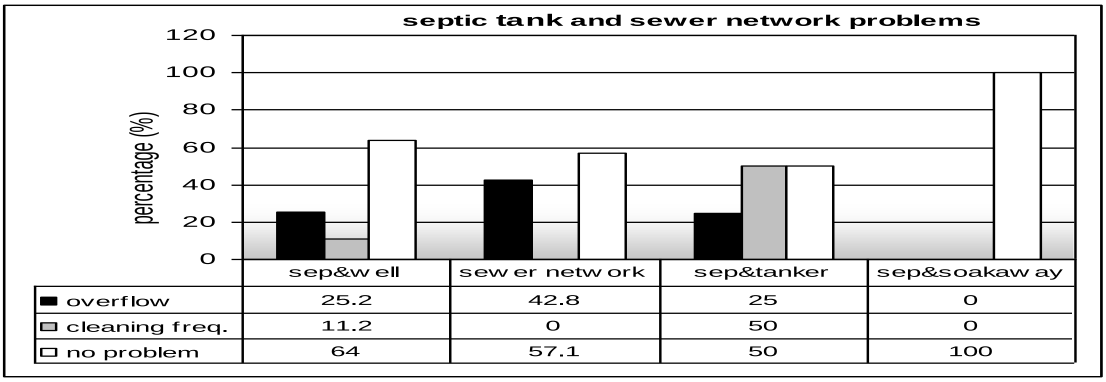

Fig. 15. Sewer network and septic tanks systems problems

poor sanitation problems or bad management of surface run off, as indicated by data in Table 4.

4.2 Mitigation Measures

The following mitigation measures can be considered to be of paramount importance in minimizing or preventing the environmental effects on health caused by poor sanitation systems in Khartoum state:

4.2.1 Improvement of Dry On-site System

The present dry on-site system (pit-latrines) will be replaced by ventilated improved pit-latrines (VIP) where ventilation pipes and pre-cast squatter plates are used by all households in the study area (i.e. coverage of up to 70% of the households in greater Khartoum).

4.2.2 Small-bore Sewer System

Small-bore sewer (SBS) can be used to provide more cost-effective solution compared to the conventional gravity sewer, to correct problems with septic tanks effluents in densely developed urban areas. The SBS can be designed to collect the effluent from the existing septic tank in greater Khartoum (21%). Since the septic tanks would remove the suspended solids that might settle or otherwise cause obstructions in the mains, smaller collector mains 10cm (4 inch) in diameter, laid on a uniform gradient to maintain only a 45 cm/sec (1.5 fps) flow velocity were permitted. This alternative has been estimated to reduce construction cost by 30 to 65%.

4.2.3 Conventional Gravity Sewers

The existing conventional gravity sewers in greater Khartoum with coverage of about 1.4% of the total area are severely overloaded. Being implemented since early 1960, the system requires major upgrading and replacements [8]. In order to increase the coverage of gravity sewers by 5% every 5 years, priority is to be given to these basic infrastructures by removing all technical and financial constraints to increase the coverage of gravity sewer in Khartoum state to about 25% within the next 20 years.

Table 4. Occurrence of diseases in Khartoum state (2007)

Disease	Percentage of occurrence (%)
Diarrhoea	15.2
Malaria	38.8
Dysentery	13.8
Inflammations	14.8
Guardia	2.4
Other*	15

*Note: sanitation systems or surface runoff are not a direct cause.

5. Cost Estimation for the Proposed Mitigation Measures

Greater Khartoum, or Khartoum state, encompasses seven localities with an estimated population of about 6.9 million inhabitants. With average persons of 7 in each household, the number of households can be estimated to one million households. The following three tables contain the proposed improvement in sanitary sewers within the next 20 years.

In order to meet the target plan for improving sanitation systems in Khartoum state by 2030: the following points have to be considered:

- 50% of the population using VIP system
- 25% of the population served by small-bore sewers
- 25% of the population served by conventional gravity sewers

The estimated cost in the four phases of implementation is as follows:

Phase	Estimated cost Million US$
2101-2015	642
2015-2020	174
2020-2025	264
2025-2030	438
Total estimated cost	1518 M US$

6. CONCLUSIONS

The following conclusions were reached from this study:

1. Surface water samples have shown high values of biochemical oxygen demand (BOD) in two locations in the White Nile "alshajra" and near the military hospital. This result indicates that there are pollution problems in these two locations. The values of chemical oxygen demand (COD) and biological tests also indicate pollution risks.
2. The values of ammonia concentration in surface water sample are above the standard. This is obvious in the hot season (June), but there is also a slight increase of ammonia concentration above the standard in the river Nile during the cold season (January).
3. Analyses of soakaway wells samples have shown that there is a high value of biochemical oxygen demand which indicates a pollution risk. This finding has been emphasized by the results of chemical oxygen demand.
4. High values of ammonia concentrations in soakawy wells samples and the absence of nitrate, indicates fresh pollution or occurrence of bacterial denitrification.
5. Most common sanitation system used in Khartoum state is pit latrine (73.4%), followed by septic tank and well (21.4%). The third one is a group of sanitation systems including open defecation, using the neighbor pit, mantling, just septic tank, and septic tank with soakaway, (3.8%).
6. The Sewer network which forms just 1.4% of the sanitation systems is serving part of central Khartoum and Khartoum North. The network was executed some 40 years ago and life age of the system was expired. Frequent bursting and surcharge of the sewer network causes serious environmental problems.
7. 12% of pit latrines have been dug until it reached the water level, this forms direct hazardousness to the groundwater quality.

The following recommendations were drawn from this study:

1. These results underline the importance of adopting a public awareness program of proper sanitation facilities. The program includes suggestion of new pit latrine types (Ventilated Improved Double-Pit Latrine, Reed odorless earth closet,….etc) and encouragement of septic tank systems without well (septic tank & soakaway, aqua privy, septic tank and vacuum tanker), a collection of septic tanks effluent by small-bore sewer network and rehabilitate and expand the gravity sewer network.
2. It is important to establish surface and ground water monitoring program in order to observe closely any change in water quality parameters through time.
3. Mitigation measures to environmental effects are suggested adapting 20 years plan **.**

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