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Water Quality and Peri-Urban Irrigation

An assessment of surface water quality for irrigation and its implications for human health in the peri-urban zone of Kumasi, Ghana

G A Cornish, E Mensah & P Ghesquire

KAR Project R7132

Report OD / TN 95
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Contract

This Technical Note is an output from the Knowledge and Research Contract R7132, Improved Irrigation in Peri-Urban Areas, carried out by the Water Management Department of HR Wallingford for the British Government's Department For International Development (DFID). The research aims to improve understanding and knowledge of the productivity and hazards of peri-urban irrigated agriculture, with the aim of identifying measures to improve output whilst minimising risks to health and the environment.

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Executive Summary

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The Technical Note presents the findings of a study into wastewater quality and its use for informal irrigation in Kumasi, Ghana. It forms part of a wider study into the productivity and hazards of peri-urban irrigation taking place in Kumasi and Nairobi, Kenya.

Peri-urban farmers using water from streams downstream of urban centres are re-using urban wastewater. As this water is often polluted with untreated municipal and industrial effluents there is a potential threat to health of both consumers and irrigators. This study has attempted to bring together the knowledge relating to wastewater reuse for agriculture, and apply it in the context of uncontrolled, informal, smallholder irrigation in the peri-urban zone of Kumasi, Ghana.

Work was carried out in two phases:

> A literature review on wastewater re-use, particularly as it relates to uncontrolled use of polluted water for informal irrigation in the peri-urban zone of African cities.
>
> A review of water quality data obtained from past studies carried out in the Kumasi peri-urban zone, supplemented by a targeted water quality sampling programme to give a first indication of the physical, chemical and microbiological quality of waters used for irrigation.

LITERATURE REVIEW

Re-use of marginal quality water. Westcot (1997) makes the important distinction between Direct and Indirect Re-use. Direct Re-use is the planned use of raw or treated wastewater, where control exists over the conveyance of the wastewater from the point of collection or discharge from a treatment works to a controlled area where it is used for irrigation. This is the situation pertaining in most developed nations. Indirect Re-use is the situation found in many developing countries, where municipal and industrial wastewater are discharged without treatment or monitoring into the watercourses draining an urban area. There is no control over the use of the water for irrigation (or domestic consumption) downstream of the urban centre. As a consequence marginal quality water of unknown composition is indirectly reused by many downstream farmers. Much of the available literature, including the development of water quality guidelines for wastewater reuse, has focused on direct reuse systems, and has little relevance in many countries in the developing world.

Microbiological Contamination. Guidelines, frequently referred to as the "WHO, or Engelberg guideline values", were published in 1989, (Mara and Cairncross, 1989). These provide limits for permissible levels of microbiological contamination to be used as design values in the design of water treatment plants. Mara and Cairncross (1989) state explicitly that the values are not intended for use in quality surveillance. The guidelines provide design values for water quality based on the number of viable nematode eggs per litre and faecal coliform bacteria per 100 ml. (Table 1 in Section 2 presents the guidelines in detail.)

These standards represent a relaxing of previous bacteriological standards that were based on a "zero risk" concept, and took no account of epidemiological evidence of what practices and effluent qualities lead to measurably greater incidence of disease in a population. Whilst the new standards are less stringent with regard bacteriological quality they do for the first time set a standard for the presence of helminths, recognising that the major health risks in many developing countries are associated with helminthic diseases.

Westcot (1997) addressed the question of how the Engelberg guidelines can be applied where there is no treatment of wastewater and farmers are irrigating using water from rivers downstream of large urban centres. He suggests that in the absence of better information it is "prudent" to use the WHO standards for faecal coliforms as the quality standard as it is impractical to use the helminth guideline in routine monitoring. He also suggests establishing a routine water quality monitoring programme, based on faecal coliform numbers, to support a certification programme for high risk or restricted crops. This requires education of consumers and encouragement of market forces whereby consumers chose to buy only certified produce. It is argued that this approach is more realistic than attempts to impose crop restrictions which are almost impossible to enforce.

A programme of this type might be difficult to establish and sustain in the poorer countries of Africa. However, it merits serious consideration by any authority concerned for the health implications of peri-urban irrigation with wastewater. The ranges of contamination and consequent recommendations put forward by Westcot provide a useful point of entry in any attempt to monitor and interpret water quality data for irrigation. These are summarised in Table 2 of Section 2.

Mara (1995) questions the validity of counting E. coli or other indicator organisms on foods. He points out that a European Union directive permits up to 10×10^{6} E. coli per 100g of hard cheese made from untreated milk, and the ICMSF permit some foods eaten raw to contain up to 10×10^{4} faecal coliform. The presence of standard indicator organisms such as thermo-tolerant coliform bacteria (faecal coliform) on foodstuffs is not a direct indication that disease will occur if the food is eaten.

Trace Elements and Heavy Metals. Mara and Cairncross (1989) assert that the health hazards due to chemical pollution are of only minor importance when considering the reuse of domestic waste water. Pescod (1992), in a review of wastewater treatment and use in agriculture acknowledges that municipal wastewater may contain toxic levels of trace elements (heavy metals and other chemical elements).

However, it is widely accepted that levels of trace elements and heavy metals in irrigation water are likely to be toxic to plants at concentrations below that at which they pose a significant risk to human health, and this provides a degree of natural protection to irrigators and consumers. (Plants fail to thrive and farmers abandon the water source well before levels present a risk to human health.) Thus, monitoring of heavy metals in wastewater reused for agriculture may not have a high priority. This study had access to atomic absorption spectroscopy equipment at UST and so samples could be monitored for a range of heavy metals. The findings indicate that heavy metals and trace elements do not present any threat to health thorough irrigation in the Kumasi peri-urban zone.

WATER QUALITY MONITORING IN THE PERI-URBAN ZONE OF KUMASI

Irrigation in the peri-urban zone of Kumasi. Kumasi has a population of approximately 1 million (Gov. of Ghana, 1996), and lies at an elevation of approximately 260 m amsl. It has a semi-humid, tropical climate with a total average annual rainfall of 1,340mm. Approximately 90% of the annual total falls between March and October, November to mid March is the main dry season. Natural drainage runs from north to south, (See Figure 3 and Annex 1), the principal streams being the Daban, Subin, Aboabo, Sisa and Wiwi. These converge into the Sisa, which flows into the Oda approximately 9 km south of Kumasi. There is no readily available flow gauging data for any of the streams in the urban area.

Small-scale irrigation of horticultural crops in the dry season is widespread in many of the villages within a 40 km radius of Kumasi. Where perennial rivers provide an assured water supply the number of farmers and scale of farming operation is greater, with the ownership and hire of small petrol pumps being commonplace. In other areas farmers draw water either from ephemeral streams which form a series of pools in the dry season or from shallow hand-dug wells. It is postulated that water drawn from shallow wells is of better quality than that in the rivers.

The most commonly irrigated crops are tomato, garden egg (a variety of aubergine) and okra. Other irrigated vegetables include hot pepper, sweet pepper, cabbage, lettuce and cucumber. The last two, although grown on a smaller scale, are significant because they are eaten raw whilst all the others are normally cooked.

Sources of municipal and industrial effluent. Salifu and Mumuni, (1998) report that the Kumasi metropolitan area has sewerage for less than 4% of its residents. 40% of residents depend on public toilets (improved pit latrines, aqua privies and pan latrines), 15% depend on septic tanks (most without soakaways), whilst less than 10% have household improved pit latrines. Between 250-350 m^3 of septage and nightsoil are collected daily by vault emptying trucks. Until recently this material was discharged into poorly maintained waste stabilisation ponds on the southern ring road. Retention time was very short and effectively untreated sewage passed directly into the Subin. Dumping at this site ceased with the completion of temporary waste stabilisation ponds 7 km south of Kumasi, north of Asago village on the Sisa river. Plans are in hand to construct a new permanent site for wastewater treatment, but there is no guarantee that this will fair better than the ponds on the ring road. Even with effective waste stabilisation ponds in place much of the domestic sewage and industrial effluent form Kumasi will continue to be discharged directly into streams passing through the city.

The major sources of industrial effluent are two breweries, a soft drinks bottling plant and a soap factory. Effluent from these industries is discharged into surface watercourses without pre-treatment. Light industrial activities at the Suame Magazine complex - draining to the north west - and sawdust mounds at sawmills also generate significant amounts of waste oil and leachate respectively.

Routine monitoring and UST studies. There is little routine monitoring of water quality by government agencies. The Environment Protection Agency (EPA) conducts annual spot sampling at selected locations measuring basic physical and chemical parameters – pH, TDS, dissolved oxygen, nitrites, nitrates, etc – and faecal coliform numbers. However, reported data are based on single samples as financial resources do not permit more frequent sampling.

Students in various departments at the University of Science and Technology (UST) have completed several studies of river water quality. Ghesquière (1999) reviewed these and a summary of her findings is given in table 5 of Section 3. Although samples were collected at different times and locations on the four main rivers a general pattern can be discerned in the data. The Subin River is the most highly polluted, with very high levels of suspended solids and recordings of 60 million faecal coliform per 100 ml – 4 orders of magnitude above the guideline limit for safe irrigation. The most extreme conditions are recorded adjacent to the Georgia Hotel where nightsoil and septage were dumped. The Aboabo, where it crosses the Accra road, has gathered effluent from a large part of northern Kumasi and this is reflected in relatively high levels of suspended solid and very high numbers of faecal coliform. The Sisa shows lower levels of suspended solids when compared with either the Subin or Aboabo and the average count of faecal coliform is two and three orders of magnitude lower than the Aboabo and Subin, respectively. The Wiwi is the cleanest of the rivers draining Kumasi, consistent with the fact that only a small portion of its catchment is under urban development.

The results of Owusu (1998) suggest the microbiological water quality of two monitored shallow wells is good. This supports the hypothesis that water from shallow dug wells may be of much better microbiological quality than river water in peri-urban areas. However, the data appear to be based on single samples taken from each well – rather than on the mean of several – and a finding of zero E. coli on crop samples is so surprising as to cast some doubt on the reliably of the data. (Water quality from wells is being studied in an ongoing project at UST and more data will be available in the near future.)

Measurements carried out for this study. A small number of sampling sites were selected for a targeted study to provide an indication of the changes in water quality upstream and downstream of Kumasi, to quantify the levels of pollution at sites thought to be highly polluted, and gauge the extent of auto-purification at sites further downstream. Field work was carried out in February and March 1999, at the end of the dry season when irrigation is widely practised, river flows are low and pollutant concentrations are at their highest. Physical, chemical and microbiological analysis of samples was carried out in several departments of the University of Science and Technology, Kumasi, who are collaborating in carrying the study. To provide a cross check one set of water samples was also returned to the UK for heavy metal analysis.

Seven sampling sites on rivers were selected. Their distribution allowed monitoring immediately upstream of Kumasi and at a number of sites at increasing distance downstream of the city. Two shallow wells adjacent to the Wiwi River where it crosses the Accra – Kumasi road were also monitored. Water samples were taken on five occasions between February 18th and March 16th 1999.

Helminths. Five different types of helminth were identified in total but of these only two - Ascaris lumbricoides, and hookworm – were intestinal nematodes (roundworms), defined by WHO (1989) as being of greatest risk to human health. There was considerable variation in nematode numbers over time and location. However, the data suggest that water both upstream and downstream of the urban centre of Kumasi exceeds the WHO guidelines with respect to nematode eggs.

Westcot (1997) concluded that because laboratory procedures for detection and enumeration of faecal coliform are easier to carry out than enumeration of helminths and they are better established as “standard practice” they should form the basis of any initial effort to quantify microbiological water quality for wastewater reuse. The data generally support this pragmatic conclusion and in the short term, it seems sensible to monitor and make judgements on the microbiological suitability of water for irrigation based on faecal coliform numbers.

Total and Faecal Coliform. There is a pattern of increasingly poor water quality moving from upstream of the main urban centre towards the most microbiologically polluted site at Asago, 9 km south of the city at the confluence of the Sisa and Oda rivers. Further south the numbers of faecal coliform reduce, but remain above the WHO guideline value for unrestricted irrigation.

It is concluded that irrigation practised on the Sisa and Wiwi rivers, upstream of Kumasi, may pose a minor threat to the health of consumers as the faecal coliform numbers are close to the monitoring limit recommended by Westcot. The nematode numbers at both these sites were high. Around Kaase, Daban and as far south as Asago the rivers are highly polluted but there is no evidence of the river water being used extensively for irrigation. This may be due to the very poor water quality or other factors. The very high counts of faecal coliform at Asago and Adwaden give cause for greater concern. Mean counts of 8.97×10^4 and 3.1×10^4 are both an order of magnitude above the WHO guideline, the Asago value almost 2 orders of magnitude greater, and in this area, particularly towards Adwaden, many farmers are irrigating with river water. The data indicate that even 32 km downstream of Kumasi faecal coliform numbers are still 5.5×10^3 per 100 ml, which is high for a river in a predominantly rural catchment. Ideally, further monitoring of water quality should take place at sites along the Oda from Asago to villages downstream of

Ofoase Kokoban to determine if, and where, the water quality improves naturally to a level where unrestricted irrigation can be considered without risk.

Data for the two shallow wells does not conform with the assumption that wells provide better quality water than the rivers, but a firm conclusion cannot be drawn on the basis of data from just two wells which are close to a major road and an area of frequent human activity. The results from the wider study of the water quality in shallow wells used for irrigation being carried out by UST would be required before any firm recommendation for the use of shallow wells on water quality grounds can be made.

Heavy Metals. There is no evidence of heavy metal concentrations in the surface waters draining from Kumasi that exceed safe limits for irrigation. (Assuming that the high levels of mercury in some samples, not found in the samples tested in the UK, are in error). The concentrations of most of the elements tested for fall below the WHO safe limits for drinking water. Assuming that the concentrations recorded represent "background" or naturally occurring concentrations of these elements it is not surprising to observe no clear difference between samples drawn from the shallow wells and those drawn from the rivers. In Kumasi it is recommended that the limited resources that are available should be directed at monitoring and reducing levels of microbiological pollution, rather than focusing on heavy metals.

Physicochemical parameters. Only one site showed pH values outside the expected normal range and measured values are consistent with those reported in previous studies. None of the locations sampled have conductivity values that would indicate a potential threat to irrigation as a consequence of dissolved salts. The trend in conductivity between sites closely follows the trend for microbiological contamination.

Nitrogen was measured as nitrate (NO_3) nitrite (NO_2) and ammonia (NH_3). Only traces of nitrate were found in any of the samples. There is marked variation in the concentrations of both ammonia and nitrite over time which reflects the effects of rainfall events over the period of sampling. It appears that the polluted waters downstream of Kumasi may make a significant contribution to the nitrogen requirements of irrigated crops. This is consistent with interviews held with farmers in the Adwaden area who believed the water provided a detectable fertiliser benefit to irrigated crops.

Phosphorous was measured as PO_{4}. Very high levels were recorded and if accurate they indicate high levels of phosphate pollution *at all the sites sampled.* This is in contrast with the data for nitrogen, which varied between sites and was very low in the shallow wells. As the sampling dates coincided with early rains at the end of the dry season and a consequent phosphate flush the mean values reported here may be "misleadingly" high.

SUMMARY OF MAIN CONCLUSIONS

Based on the literature review and the field data the study draws the following key conclusions:

Executive Summary *continued*

i) The Engelberg Guidelines for microbiological quality of wastewater use for irrigation are intended as a guide for the design of treatment plants, not as quality surveillance norms.

ii) Monitoring for the presence of intestinal nematode eggs is too complex and time consuming to be adopted as a routine procedure where resources are limited.

iii) Levels of microbiological pollution at all sites monitored downstream of Kumasi exceed FAO guidelines for unrestricted irrigation. Rivers upstream are relatively clean.

iv) There is no evidence of significant pollution with heavy metals or other chemical pollutants that pose a threat to irrigated cropping.

v) Water salinity does not pose a threat to crop production in this area.

vi) Shallow wells do not always offer a cleaner water source than surface streams and rivers.

vii) It may be possible to show that with simple precautions shallow wells provide water of a much higher quality than river water in the Sisa and Oda downstream of Kumasi.

This is a practical area of intervention but one requiring further study before firm recommendations can be made.

vii) The relative risk to consumers resulting from wastewater irrigation and the misuse of agrochemicals remains unclear.

viii) The data set brought together by this study provides a baseline against which future trends can be compared.

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Annexes

1. INTRODUCTION

This Technical Note is an output from the Knowledge and Research Contract R7132, Improved Irrigation in Peri-Urban Areas, carried out by the Water Management Department of HR Wallingford for the British Government's Department For International Development (DFID). The research aims to improve understanding and knowledge of the productivity and hazards of peri-urban irrigated agriculture, with the aim of identifying measures to improve output whilst minimising risks to health and the environment. Fieldwork has been conducted in and around Kumasi, Ghana, and Nairobi, Kenya.

The note presents the findings of studies carried out in Kumasi, Ghana, to provide a preliminary assessment of the health risks posed to irrigators and consumers as a consequence of using waters polluted by urban effluents for irrigation. The report is based upon studies carried out by Ghesquière (1999) in a dissertation for a diploma in Water and Environment at the French National School of Water and Environmental Engineering (ENGEES), Strasbourg, when working at HR Wallingford. The study was carried out in collaboration with the Institute of Land Management and Development (ILMAD) and the Department of Agricultural Engineering at the University of Science and Technology, (UST) Kumasi.

Peri-urban farmers who take irrigation water from streams downstream of urban centres are practising indirect reuse of urban wastewater. As this water is often highly polluted with untreated municipal and industrial effluents concern is often raised by municipal authorities and government ministries regarding the potential threat to health of consumers and irrigators alike. However, although concern is expressed there is frequently a lack of quantitative information available on which to make sound judgements. This study has attempted to bring together the knowledge that exists relating to wastewater reuse for agriculture and apply it in the context of uncontrolled, informal, smallholder irrigation in the peri-urban zone of Kumasi.

Field work was carried out in February and March 1999. This is the end of the dry season when irrigation is widely practised, river flows are towards their lowest and pollutant concentrations are consequently higher. The aim of the work was to give a first indication of the physical, chemical and microbiological quality of waters used for irrigation within the peri-urban zone of Kumasi. With the limited resources available a small number of sampling sites were selected to provide an indication of the changes in water quality upstream and downstream of Kumasi, to quantify the levels of pollution at sites thought to be highly polluted and gauge the extent of auto-purification at sites further downstream.

The focus of the study was on the streams and rivers draining Kumasi but two shallow well sites were also sampled to allow some comparison between the two types of water sources most widely used for irrigation. (A wider study of water quality in shallow wells is on going in the Environmental Engineering Section of the Department of Civil Engineering at UST but the findings have not yet been published.)

Physical, chemical and microbiological analysis of samples was carried out in several departments of the University of Science and Technology, Kumasi. To provide a degree of cross-checking one set of water samples was also returned to the UK for heavy metal analysis.

The report is structured in the following way:
Section 2 provides definitions of terms and concepts relevant to the study and sets out the current state of knowledge on wastewater re-use, particularly as it relates to uncontrolled use of polluted water for informal irrigation.

Section 3 gives a brief description of Kumasi and reviews water quality data obtained from past studies and reports. It then describes the sampling sites and parameters measured in this study.

Section 4 discusses the results of the sampling programme and compares the findings with the previous studies referred to in section 3. Finally, section 5 sets out the conclusions and recommendations that can be drawn from this work.

2. THE STATE OF KNOWLEDGE

2.1 Definitions and Terms

The literature relating to wastewater quality, treatment and reuse uses a range of terms that require definition. The following paragraphs give working definitions of different terms used, the aspects of wastewater treatment and re-use to which they refer and the significance of those different aspects to peri-urban irrigation. An explanation of terms referring to smallholder peri-urban irrigation is also provided.

2.1.1 Wastewater

Wastewater is a broad term which it is helpful to sub-divide into the following categories:

a) **Raw or untreated wastewater** Liquid discharged from homes or commercial premises to individual systems or municipal sewers. It is a mixture of domestic sewage - dirty water and human excreta - and municipal wastewater. It may or may not contain substantial quantities of industrial effluent.

b) **Treated/partially treated wastewater** Wastewater that has been treated by a natural or artificial purification process to improve its physical, chemical or bacteriological quality before it is discharged into a surface water body. The degree of treatment can vary greatly. Partially treated wastewater may still pose a threat to some receiving environments.

c) **Industrial Effluent** Water polluted by industrial processes and containing high levels of heavy metals or other chemical or organic constituents. Industrial effluent does not normally contain high levels of microbiological pollution.

2.1.2 Marginal Quality Water

A term normally referring specifically to water which is "marginal" for use in agriculture. Abbott and Hasnip (1997) define it as, "water which might pose a threat to sustainable agriculture and/or human health by virtue of its quality but which can be used safely for irrigation provided certain precautions are taken." It describes water which has been polluted as a consequence of mixing with wastewater or agricultural drainage.

2.1.3 Terms Relating to Excreta

Nightsoil - Human faeces and urine transported without flushing water

Sludge - A mixture of solids and water deposited on the bottom of stabilisation ponds, septic tanks etc.

Septage - Sludge removed from septic tanks

2.1.4 Forms of Wastewater Reuse

Westcot (1997) makes the important distinction between:

a) Direct Reuse The planned use of raw or treated wastewater where control exists over the conveyance of the wastewater from the point of collection or discharge from a treatment works to a controlled area where it is used for irrigation. This is the situation pertaining in most developed nations where physical and institutional infrastructure is well established to monitor and control the quality of the water and the area where it is used for irrigation.

b) Indirect Reuse The situation found in many developing countries where much municipal and industrial wastewater is discharged without treatment, monitoring or control into the watercourses draining an urban area. The resulting water quality varies according to the flow regime of the water course and the volume and composition of effluent that drains into it. There is no control over the use of the water for irrigation (or domestic consumption) downstream of the urban centre. As a consequence wastewater or marginal quality water of unknown composition is indirectly reused by many downstream farmers. However, without knowledge of the water quality and the autopurifier effect of the river the risks associated with this indirect reuse are unknown.

Much of the available literature, including the development of water quality guidelines for wastewater reuse, has focused on direct reuse systems where regulation and control can be applied at the point of treatment and discharge and over the area where the water is used. This has little direct application for many countries in the developing world. The recent work by Westcot (1997) is one of the few texts to have recognised and addressed this issue.

2.1.5 Smallholder

A farmer practising a mix of commercial and subsistence production where the family provides the majority of labour and the farm provides the principal source of income. A smallholder will often derive his/her livelihood from an irrigated holding of less than 0.2 ha but holdings vary in size and may be as large as 5 ha or more.

2.1.6 Formal and Informal Smallholder Irrigation

a) **Formal smallholder Irrigation** — Irrigation that is reliant on some form of fixed infrastructure that was designed and may or may not be operated by an external government or donor agency and which is used by more than one farm household.

b) **Informal smallholder irrigation** — Irrigation carried out by an individual or a group of farmers without reliance on irrigation infrastructure that is planned, constructed or operated through the intervention of a government or donor agency. It includes the irrigation of seasonal wetlands and inland valley bottoms during the dry season and irrigation of land adjacent of perennial streams which may occur throughout the year. The informal irrigation sector embraces a wide range of investment in equipment and land forming from farmers using motorised pumps and maintaining weed-free, levelled, raised beds to farmers raising water with a calabash and planting on partially cleared, broken terrain.

This study focuses on informal irrigation in the peri-urban zone.

2.1.7 Peri-Urban Zone

A precise definition of the peri-urban zone is illusive. Definitions are pragmatic, being drawn up by researchers to include that portion of the physical or economic interface between the fully urban and the fully rural in which they have an interest. It is not possible to delineate precise boundaries where the peri-urban zone begins and ends but it is the area adjacent to an urban centre that is influenced by:

- Pressure on land use – conversion from rural to urban usage
- Ready access to a large market
- Ready access to services and physical inputs
- Increasing problems of waste management and pollution from the urban centre

The geographic range of each of these influences is different. Kumasi Central Market is a major market centre with trading links across West Africa but it is seldom helpful to define that entire market catchment as the peri-urban zone of Kumasi. This study of peri-urban irrigation practices, of which the study of water quality issues is a part, has looked at irrigation occurring within a 40 km radius of Kumasi centre. Within this area pressure on land use and the associated problems of insecurity of tenure and rising land values are generally only seen in those villages closer to Kumasi but the other influences – market, service and input provision and resource pollution – are significant throughout the area.

2.2 Synopsis of Key References

The synopsis presented here provides a summary of a wider literature review carried out by Ghesquière (1999). The full list of references consulted in that review is given in the bibliography of this report.

2.2.1 Microbiological Contamination

Although the volume of published information on wastewater reuse for irrigation and its implications for human health is substantial a smaller number of major studies and publications can be identified which are listed here in date order:

Cross & Strauss, 1985	Health Aspects of Nightsoil and Sludge use in Agriculture and Aquaculture. Part I, Existing Practices and Beliefs in the utilization of Human Exceta. Part II, Pathogen Survivial. IRCWD Report no. 04/85
Blum & Feacham 1985	Health Aspects of Nightsoil and Sludge use in Agriculture and Aquaculture, Part III. An Epidemiological Perspective. IRCWD Report no. 05/85
IRCWD, 1985	Health Aspects of Wastewater and Excreta Use in Agriculture and Aquaculture: The Engelberg Report. IRCWD News No. 23, December 1985.
Shuval *et al.*, 1986	Wastewater Irrigation in Developing Countries. World Bank Technical Paper No. 51. World Bank, Washington, USA.
Mara & Cairncross 1989	Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture: Measures for Public health Protection. WHO, Geneva.
Westcot 1997	Quality Control of Wastewater for Irrigated Crop Production. FAO Water Report No. 10. FAO, Rome.

1981 and 1982 saw the initiation of two major, parallel studies into the use of excreta (Nightsoil and sludge) and wastewater in agriculture. The division of the topic between two different implementing agencies was done for "practical reasons". The International Reference Centre for Waste Disposal (IRCWD) at Dubendorf, Switzerland sought to determine the actual health risks associated with the use of human excreta. The work was sponsored by the WHO and UNEP. The World Bank, under the UNDP Integrated Resource Recovery Project, commissioned a team of consultants to study the health effects of wastewater irrigation. These two studies resulted in what were state-of-the-art reports in 1985 and 1986.

The findings of the two studies were reviewed at a meeting in Engelberg, Switzerland, in July 1985, (IRCWD, 1985). Here a new set of guidelines for the use of *treated* wastewater and excreta were drafted,

"based on epidemiological evidence of actual risks to public health, rather than on potential hazards indicated by the survival of pathogens on crops and in the soil." (Mara and Cairncross, 1989).

The draft guidelines were reviewed at a second meeting of experts in Adelboden, Switzerland in June 1987 where the use of wastewater and excreta for aquaculture were considered. They were finally published in 1989, (Mara and Cairncross, 1989).

The resulting guideline values, frequently referred to as the "Engelberg guideline values", provide guidelines for permissible levels of microbiological contamination to be used as design values in the design of water treatment plants. Mara and Cairncross (1989) state explicitly that the values are not intended for use as quality surveillance norms though they offer no suggestion as to what norms might be used in this respect. The guidelines provide design values for water quality based on the number of viable nematode eggs per litre and faecal coliform bacteria per 100 ml. Table 1 presents the guidelines in detail.

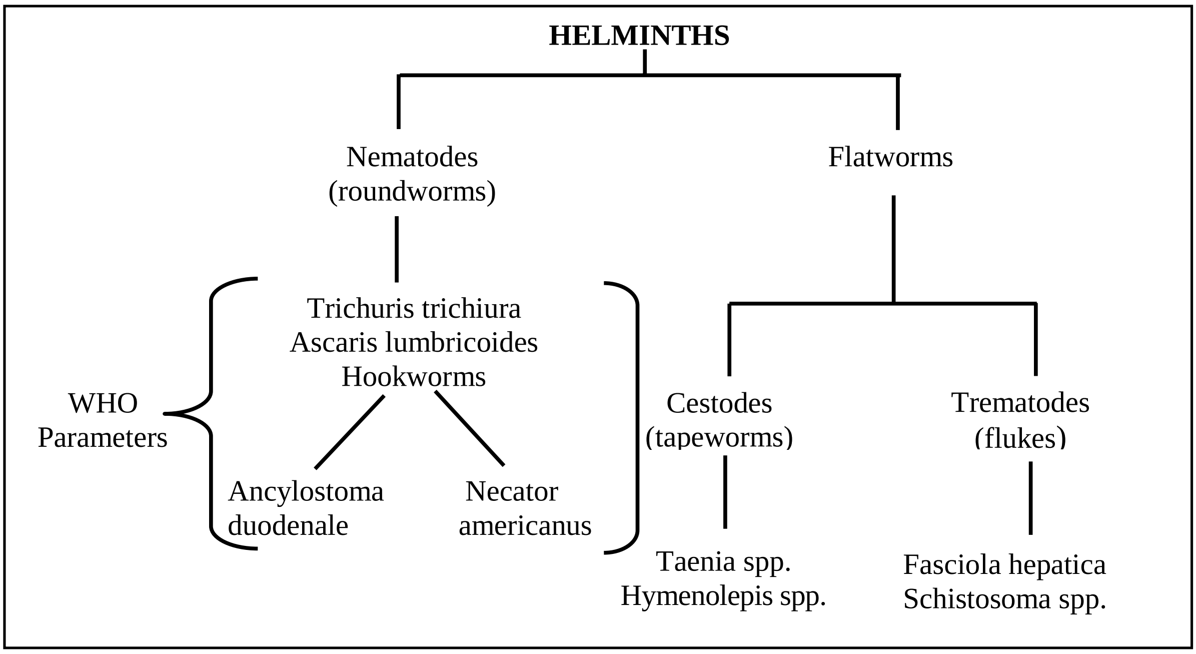


Figure 1 Characterisation of Helminths showing those Considered under WHO (Engelberg) Guidelines

These standards represent a relaxing of previous bacteriological standards that can be traced back to standards of the California State Health Department. Those early standards were based on a "zero risk" concept and took no account of epidemiological evidence of what practices and effluent qualities actually lead to measurably greater incidence of disease in a population. Whilst the new standards are less stringent with regard bacteriological quality they did for the first time set a standard for the presence of helminths, recognising that the major health risks in many developing countries are associated with helminthic diseases.

These major studies and the guidelines arising from them represented a major advance in the state of knowledge concerning wastewater reuse. However, the guidelines were intended for use in the design of wastewater treatment plants in the possibly optimistic belief that the relatively simple and low cost technology of waste stabilisation ponds could be constructed to treat the wastewater of the developing world's urban areas. In the medium to long term this goal may be realised, but in the short term the uncontrolled discharge of municipal and industrial effluent into natural watercourses will remain the norm for many cities.

Table 1 Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture [a]

Category	Reuse condition	Exposed group	Intestinal nematodes [b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A Unrestricted	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [d]	Workers, Consumers public	≤ 1	≤ 1000[d]	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B Restricted	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds 8-10 days or equivalent helminth and faecal coliform removal
C Localised	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
[b] *Ascaris* and *Trichuris* species and hookworms. See Figure 1.
[c] During the irrigation period.
[d] A stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e] In the case of fruit trees, irrigation should cease two weeks before is picked and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Source: WHO (1989), cited by Pescod (1992)

Westcot (1997) addressed the question of how the Engelberg guidelines can be applied where there is no treatment of wastewater and farmers downstream of large urban centres are irrigating with wastewater of variable composition and dilution – a practice he describes as indirect reuse. He predicts this form of reuse will, "expand rapidly in the future as urban population growth outstrips the financial resources to build adequate treatment works." Having acknowledged that the Engelberg guidelines are intended as design guidelines he suggests that in the absence of better information it is "prudent" to use the Engelberg standards for faecal coliforms as the quality standard to aim for in waters that are known to currently fall short of that quality. Shuval *et al* (1986) concluded that the presence of helminth eggs in irrigation water (specifically roundworms of the species Ascaris and Trichuris, see Figure 1) posed the greatest risk to health. They have long persistence in the environment, require only a small number to cause infection and there is little possibility of immunity occurring in the human population. However, there are no routine and simple techniques available to monitor helminth egg numbers in water samples and therefore Westcot considers it impractical to use the helminth guideline in routine monitoring of water quality for irrigation.

Westcot (1997) argues in favour of establishing a routine water quality monitoring programme, based on faecal coliform numbers, to support a certification programme certifying that high risk or restricted crops – mainly vegetables and particularly those eaten raw – are produced in a safe environment. This in turn requires education of consumers and encouragement of market forces whereby consumers chose to buy only certified produce. It is argued that this approach is more realistic under conditions of disbursed and uncontrolled wastewater reuse than attempts to impose crop restrictions which are almost impossible to enforce.

A programme of this type might be difficult to establish and sustain in the poorer countries of Africa. However, the approach merits serious consideration by any authority concerned for the health implications of peri-urban irrigation with wastewater. In particular the ranges of contamination and consequent recommendations put forward by Westcot provide a useful point of entry in any attempt to monitor and interpret water quality data for irrigation. These are summarised in Table 2.

Table 2 Ranges of Contamination and Recommendations (after Westcot, 1997)

Mean number of faecal coliform / 100 ml [a]		Recommendation
< 1,000	[< 10^3]	Appropriate for irrigation of vegetables
1,000 – 10,000	[10^3 – 10^4]	Potentially safe if the source of contamination (presumed to be localised) can be eliminated
10,000 – 100,000	[10^4 – 10^5]	Heavy contamination requiring treatment before the water can be used for unrestricted cropping
> 100,000	[>10^5]	Extensive heavy contamination – highly unsuited for irrigation.

[a] Based on a minimum of 5 samples taken over the irrigation season

2.2.2 Trace Elements and Heavy Metals

Both the major programmes of research that culminated in the Engelberg guidelines focused on the microbiological aspects of wastewater quality. They make only passing reference to the potential or actual risk from trace elements and heavy metals. Mara and Cairncross (1989) assert that the health hazards due to chemical pollution are of only minor importance when considering the reuse of domestic wastes. Pescod (1992) in a review of wastewater treatment and use in agriculture acknowledges that municipal wastewater may contain toxic levels of trace elements (heavy metals and other chemical elements).

It is widely accepted that levels of trace elements and heavy metals in irrigation water are likely to be toxic to plants at concentrations below that at which they pose a significant risk to human health and this provides a degree of natural protection to irrigators and consumers alike, i.e. plants fail to thrive and farmers abandon the source well before levels present a risk to human health. There is concern over the possible long-term accumulation of some heavy metals in soil as a result of wastewater irrigation (Kaddous and Stubbs, 1983; Siebe and Cifuentes, 1995), but this lies outside the scope of this review and field study. There are currently no guidelines for permissible levels of trace elements and heavy metals in wastewater used for irrigation which relate to the potential risk to human health as a consequence of crop uptake and bio-accumulation. Most authors cite either a table of phytotoxic thresholds prepared by the National Academy of Sciences (1972) and Pratt (1972), or refer to the WHO drinking water guidelines (WHO, 1993). These data are reproduced in Table 3.

Table 3 WHO and EU Drinking Water Quality Guidelines for Heavy Metals and Threshold Values Leading to Crop Damage (mg/l).

Element	WHO drinking water guideline [a]	EU drinking water guideline [b]	Recommended maximum concentration for crop [c]
Arsenic	0.01	0.05	0.1
Cadmium	0.003	0.005	0.01
Chromium	0.05	0.05	0.1
Copper	2	0.1 – 3.0	0.2
Iron	0.3	0.2	5.0
Mercury	0.001	0.001	-
Manganese	0.5	0.05	0.2
Nickel	0.02	0.05	0.2
Lead	0.01	0.05	5.0
Zinc	3	0.1 – 5.0	2.0

Sources:
a WHO (1993)
b Cited by Chapman (1996)
c Cited by Pescod (1992)

Ghesquière (1999) prepared a summary of the effects of heavy metals on plants and human health which is reproduced in Table 4.

Table 4 Heavy Metals and Their Effects on Plants and Human Health

Element	Sources	Agronomic effects	Effect on health
As	Industrial effluents, an impurity in some detergents	Toxicity to plants varies widely	Very harmful, cumulative poison, carcinogenic, skin diseases.
Cd	Washing powders as an impurity in phosphates, impurity in zinc steel industry, paint, plastic	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Risk of accumulation in plants and soils.	Very harmful, cumulative poison. Food main source of intake.
Cr	Leather tanneries (about 40 mg/l in surface discharges)	Not generally recognised as an essential growth element. Lack of knowledge on its toxicity to plants	Carcinogenic, dermatitis, painful chrome ulcers. Food main source of intake.
Cu	Plumbing, animal wastes, pesticides, earth's crust	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions	Liver cirrhosis food main source of intake, uncertain toxicity in humans.
Fe	Plumbing, earth's crust	Essential element of nutrition, not toxic to plants	Not a major hazard to health.
Hg	Pesticides, industrial effluents		Very harmful, for pregnant women, cumulative poison, neurological diseases.
Mn	Industrial effluents	Toxic to a number of crops at a few-tenths to a few mg/l	No convincing data of human toxicity.
Ni	Industrial effluents	Toxic to a number of plants at 0.5 mg/l to 1 mg/l.	Carcinogenic, lack of data on carcinogenic by the oral route
Pb	Lead-acid batteries, solder, alloys	Decrease respiration of soil organisms and inhibit plant cell growth at very high concentrations	Accumulate in skeleton, harmful for children and pregnant women
Zn	Plumbing, animal wastes, pesticides	Toxic to many plants at widely varying concentrations	Not a major hazard to health

Source: Ghesquière (1999). Data drawn from: Pratt (1972); FWR (1993); WHO (1993); Tiller *et al.*, 1994; Leita *et al.* (1995); Birley and Lock (1998)

Reliable detection of heavy metals at the concentrations likely to be encountered in municipal wastewater requires use of sophisticated laboratory equipment and appropriately trained staff. Pearce *et al* (1999) evaluated the use of recently developed field equipment to measure heavy metal concentrations in water samples but were unable to endorse the use of such equipment as results were inconsistent and doubts existed over the methods' efficacy in water carrying a high sediment load.

The difficulties and cost associated with the accurate measurement of heavy metals and the understanding that heavy metals are unlikely to pose a threat to human health through consumption of irrigated vegetables mean that the monitoring of heavy metals in wastewater reused for agriculture is not a priority. This study had access to atomic absorption spectroscopy equipment at UST and so samples were monitored for a range of heavy metals. However, comparing the results with the sparse guidelines that are available suggest that there is little risk to irrigated crop production from heavy metal pollution, (see section 4.2).

3. WATER QUALITY MONITORING IN THE PERI-URBAN ZONE OF KUMASI

3.1 The Drainage Basin and Areas of Irrigated Agriculture

Kumasi, with a population of approximately 1 million (Gov. of Ghana, 1996), lies at an elevation of approximately 260 m amsl. It has a semi-humid, tropical climate with a total average annual rainfall of 1,340mm. The inter-tropical convergence zone influences rainfall distribution. Roughly 90% of the annual total falls between March and October but July and August are drier than the surrounding months, i.e. rainfall distribution is weakly bimodal. November to mid March is the main dry season. Figure 2 shows the average monthly rainfall figures.

The natural drainage of Kumasi runs from north to south, the principal streams being the Daban, Subin, Aboabo, Sisa and Wiwi. These converge into the Sisa, which flows into the Oda approximately 9 km south of Kumasi. A small portion of the north west of the city, including the environmentally important Suame Magazine vehicle breaking area, drains to the northwest into the catchment of the Owabi dam and thence into the Ofin River. (See Figure 3 and Annex 1).

There is no readily available flow gauging data for any of the streams in the urban area. Water levels are reported as being monitored on the Aboabo and Wiwi – streams to the east of the city centre – but no calibration is available to link stage to discharge.

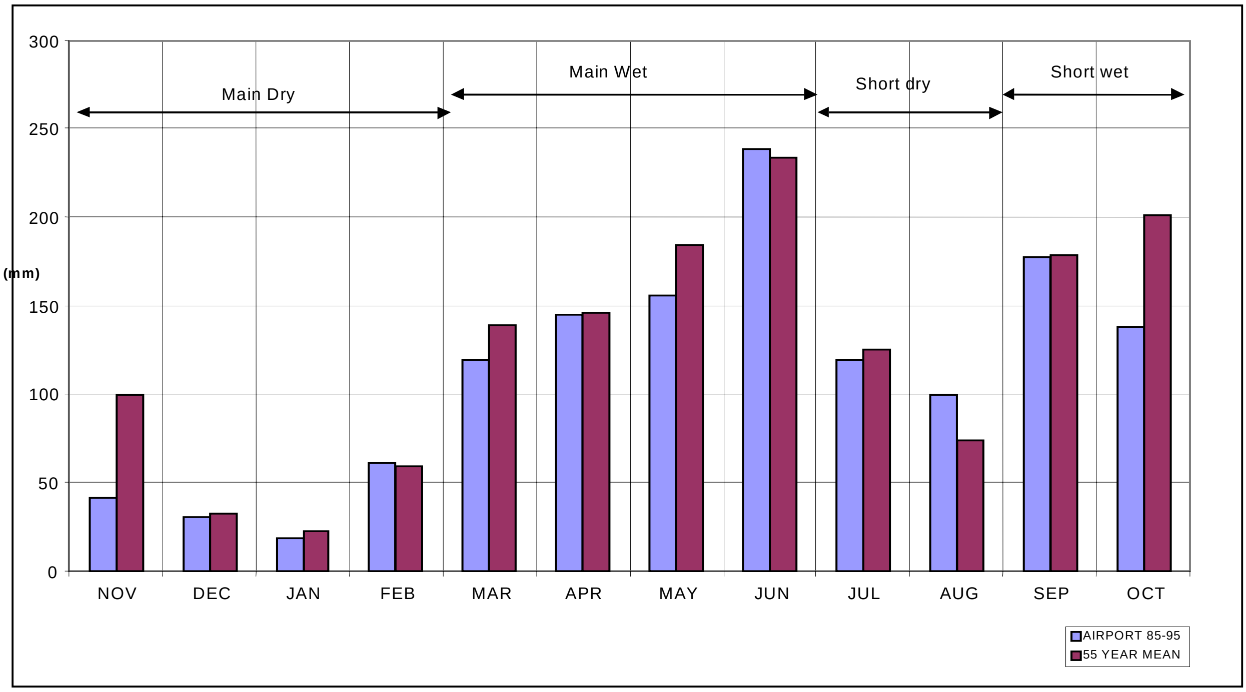


Figure 2 Monthly Rainfall, Kumasi

Cornish and Aidoo (1999) present the findings of a survey of peri-urban irrigation practices around Kumasi. Small-scale irrigation of horticultural crops is widespread in many of the villages within a 40 km radius of Kumasi during the dry season from November to March. Where perennial rivers provide an assured water supply the number of farmers and scale of farming operation is greater with the ownership and hire of small petrol pumps being commonplace. In other areas farmers draw water either from ephemeral streams which form a series of pools in the dry season or from shallow hand-dug wells. The large number of farmers who draw water from the Sisa and the Oda downstream of Asago village are using water of unknown quality which is heavily polluted with the domestic and industrial effluent of Kumasi. It is postulated that water drawn from shallow wells is of better quality than that in the rivers draining Kumasi.

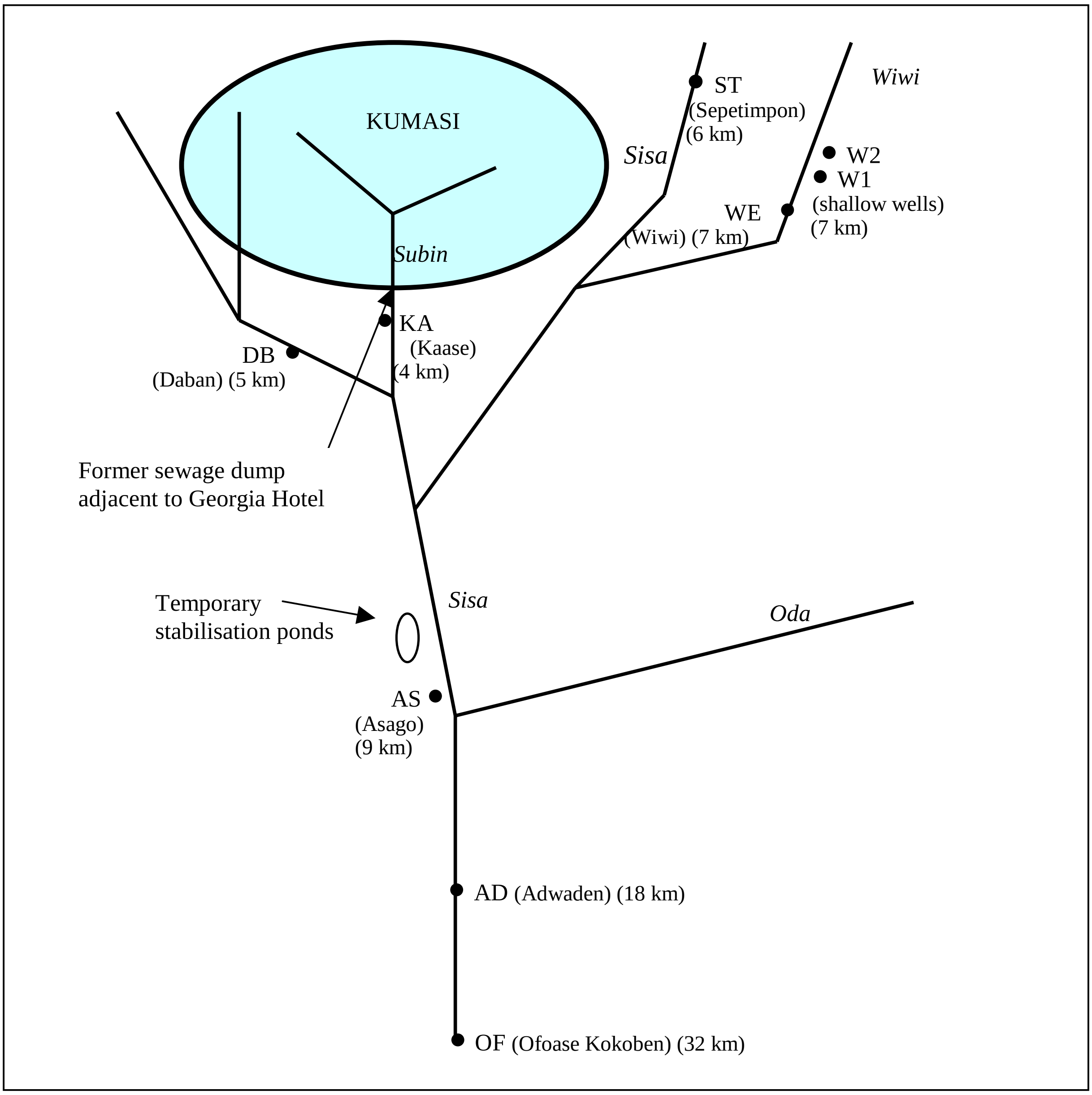


Figure 3 Schematic Map showing Sampling Sites and their Distance from the Centre of Kumasi

The most commonly irrigated crops are tomato, garden egg (a variety of aubergine) and okra. Other irrigated vegetables include hot pepper, sweet pepper, cabbage, lettuce and cucumber. The last two, although grown on a smaller scale, are significant because they are eaten raw whilst all the others are normally cooked.

3.2 Management of Municipal and Industrial Effluent in Kumasi

Salifu and Mumuni, (1998) report that the Kumasi metropolitan area has sewerage for less than 4% of its nearly one million residents. 40% of residents depend on public toilets (improved pit latrines, aqua privies and pan latrines), 15% depend on septic tanks (most without soakaways), whilst less than 10% have household improved pit latrines. Between 250-350 m^3 of septage and nightsoil are collected daily by vault emptying trucks. Until mid February 1999 this material was discharged into poorly maintained waste stabilisation ponds on the southern ring road adjacent to the Subin River. Due to the accumulation of sludge in these ponds retention time was very low and effectively untreated sewage passed directly into the Subin. Dumping at this site ceased in mid February with the completion of temporary waste stabilisation ponds 7 km south of Kumasi, north of Asago village on the Sisa river. Plans are in hand to construct a new permanent site for wastewater treatment but there is no guarantee that this will fair better than the ponds on the ring road. Even with effective waste stabilisation ponds in place to treat tanker collected nightsoil and septage, much of the domestic sewage and industrial effluent form Kumasi will continue to be discharged directly into streams passing through the city.

The major sources of industrial effluent in the city are two breweries, a soft drinks bottling plant and a soap factory. Effluent from these industries is discharged into surface watercourses without pre-treatment. Light industrial activities at the Suame Magazine complex - draining to the north west - and sawdust mounds at sawmills also generate significant amounts of waste oil and leachate respectively.

3.3 Routine Monitoring and Past Studies of Water Quality

There is little routine monitoring of water quality by government agencies in and around Kumasi. The Environment Protection Agency (EPA) conducts annual spot sampling at selected locations measuring basic physical and chemical parameters – pH, TDS, dissolved oxygen, nitrites, nitrates, etc – and faecal coliform numbers. However, reported data are based on a single sample as financial resources do not permit more frequent sampling.

Students in various departments at the University of Science and Technology (UST) have completed a number of studies of river water quality and more limited number of studies of crop contamination. Ghesquière (1999) carried out a review of these studies and a summary of the findings is given here. Table 5 provides a summary of the water quality data available for each river.

Although the UST studies were done at different times and took samples from different locations on the four main rivers running through Kumasi a general pattern can still be discerned in the data. The Subin River is the most highly polluted with very high levels of suspended solid and recordings of 60 million faecal coliform per 100 ml – 4 orders of magnitude above the guideline limit for safe irrigation. The most extreme conditions are recorded adjacent to the Georgia Hotel where nightsoil and septage are dumped. The other locations are further upstream and the lower numbers of faecal coliform and the presence of dissolved oxygen indicate that pollution is not so extreme at these sites. The Aboabo, where it crosses the Accra road, has gathered effluent from a large part of northern Kumasi and this is reflected in relatively high levels of suspended solid and very high numbers of faecal coliform. The Sisa shows lower levels of suspended solids when compared with either the Subin or Aboabo and the average count of faecal coliform is two and three orders of magnitude lower than the Aboabo and Subin, respectively. The faecal coliform count is one or two orders of magnitude higher in the upstream reach of the Sisa where it crosses the Accra road than in Asago village even though Asago is downstream of the Subin / Sisa confluence and is therefore influenced by the sewage dumping at the Georgia hotel. The Wiwi is the cleanest of the rivers draining Kumasi. This is consistent with the fact that only a small portion of its catchment is under urban development.

Table 6 summarises data presented by Amankwah (1993) who analysed a number of vegetables purchased from Kumasi market for their heavy metal content. Only the hot peppers and the local vegetable, ntonkom showed levels of copper and zinc above the UK's Ministry of Agriculture Fisheries and Food guidelines for food safety, (MAFF, 1999). Without greater knowledge of the "standard" concentration of metals in these vegetables it is impossible to draw conclusions from this one set of data and there is no evidence to suggest that the metal contents were raised as a consequence of irrigation with polluted water.

Ogoe (1996) and Owusu (1998) report studies of the microbiological quality of irrigation water and the number of faecal coliforms found on vegetables irrigated with that water. Ogoe sampled water and crops from an unnamed stream close to Kumasi airport. Owusu studied water and crops in both Accra and Kumasi with the study in Kumasi focusing on crops irrigated from shallow wells rather than from streams. The results are presented in Tables 7 and 8 and are compared with the guideline values for numbers of E. coli permissible on foods set out by the International Commission on Microbiological Specifications for Food Guidelines (ICMSF, 1978, cited by Vaz da Costa Vargas *et al*, 1996).

Table 5 Summary of Water Quality Data Reported in Student Theses at UST

River	Location	Reference	pH	Suspended solids mg/l	TDS Mg/l	DO mg/l	BOD_5 mg/l	Faecal coliform /100ml
Subin	Georgia hotel	Gah (1991)	6.62	421	-	0	369	9.3×10^7
	Georgia hotel	Appiah (1991)	6.77	-	-	0	93	2.2×10^8
	-	Gov. of Ghana (1996)	6.62	451	-	0	440	-
	Kumasi Zoo	EPA (1997)	7.2	-	-	1.8	120	2.0×10^2
	Asafo market	EPA (1997)	7.6	-	-	0.9	210	2.5×10^2
	Ahodwo bridge	EPA (1997)	7.4	-	-	0.3	100	6.6×10^3
	Limex road	Salifu & Mumuni (1998)	7.37	-	809	2.35	-	-
	Mean Values		**7.08**	**436**	**809**	**0.76**	**114**	**6.3×10^7**
Aboabo	Accra Rd	Gah (1991)	7.39	147	-	0	57	2.2×10^6
	Accra Rd	Appiah (1991)	6.8	-	-	1.6	5	3.7×10^5
	-	Gov. of Ghana (1996)	6.73	121	-	0	180	-
	Accra Rd	Salifu & Mumuni (1998)	7.01	-	318	1.8	-	-
	Mean Values		**6.98**	**134**	**318**	**0.85**	**81**	**1.3×10^6**
Sisa	Accra Rd	Gah (1991)	6.78	32	-	0	16	5×10^4
	Accra Rd	Appiah (1991)	6.29	-	-	1.3	2	1.16×10^5
	-	Gov. of Ghana (1996)	6.22	56	-	0	37	-
	Asago village	EPA (1997)	7.88	-	-	0.2	990	1.28×10^3
	Asago village	Kasanga (1998)	6.78		38		-	TC > 1×10^3
	-	Salifu & Mumuni (1998)	5.83	-	671	0	-	-
	Mean Values		**6.63**	**44**	**354**	**0.3**	**261**	**4.2×10^4**
Wiwi	Ayeduade Rd	Fleisher-Djoleto (1990)	6.4	-	-	6.5	60	-
	Wiwi/Kantinkronu confluence	Gah (1991)	6.32	27	-	.5	22	1.26×10^4
	UST campus	Appiah (1991)	6.23	-	-	2.3	2	7.0×10^3
	-	Gov. of Ghana (1996)	6.38	33		0.5	16	-
	UST Campus	Awuletey (1994)	6.54	18	-	5	6	7.41×10^3
	Mean Values		**6.37**	**26**		**3.0**	**21**	**9×10^3**

Ogoe reports total coliform numbers rather than faecal coliform but states that confirmatory tests showed the coliforms to be E. coli, variety I. On this basis both the water samples exceed the guideline for safe irrigation as proposed by Westcot (1997). However, the numbers of E. coli bacteria detected on the crops by thoroughly washing the crop surface with distilled water falls well below the levels described by the ICMSF as undesirable. The results of Owusu (1998) suggest the microbiological water quality of the two shallow wells is very good and even the surface water contained only a very low count of faecal coliforms. No faecal coliforms were detected on the crop samples.

Table 6 Heavy Metal Content (mg / kg) of Selected Raw and Cooked Vegetables (Mean of 10 samples)

	Copper		Zinc		Iron	
Vegetable	**Raw**	**Cooked**	**Raw**	**Cooked**	**Raw**	**Cooked**
MAFF permissible limit	50	50	20	20	N/a	N/a
Hot pepper	77.63	62.74	62.47	62.43	8.10	106.4
Ntonkom	65.11	62.46	68.44	67.68	6.72	6.70
Sweet pepper	41.35	7.41	4.87	5.96	10.56	7.95
Nsusua	21.43	20.02	12.83	7.66	7.12	6.9
Garden egg	15.08	8.37	5.83	5.14	5.82	5.04
Okra	2.5	11.93	3.35	5.33	4.13	4.78

Source: Amankwah (1993)

Table 7 Total Coliform Count Per 100 ml found in Water and Crop Samples at a Site Adjacent to Kumasi Airport

	Location	
Sample type	**A**	**B**
Water	85×10^{3}	60×10^{3}
Cabbage	42×10^{2}	34×10^{2}
Carrots	36×10^{2}	27×10^{2}
Lettuce	40×10^{2}	30×10^{2}
Onion	32×10^{2}	26×10^{2}

Source: Ogoe (1996)

ICMSF guideline: $> 1 \times 10^{3}$ E. Coli type I per 100g fresh weight is "undesirable"
$> 1 \times 10^{5}$ E. Coli type I per 100g fresh weight is "unacceptable"

Table 8 Number of E. coli Found in Water and Vegetable Samples, After Owusu (1998)

	Location		
	Hand dug well, Kwadaso	**Hand dug well, Chirapatre**	**Surface water, UST campus**
Water	0	0	45
Vegetable sample	0	0	0

The limited data from Owusu (1998) supports the hypothesis that water from shallow dug wells is of much better microbiological quality than river water in peri-urban areas. However, the data appear to be based on single samples taken from each well – rather than on the mean of several – and the finding of zero E. coli in the samples is so surprising as to cast some doubt on the reliably of the data.

The analysis of numbers of coliforms on plant surfaces is of limited value. The WHO (Engelberg) guidelines are based on epidemiological evidence. That is, they are based on an assessment of the likelihood of disease occurring as a consequence of water of a particular quality being used. They are explicitly distanced from earlier standards based purely on detection of indicator organisms in water or on irrigated crops. Mara (1995) calls into question the validity of counting E. coli or other indicator organisms on foods. He points out that a European Union directive permits up to 10×10^{6} E. coli per 100g of hard cheese made from untreated milk, (Official Journal of the European Communities, 1992) and the ICMSF permit some foods eaten raw to contain up to 10×10^{4} faecal coliform. The presence of standard indicator organisms such as thermo-tolerant coliform bacteria (faecal coliform) on foodstuffs is not a direct indication that disease will occur if the food is eaten. The data of Ogoe (1996) and Owusu (1998) show very low counts of coliform bacteria but even the detection of higher numbers is not a reliable indication of risk. In short, it seems better to be guided by the water quality guidelines of Mara and Cairncross (1989) and Westcot (1997) rather than attempt to count bacteria on foodstuffs when laboratory methods and guideline levels are so variable.

Table 9 Descriptions of the Selected Monitoring Sites

Site No.	Code	Site Name	Description
1	ST	Sepetimpon	River Sisa upstream of the urban centre of Kumasi. Sampled at the road crossing. Small areas of irrigated cropping draw water close to this sampling location.
2	WE	River Wiwi	Sampled on the downstream side of the Accra – Kumasi road crossing. Extensive area of irrigation drawing water here and immediately downstream. The Wiwi catchment is predominantly rural at this site.
3	KA	Kaase	Subin river sampled 1.5 km south of the waste stabilisation ponds at the Georgia Hotel. The river is heavily polluted from this source and other municipal waste from the city centre. Tarro and bananas grow on wetlands adjacent to the river. There is no evidence of irrigated horticulture in this area.
4	DB	Daban	Daban river sampled at Old Bekwai Road crossing. The upstream catchment drains much of the urban west of Kumasi.
5	AS	Asago	River Oda sampled immediately downstream of the confluence with the Sisa. 9km south of Kumasi city centre. Irrigated cropping occurs from this point south on the Oda.
6	AD	Adwaden	River Oda sampled due west of Adwaden village. 18km south of the Central market in Kumasi.
7	OF	Ofoase Kokoben	River Oda sampled at the Bekwai – Boni road crossing. Farmers from Ofoase Kokoben (2 km NNW) cultivate in this area. 32 km south of Kumasi central market
8	W1	Shallow well 1	About 20m east of the Wiwi south of Accra – Kumasi road crossing. The well may capture run-off from the road.
9	W2	Shallow well 2	About 50m east of the Wiwi south of Accra – Kumasi road crossing. No obvious source of surface pollution into this well.

3.4 Selection of Sampling Sites and Water Quality Parameters

The aim of the work was to give a first indication of the physical, chemical and microbiological quality of waters used for irrigation within the peri-urban zone of Kumasi. With the limited resources available a small number of sampling sites were selected to provide an indication of the changes in water quality upstream and downstream of Kumasi, to quantify the levels of pollution at sites thought to be highly polluted and gauge the extent of auto-purification at sites further downstream.

The focus of the study was on the streams and rivers draining Kumasi but two shallow well sites were also sampled to allow some comparison between the two types of water sources most widely used for irrigation.

3.4.1 The Sampling Sites

The Subin / Sisa / Oda river system provides the main natural drainage of Kumasi and there are known to be high numbers of farmers irrigating vegetable crops along the river, south of Asago village. There is much less evidence of irrigation to the north of Asago.

To obtain information on the dilution and autopurifier effects of the river system on water quality seven sampling sites were selected. Their distribution allows monitoring immediately upstream of Kumasi and at a number of sites at increasing distance downstream of the city. The locations are shown on the map in Annex 1 and schematically in Figure 3.

In addition to the seven river sites, two shallow wells adjacent to the Wiwi river where it crosses the Accra – Kumasi road were also monitored. A large percentage of the total irrigated crop production around Kumasi is irrigated from shallow wells rather than directly from rivers. Data from two wells cannot give a full picture of the water quality found in the hundreds of shallow dugouts used for irrigation but the data serve to give a first indication of the likely water quality in such wells. A larger study of water quality in shallow wells is being carried out by the Environmental Engineering Section of the Department of Civil Engineering at the University of Science and Technology which should greatly expand the present knowledge of shallow groundwater quality and its impact on irrigation in the region.

3.4.2 Quality Parameters

Water samples were taken on five occasions between February 18th and March 16th 1999. This period corresponds with the end of the main dry season when river flows are at their lowest and there is therefore least dilution of municipal and industrial discharges. Water quality in the rivers is likely to be at its worst in this period but it is a time that coincides with widespread irrigation activity as farmers take advantage of the high prices for vegetables at this time and in the holiday period of Easter. Table 10 indicates the dates of sampling and the parameters measured on each occasion.

At each site a 200 ml beaker was used to take water from four or five points in the stream or well. The beaker was pointed upstream and effort was made to draw water from a depth similar to that taken by farmers using buckets. The four or five 200ml samples were mixed together in a clean, plastic, one-litre container. 10ml of this mixed sample were then decanted into a sterilized glass bottle which was stored in a cold box to maintain the temperature below 10^{o} C for transport back to UST laboratories. Parts of the remaining sample were used for the determination of heavy metals and physicochemical properties.

For the analysis of helminths 2 litre samples were taken, again by sampling at a number of adjacent points and collecting those samples in a single container. The first sample taken was of “clear” water, i.e. without stirring up sediment from the bed. A second sample was then taken after deliberately disturbing the bed to simulate the agitation that might occur when filling a bucket. It was anticipated that a greater number of helminths would be detected in the second sample as the eggs tend to settle out under their own weight.

Table 10 Dates of Sampling and Parameters Measured

Parameter	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99
Total coliforms	●	●	●	●	●
Faecal coliforms	-	-	●	●	●
Helminths (clear)	-	●	-	●	●
Helminths (sediment)	-	●	-	●	-
Heavy metals	●	-	●	-	●
Electrical Conductivity	●	●	●	●	●
PH	●	●	●	●	●
NH_3	●	●	●	●	●
NO_2^-	●	●	●	●	●
PO_4^{3-}	●	●	●	●	●

Due to a shortage of reagents and laboratory consumables at the beginning of the sampling period confirmatory tests of faecal coliform numbers were only completed on the last three samples. Faecal coliform numbers in samples taken on the first two dates were estimated from regression analysis of total coliform numbers against faecal coliforms in the three sets of samples taken in March. Because of the limited availability of laboratory facilities and staff, samples were analysed for the presence of helminth eggs on only three occasions and on the last date only a clear water sample was taken.

4. RESULTS & DISCUSSION

4.1 Microbiological Results

4.1.1 Helminths

The results of the helminth analysis are shown in Table 11. Five different types of helminth were identified in total but of these only two - Ascaris lumbricoides, and hookworm – were intestinal nematodes (roundworms), defined by WHO (1989) as being of greatest risk to human health. High numbers of Hymenolepis diminuta are reported to be evidence of a high rodent population, (Garcia and Bruckner, 1988; Gentilini *et al*., 1993).

Intestinal nematode eggs were found at six of the nine sampling locations. Asago, Ofoase Kokoban and one of the two shallow wells were the only sites which did not show any intestinal nematode eggs on any of the three sampling dates.

Table 11 Arithmetic Mean Number of Different Helminths Eggs per Litre

Site	Parasite/helminth species	Intestinal Nematode	24/02/99 [a]	08/03/99 [a]	16/03/99 [a]	Mean [b]
ST (clear)	Ascaris lumbricoides	Yes	6	0	0	2
	Hymenolepis diminuta	No	6	0	8	5
ST (sediment)	Hymenolepis diminuta	No	17	0		9
WE (clear)	Hookworm	Yes	5	0	10	5
WE (sediment)	Hymenolepis diminuta	No	17	0		9
KA (clear)	Ascaris lumbricoides	Yes	13	8	0	7
	Fasciola hepatica	No	6	8	0	5
	Hymenolepis diminuta	No	0	42	18	20
KA (sediment)	Ascaris lumbricoides	Yes	0	5		3
	Hymenolepis diminuta	No	33	8		21
DB (clear)	Ascaris lumbricoides	Yes	6	0	0	2
	Hymenolepis nana	No	0	0	8	3
	Hymenolepis diminuta	No	7	0	0	2
DB (sediment)	Hymenolepis diminuta	No	0	8		4
AS (clear)	Hymenolepis diminuta	No	0	0	8	3
AS (sediment)	-		0	0		0
AD (clear)	Ascaris lumbricoides .	Yes	4	0	0	1
	Taenia sp	No	4	0	0	1
	Fasciola hepatica	No	8	0	0	3
	Hymenolepis diminuta	No	0	0	17	6
AD (sediment)	Ascaris lumbricoides	Yes	0	7		4
	Hookworm	Yes	8	0		4
	Fasciola hepatica	No	0	13		7
	Hymenolepis diminuta	No	17	13		15
OF (clear)	-		0	0	0	0
OF (sediment)	-		0	0		0
W1 (clear)	-		0	0	0	0
W1 (sediment)	-		0	0		0
W2 (clear)	Ascaris lumbricoides	Yes	25	0	0	5
	Hookworm	Yes	4	0	0	1
	Hymenolepis diminuta	No	8	0	0	3
W2 (sediment)	Ascaris lumbricoides	Yes	4	0		2
	Hymenolepis diminuta	No	4	0		2
Tap water	-		0	0	0	0

[a] Mean of duplicate determinations (rounded to the nearest whole number)
[b] Mean rounded to the nearest whole number

There is considerable variation in nematode numbers over time and location. At most locations the highest incidence was recorded on the first sampling date. Shallow well 2 illustrates this clearly. The high count of Ascaris lumbricoides (25 eggs per litre) and 4 hookworm eggs was most probably the result of recent human defecation on land immediately adjacent to the well. The variation over time in the river system cannot be so easily explained but it reflects the influence of numerous natural and sampling factors. The expected pattern of higher numbers of eggs in water containing bed sediments was not widely born out by the results. At Adwaden there was a higher count in the sediment and water mixture but the reverse was seen at Kaase.
Because of the variations in count over time and between clear water and that containing sediments the arithmetic mean number of intestinal nematodes at each site for the three dates of sampling and two types of sample are presented in Figure 4.

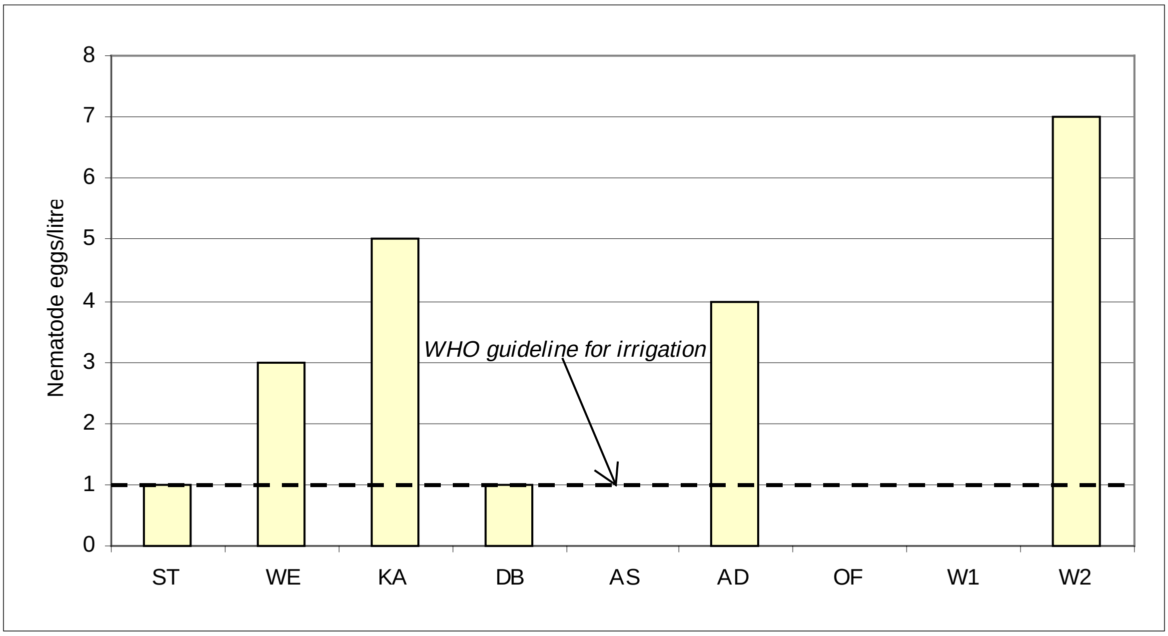


Figure 4 Mean Number of Intestinal Nematode Eggs

The apparent absence of nematode eggs at Asago is surprising, as this had the highest mean number of faecal coliforms of any of the nine sites (See 4.1.2 and Table 12, below). This may be a consequence of helminth eggs from sewage discharged in Kumasi settling out upstream of Asago whilst bacteria remain suspended but then an explanation must be sought for the relatively high number of eggs at Adwaden. The high number of eggs in shallow well 2 indicates that wells do not necessarily guarantee better quality water than that drawn from polluted streams and rivers.

Table 12 Comparison between Bacteriological and Parasitological Quality and WHO Guidelines

Sampling site	Nematodes eggs/l		FC/100 ml		Consistency
ST	1 = 1	Equal	890 < 1,000	Below	Inconsistent
WE	3 > 1	Exceeds	1,277 > 1,000	Exceeds	Consistent
KA	5 > 1	Exceeds	8,658 > 1,000	Exceeds	Consistent
DB	1 = 1	Equal	6,524 > 1,000	Exceeds	Consistent
AS	0 < 1	Below	89,707 > 1,000	Exceeds	Inconsistent
AD	4> 1	Exceeds	31,180 > 1,000	Exceeds	Consistent
OF	0 < 1	Below	5,545 > 1,000	Exceeds	Inconsistent
W1	0 < 1	Below	20,478 > 1,000	Exceeds	Inconsistent
W2	6 > 1	Exceeds	1,390 > 1,000	Exceeds	Consistent

Interpreting data on the numbers of intestinal nematode eggs in samples is problematic particularly in view of the fact that,

> "The most sensitive techniques currently available for the detection of helminth eggs in wastewater are able to detect a minimum of the order of one egg per litre"

WHO (1989), Cited by Westcot, (1997).

However, the data suggest that water both upstream (ST and WE) and downstream of the urban centre of Kumasi (DB and AD) fails to comply with the WHO guidelines with respect to nematode eggs.

Westcot (1997) concludes that because laboratory procedures for detection and enumeration of faecal coliform are easier to carry out than enumeration of helminths and they are better established as "standard practice" they should form the basis of any initial effort to quantify microbiological water quality for wastewater reuse. The data in Table 12 generally support this pragmatic conclusion with the exception of the Sepetimpon site, which has a faecal coliform count just below 1000 per 100 ml but two nematode eggs per litre in the clear water sample. In the short term, it seems sensible to monitor and make judgements on the microbiological suitability of water for irrigation based on faecal coliform numbers. If waters could be brought to consistently comply with the guideline of less than 1000 FC / 100 ml, *then* attention might be turned to monitoring nematode egg numbers.

4.1.2 Total and Faecal Coliform

Table 13 and Figure 5 show the numbers of faecal coliform detected in samples from each site for the last three sampling dates. Samples taken on 18th and 24th February were only analysed for total coliform number and the faecal coliform count was calculated from these data based on the correlation between total and faecal coliform observed over the last three sampling dates. Numeric data and the regression analysis are included in Annex 2.

Table 13 Number of Faecal Coliform per 100 ml on 5 Sampling Dates

Site	18/02/99 [a]	24/02/99 [a]	02/03/99	08/03/99	16/03/99	Mean	S
ST	2,844	2,133	729	1,500	84	890	1,095
WE	*0* [b]	4,976	176	3,384	897	1,277	2,221
KA	28,436	7,820	7,650	400	71,500	8,658	28,976
DB	63,981	7,820	810	4,000	7,290	6,524	26,536
AS	355,450	781,990	51,700	7,500	53,900	89,707	153,748
AD	63,981	28,436	75,900	110,000	1,940	31,180	46,512
OF	2,844	4,976	17,010	6,480	3,360	5,545	5,811
W1	14,929	*0* [b]	*<3* [b]	50,000	19,500	24,416	19,066
W2	2,844	2,844	273	2,162	*0* [b]	1,478	1,215

a Determined by correlation with total coliform number
b Samples reported to have zero coliform were considered to result from sampling or analytical error, possible through inadvertent sterilisation of the sample by residues of disinfectant in the sample bottles. The data were discounted when calculating the mean over the sampling period.
S = Standard Deviation

Figure 5 shows that there was considerable variation in the number of faecal coliform at any one sampling location over the five week sampling period but there is no discernible trend in the variations when different sampling sites are compared. Mean values for each site are shown in Figure 6.

The first seven sampling sites on the graphs are arranged according to their location in the catchment – moving from left to right represents a move from upstream of central Kumasi to sites well downstream of the city. W1 and W2 are the shallow wells, adjacent to the river Wiwi at the WE sampling site. There is a pattern of increasingly poor water quality moving from the Sepetimpon (ST) and Wiwi (WE) sites, upstream of the main urban centre towards the most microbiologically polluted site at Asago (AS), 9 km south of the city at the confluence of the Sisa and Oda rivers. Further south of Asago, at Adwaden (AD) and Ofoase Kokoban (OF), the numbers of faecal coliform drop but remain above the WHO guideline value for unrestricted irrigation.

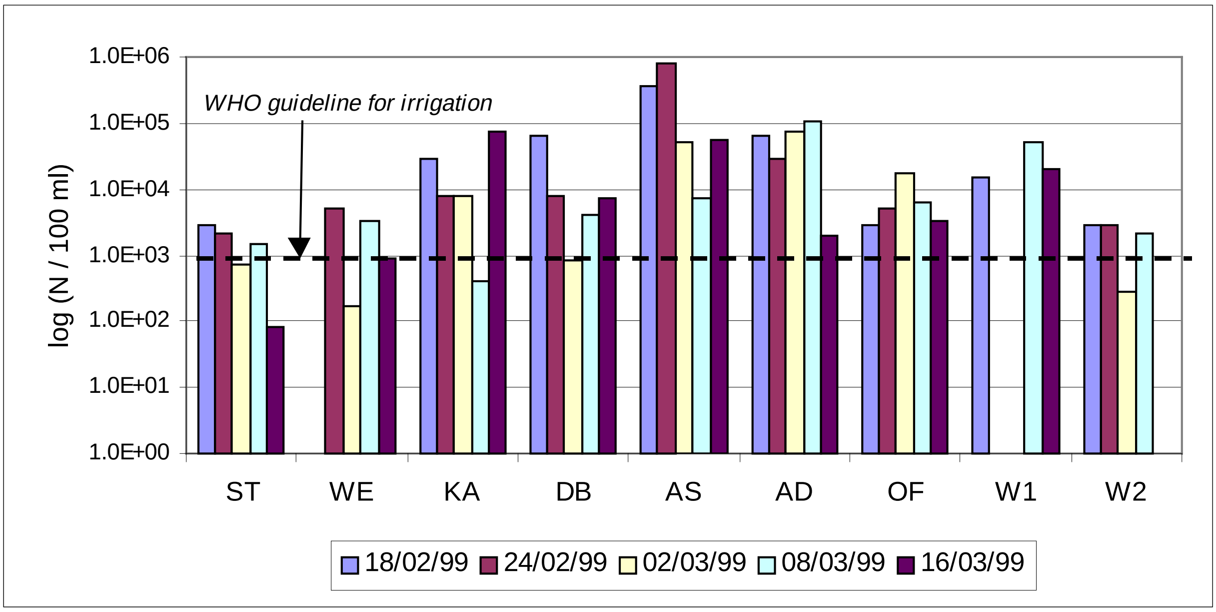


Figure 5 Faecal Coliform Count per 100 ml

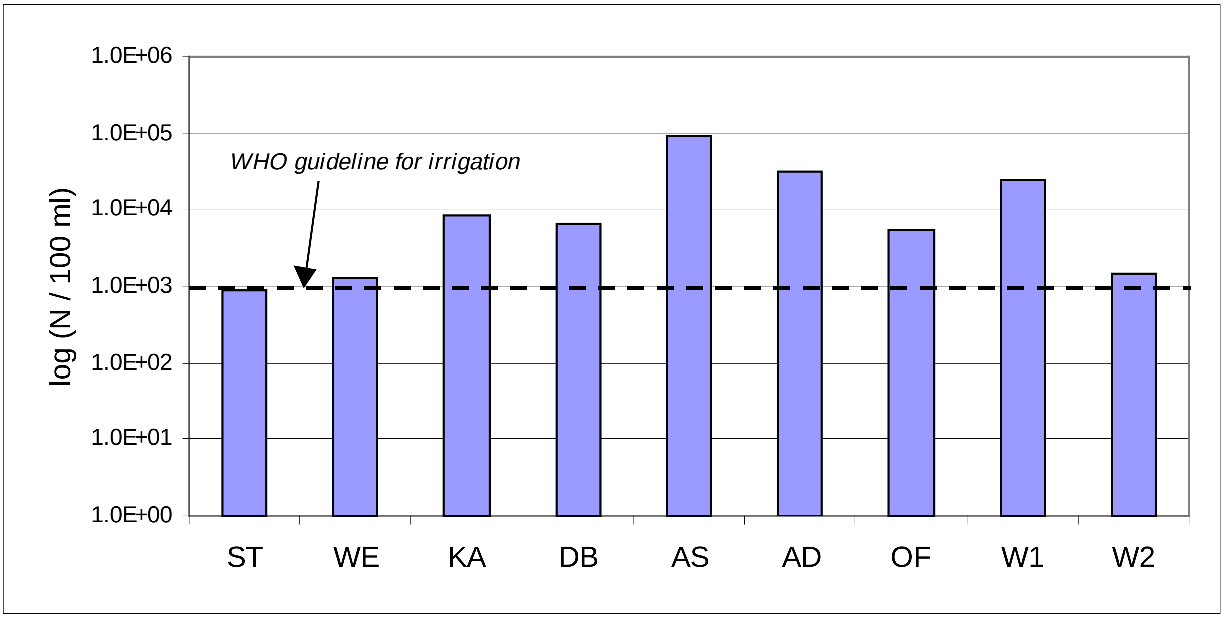


Figure 6 Mean Count of Faecal Coliform per 100 ml Recorded over Sampling Period

4.1.3 Discussion of Microbiological Data

Based on this small data set it might be concluded that irrigation practised on the Sisa and Wiwi rivers, upstream of Kumasi, may pose a minor threat to the health of consumers as the faecal coliform numbers are close to the monitoring limit recommended by Westcot. The nematode numbers at both these sites were high. Around Kaase, Daban and as far south as Asago there is no evidence of the river water being used extensively for irrigation. This may be due to the water quality or may be a consequence of other factors not related to water quality. Further investigation would be needed to determine this. The very high counts of faecal coliform at Asago and Adwaden give cause for greater concern. The mean counts of 8.97×10^4 and 3.1×10^4 are both an order of magnitude above the WHO guideline, the Asago value almost 2 orders of magnitude greater and in this area, particularly towards Adwaden, there are known to be many farmers irrigating with river water. The risk may not be so great if only cooking vegetables are grown in this area. Ideally, further monitoring of water quality should take place at sites along the Oda from Asago to villages downstream of Ofoase Kokoban (OF) to determine if, and where, the water quality improves naturally to a level where unrestricted irrigation can be considered without risk. The data at Ofoase Kokoban indicate that at this point – 32 km downstream of Kumasi – faecal coliform numbers are still 5.5×10^3 per 100 ml which is high for a river in a predominantly rural catchment.

Direct comparisons of these data with those of earlier studies reported in Table 5 may be misleading as different sampling locations and dates were used but some observations can be made. Samples from the Wiwi in this study had a mean faecal coliform count of 1.3×10^3. This is lower than the mean of the studies reported in Table 5, 9×10^3 though still in the same order of magnitude. The site at Kaase on the Subin River can be compared with the EPA data at Ahodwo bridge and here there is close agreement between the EPA data, 6.6×10^3, and the mean of this data set, 8.6×10^3. The data from Asago village, 9×10^4, suggests higher levels of contamination than the values reported in earlier studies. Because of the great variation between samples taken on different dates from the same location – see Table 13 and Figure 5 – no conclusions can be drawn from these comparisons regarding improving or deteriorating quality over time. Such conclusions could only be drawn from long term, consistent monitoring which is not currently available.

With the cessation of dumping of nightsoil and septage on the Subin river and the commissioning of new waste stabilisation ponds the present data provide a useful baseline for future comparisons to determine if there is any discernible improvement in the quality of the Oda in subsequent dry seasons.

The data for the two shallow wells calls into doubt the assumption that wells provide better quality water than the rivers. No firm conclusion can be drawn on the basis of data from just these two wells which are close to a major road and an area of frequent human activity. A wider study of the water quality in shallow wells used for irrigation would certainly be required before any firm recommendation in their favour could be made.

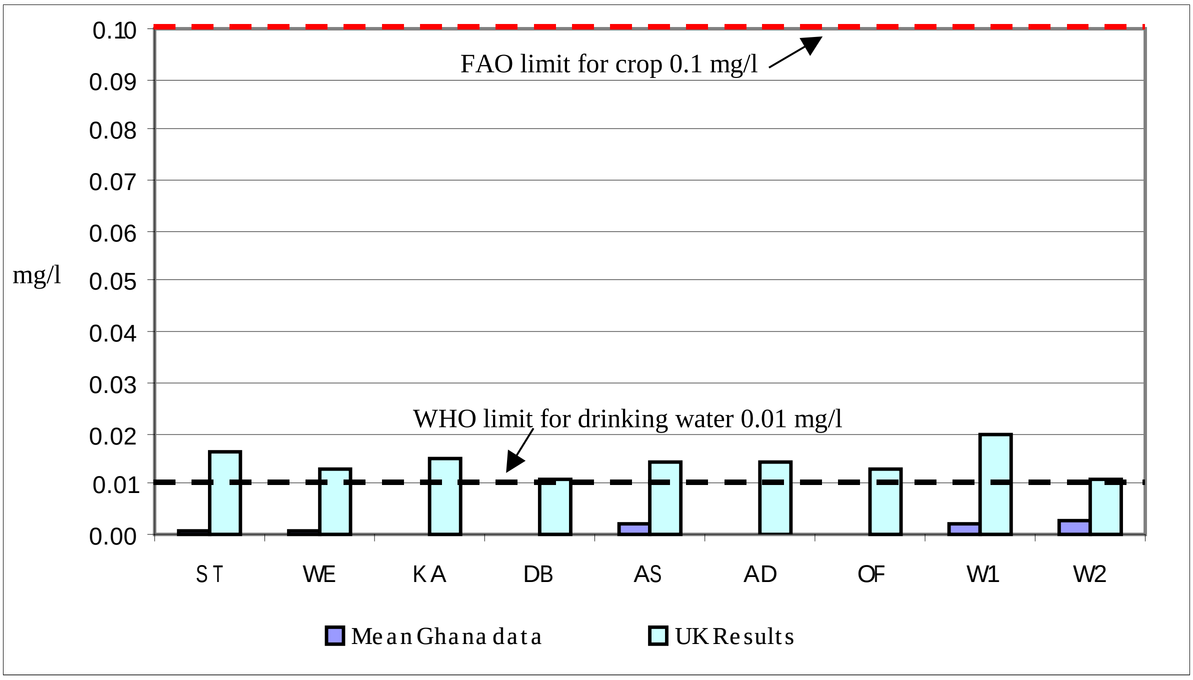
4.2 Heavy Metals

Results of the heavy metal analysis for 10 elements are summarised in Figure 7 and presented in Annex 3. Figure 7 shows the mean values from samples analysed in the department of Mining and Minerals at the University of Science and Technology, Kumasi, (UST). In addition to the three samples analysed at this laboratory a duplicate sample taken on the last sampling date, 16th March 1999, was analysed in the UK and the results of this are also shown.

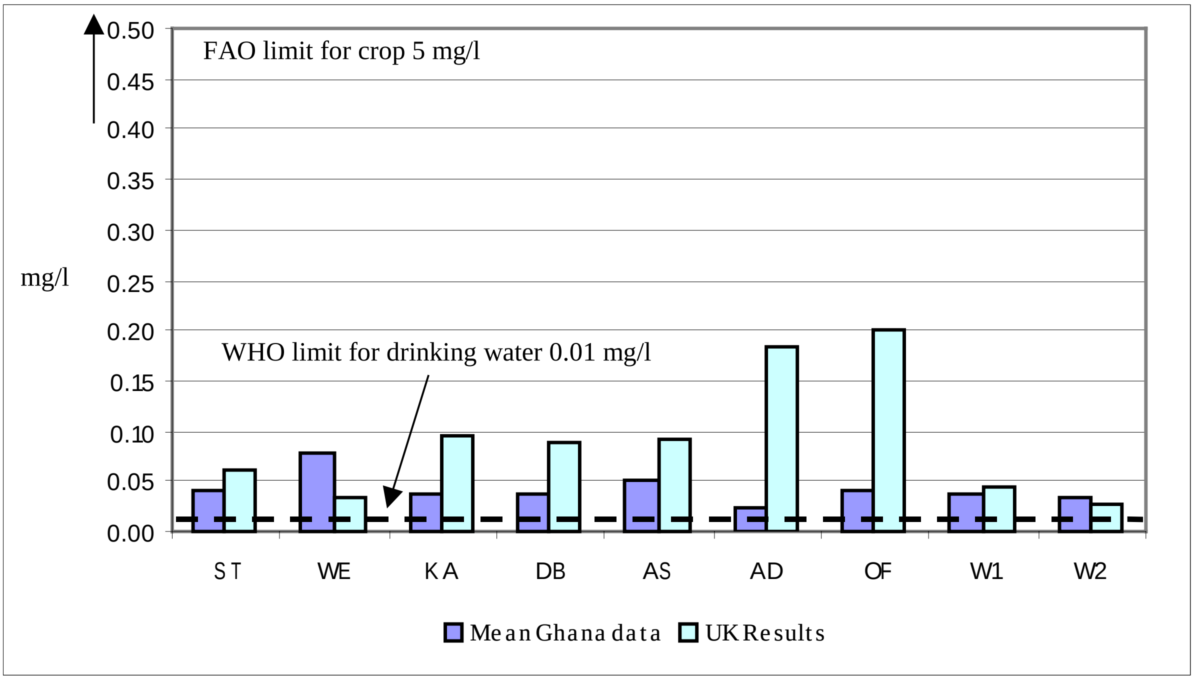
When the results are compared with the threshold levels for trace elements for crop production cited by Pescod (1992), three elements lie close to or exceed those threshold values – cadmium, manganese and iron. The levels of mercury detected at the UST laboratory also merit comment.

4.2.1 Mercury

Pescod gives no guidance for this element but mean values apparently as high as 0.03 mg/l give rise to concern. However, there was considerable uncertainty surrounding the reliability of this element's detection at UST and none of the samples analysed in the UK reported values greater than the detection limit of 0.0001 mg/l. In view of this, these apparently high values more likely reflect experimental error than a genuine high risk of mercury pollution.

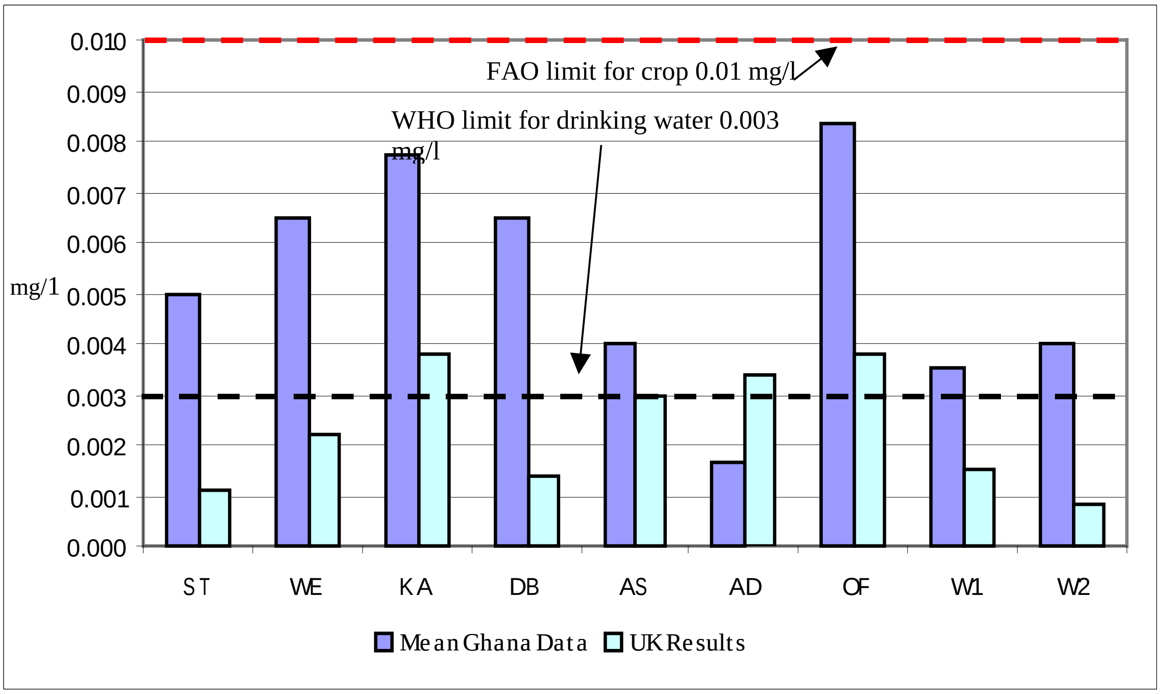


Arsenic

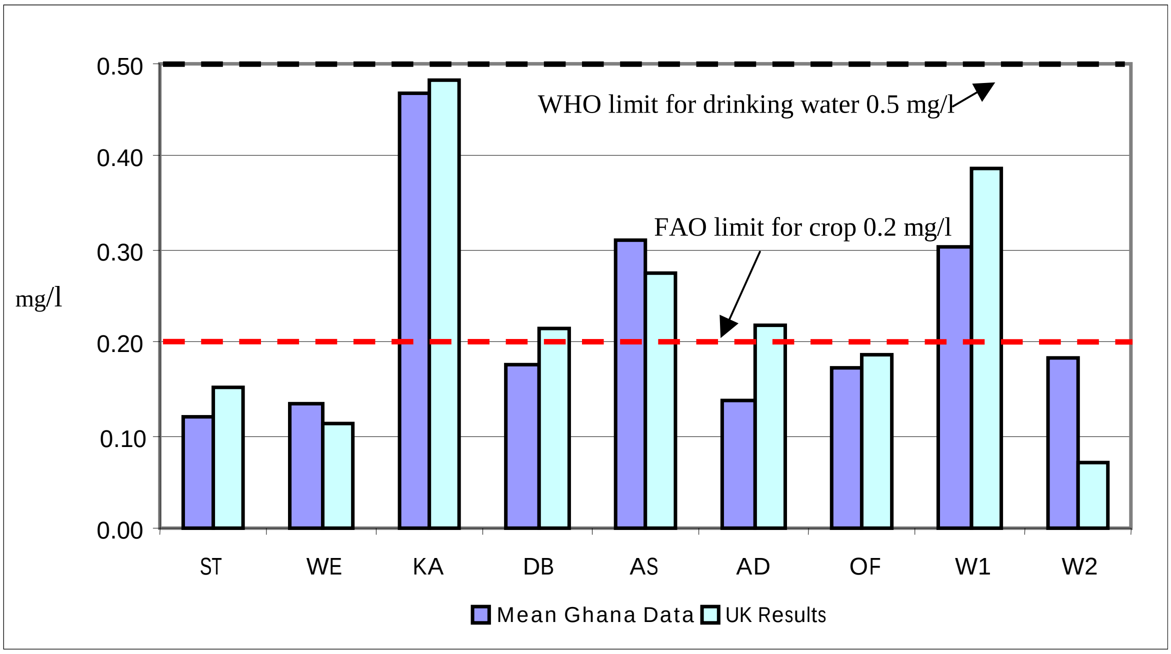


Lead

Figure 7a Mean Concentrations of Arsenic and Lead

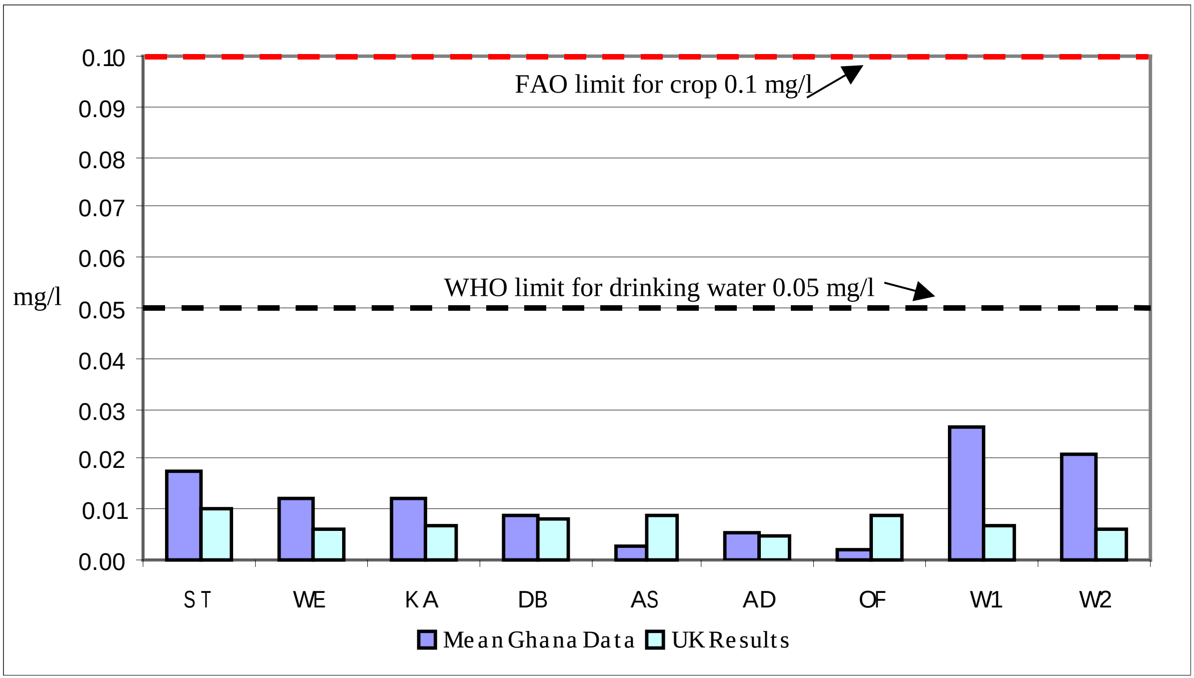


Cadmium

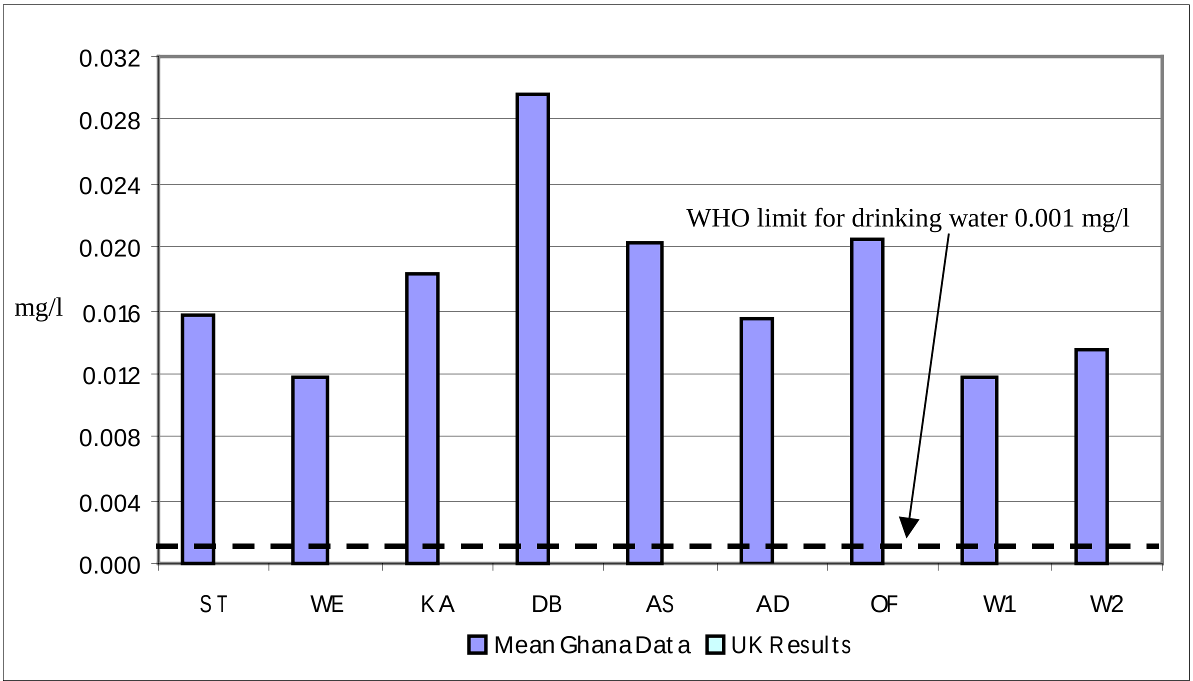


Manganese

Figure 7b Mean Concentrations of Cadmium and Manganese

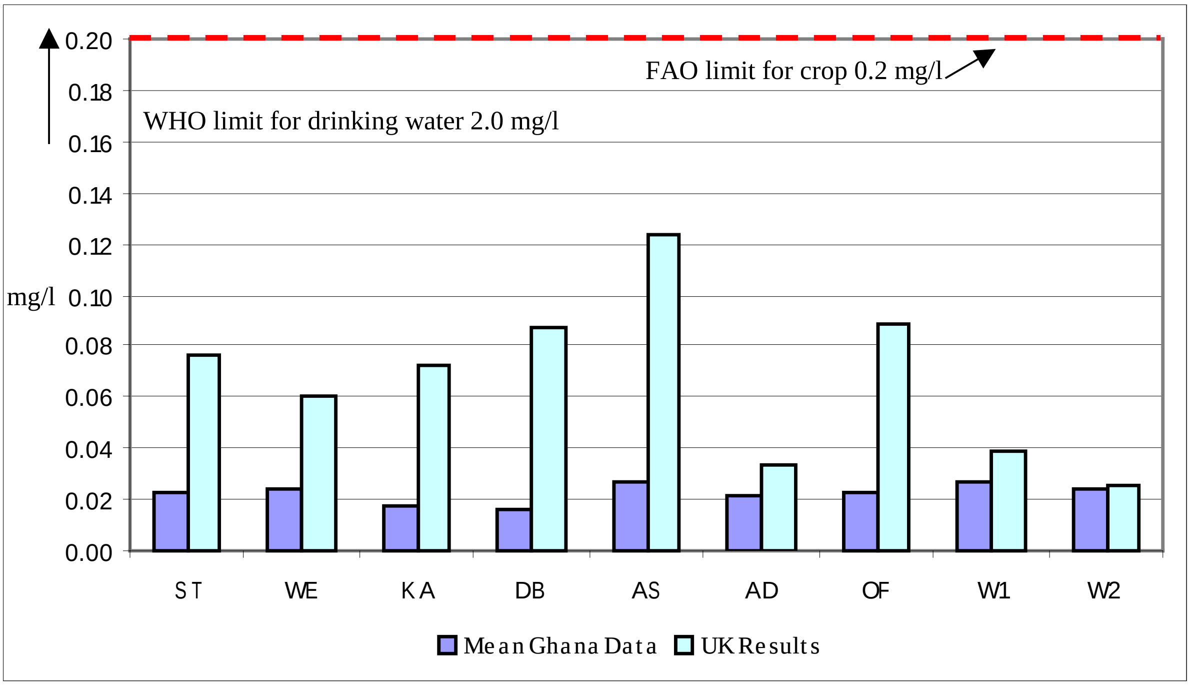


Chromium

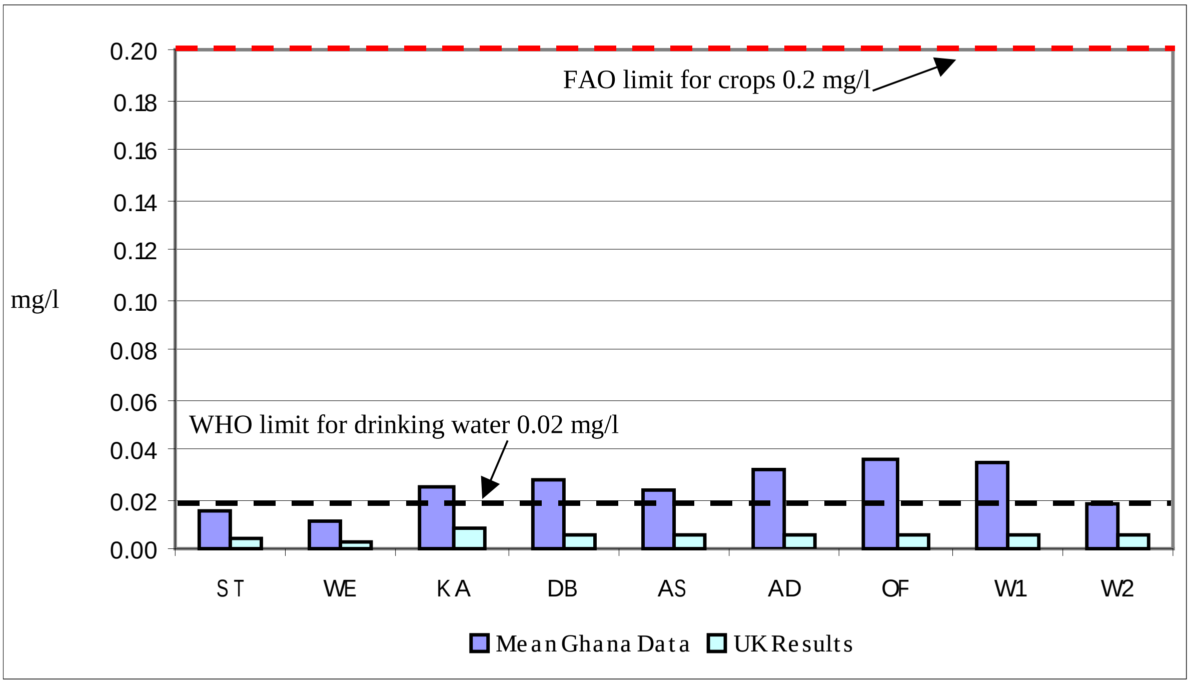


Mercury

Figure 7c Mean Concentrations of Chromium and Mercury

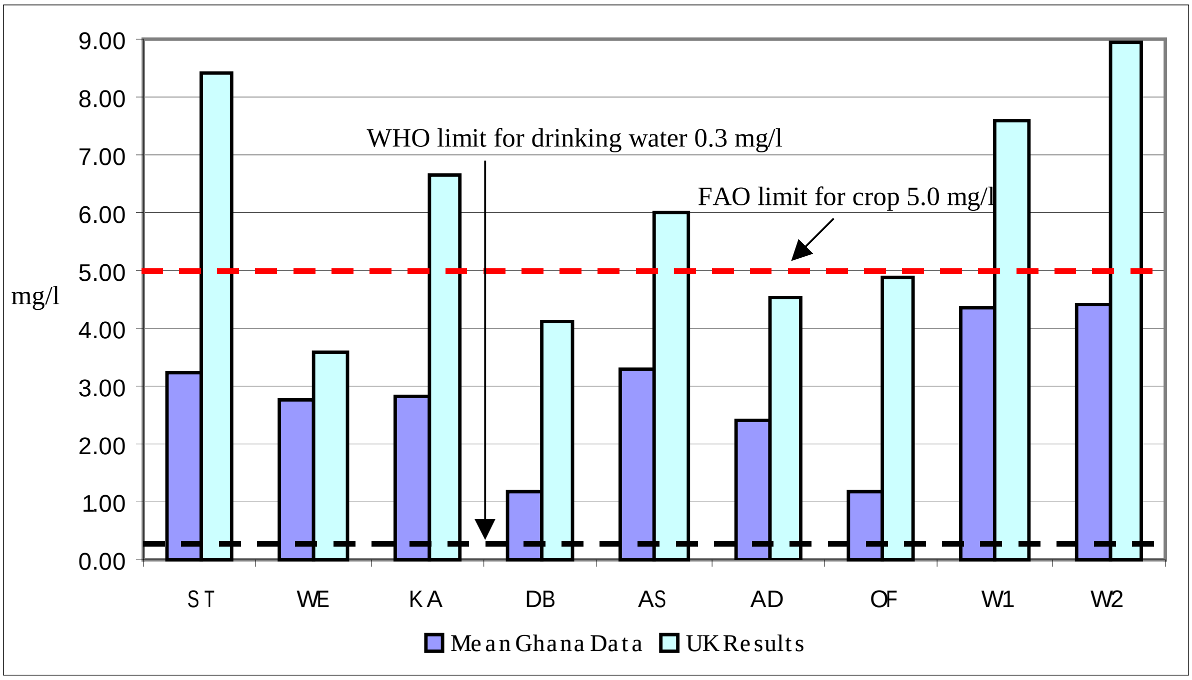


Copper

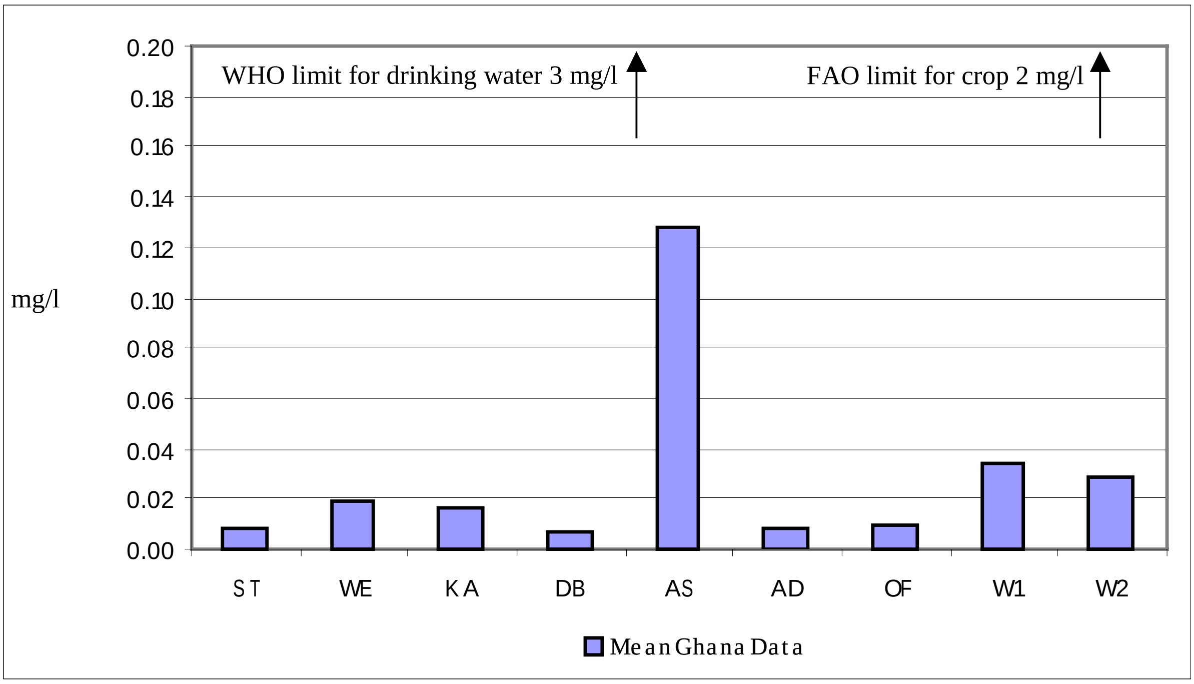


Nickel

Figure 7d Mean Concentrations of Copper and Nickel



Iron



Zinc

Figure 7e Mean Concentrations of Iron and Zinc

4.2.2 Cadmium

The mean concentration of cadmium does not exceed the FAO threshold at any of the sampling locations though samples taken on the River Wiwi, at the Accra road (WE) and on the Subin River at Kaase (KA) on March 16th had concentrations of 0.01 mg/l, just on the threshold. Comparison of the results from UST and the UK laboratory for samples taken on March 16th shows that UST reports higher concentrations at 6 locations – between 2 to 4 times the UK laboratory. At three locations, Asago, Adwaden and shallow well 1 – the UK results indicate higher concentrations than UST, between 0.5 to 3 times. There is therefore no general trend in comparing the results of the two laboratories for this element.

The threshold level of 0.01 mg/l is described by Pescod (1992) as conservative due to the potential danger of bio-accumulation in plants and soils. As the concentrations of cadmium do not exceed even this conservative threshold at any location pollution by this element does not pose a serious threat for irrigation.

4.2.3 Manganese

There is very close agreement between the UST and UK results for samples taken on March 16th so there is no cause to question the reliability of the data.

The concentration of manganese exceeds the FAO threshold for crops (0.2 mg/l) at three sites – Kaase, on a highly polluted stretch of the Subin downstream of the site where sewage tankers dump their load,

Asago, downstream on the same river, and in shallow well 1. The origin of these particularly high concentrations at these sites is not certain. Manganese phosphate is used in vehicle lubricants and this may explain the high concentration in Shallow well 1, which receives run-off from vehicle washing. Ghesquière (1999) reports finding no data on health risks associated with high concentrations of manganese in foods, while Pescod (1992) reports that high concentrations may be toxic to some crops.

Although concentrations of manganese are high at these selected locations it seems unlikely that use of these polluted waters for irrigation will give rise to any risk to human health.

4.2.4 Iron

The concentration of iron in all samples on all dates is high. Every sample exceeds the WHO guideline of 0.5 mg/l for drinking water. There is notable variation between the results from UST and those from the UK laboratory. UK values are consistently higher, the difference ranging between 1½ and 3 fold. The UK data shows 5 sites – Sepetimpon, Kaase, Asago and the two shallow wells – with iron concentrations exceeding the FAO recommended maximum value for irrigation of 5 mg/l. Only the shallow well W1 exceeds this value in the UST data set.

The precise concentrations of iron in the samples are not important to the discussion. The generally high levels of iron in all surface water sources in the area are a consequence of the high iron content of the region's soils rather than an indication of pollution. Use of the water for irrigation does not present any direct threat to human health or crop production though problems of nutrient availability in low pH, iron rich, soils may be observed.

4.2.5 Other Heavy Metals

Concentrations of the following heavy metals were consistently low:

Arsenic	Lead
Chromium	Nickel
Copper	Zinc

Although there were some disparities between samples analysed at UST and in the UK, in no case did measured concentrations come close to the FAO recommended safe levels for irrigation. Only the elements arsenic, lead and nickel had concentrations close to or exceeding the WHO limits for drinking water.

4.2.6 Discussion of Heavy Metal Data

There is no evidence of urban pollution resulting in heavy metal concentrations in the surface waters draining from Kumasi that exceed safe limits for irrigation (assuming that the reported levels of mercury are a detection error rather than truth). The concentrations of most of the elements tested for fall below the WHO safe limits for drinking water.

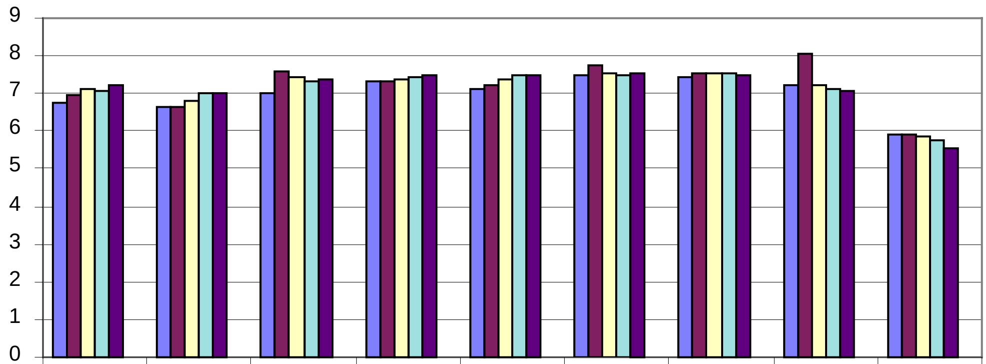
There are no clear or notable trends between locations. No site stands out as having higher or lower concentrations of the elements tested for. Assuming that the concentrations recorded represent “background” or naturally occurring concentrations of these elements it is not surprising to observe no clear difference between samples drawn from the shallow wells and those drawn from the rivers.

While urban pollution is causing serious microbiological contamination of waters potentially used for irrigation there is currently no evidence of heavy metal pollution. The limited resources that are available should therefore be focused on monitoring and reducing levels of microbiological pollution, rather than focusing on heavy metals.

4.3 Physicochemical Parameters

4.3.1 pH

The pH values of all the samples are shown in Figure 8.



	ST	WE	KA	DB	AS	AD	OF	W1	W2
18/02/99	6.73	6.65	7.03	7.34	7.12	7.46	7.43	7.23	5.89
24/02/99	6.97	6.65	7.58	7.33	7.23	7.72	7.53	8.08	5.89
02/03/99	7.10	6.82	7.42	7.39	7.37	7.56	7.56	7.20	5.86
08/03/99	7.09	7.00	7.35	7.43	7.46	7.50	7.51	7.11	5.77
16/03/99	7.20	7.01	7.40	7.50	7.50	7.53	7.48	7.07	5.56
Mean	7.02	6.83	7.36	7.40	7.34	7.55	7.50	7.34	5.79

Figure 8 pH Values at 9 Sites on Five Sampling Dates

Samples from the shallow well W2 were consistently acidic whilst those from the adjacent well, W1, lay within the range of most of the other sites which were neutral or very mildly alkali (the river Wiwi is an exception being very mildly acidic). The likely explanation for this acidic reaction is the presence of decomposing vegetation in the well W2, generating humic and fulvic acids. W1 was used more frequently for vehicle washing and had no accumulation of plant material within it. It is unlikely that the acidity is a consequence of urban pollution. The finding underscores the fact that it cannot be assumed that shallow wells will necessarily provide "better quality" water for irrigation than water drawn from streams. It also indicates that efforts should be made to keep wells used for irrigation free from decaying vegetation.

None of the other sites showed pH values outside the expected normal range. They are consistent with the values reported in previous studies that are shown in Table 5.

4.3.2 Conductivity

The data for all samples are reported in Annex 4. Mean conductivity values are shown in Figure 9.

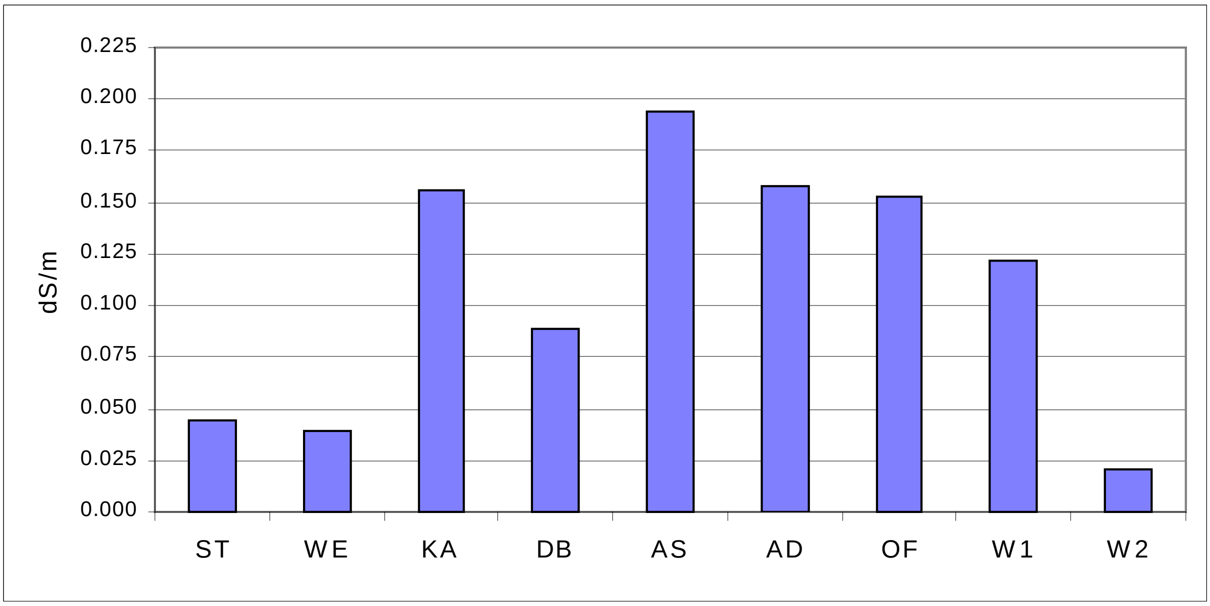


Figure 9 Mean Electrical Conductivity at 9 sites (Deci Siemens / m)

Ayers and Westcot (1985) indicate that water with conductivity below 0.7 dS/m will cause no long-term salinity problems when used for irrigation. None of the locations sampled have conductivity of even a third of this value and therefore none of these waters is likely to present a threat to irrigation as a consequence of dissolved salts.

The trend in conductivity between sites closely follows the trend for microbiological contamination. The Sisa at Sepetimpon (ST) and the Wiwi at the Accra road (WE) are upstream of Kumasi and relatively unpolluted. The Sisa at Kaase (KA) is highly polluted by urban run-off and this is reflected in the increased conductivity at that site. Conductivity of the Daban river at the old Bekwai road crossing (DB) is lower than the Sisa at Kaase, repeating the trend in faecal coliform numbers at these two sites. The Asago site at the confluence of the sisa and Oda rivers shows the highest conductivity and highest faecal coliform count. Conductivity then drops slightly at Adwaden and Ofoase Kokoban, probably as a consequence of dilution effects at increasing distance from Kumasi.

4.3.3 Nitrogen

Nitrogen was measured as nitrate (NO_3) nitrite (NO_2) and ammonia (NH_3). Only traces of nitrate were found in any of the samples and these are not reported. Levels of ammoniacal and nitrite nitrogen are reported in full in Annex 4. There is marked variation in the concentrations of both ammonia and nitrite over time which reflects the effects of rainfall events over the period of sampling.

Mean concentrations of nitrogen over the five sampling dates are presented for each site in Table 14. The table also shows the equivalent fertiliser nitrogen value derived from the water assuming a total application depth of 200mm to a crop over a growing season.

Table 14 Mean Concentrations of Nitrogen (mg / l) and its Equivalent Fertiliser Value (kg /ha) Assuming 200mm Depth of Irrigation Water Applied.

	ST	WE	KA	DB	AS	AD	OF	W1	W2
$NH_3 – N$	1.19	1.75	17.03	11.53	24.38	18.45	16.31	0.96	1.11
$NO_2 – N$	0	0.0004	0.007	0.0004	0.002	0.03	0.031	0	0.00002
Total N	1.190	1.7504	17.037	11.530	24.382	18.48	16.362	0.960	1.110
Fertiliser benefit Kg N / ha	2.2	3.5	34.0	23.0	48.8	37	32.7	1.9	2.2

The polluted waters downstream of Kumasi may make a significant contribution to the nitrogen requirements of irrigated crops. This is consistent with interviews held with farmers in the Adwaden area who believed the water provided a detectable fertiliser benefit to irrigated crops.

4.3.4 Phosphorus

Phosphorous was measured as PO_4. Levels of phosphate were much higher on the last three sampling dates at all sites. This was most probably a result of rainfall flushing phosphate rich pollutants or agricultural fertiliser into the water bodies. Mean values of elemental phosphorous as PO_4 are reported in Table 15 together with the equivalent fertiliser value, applied as P_2O_5, assuming 200 mm of irrigation. The full results are given in Annex 4.

Table 15 Mean Concentrations of Phosphorous (mg / l) and its Equivalent Fertiliser Value as P_2O_5 (kg /ha) Assuming 200mm Depth of Irrigation Water Applied.

	ST	WE	KA	DB	AS	AD	OF	W1	W2
$PO_4 – P$	44.2	39.1	41.5	45.6	42.0	42.7	33.7	37.3	45.6
Fertiliser benefit kg P_2O_5/ ha	202	179	190	209	188	196	155	171	104

These levels are very high and if accurate they indicate high levels of phosphate pollution *at all the sites sampled.* This is in contrast with the data for nitrogen, which varied between sites and was very low in the shallow wells. As the sampling dates coincided with early rains at the end of the dry season and a consequent phosphate flush the mean values reported here may be “misleadingly” high.

Further monitoring over an extended period would be required to clarify the situation regarding phosphate levels in the water sources used for irrigation over the entire dry season.

5. CONCLUSIONS AND RECOMMENDATIONS

The results of the field studies carried out during February and March 1999 and the findings of previous studies carried out around Kumasi have to be interpreted in the light of guidelines and information available in the international literature.

The key conclusions are:

1. The Engelberg Guidelines for microbiological quality of wastewater use for irrigation are intended as a guide for the design of treatment plants. They were not intended as quality surveillance norms.

The FAO report by Westcot (1997) recognises that the Engelberg Guidelines are not an ideal standard by which to monitor the indirect reuse of wastewater. The report uses the guidelines as "interim standards" for quality monitoring and promotes the standard of <1000 FC /100 ml as a performance goal to work towards. The comparison of measured levels of faecal coliform with this guideline provides an indicator of potential risk but further epidemiological studies are required to determine if the standard is too stringent or too weak to prevent significant disease risk from the indirect use of wastewater for irrigation.

2. Monitoring of samples for the presence of intestinal nematode eggs is too complex and time consuming to be adopted as a routine procedure where resources are limited.

Samples in this study were analysed for the presence of nematode eggs but the procedure was time consuming and the results erratic with little correlation with faecal coliform numbers. The study therefore concurs with the conclusion of Westcot (1997) that it is impractical to use the helminth guideline in routine monitoring of water quality for irrigation, particularly where laboratory facilities are limited.

3. Levels of microbiological pollution at all sites monitored downstream of Kumasi exceed FAO guidelines for unrestricted irrigation. Rivers upstream are relatively clean.

The highest mean count of faecal coliform was found at Asago at the confluence of the Sisa and Oda rivers. The mean count of approximately 90,000 FC / 100 ml exceeds the FAO guideline by a factor of 90. The mean faecal coliform count falls with distance from Kumasi – 31,000 FC /100ml at Adwaden (18 km d/s of Kumasi city) and 5,500 FC / 100 ml at Ofase Kokoben, 32 km d/s.

Levels of faecal coliform at the two sites upstream of Kumasi – Sepetimpon and the Wiwi – 890 FC/100 ml and 1200 FC / 100ml, suggest that those waters are effectively safe for unrestricted irrigation, although the high number of hookworm eggs in two samples from the Wiwi raises some doubts over that conclusion.

There was large variation in faecal coliform counts at all locations. This underscores the need for regular monitoring with quality assessments based on the mean value over the season.

It must be emphasised that the guideline of < 1,000 FC /100ml is a guide for the irrigation of crops likely to be eaten raw. While the crops irrigated are horticultural almost all, with the exception of lettuce and cucumber, are cooked before eating. This single factor significantly reduces the degree of risk faced by the consumers of these irrigated crops but the workers irrigating crops with polluted water are exposed to a high risk of disease.

4. There is no evidence of significant pollution with heavy metals or other chemical pollutants that pose a threat to irrigated cropping.

5. Water salinity does not pose a threat to crop production.

The electrical conductivity, and therefore salt content, of water downstream of Kumasi is between two to five times higher than at sites upstream of the city but at no site does the level pose a threat to cropping. The highest mean conductivity, 0.19 dS/m at Asago, is well below the threshold of 0.7 dS/m at which problems may occur for salt sensitive crops.

There is a marked difference in the salt content of the two shallow wells. W1 has a conductivity six times higher than W2. This is probably a consequence of well W1 being close to the main road and being used regularly for vehicle washing. Soluble salts and detergents are thereby washed into the well.

6. Based on these results shallow wells do not always offer a cleaner water source than surface streams and rivers.

The shallow well W1, adjacent to the Wiwi River, recorded a higher mean number of faecal coliform than the river and W2 had the highest count of helminth eggs recorded at any site. These findings are important because a larger percentage of the irrigated crops grown in the Kumasi area is irrigated from shallow wells than is irrigated by direct abstraction from rivers.

The pollution of these wells is most likely caused by run-off from land adjacent to the well draining directly into the well. There is usually no attempt made when a well is located or excavated to prevent surface water draining into it and with open defecation in the fields a common practice the potential for pollution of the wells is high.

The Environmental Engineering Section of the Department of Civil Engineering at the University of Science and Technology is carrying out a wider study of water quality in shallow wells which should indicate whether the findings of this study are representative of the large number of wells in the region used for irrigation.

7. It may be possible to show that with simple precautions shallow wells provide water of a much higher quality than river water in the Sisa and Oda downstream of Kumasi.

If this hypothesis can be validated then efforts should be made to raise public awareness of these precautions and of the health risks associated with river water irrigation downstream of major urban centres. Farmers should then be encouraged to protect their wells and wherever possible use them in preference to direct abstraction from rivers. This is an area requiring further study before firm recommendations can be made.

8. The relative risk to consumers resulting from wastewater irrigation and the misuse of agrochemicals remains unclear.

This study shows that the rivers draining Kumasi are polluted to a degree that presents a risk of disease transmission through the irrigation of food crops – particularly those consumed raw. However, the actual incidence of disease occurring as a consequence of this transmission route cannot be determined without far more extensive epidemiological studies. It cannot, therefore, be determined if the threat to health posed by wastewater irrigation is significantly greater or less than the threat posed by the misuse of agrochemicals on vegetable crops –a practice which is known to be widespread but the consequences of which are again difficult to quantify.

9. The data set brought together by this study provides a baseline against which future trends can be compared.

Work is underway to build new wastewater stabilisation ponds and eliminate sewage discharges into the Sisa at the Georgia Hotel. Field studies are also being carried out into a number of aspects of water quality and management in the Kumasi Metropolitan Area. The data presented here may provide useful reference or comparative information for these projects.

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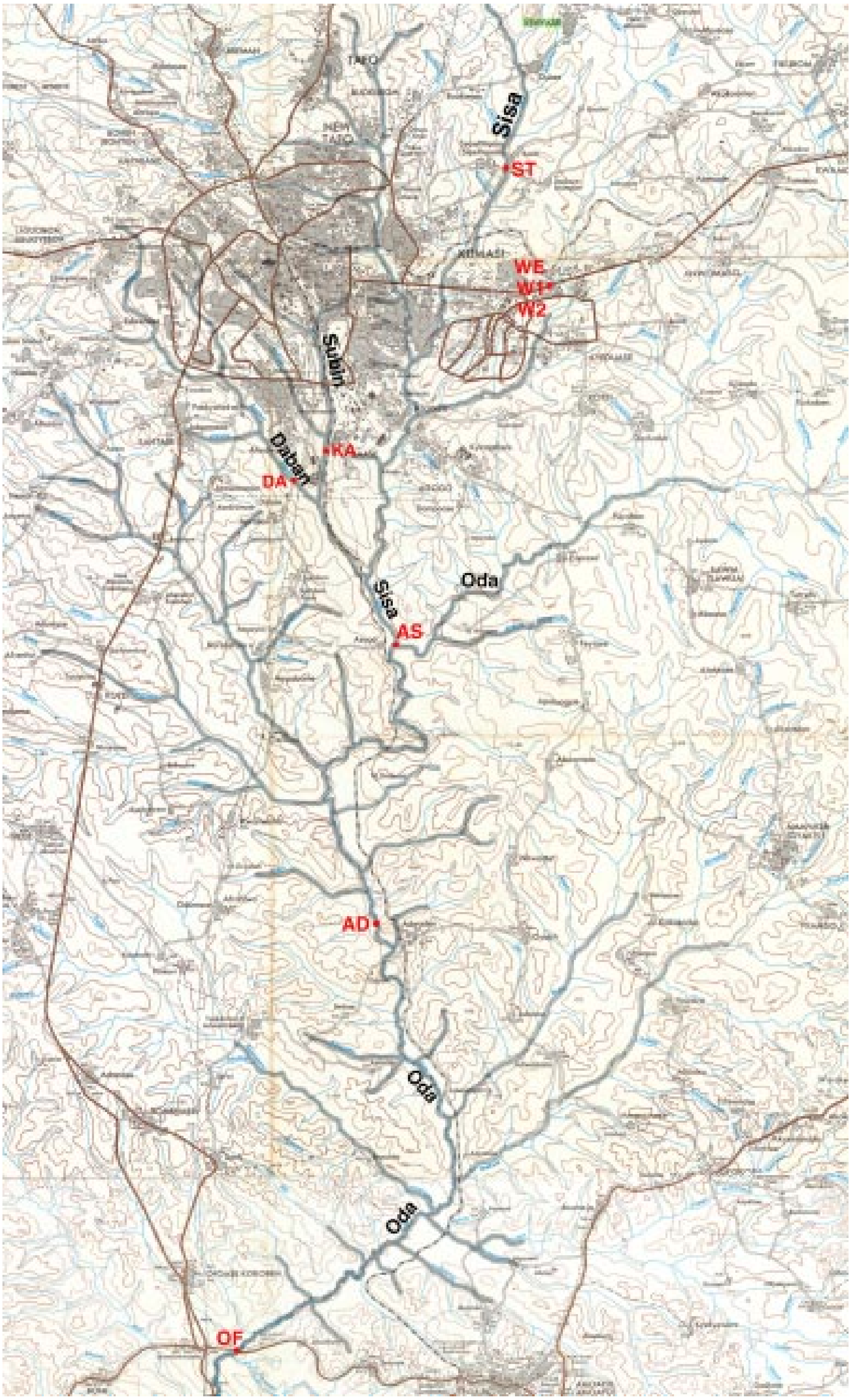
Annexes

Annex 1

Map of Kumasi and the sampling sites. (1:50,000) (Source: survey of Ghana, 1973)


Sisa
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Annex 2

Total and Faecal Coliform results and regression analysis to relate faecal coliform numbers to total coliform count.

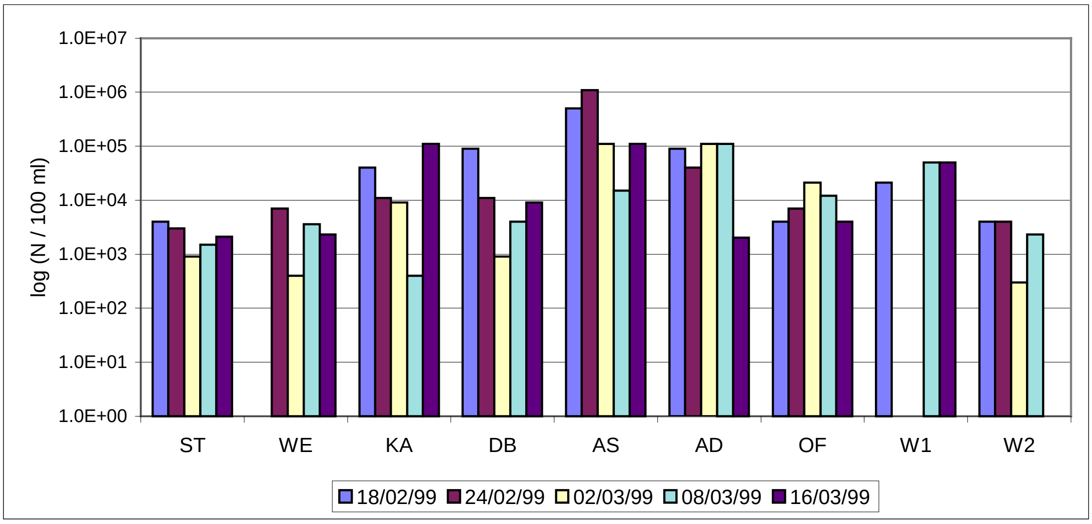
Annex 2 Total and Faecal Coliform results and regression analysis to relate faecal coliform numbers to total coliform count.

Total coliforms count per 100 ml

Sample	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99	geometric mean	S
ST	4,000	3,000	900	1,500	2,100	2,025	1,227
WE	*0*	7,000	400	3,600	2,300	2,194	2,780
KA	40,000	11,000	9,000	400	110,000	11,175	44,986
DB	90,000	11,000	900	4,000	9,000	7,966	37,678
AS	500,000	1,100,000	>110,000	15,000	110,000	158,434	214,593
AD	90,000	40,000	>110,000	110,000	2,000	38,728	50,227
OF	4,000	7,000	21,000	12,000	4,000	7,765	7,162
W1	21,000	*0*	*<3*	50,000	50,000	37,444	16,743
W2	4,000	4,000	300	2,300	*0*	1,823	1,760

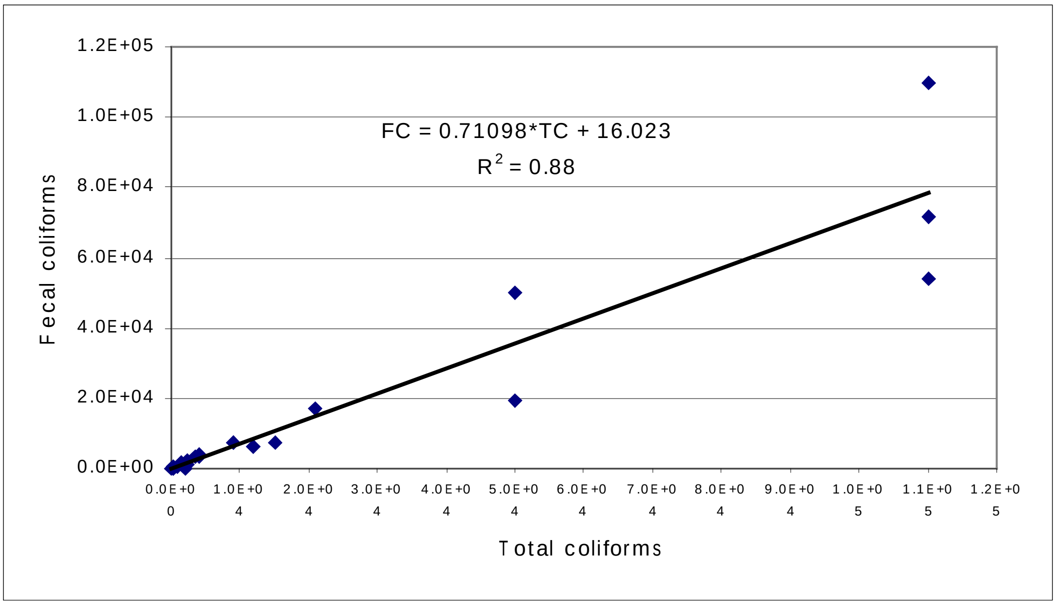
Values represent number of coliforms per 100 ml of sample at 95% confidence level

Samples reported to have zero coliform were considered to result from sampling or analytical error, possible through inadvertent sterilisation of the sample by residues of disinfectant in the sample bottles. The data were discounted when calculating the mean over the sampling period.



Batch No.		Total Coliform	Faecal Coliform
3	ST	9.0E+02	7.290E+02
3	WE	4.0E+02	1.760E+02
3	KA	9.0E+03	7.650E+03
3	DB	9.0E+02	8.100E+02
3	AS		
3	AD		
3	OF	2.1E+04	1.701E+04
3	W1		
3	W2	3.0E+02	2.730E+02
4	ST	1.5E+03	1.500E+03
4	WE	3.6E+03	3.384E+03
4	KA	4.0E+02	4.000E+02
4	DB	4.0E+03	4.000E+03
4	AS	1.5E+04	7.500E+03
4	AD	1.1E+05	1.100E+05
4	OF	1.2E+04	6.480E+03
4	W1	5.0E+04	5.000E+04
4	W2	2.3E+03	2.162E+03
5	ST	2.1E+03	8.400E+01
5	WE	2.3E+03	8.970E+02
5	KA	1.1E+05	7.150E+04
5	DB	9.0E+03	7.290E+03
5	AS	1.1E+05	5.390E+04
5	AD	2.0E+03	1.940E+03
5	OF	4.0E+03	3.360E+03
5	W1	5.0E+04	1.950E+04
5	W2	0.0E+00	0.000E+00

correl = 0.938077
R^2 0.879988



Annex 3

Results of Heavy Metal analysis

Annex 3 Results of Heavy Metal analysis.

3.1 Arsenic mg / l

SITE	18/02/99	02/03/99	16/03/99	16/03/99 UK total	Mean	s
ST	<0.00002	0.002	-	0.016	0.00101	0.0014
WE	0.001	<0.00002	-	0.013	0.00051	0.0007
KA	< 0.00002	<0.00002	-	0.015	0.00002	0.0000
DB	<0.00002	<0.00002	-	0.011	0.00002	0.0000
AS	<0.00002	0.004	-	0.014	0.00201	0.0028
AD	<0.00002	<0.00002	-	0.014	0.00002	0.0000
OF	<0.00002	<0.00002	-	0.013	0.00002	0.0000
W1	<0.00002	0.004	-	0.020	0.00201	0.0028
W2	0.002	0.003	-	0.011	0.00250	0.0007

3.2 Cadmium mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/99 glass	16/03/99 UK total	Mean	s
ST	0.006	0.005	<0.001	0.008	0.0011	0.005	0.003
WE	0.003	0.004	0.010	0.009	0.0022	0.007	0.004
KA	0.006	0.006	0.009	0.010	0.0038	0.008	0.002
DB	0.003	0.006	0.009	0.008	0.0014	0.007	0.001
AS	0.004	0.009	0.002	<0.001	0.0030	0.004	0.004
AD	<0.0005	0.004	<0.001	<0.001	0.0034	0.002	0.002
OF	*0.03 error*	0.009	0.007	0.009	0.0038	0.008	0.001
W1	0.005	0.007	<0.001	0.001	0.0015	0.004	0.003
W2	0.006	0.008	<0.001	<0.001	0.0008	0.004	0.004

3.3 Chromium mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/99 glass	16/03/99 UK total	Mean	s
WE	0.031	0.016	<0.001	<0.001	0.006	0.012	0.014
KA	0.010	0.036	<0.001	0.002	0.007	0.012	0.016
DB	0.005	0.027	0.001	<0.001	0.008	0.009	0.012
AS	0.007	<0.002	<0.001	0.002	0.009	0.003	0.003
AD	0.018	<0.002	0.001	<0.001	0.005	0.006	0.008
OF	0.002	<0.002	0.001	0.003	0.009	0.002	0.001
W1	0.042	0.062	<0.001	<0.001	0.007	0.027	0.031
W2	0.014	0.067	<0.001	0.001	0.006	0.021	0.031

3.4 Copper mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/9 glass	16/03/99 UK total	Mean	s
ST	0.044	0.008	0.015	0.024	0.076	0.023	0.016
WE	0.040	0.005	0.013	0.037	0.061	0.024	0.017
KA	0.021	0.009	0.016	0.026	0.072	0.018	0.007
DB	0.012	0.014	0.016	0.020	0.087	0.016	0.003
AS	*0.821*	0.013	0.019	0.050	0.124	0.027	0.020
AD	0.017	0.006	0.013	0.049	0.033	0.021	0.019
OF	0.021	0.011	0.012	0.046	0.089	0.023	0.016
W1	0.023	0.017	0.018	0.052	0.039	0.028	0.017
W2	0.052	0.007	0.017	0.023	0.026	0.025	0.019

3.5 Iron mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/9 glass	16/03/99 UK total	Mean	s
ST	4.656	2.764	2.42	3.06	8.42	3.23	0.99
WE	4.155	2.059	2.17	2.62	3.57	2.75	0.97
KA	3.584	2.524	1.76	3.51	6.67	2.84	0.87
DB	1.095	1.372	1.03	1.26	4.09	1.19	0.16
AS	3.268	2.621	3.27	3.91	5.99	3.27	0.53
AD	2.408	2.286	2.05	2.85	4.54	2.40	0.34
OF	1.283	0.688	1.24	1.44	4.88	1.16	0.33
W1	1.776	4.419	5.34	5.81	7.56	4.34	1.80
W2	4.591	4.760	2.94	5.43	8.95	4.43	1.06

3.6 Lead mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/9 glass	16/03/99 UK total	Mean	s
ST	<0.01	0.10	<0.01	0.04	0.061	0.040	0.042
WE	0.13	0.14	<0.01	0.03	0.035	0.078	0.067
KA	0.02	0.04	<0.01	0.08	0.094	0.038	0.031
AS	0.11	*0.05*	<0.01	0.04	0.091	0.053	0.042
AD	<0.01	<0.01	<0.01	0.06	0.184	0.023	0.025
OF	1.39 error	0.09	<0.01	0.02	0.201	0.040	0.044
W1	0.05	<0.01	<0.01	0.08	0.045	0.038	0.034
W2	0.08	<0.01	<0.01	0.03	0.026	0.033	0.033

3.7 Manganese mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/9 glass	16/03/99 UK total	Mean	s
ST	0.10	Error	0.135	0.128	0.151	0.121	0.019
WE	0.17	Error	0.116	0.113	0.114	0.133	0.032
KA	0.42	Error	0.467	0.523	0.482	0.470	0.052
DB	0.14	Error	0.180	0.205	0.216	0.175	0.033
AS	0.30	Error	0.324	0.306	0.276	0.310	0.012
AD	0.05	Error	0.182	0.176	0.219	0.136	0.075
OF	0.22	Error	0.138	0.162	0.185	0.173	0.042
W1	0.16	Error	0.438	0.315	0.387	0.304	0.139
W2	0.38	Error	0.060	0.112	0.071	0.184	0.172

3.8 Mercury mg / l

SITE	18/02/99	02/03/99	16/03/99 plastic	16/03/9 glass	16/03/99 UK total	Mean	s
ST	0.004	0.039	<0.01	<0.01	<0.0001	0.016	0.016
WE	0.002	0.025	<0.01	<0.01	<0.0001	0.012	0.010
KA	0.034	0.011	<0.01	*0.3 error*	<0.0001	0.018	0.014
DB	0.057	0.022	<0.01	*0.1 error*	<0.0001	0.030	0.024
AS	0.040	0.011	<0.01	*0.4 error*	<0.0001	0.020	0.017
AD	0.029	0.013	<0.01	<0.01	<0.0001	0.016	0.009
OF	0.026	0.006	<0.01	0.04	<0.0001	0.021	0.016
W1	0.004	0.023	<0.01	<0.01	<0.0001	0.012	0.008
W2	0.010	0.024	<0.01	<0.01	<0.0001	0.014	0.007

3.9 Nickel mg / l

SITE	18/02/99	02/03/99	16/03/99	16/03/99 UK total	Mean	s
ST	0.004	0.027	-	0.004	0.0155	0.016
WE	<0.001	0.017	-	0.003	0.0105	0.009
KA	0.016	0.033	-	0.008	0.0245	0.012
DB	0.025	0.030	-	0.006	0.0275	0.004
AS	<0.001	0.043	-	0.005	0.0235	0.028
AD	0.020	0.043	-	0.006	0.0315	0.016
OF	0.028	0.045	-	0.005	0.0365	0.012
W1	0.021	0.047	-	0.005	0.034	0.018
W2	0.010	0.027	-	0.005	0.0185	0.012

3.10 Zinc mg / l

SITE	18/02/99	02/03/99	16/03/99	16/03/99 UK total	Mean	s
ST	0.010	0.007	-	16.400	0.009	0.002
WE	0.033	0.005	-	16.400	0.019	0.020
KA	0.027	0.006	-	18.700	0.017	0.015
DB	0.008	0.006	-	20.000	0.007	0.001
AS	0.244	0.012	-	19.800	0.128	0.164
AD	0.009	0.006	-	14.100	0.008	0.002
OF	0.012	0.006	-	19.700	0.009	0.004
W1	0.033	0.035	-	19.200	0.034	0.001
W2	0.049	0.007	-	21.600	0.028	0.030

Annex 4

Physicochemical Results

Annex 4 Physicochemical Results

4.1 pH

Site	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99	Mean	s
ST	6.73	6.97	7.10	7.09	7.20	7.02	0.18
WE	6.65	6.65	6.82	7.00	7.01	6.83	0.18
KA	7.03	7.58	7.42	7.35	7.40	7.36	0.20
DB	7.34	7.33	7.39	7.43	7.50	7.40	0.07
AS	7.12	7.23	7.37	7.46	7.50	7.34	0.16
AD	7.46	7.72	7.56	7.50	7.53	7.55	0.10
OF	7.43	7.53	7.56	7.51	7.48	7.50	0.05
W1	7.23	8.08	7.20	7.11	7.07	7.34	0.42
W2	5.89	5.89	5.86	5.77	5.56	5.79	0.14

4.2 Conductivity dS / m

Site	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99	Mean	s
ST	0.049	0.048	0.042	0.039	0.043	0.044	0.004
WE	0.046	0.039	0.039	0.039	0.036	0.040	0.004
KA	0.135	0.205	0.155	0.140	0.145	0.156	0.028
DB	0.032	0.120	0.119	0.118	0.055	0.089	0.042
AS	0.145	0.228	0.225	0.180	0.191	0.194	0.034
AD	0.140	0.197	0.173	0.164	0.117	0.158	0.031
OF	0.145	0.178	0.201	0.137	0.100	0.152	0.039
W1	0.105	0.113	0.143	0.123	0.124	0.122	0.014
W2	0.027	0.018	0.019	0.020	0.020	0.021	0.004

4.3 Nitrogen as Ammonia mg / l

Site	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99	Mean	s
ST	1.48	1.98	0.92	0.63	0.92	1.19	0.54
WE	3.95	1.98	0.99	1.15	0.70	1.75	1.32
KA	7.91	17.13	29.65	17.29	13.18	17.03	8.02
DB	8.56	19.76	7.91	14.82	6.59	11.53	5.59
AS	12.35	31.29	30.47	24.71	23.06	24.38	7.61
AD	11.53	28.00	23.06	18.12	11.53	18.45	7.22
OF	12.35	19.76	31.29	11.53	6.59	16.31	9.61
W1	1.98	0.49	0.86	0.96	0.53	0.96	0.60
W2	2.96	0.99	0.66	0.66	0.30	1.11	1.06

4.4 Nitrogen as Nitrite mg / l

Site	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99	Mean	s
ST	0.000	0.000	0.000	0.000	0.000	0.000	0.000E+00
WE	0.000	0.002	0.000	0.000	0.000	0.000	8.074E-04
KA	0.001	0.027	0.003	0.000	0.004	0.007	1.152E-02
DB	0.002	0.000	0.000	0.000	0.000	0.000	8.339E-04
AS	0.000	0.006	0.002	0.000	0.000	0.002	2.515E-03
AD	0.015	0.005	0.067	0.003	0.061	0.030	3.102E-02
OF	0.001	Error	0.122	0.000	0.003	0.031	6.020E-02
W1	0.000	0.000	0.000	0.000	0.000	0.000	0.000E+00
W2	0.000	0.000	0.000	0.000	0.000	0.000	4.083E-05

4.5 Phosphorous as PO_4 mg / l

Site	18/02/99	24/02/99	02/03/99	08/03/99	16/03/99	Mean	s
ST	0.07	0.13	71.79	78.32	71.79	44.42	40.55
WE	0.20	5.87	71.79	58.74	58.74	39.07	33.38
KA	0.39	4.57	71.79	71.79	58.74	41.46	36.01
DS	0.26	5.87	78.32	71.79	71.79	45.61	38.97
AS	1.04	45.68	45.68	71.79	45.68	41.98	25.52
AD	1.17	35.89	45.68	78.32	52.21	42.66	28.01
OF	0.65	4.57	58.74	71.79	32.63	33.68	31.70
W1	0.39	22.84	45.68	71.79	45.68	37.28	26.93
W2	0.07	5.87	71.79	78.32	71.79	45.57	39.03

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