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INVESTIGATION OF QUALITY AND USAGE OF GROUNDWATER NEAR SLAUGHTER HOUSES IN BASEMENT COMPLEX OF OSUN STATE, NIGERIA

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ABSTRACT

The importance of groundwater as a source of drinking water for the rural populace of southwestern Nigeria has stimulated public interest in the impact of continuous discharge of untreated wastewater from slaughter houses on water quality in the region. Physical and chemical properties of groundwater located near slaughter houses in Osun State, southwestern Nigeria were evaluated. Groundwater samples from six randomly selected well sites were analyzed for turbidity; pH; total suspended solids (TSS); total dissolved solids (TDS); electrical conductivity (EC); sodium adsorption ratio (SAR); Na^+, K^+, Ca^{++}, Mg^{++} and $NO3^-$ ion concentrations and the microbial content to determine the suitability of the water for drinking or irrigation purposes. The qualitative analysis reveals that only two sites (4 and 6) having values of 300 mg/mL and 460 mg/L respectively, out of the six locations considered, had groundwater quality within the recommended limits for TDS (<500 mg/L for drinking purposes). Three sites (2, 4 and 6) had EC values of 748.8, 504.4, and 184.3 µS/cm respectively, (<750µS/cm recommended for irrigation water), and thus can be used for irrigation with adequate attention on irrigation duration and frequency, drainage, and crop species. However, none of the groundwater samples satisfy the World Health Organization (WHO) guidelines for drinking water quality and are therefore not recommended for drinking.

KEYWORDS: slaughter houses wastewater; groundwater quality; irrigation uses, southwestern Nigeria.

1. INTRODUCTION

Water is an important aspect of available natural resource in any community and an essential to all life - human, animal and vegetation. Water quality; accessibility and management are vital to the health, social and economic development of the community. Groundwater is an important source of drinking water for the rural southwestern Nigeria and the impact of continuous discharge of untreated wastewater has been a major concern on water quality in the region (Awofolu, 2006; Osibanjo and Adie, 2007). Historically, the location and development of human settlements were greatly influenced by the presence of streams, rivers, lakes and springs. Where such surface water bodies were not available or where they were considered unsuitable for use, wells were dug to abstract water from beneath the surface of the earth for use.

Water wells are hydraulic structures dug through the surface of the earth for the purpose of abstracting groundwater, which are usually of good quality. Groundwater plays an increasingly important role in public water supply systems of many developing countries. Many developing countries, like Nigeria, rely heavily on shallow wells for their drinking water supply, especially the community-village settlements. It was long assumed that groundwater is an inexhaustible, safe and invaluable resource. It was not apparent that aquifer pollution is a hidden process, contaminant transport slow, and the retention of contaminants in the hydrogeologic system long (Vrba, 1991). Most developing countries do not realize the extent of groundwater contamination (Hamza (1991).

Slaughter houses are facilities used for slaughtering animals for meat and meat products. Slaughter house activities include (i) receiving and holding livestock; (ii) slaughtering and dressing of animal carcasses; (iii) drying of skins and; (iv) waste and wastewater disposal. Slaughter houses require a good supply of water in animal processing operations; resulting in producing large amounts of wastewater that ought to be treated before disposal. Other sources of waste from slaughter houses may include solid wastes from animal holding area, slaughter house and processing areas, unwanted hides/skins, carcasses and carcass parts. These wastes may be considered as potential groundwater pollutants, especially the wastewater, depending on the mode of waste disposal adopted by the slaughter house operators.

Generally, waste produced from slaughter houses includes undigested food, flesh, skin, horns and effluent containing blood, animal waste, urine and detergent used to wash the area (Benkacoker and Ojior, 1995). Wastewater produced in animal slaughter areas typically has a high biochemical oxygen demand

(BOD) and is very saline with high levels of nutrients, suspended solids and bacterial contamination. Apart from animal slaughtering, skin preservation is another activity of the slaughter houses. Skin preservation by dry salting is common at small slaughter houses that are remote from tanning equipment, that often export their hides and skin for tanning after the initial dry salting. After salting, the hides are hung to dry for a minimum of five days. During this period, the salt draws the moisture out of the hide, together with the protein-filled fluids from the attached flesh. The effluent from drying sheds is therefore highly saline and has a very high BOD (Mittal, 2006).

Singh and Sexhon (1976) attributed high nitrate concentrations observed in some village wells in Punjab State, India to animal waste; and the presence of cattle markets were implicated in elevated nitrate concentrations found in adjacent wells (Owoade et al., 1989; Malomo et al., 1990). Rising levels of nitrate in both surface and groundwater created fear for both animal and human health. Nitrosamines created in the human gut in the presence of high levels of nitrogen were identified as carcinogens (Jones, 1997). This led to the 1980 European Union (EU) directive on the quality of water for human consumption, which adopted the earlier World Health Organization (WHO) limit of 50 mg/L as the maximum permissible concentration of nitrate in drinking water (WHO, 1985). Other uses of groundwater, apart from drinking may also be affected.. For example, irrigation water should be low in salinity otherwise crop growth and development may be hampered.

Water quality may be considered a social issue because securing a quality of life consistent with human dignity requires access to safe drinking water and sustainable water resources for other purposes (Hamza, 1991). Quality certainly places constraints on the suitability of water for certain purposes, drinking being the most sensitive. It is quite impossible to compromise the quality of potable water supply in a community without risk to public health. For instance, increased nitrate concentration in drinking water was linked to *methaemoglobinaemia* in infants and stomach cancer in adults (Connelly and Taussig, 1995). Such a compromise of water quality may occur through pollution which may be cyclical or follow a trend both as a result of natural and/or man-induced processes (Custodio, 1989). With respect to groundwater, Foster (1995) defined anthropogenic pollution as those groundwater quality problems consequent upon the activities of man on the land surface. One of such activities is the commercial slaughtering of animals such as cattle, sheep, pigs and poultry in slaughter houses.

Therefore, this study is aimed at (i) providing information on the effect of slaughter house wastewater discharge on the physical, chemical and biological properties of groundwater in their vicinity and (ii) ascertaining whether the proximity of these wells to slaughter houses affects water quality for drinking and irrigation, in the respective communities.

2. STUDY AREAS AND FIELD PROCEDURE

2.1. Study Area

Three towns in Osun State, southwestern Nigeria (*Ede*, *Ilesa* and *Osogbo*) were considered for this study. *Ede*, lying within 7.44°N and 4.31°E has an area of about 15 km^2 of generally undulating land that falls within the basin of River Osun, and having major rock types as migmatite-gneiss; mica schist; pegmatite and quartz vein (Rahman, 1975). Precambrian basement rock of Nigeria underlies this area. *Ilesa*, lying within 7.39°N and 4.38°E, belongs to the hot humid equatorial climate characterized by alternate dry and wet seasons. Major rock groups in this area are: migmatize gneiss – quartzite complex, slightly migmatized to non-migmatized meta-sedimentary and meta-igneous rocks (Rahman, 1975). *Osogbo, lying within* 7.50°N and 4.35°E has the same major rock types as *Ede* and is underlain by Precambrian basement complex. The mean annual rainfall of the study area is about 1500 mm with rainfall distribution bimodal having peaks in June and September. The dry season extends from November to March, while the average minimum and maximum air temperatures are 20 °C and 32 °C respectively.

2.2. Sampling

Two slaughter houses each were chosen from the three towns by stratified random sampling. The six slaughter houses were purposely selected for their proximity to groundwater; scale of operation (total number of animals slaughtered per day); waste disposal methods; and the major uses of groundwater in the areas. All the slaughter houses selected are located within a range of 4 m to 9 m upslope from wells constructed to serve both as source of water for the slaughter house activities such as cleaning slaughter slabs, washing animal carcass parts, tools used in slaughtering operations and for domestic purposes (mostly drinking) for members of the immediate community. All the wells considered are relatively shallow, ranging from 3 m to 6 m below ground surface. Table 1 shows the details of the well dimensions from where water samples were collected.

Table 1: Summary of well dimension and miscellaneous observations at the water sampling sites

Site No	Distance of well from slaughter slab, *m*	Depth of water in the well from ground surface, *m*	No of animals slaughtered/day	Other well descriptions
1	9	3	2	Uncovered, cased partly with concrete, earth lining
2	4	4	1	Uncovered and with earth lining
3	6	4	6	Covered and with earth lining
4	9	3.5	1	Uncovered and with earth lining
5	4	5	1	Covered and with earth lining
6	6	6	2	Uncovered and with earth lining

2.3. Water sample collection and laboratory analysis

The groundwater samples were collected in glass bottles. The bottles used were cleaned with aqueous sodium thiosulphate solution (100 g/L) with aluminum foil tied around the neck of the bottles and a stopper inserted. The bottles were earlier sterilized in hot air oven for 1 hour at a temperature of 170°C before filling with the groundwater samples. The water samples, after collection, were kept in the refrigerator for 24 hours at 4°C within 2 hours of collection before they were transferred to the laboratory for analysis (Eaton et al., 2005).

Turbidity tests on all the six water samples were carried out with the use of a turbidity meter at the Civil Engineering

Department. The concentrations of sodium, potassium, calcium and magnesium ions were determined using atomic absorption spectrometer (Chemtech Analytical UK) at the Center for Energy Research and Development, while the pH was determined using a pH meter. The electrical conductivity (EC) was measured with the aid of electrical conductivity meter at 25°C (Eaton et al., 2005) and the sodium adsorption ratios (SAR) of the water samples were calculated using the equation given by Michael (1999) as:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}} \quad \text{(i)}$$

Nitrate was measured using phenol disulfonic acid method while total solids, suspended solids and dissolved solids were measured by gravimetric method. Total solids were determined by evaporating samples of the well water to dryness and weighing the residue. Suspended solids were determined by filtering the water samples and the difference between total solids and suspended solids represents the total dissolved solids (TDS) (TAES, 1996).

The average bacterial count was performed with nutrient agar using the spread-plate technique. The total coliform population of the water samples was determined by the most probable number (MPN) technique using sterile lactose bath followed by incubation at 37 °C for 48 hours (Eaton et al., 2005).

3. RESULTS AND DISCUSSION

Information on the geological characteristics of the three areas under consideration shows that all the towns have similar rock formations with little differences. Thus, variations in the values of parameters evaluated for each town may be unrelated to any differences in the geologic history of each area. These variations may then be associated with some other well properties such as the depth of well and distance of well from slaughter slab.

Table 2 gives the result of physico-chemical analysis of groundwater samples from the study area. Groundwater sample from site 1 shows high values of electrical conductivity, sodium adsorption ratio, total dissolved solids and NO_3^- concentration. This may be attributed to the well depth, which is 3 m indicating a high water table in those areas. High water table implies that the aquifer may be quickly recharged since the pollutants are introduced from the ground surface.

Groundwater sample from site 6 has the lowest overall values of EC and SAR (184.3 µS/cm and 10.99 respectively). This may also be as a result of the depth of the well (6 m). Well number 6 is the deepest of all the six wells considered in this study and because of the deep water table, the aquifer in this area is likely to have minimal vulnerability to pollution. From interaction with workers in these slaughter houses, site 3 is the longest operating slaughter house and it has the largest capacity of six animals slaughtered per day.

The turbidity of the water sampled from the six wells located close to the slaughter houses range from 4.5 NTU to as high as 24.5 NTU (Table 2). The recommended guideline value for potable water is 5 NTU (WHO, 1993). High levels of turbidity can protect micro-organisms from disinfection, stimulate bacterial growth and exert significant chlorine demand, and these will lead to greater difficulty of water treatment. Out of the six groundwater samples, only two (33.3%) i.e from sites 2 and 4 had values less than the recommended 5 NTU.

The pH values obtained are acidic ranging from 4.70 to 6.89. However, recommended values of pH for drinking water range from 6.5 to 7.5 (Greppi and Preti, 1999; Schwab et al., 1993). The pH is important because it regulates biological functions and may have an inhibitory effect on process rates. Only groundwater from sites 1, 2 and 5 has pH within the recommended range.

Total solids in all the groundwater samples range from 400 mg/mL to as high as 1,200 mg/mL. Total solid is a summation of total dissolved and suspended solids in the groundwater samples. Permissible limits for classes of irrigation water (Table 3) are normally recommended specifically where sprinkler or trickle irrigation systems are employed. High levels of total solids are undesirable because they cause frequent blockage of nozzles and emitters, thereby reducing system efficiency and otherwise increasing costs incurred in water treatment required to make the water suitable for such irrigation systems. Well located on site 4 has the lowest value of TDS while site 1 has the highest value of TDS.

The values obtained for the TDS in the six groundwater samples vary from 300 mg/mL to 900 mg/mL. TDS is one of the parameters used to measure the salinity of water, sometimes referred to as the total salinity. According to the United States Environmental Protection Agency (USEPA), TDS in drinkable water should be 500 mg/mL (USEPA, 1986). Out of all the six sites investigated, only groundwater from the wells located on sites 4 and 6 (33.33% of the samples) meet the drinking water standard with TDS values of 300 mg/mL and 460 mg/L respectively.

Nitrates are common chemical pollutants of water. Nitrate concentrations greater than 3 mg/L usually relates to human activities such as fertilizer applications and septic systems (Schwab et al., 1993). Drinking water standard of 10 mg/L is recommended for nitrate concentration in water (Morgon, 1989). This standard was exceeded in five out of the six groundwater samples analyzed (83.3 %), this indicates that considering nitrate concentration, only one site met this requirement. Groundwater from site 1 has the highest value of 59.14 mg/L which may be due to the combination of factors such as depth of the water table (shallowest out of all the wells investigated) and number of animals slaughtered per day. However, recommended limit for nitrate in irrigation water is 100 mg/L (WHO, 1993). This implies that as far as nitrate concentration is concerned, all the groundwater is suitable for irrigation purposes.

Table 2: Physico-chemical properties of well water samples analyzed.

	Parameters											
Site No	Na^+ (ppm)	K^+ ppm)	Ca^{++} ppm	Mg^{++} ppm	NO_3^- ppm	TDS ppm	TSS ppm	TS ppm	pH	EC	SAR	Turbidity (NTU)
1	878.67	13.01	23.77	11.70	59.14	900	300	1200	6.50	1338.6	36.72	6.5
2	376.83	7.50	18.08	9.50	19.30	640	160	800	6.45	748.8	17.79	4.5
3	622.63	11.25	16.30	19.55	40.50	680	120	800	5.88	1125.2	24.49	24.5
4	327.81	3.29	3.49	3.80	21.85	300	100	400	5.56	504.4	28.76	4.8
5	597.29	32.09	65.34	21.85	4.80	880	120	1000	6.89	1532.6	16.28	10.5
6	100.44	4.14	1.73	2.75	43.60	460	140	600	4.70	184.3	10.99	9.5

The salinity of irrigation water is determined by measuring the EC, which is an index of the total soluble salts in the water. Salinity restricts the availability of soil water to the plant (James, 1993); thereby influencing crop physiology and yield. The presence of salt in soil water increases the energy needed to remove the water from the soil. Cell enlargement and division, the production of proteins and nucleic acids, and the rate of increase in plant mass are physiological processes that are retarded by high levels of salinity. Permissible limits for classes of irrigation water are given in Table 3 (Texas Agricultural Extension Service (TAES), 1996)

From Table 3, only groundwater from site 6 meets the Class 1 (Excellent) recommended limit of electrical conductivity (i.e.184.3 μS/cm) for irrigation water. This may be due to the distance of the well from the slaughter house (6 m), coupled with the depth of the well (6 m) i.e. the deepest. Groundwater from this well may not pose any salinity problems when used for irrigation purpose on any crop. Similarly, groundwater from site 4 meets Class 2 (Good) recommended limit of EC for irrigation water (504.4 μS/cm). This groundwater will have no detrimental effect on any crop when used for irrigation. Water from the other sites will have detrimental effects on crops and may require careful management practices when used for irrigation.

Table 3: Permissible limits for classes of irrigation water.

Classes of water	Concentration, total dissolved solids	
	Electrical conductivity, μS/cm*	Gravimetric, ppm
Class 1, Excellent	250	175
Class 2, Good	250 -750	175 - 525
Class 3, Permissible [1]	750 - 2000	525 -1400
Class 4, Doubtful[2]	2000 - 3000	1400 -2100
Class 5, Unsuitable[2]	3000 and above	2,100 and above

*μS/cm at 25 degrees C (TAES,1996).
[1]Leaching needed if used
[2]Good drainage needed and sensitive plant will have difficulty obtaining stands/establishment.

Adsorption of sodium by clay in the soil contributes to a reduction of fertility. Sodium can substitute for other metals, such as potassium and other useful cations attracted to negatively charged ions in the soil, thereby reducing the availability of essential elements for plant development (Greppi and Preti, 1999)). Sodium hazard is usually expressed in terms of sodium adsorption ratio (SAR). The SAR values calculated for the six samples show that groundwater from site 1 has the highest value of 36.72 and groundwater from site 6 has the least value of 10.99. Table 4 shows the classification of irrigation waters with regard to SAR values (United States Department of Agriculture (USDA), 1954).

Groundwater from sites 1 and 4 fall into the class of very high sodium hazard because of very high values of SAR (>26); groundwater from these two wells are generally unsuitable for any use (Table 4), even though members of the community still drink from these wells and use the water during the dry season to irrigate vegetables planted in the surrounding farmlands. The remaining groundwater even though relatively high in SAR can still be used to irrigate crops that are salt tolerant. However, groundwater from site 3 is high in SAR (24.49) and is generally unsuitable for continuous

Table 4: The Sodium hazard of water based on SAR values

SAR values	Sodium hazard of water	Comments
1-10	Low	Use on Sodium sensitive crops must be avoided
10-18	Medium	Amendments and leaching needed
18-26	High	Generally unsuitable for continuous use
>26	Very high	Generally unsuitable for use

Source: Greppi and Preti (1999).

use. Groundwater from the remaining three wells are medium in SAR values and can thus be used on any crop provided soil amendments can be added to the soil and leaching done.

Table 5 gives the result of the microbial and bacteriological analysis of the groundwater samples. The recommended guideline for drinking water is zero coliform and bacterial count (WHO, 1985). It is observed that none of the water samples meets this recommended quality criteria for potable water. However, the presence of micro-organisms in irrigation water may not affect the vegetation or the fertility of the soils.

Table 5: Microbial analysis of water samples from each site

Site No	Average TBC ($x10^3$) (cfu/ml)	TCC (MPN/100ml)
1	216.0	1100+
2	42.0	1100
3	84.0	240
4	36.0	93
5	240.0	1100+
6	56.6	240

TBC – total bacterial count; TCC – total coliform count; TFC – total fungal count

4. CONCLUSIONS

The groundwater quality of six randomly selected wells near slaughter houses from three towns in Osun State, southwestern Nigeria is given in terms of pH, turbidity, total suspended solids, electrical conductivity (EC), sodium adsorption ratio (SAR), concentrations of Na^+, K^+, Ca^{++} and NO_3^-, and microbial content. Results obtained indicate differences in groundwater quality within each town and amongst all the six locations. Differences in geologic characteristics was eliminated as being responsible for the variations observed since Precambrian basement complex rocks of Nigeria underlie all the three towns, with similar major rock types: migmatite-gneiss, mica-schist, pegmatite and quartz. The variations in groundwater quality may then be related to the slaughtering operations done near the wells examined. Inadequate waste disposal methods and high water table increase the likelihood of the pollution of groundwater in these slaughter house locations.

As soil salinity increases in the root zone, plants adjust more of their available energy and salt concentrations within their tissues (osmotic adjustment) in order to obtain water from the soil, thereby reducing the energy available for plant growth (Greppi and Preti, 1999). Generally, TDS levels less than 500 mg/L and EC not more than 750 μS/cm, do not have any adverse effect when considering irrigation water. With these criteria, only sites 4 and 6 are recommended as suitable for irrigation purposes. However, none of the water samples satisfied WHO guidelines for drinking water quality and are therefore not recommended for drinking.

REFERENCES

Awofolu, O.R. "Elemental contaminants in groundwater: A study of trace metals from residential area in the vicinity of an industrial area in Lagos, Nigeria". *Environmentalist* 26 (4): 285-293, 2006

Benkacoker, M.O. and Ojior, O.O. "Effect of slaughterhouse wastes on the water-quality of Ikpoba river, Nigeria". Bioresource Technology, 52(1): 5-12, 1995.

Connelly, R. J., and Taussig, D. "Nitrate contamination of groundwater in the Kutama and Sinthumule districts of Venda, South Africa", in: Nash, H.,and McCall, G.J.H. (Eds.), Groundwater Quality. Chapman and & Hall, London. pp.145-151, 1995.

Custodio, E. "Role of groundwater quality in the decision making process for water resources", in: Sahinquillo, A., Andrew, J., Daniel, T.O. (Eds), Groundwater Management: Quantity and Quality (Proceedings of the Benidorm Symposium), pp 89- 99, 1989.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E.."Standard Methods for the Examination of Water and Wastewater". American Public Health Association, (APHA), American Water Works Association,(AWWA), and Water Environment Federation (WEF). 21st Centennial Ed. Washington DC, 2005.

Foster, S.S. "Groundwater for Development - An Overview of Quality Constraints", in: Nash, H., and McCall, G.J.H. (Eds), Groundwater Quality. Chapman & Hall, London, pp. 1-3, 1995.

Greppi, M and Preti, F. "Water Quality in Agriculture". In: Land and Water Engineering. CIGR Handbook of Agricultural Engineering. The ASAE, Miami, pp. 507- 544, 1999.

Hamza, A."Water quality monitoring in the developing world". In: Criteria for and Approaches to Water Quality Management in Developing Countries, UN Department of Technical Cooperation for Development, pp.123-154, 1991.

James, L.G. "Principles of Farm Irrigation System Design". Reprint Edition, Krieger Publishing Company, Florida, 1993.

Jones, J.A.A. "Global Hydrology: Processes, resources and environmental management". Addison Wesley Longman, England, 1997.

Malomo,S.; Okufarasin, V.A.; Olorunniwo M.A. and Omode, A.A. "Groundwater chemistry of weathered zone aquifers of an area underlain by basement complex rocks". Journal of African Earth Sciences, 2 (¾), pp. 357 - 371, 1990.

Michael, A.M. "Irrigation: Theory and Practice". Reprint Edition. Vikas Publishing House, PVT Ltd. New Delhi,1999.

Mittal, G.S. "Treatment of wastewater from abattoirs before land application - a review". Bioresource Technology 97(9): 1119-1135, 2006.

Morgon, P. "Rural Water Supplies and Sanitation". Macmillan, London, pp 248- 254, 1989.

Osibanjo, O. and Adie, G.U. "Impact of effluent from Bodija abattoir on the physicochemical parameters of Oshunkaye stream Ibadan City, Nigeria". African Journal of Biotechnology 6(15): 1806 -1811, 2007.

Owoade, A.; Hutton, L.G.; Moffat W.S.; and Bako, M.D. "Hydrology and water chemistry in the weathered crystalline rocks of the southwestern Nigeria", in: Groundwater Management: Quantity and Quality (Proceedings of the Benidorm Symposium, October 1989), International Association of Hydrologists Series Publication, No 988 pp.201- 214, 1989.

Rahman, A.O. "Groundwater Recovery", 2nd Edition. Macmillan Press Ltd. London and Basingstoke. pp 283, 1975.

Schwab, G.O.; Frevert, R.K.; Edminster, T.W. and Barnes, K.K. "Soil and Water Conservation Engineering". 4th Edition. John Wiley and Sons Inc. New York, 1993.

Singh, B and Sexhon, G.S. "Nitrogen Pollution of Groundwater from Nitrogen Fertilizers and Animal Waste in the Punjab, India". Agricultural Environment, 3:57-67, 1976.

TAES. "Irrigation Water Quality Standards and Salinity Management Strategies". Texas Agricultural Extension Service. The Texas A&M University System Paper B-1667, College Station, Texas, 1996.

USDA. "Handbook No. 60: Diagnosis and Improvement of Saline and Alkali Soils". U.S. Department of Agriculture GPO, Washington DC, 1954.

USEPA. 'Quality Criteria for Water', USEPA Office of Water Regulations and Standards, Washington DC, 20460. 1986

Vrba, J. "Hydrological Aspects of Groundwater Protection and Pollution". In: United Nations Department for Technical Cooperation for Development, 1999/155-202, 1991.

WHO. "Guidelines for Drinking Water Quality- Drinking water quality control in small community supplies". Vol.3. World Health Organization, Geneva, 1985.

WHO. World Health Organization. "Guideline for Drinking-Water Quality", Vol 1-Recommendation, (2nd edn.), WHO, Geneva. 1993