New trends in infections associated with swimming-pools

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Abstract

It has long been known that swimming-pools and related recreational facilities can sometimes transmit any of a wide variety of infectious diseases. The frequency of different pathogen involvement is subject to many factors. Current trends which play an important role in the selection of infection risks, include the growing popularity of indoor pools, heated pools, whirlpools (jacuzzis), water slides and waterfalls. These new facilities, in combination with other changing factors, favour pathogens and risks of infection which previously had been less important. Health risks are, therefore, moving targets which present ongoing and special challenges to research and quality control in the pool industry.

Introduction

The transmission of a wide variety of infectious diseases by swimming-pool water has been confirmed by sound evidence based on epidemiological findings and data on the quality of the water concerned. Immersion of the entire body into water offers many routes of entry to pathogenic micro-organisms. These routes include the gastro-intestinal tract due to the swallowing of water. In addition, pathogens have direct access to susceptible tissues such as mucous membranes of the respiratory and urogenital tracts, the conjunctiva of the eyes, epithelial cells in skin abrasions and wounds, and soft tissues of the ear and middle ear.

Pathogens may directly enter the blood stream through wounds and even minor skin lesions. The consistent inhalation of aerosols, and occasionally even water, offers direct access to the lungs.

The epidemiology of infectious diseases associated with swimming-pools and related water recreation is complicated by various factors which tend to either overestimate or underestimate the role of the water *per se*. For instance, water recreation offers ideal opportunities for the transfer of pathogens through routes other than water. Most important is close personal contact which facilitates the transfer of pathogens through droplets and direct inoculation into susceptible tissue, as well as transfer through the sharing of towels, etc.

It must also be kept in mind that man is not a water animal, but a land animal. His armament of resistance to pathogens does, therefore, only make limited provision for attack through external exposure to water. For instance, prolonged and vigorous activity in water reduces natural resistance by removal of protective layers such as mucus, wax and scab, which protect vulnerable tissue, skin lesions and wounds. This results in increased susceptibility to infection, often including susceptibility to a person's own natural flora, as well as various opportunistic pathogens.

The role of swimming-pools in the transmission of disease often tends to be underestimated in terms of secondary and even tertiary spread of infections. This refers to the situation where an individual contracts an infection in a pool and then transmits the pathogens to other people by means such as personal contact which have nothing directly to do with the pool. Indirectly, however, the pool remains the source of infection.

The secondary spread of infections is difficult to trace epidemiologically. This becomes virtually impossible when the individual who becomes infected in the pool develops a subclinical infection. In children the great majority of infections by viruses such as polio, coxsackie and hepatitis A are subclinical. This event may also take place in adults. Although all these people show no symptoms of disease, they do excrete the pathogens and can infect others who in their turn again may or may not develop clinical disease. Despite difficulties, secondary and even tertiary transmission of infections contracted in swimming-pools has been confirmed epidemiologically (Kappus *et al.*, 1982).

Although the transfer of many pathogens by swimming-pool water has been proven, and many other pathogens are potentially transferable but not yet confirmed, there are certain pathogens for which transfer through swimming-pool water is most unlikely if not impossible. This would, for instance include those pathogens which are transmitted by the direct inoculation of blood or blood products, such as the viruses which cause rabies, haemorrhagic fevers, hepatitis type B, and the acquired immuno deficiency syndrome (AIDS).

Despite indications that the AIDS virus can survive for some time in water (Slade *et al.*, 1989), sound evidence on the minimal infectious dose, survival in environments other than the human body, blood or blood products, and susceptibility to disinfectants such as chlorine, render the possibility for transfer of the virus via water negligible (Zuckerman, 1986; AIDS Review, 1987). This does, of course, exclude circumstances in which personal contact in the pool is extended to the level of sexual intercourse or other means of parenteral blood transfer. In this case the pool could hardly be blamed, at least not directly, for the infection.

An important feature of diseases transmitted by pools is that the risk for various infections is not consistent but follows certain trends. This is because the many factors which play a role in the selection of pathogens, and the mode of exposure to these pathogens, change continually, sometimes quite rapidly and drastically. Factors which currently direct these trends include the increasing popularity of indoor pools, heated pools and whirlpools (jacuzzis), all of which result in extended exposure, exposure during cooler times of the year, prolonged personal contact, and selection for different pathogens.

A particularly important factor of new facilities such as whirlpools, water slides and waterfalls, is the extensive generation of aerosols. The prolonged inhalation of such aerosols creates ideal opportunities for respiratory tract infections. The classical example is *Legionella pneumophila*, which causes legionellosis, a pneumonia-like disease also known as "Legionnaire's disease". In addition, the proliferation of *L. pneumophila* is enhanced by elevated temperatures in now popular facilities such as whirlpools (Highsmith and Favero, 1985).

Other changing factors which affect the incidence and selection of diseases transferable by water recreation, include well-known

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fluctuations in diseases prevailing in the community at large, which in their turn are subject to many factors including the standard of living and general hygiene, social life-style, disease epidemics, and immunisation campaigns. Other factors include changes in disinfectants and disinfection practices, new pool designs, and new materials for the construction of pools.

Pathogens

Pathogens associated with swimming-pool transmission include the following:

Bacteria

In terms of numbers, the great majority of micro-organisms released by bathers into pool water are members of the natural skin flora. Most of these are bacterial cocci, primarily members of the genera *Neisseria, Sarcina, Micrococcus, Staphylococcus,* and also *Streptococcus.* It has been estimated that during each swimming event the average person releases some 2 x 10^8 bacteria into the water, the majority of which consist of these organisms (Mood, 1977). The skin on the head and the hair by which it is covered, offer an ideal habitat for the proliferation of this group of organisms, which is the reason for the compulsory wearing of bathing caps in some public pools. The most important health significance of these bacteria is that at least some of them are opportunistic pathogens, and the role of particularly *Staphylococcus aureus* in septic wounds and skin lesions such as impetigo, is well known (Havelaar and During, 1985; Klapes and Vesley, 1986).

Pseudomonas aeruginosa, an ubiquitous organism which proliferates in certain water environments and often is a member of the human skin flora, is an opportunistic pathogen which causes a variety of infections. It is of major importance in swimming-pools where its health significance is particularly associated with infections of the outer ear, known as otitis externa (Highsmith and Favero, 1985; Seyfried and Fraser, 1978). The organism has also been associated with skin rash (Hoadley, 1977), dermatitis (Chandrasekar *et al.,* 1984; Levine *et al.,* 1990), folliculitis (Insler and Gore, 1986), wound infections (Ringham, 1989), mastitis (Aspinall and Graham, 1989), urinary tract infections (Aspinall and Graham, 1989), pneumonia (Holmes and Kozinn, 1986) and corneal uncers with the potential loss of sight (Insler and Gore, 1986).

As mentioned earlier, *Legionella pneumophila* has become important only recently as a result of new pool technology such as whirlpools in which the temperature of the water is elevated and excess aerosols are generated (Highsmith and Favero, 1985; Levine *et al.,* 1990). Infection is caused by the inhalation of aerosols which contain the organisms; they thereby gain direct access to the lungs and cause legionellosis which may have a fatal outcome, particularly among the elderly. The organisms are, therefore, of major importance in facilities such as rheumatic baths, hydrotherapy pools, hot tubs and high temperature artesian mineral baths which are frequented by the elderly.

Various members of the genus *Mycobacterium* constitute health risks in swimming-pools. *Mycobacterium marinum* causes skin lesions known as "swimming-pool granuloma" (Mood, 1977), considered by some as an occupational hazard of lifeguards (Fisher, 1988). Lung infection with *M.chelonei* have been associated with a hospital hydrotherapy pool (Begg *et al.,* 1986).

Protozoa

Species of the genera *Naegleria* and *Acanthamoeba* are of special concern because they have frequently been associated with swimming-pool derived primary amoebic meningoencephalitis which has a high mortality rate (N'Diaye *et al.,* 1985; Standard Methods, 1989). For as yet unknown reasons these organisms seem to have a particularly high incidence in swimming-pools in South Australia, where some 10% of cases recorded world-wide have been detected (Esterman *et al.,* 1984).

Gastroenteritis caused by species of *Giardia* and *Cryptosporidium* organisms has in recent times rapidly gained importance as a water-borne disease. At the end of 1988 an outbreak of cryptosporidiosis involving more than 70 cases, most of which children, was traced to a swimming-pool in England (Casemore, 1990). Outbreaks of giardiasis have been associated with swimming-pools in the United States (Levine *et al.,* 1990).

Fungi

A wide variety of fungi, some of which are opportunistic pathogens and may cause skin infections as well as more serious disease, have been associated with swimming-pools (Aho and Hirn, 1981). These organisms include species of the genera *Candida, Aspergillus, Petriellidium, Alternaria, Fusarium, Geotrichium* and *Penicillium,* as well as *Tinea pedis,* the cause of "athlete's foot" infections. *Sporotrichum schenckii,* which causes sporotrichosis (subcutaneous abscesses), has been isolated from the floor near a shower at an indoor swimming-pool (Staib and Grosse, 1983).

Viruses

According to McCabe (1977) epidemiological data reported in the United States indicated that viruses and mycobacteria were more often involved in swimming-pool related infections than any other organisms. In a survey of swimming and wading-pools Keswick *et al.* (1981) detected human viruses in 10 of 14 samples. Viruses recovered from pool water in this and earlier studies included the following: polio type 1; coxsackie types B1, B3, B4 and B6; echo types 3, 6, 7 and 11; parainfluenza type 1; and adeno type 4.

The best known viral infection associated with swimming-pools is pharyngoconjunctival fever, commonly referred to as "swimming-pool eyes". This infection, which is highly contagious and spreads rapidly, is caused by adenovirus types 3 and 4, and possibly also other types of this virus (D'Angelo *et al.,* 1979). Results of the latter study show a linear relation between the amount of time spent in the water and the attack rate.

In 1988 an outbreak of adenovirus conjunctivitis affected large parts of the Cape Province (Editor, 1988). In a Cape Town boarding school some 13% of the 240 boarders developed the infection. The index case was a member of a water polo team and within a few days many of the other members of that team had become infected. However, the role of swimming-pool water in the spread of the infection has never been established.

According to Scharf and Standtke (1988), the incidence of infections with molluscum contagiosum and papilloma viruses may be second only to those of adenoviruses. The former virus causes benign skin tumours in the form of small nodules. Papilloma viruses cause plantar warts, and play a role in the development of cervix carcinoma. In swimming-pools molluscum contagiosum and papilloma viruses are transmitted primarily among children through body contact, sharing of towels, and contact with floors, benches, etc., while pool water plays a minor role.

A swimming-pool was identified as the source of a community outbreak of adenovirus type 7a pharyngitis (Turner *et al.,* 1987). Outbreaks of aseptic meningitis and a febrile enterovirus-like illness were likewise associated with swimming-pools (Levine *et al.,* 1990).

TABLE 1
INDICATOR LIMITS RECOMMENDED FOR SWIMMING-POOL WATER

1. Staphylococci	:	<	100/100 mℓ		(Mood, 1977)
2. Coliform organisms	:		0/100 mℓ	(100% of samples)	
Standard plate count (37°C)	:	<	10/1 mℓ	(75% of samples)	
		<	100/1 mℓ	(100% of samples)	(Mood, 1977)
3. Coliform organisms	:		1/50 mℓ	(15% of samples)	
Standard plate count (35°C)	:	<	200/1 mℓ	(15% of samples)	(Mood, 1977)
4. Human viruses	:		1/10 gallons (38 ℓ)		(Keswick *et al.*, 1981)
5. Standard plate count (20°C)	:	<	100/1 mℓ	(100% of samples)	
Standard plate count (36°C)	:	<	100/1 mℓ	(100% of samples)	
Coliform organisms	:		0/100 mℓ	(100% of samples)	
Escherichia coli	:		0/100 mℓ	(100% of samples)	
Pseudomonas aeruginosa	:		0/100 mℓ	(100% of samples)	(DIN, 1984)

The contraction of viral gastroenteritis has also been linked to swimming-pools (Zuckerman, 1986; Levine *et al.*, 1990). In some of these outbreaks secondary and tertiary transmission has been confirmed (Kappus *et al.*, 1982).

Unconfirmed potential infections

Apart from the above infections for which an association with pools has been confirmed, there are many other pathogens which are potentially transferable via this route, but not yet confirmed. For instance, increased incidences of respiratory illnesses have been observed among bathers, but the etiological agents have neither been identified nor recovered from the water (Mood, 1977). No doubt many other viruses must be released into pool water and related environments (Zuckerman, 1986). Among these are viruses associated with various forms of cancer and slow viral infections of the brain. These viruses have long incubation periods, and too little is known about their mode of transmission, mechanism of infection, and even health significance to establish a meaningful health risk related to swimming-pools.

Quality criteria

The following are some of the most important approaches which have been developed for routine safety surveillance of swimming-pool water:

Microbiological quality

Since for all practical purposes it is impossible to routinely analyse pool water for the wide variety of pathogens which may be present, indicator organisms are used to assess the microbiological safety of these waters. Coliform bacteria are generally used as indicators of the sanitary quality of drinking water (Grabow, 1986), and they are, therefore, sometimes also used as indicators of pool water.

However, most pathogens of concern in water recreation happen to be more resistant than coliforms to chlorine which is the disinfectant most commonly used. For instance, staphylococci and enterococci were found to be 5 to 20 times more resistant to chlorine than coliforms (Mood, 1977). Mycobacteria may survive more than 1 mg/ℓ free chlorine residual (Mood, 1977), and viruses are even more resistant (Keswick *et al.*, 1981). Protozoan cysts are probably the most resistant of all (Esterman *et al.*, 1984). It is, therefore, not surprising that in a survey of swimming and wading-pools Keswick *et al.* (1981) recovered viruses from 6 of 14 samples which were free of coliforms. In view of this important shortcoming of coliforms, various other indicators have been recommended for swimming-pools.

Some currently used indicators and limits for their presence in swimming-pool water recommended by various authorities and researchers are listed in Table 1.

The following organisms have also been suggested as indicators (Mood, 1977; Mossel, 1986; Tosti and Volterra, 1988; Standard Methods, 1989): *Staphylococcus aureus*, *Pseudomonas* species, *Streptococcus* species, *Legionella* species, *Mycobacterium* species, *Candida albicans* and coliphages.

The guideline most commonly used today is the 37°C/48h standard plate count (heterotrophic plate count) which gives an indication of the general bacteriological quality of water and has been found to correlate reasonably well with the presence of pathogens. A maximum allowable limit of 100/1 mℓ is generally accepted (Mood, 1977; DIN, 1984). This guideline is relatively reliable, rapid, simple and economical. An important reason for accepting the guideline is that there is good reason for expecting swimming-pool water to be of at least the same quality as drinking water, and this plate count limit is widely considered as indicative of high quality drinking water (Grabow, 1986).

It must be kept in mind, however, that the plate count can only be used as a guideline and not as a fail-safe guarantee under all circumstances. For instance, viruses have been recovered from swimming-pool water which had met plate count limits (Keswick *et al.*, 1981), and the correlation of many other pathogens with the plate count has not yet been established.

The United States Environmental Protection Agency has recently published a regulation for the quality of public drinking-water supplies according to which less than one microbiologically caused illness per year per 10 000 consumers is considered an acceptable risk level (EPA, 1989). As far as can be established, this is the first time that a public authority has defined an acceptable risk level for the quality of drinking water. This risk level has far-reaching implications for the drinking-water industry because for the first time now a sound basis is available on which microbiological quality guidelines and standards can be formulated. Since swimming-pool water is generally expected to be of the same microbiological quality as drinking water, the EPA risk limit may be interpreted as also applying to swimming-pool water.

No official microbiological quality standards or guidelines for swimming-pool water have as yet been formulated in South Africa. On enquiry authorities concerned, such as the Department of National Health and Population Development, and the South African Bureau of Standards, will probably indicate that swimming-pool water is basically expected to at least meet the microbiological quality of drinking water, for which specifications are available (SABS, 1984).

Disinfection capacity

In this approach to assessment of the microbiological safety of swimming-pool water, known quantities of cultures of selected laboratory strains of micro-organisms are added to samples of the water to be tested, followed by monitoring the survival time of the organisms. The test thus gives an indication of the survival time of pathogens released by bathers into the pool water. Organisms used for this purpose include *Staphylococcus aureus* (Havelaar and During, 1985), and *Escherichia coli*, *Pseudomonas aeruginosa* and *Legionella pneumophila* (Seidel *et al.*, 1991). Results obtained by the latter authors suggest that a 4 log reduction in counts of *Pseudomonas aeruginosa* (ATCC 15442) within 30s, is a reliable and practical criterion for the disinfection capacity of swimming-pool water.

Disinfection efficiency

This approach is based on monitoring levels of disinfectants and related determinants to ensure that conditions required for effective inactivation of pathogens are maintained at all times. The following are some examples of levels and related conditions recommended for chlorine, the most commonly used disinfectant in the swimming-pool industry: 0,4 mg/ℓ free residual chlorine at pH 7,2 to 8,2 and low turbidity (Keswick *et al.*, 1981); 0,8 mg/ℓ free chlorine, residual (Wyatt and Wilson, 1979); 1,0 mg/ℓ free chlorine residual at pH 7,0 to 7,6 (Esterman *et al.*, 1984).

It is essential to keep in mind, however, that conditions may develop under which these levels of chlorine are not adequate to satisfactorily disinfect swimming pool water. For instance, in the presence of cyanuric acid the condition known as a "chlorine lock" may develop which requires higher levels and regular shock doses of free chlorine (DIN, 1984; Yamashita *et al.*, 1988; Aspinall and Graham, 1989; Ringham, 1989).

Water treatment efficiency

Scrupulous monitoring, sound management and optimal operation of water treatment facilities at all times are essential to ensure the safety of swimming-pool water (DIN, 1984; Scharf and Standke, 1988). For instance, the cysts of protozoa such as *Naegleria, Giardia* and *Cryptosporidium* are not inactivated by levels of chlorine generally applied in swimming-pools, and standard plate counts are, therefore, not reliable indicators of their presence. The only means of effectively removing these cysts is by highly efficient filtration (Esterman *et al.*, 1984; Casemore, 1990). Another important reason for optimal filtration is to keep turbidity, which interferes with most disinfection processes, at an absolute minimum.

General hygiene

Protection against infectious diseases is also enhanced by maintaining high levels of general hygiene not only with respect to the water, but also all other facilities (DIN, 1984; Scharf and Standke, 1988). For instance, cracks and crevices in pool walls or floors of showers and dressing rooms, and poorly designed water circulating systems, offer protective environments in which free-living pathogens such as *Naegleria* and *Pseudomonas* can flourish (Esterman *et al.*, 1984). General hygiene in many public swimming-pool facilities is also enhanced by the compulsory wearing of bathing caps.

Overall quality control

Protection against infectious diseases in the swimming-pool environment is best promoted by rigorous application at all times of a balanced and functional policy which makes provision for each of the quality criteria and control measures mentioned above. This policy at the same time ensures aesthetically attractive conditions.

Disinfection processes

Although chlorine is the most commonly used disinfectant in the swimming-pool industry, a variety of other antimicrobial agents and disinfection processes are being used. These include halogens other than chlorine, ozone, ultraviolet light irradiation, and ions of metals such as silver and copper (Grabow, 1979; 1982; Shaw, 1984). All of these disinfectants have certain advantages and disadvantages.

Disadvantages of chlorine include difficulties in maintaining levels, particularly in indoor, whirlpool and warm-water facilities, which are sufficiently germicidal without causing objectionable odours, or eye and skin irritation. In addition, optimal disinfection requires careful pH control and the maintenance of turbidity at an absolute minimum (Grabow, 1979; 1982). Low turbidity is also essential because chlorine reacts with organic matter in water to form organohalogens which are the primary cause of eye irritation in chlorinated water (Eichelsdörfer *et al.*, 1976).

New technology for the disinfection of swimming-pool and related waters is continually being developed. This includes combinations of disinfectants with synergistic effects which increase efficiency and reduce costs or undesirable side effects (Landeen *et al.*, 1989). The pros and cons of new technology have to be evaluated continually for selection of the best options for the wide variety of requirements in the swimming-pool industry.

Conclusions

Accumulating evidence on diseases transmitted by swimming-pools and related environments, emphasises the importance of consistent endeavours to maintain the highest possible hygienic conditions at all times. These endeavours are complicated by a significant variation in the pathogens concerned as a result of factors such as changing trends in the design and construction of facilities, disinfection procedures, modes of exposure to pathogens, and fluctuations in numbers and types of pathogens carried by the user population.

The current increasing popularity of water recreation facilities which provide for water at elevated temperatures and prolonged exposure to aerosols, constitute higher risks for respiratory infections and exposure to pathogens selected by these conditions. Epidemiological trends in populations at large which have little to do with swimming-pools, include the increasing incidence of gastroenteritis caused by *Giardia, Cryptosporidium* and a variety of viruses. These infections are, therefore, also being associated with swimming-pools at rising frequency (Casemore, 1990; Levine *et al.*, 1990).

The control of infection risks does, therefore, require ongoing research on the pathogens concerned; the development of reliable and practical methods for routine quality surveillance; assessment of the efficiency of disinfection processes; and evaluation of the behaviour and survival of pathogens in new swimming-pool and related facilities.

In South Africa information on infections associated with swimming-pools is, as far as could be established, limited to anecdotal data. This tends to create a false sense of security. In view of details from other parts of the world, it would appear that attention to this potential public health risk is justified, particularly in terms of the increasing popularity of water-related recreation.

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GUIDE TO AUTHORS

AIMS AND SCOPE

This journal publishes refereed, original work in all branches of water science, technology and engineering. This includes water resources development; the hydrological cycle; surface hydrology; geohydrology and hydrometeorology; limnology; mineralisation; treatment and management of municipal and industrial water and wastewater; treatment and disposal of sewage sludge; environmental pollution control; water quality and treatment; aquaculture; agricultural water science; etc.

Contributions may take the form of a paper, a critical review or a short communication. A **paper** is a comprehensive contribution to the subject, including introduction, experimental information and discussion of results. A **review** may be prepared by invitation or authors may submit it for consideration to the Editor. A **review** is an authoritative, critical account of recent and current research in a specific field to which the author has made notable contributions. A **short communication** is a concise account of new and significant findings.

GENERAL

Submission of manuscripts

The submission of a paper will be taken to indicate that it has not, and will not, without the consent of the Editor, be submitted for publication elsewhere. Manuscripts should be submitted to: **The Editor, WATER SA, PO Box 824, Pretoria, 0001, South Africa.**

Reprints

One hundred free reprints of each paper will be provided. Any additional copies or reprints must be ordered from the printer (address available on request).

Language

Papers will be accepted in English or Afrikaans. Papers written in Afrikaans should carry an extended English summary to facilitate information retrieval by international abstracting agencies.

Abstracts

Papers should be accompanied by an abstract. Abstracts have become increasingly important with the growth of electronic data storage. In preparing abstracts, authors should give brief, factual information about the objectives, methods, results and conclusions of the work. Unsubstantiated viewpoints should not be included.

Refereeing

Manuscripts will be submitted to and assessed by referees. Authors bear sole responsibility for the factual accuracy of their publications.

Correspondence

State the name and address of the author to whom correspondence should be addressed on the title page.

SCRIPT REQUIREMENTS

Lay-out of manuscripts

An original typed script in double spacing together with three copies should be submitted. Words normally italicised should be typed in italics or underlined. The **title** should be concise and followed by authors' names and complete addresses. A paper may be organised under main headings such as **Introduction, Experimental, Results, Discussion** (or **Results** and **Discussion**), **Conclusions, Acknowledgements** and **References.**

Contents of manuscripts

The International System of Units (SI) applies. Technical and familiar abbreviations may be used, but must be defined if any doubt exists.

Tables

Tables are numbered in arabic numerals (Table 1) and should bear a short but adequate descriptive caption. Their appropriate position in the text should be indicated.

Illustrations and line drawings

One set of original figures and two sets of copies should accompany each submission. Photographs should be on glossy paper (half-tone illustrations should be kept to a minimum) and enlarged sufficiently to permit clear reproduction in half-tone. All illustrations, line-drawings and photographs must be fully identified on the back, numbered consecutively and be provided with descriptive captions typed on a separate sheet. Authors are requested to use proper drawing equipment for uniform lines and lettering of a size which will be clearly legible after reduction. Freehand or typewritten lettering and lines are not acceptable. The originals should be packed carefully, with cardboard backing, to avoid damage in transit.

References

Authors are responsible for the accuracy of references. References to published literature should be quoted in the text as follows: Smith (1982) or (Smith, 1982). Where more than two authors are involved, the first author's name followed by *et al.* and the date should be used.

All references are listed alphabetically at the end of each paper and not given as footnotes. The names of all authors should be given in the list of references. Titles of journals of periodicals are abbreviated according to **Chemical Abstracts Service Source Index** (Cassi).

Two examples of the presentation of references are the following:

Grabow, WOK, Coubrough, P, Nupen, EM and Bateman, BW (1984) Evaluations of coliphages as indicators of the virological quality of sewage-polluted water. *Water SA* **10**(1) 7-14.

Wetzel, RG (1975) *Limnology*. WB Saunders Company, Philadelphia. 324.