



STRENGTHENING CAPACITY FOR WATER RESOURCES RESEARCH IN DEVELOPING COUNTRIES

Addressing the Peaceful Application of Chemistry

International seminar
in conjunction with the
Stockholm Water Symposium 2003

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Organisations supporting the seminar

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International Network for Capacity Building in Integrated Water Resources Management (Cap-Net)

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Cap-Net aims to enhance human resources development for Integrated Water Resource Management (IWRM) by means of establishing and strengthening regional capacity building networks.

Preface

This report is the product of an international seminar on *Strengthening capacity for water resources research in developing countries - Addressing the peaceful application of chemistry*. The seminar was arranged by the International Foundation for Science (IFS) in conjunction with the Stockholm Water Symposium on August 10, 2003. Funding was mainly provided through the Organisation for the Prohibition of Chemical Weapons (OPCW), with additional funding provided by the International Programme in the Chemical Sciences of the International Science Programme at Uppsala University (ISP), the International Network for Capacity Building in Integrated Water Management (Cap-Net), and the Organization of Islamic Conference Standing Committee on Scientific and Technological Cooperation (COMSTECH).

The first section of the report comprises introductory papers. Thereafter follows a number of papers that describe ongoing research projects in developing countries with the aim of relating actual scientific capacity. A third section consists of presentations by organisations in which the issue of strengthening scientific capacity in developing countries is further addressed.

All papers presented during the workshop have been included in the report. The papers have been edited for language and the layout has been standardised. The authors have been included in the editing process and have been able to comment on changes.

The objective of the seminar was to highlight the needs and preferences of developing country scientists. The seminar report will hopefully promote collaboration between organisations addressing capacity needs and between researchers by identifying constraints and discussing solutions.

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Contents

Introductory paper: <i>Strengthening scientific capacity in developing countries to combat poverty and water crises</i> by Cecilia Öman.....	4
Keynote paper: <i>Opening remarks</i> by Michael Ståhl.....	14
Section 1: Researchers from developing countries relating their research to the scientific capacity of their country.....	17
<i>Management of arsenic-contaminated groundwater in Bangladesh: Research needs and capacity building</i> by Kazi Matin Ahmed.....	18
<i>Study of the role of arsenic in water resources in Bangladesh</i> by A. M. Shafiqul Alam.....	22
<i>Study of water pollution by organic compounds in Burkina Faso: Evaluation and remediation</i> by Yvonne Bonzi née Coulibaly.....	30
<i>Impacts of the use of agricultural pesticides on surface water in the north of the Republic of Benin</i> by Henri H. Soclo.....	34
<i>Toxic substances in water in the Rift valley of Ethiopia</i> by Feleke Zewge.....	41
Section 2: Organisations addressing scientific capacity building in developing countries.....	45
<i>Water resources research in Swaziland</i> by N. O. Simelane, TWOWS.....	46
<i>Capacity building for improved water management in Africa: Breaking the vicious cycle through effective linkages between science and policy</i> by Madiodio Niasse, IUCN.....	51
<i>Greywater reuse: A sustainable water resources management approach</i> by Murad J. Bino, INWRDAM and COMSTECH.....	54
<i>Strengthening research capacity in integrated water resources management in the Central American region</i> by Lilliana Arrieta, REDICA.....	62
<i>Networks as instruments for scientific capacity building</i> by Kees Lendertse, Cap-Net.....	69
<i>Promoting basic scientific research on water in Southern Africa</i> by Yogeshkumar S. Naik and Malin Åkerblom, ISP.....	75
<i>Building water management research capacity in developing countries</i> by David Molden, IWMI.....	79
<i>Supporting scientific capacity by strengthening infrastructure</i> by Cecilia Öman, IFS.....	85
Appendix: Speakers and representatives of co-organisers.....	91

Introductory paper

Strengthening scientific capacity in developing countries to combat poverty and water crises

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Summary

It is evident that poverty and water crises cannot be combated without the support from developing country scientists. A number of severe situations have been described by scientists from Bangladesh, Burkina Faso, Benin, Ethiopia, Swaziland, Jordan and Costa Rica during the “International Seminar on Strengthening Capacity in Developing Countries for Water Resources Research, 10 August 2003”. It was concluded that a strengthening of scientific capacity is an urgent need in these countries and that this involves activities such as making funds available, creating access to scientific equipment, scientific literature and the internet, recognising and implementing scientific results, promoting networking and collaboration, and creating a gender balance among researchers and decision-makers.

It was also concluded that support for scientific capacity in developing countries requires a holistic approach whereby actions are taken at several levels; including creating an enabling environment, institutional development and the development of human resources. Important principles were identified, such as local ownership, partnerships and responding to demands.

Introduction

This introductory paper is based on results and recommendations presented by the participants during the “International Seminar on Strengthening Capacity in Developing Countries for Water Resources Research, 10 August 2003”. The purpose of the paper was to create a synthesis of recommendations given by different stakeholders addressing the issue of how to strengthen scientific capacity for water resources research in developing countries. The synthesis gives an overview of how scientific capacity building is perceived by different stakeholders. The most important issues related to scientific capacity may for some stakeholders be the access to spare parts, consumables and trained technicians, whereas scientific capacity for other stakeholders is perceived as the mechanisms for consultation between science and policy. This paper underlines the wide definition of scientific capacity building and points out that all aspects are equally important. Capacity building programmes should acknowledge the different perspectives.

Pressing need for water resources research in developing countries

“Eradicating poverty is the greatest challenge facing the global community as we move into the new millennium”. Such is the conclusion in the Millennium Declaration, the outcome document of the United Nations Millennium Summit held in 2000, in which 188 heads of state participated. The importance of necessary and mutually supportive actions in the fight against poverty has been formulated in the eight Millennium Development Goals (MDG). The fact that the earth is facing a serious water crisis, and that the poorest are the most vulnerable to the effects of the

crisis, underscores the need for action. Commitment to poverty eradication was reconfirmed by world leaders at the World Summit for Sustainable Development (WSSD) in Johannesburg 2002, where water and sanitation goals were re-emphasized as central to developments as well as for achieving the target set to reduce by half the number of people lacking adequate water and sanitation conditions by 2015.

The last 50 years have witnessed enormous changes in the way people use water for productive and economic purposes (Molden et al., this report). Between 1950 and 2000, the world's population increased from 2.5 to 6.0 billion. Concurrently, there was a ten-fold increase in the number of large dams, from 4270 dams to over 47000 (International Commission on large dams, 1998). Water withdrawals have jumped from 1360 km³ to 4000 km³ (Shiklomanov, 2000). At the same time it is estimated that the total global average annual water availability per capita will fall from 6600 m³ to 4800 m³ (Bino, M., this report) between 2000 and 2024. Due to uneven distribution of water resources, some 3 billion people will be living in countries wholly or semi-arid where the availability of water will amount to less than 1700 m³ per capita. Countries or regions are broadly considered water stressed when annual per capita availability is between 1000 and 2000 m³. With availability below 1700 m³, a country is deemed water scarce, and if a country has less than 1000 m³, it is classed as severe.

Water resources development has not only led to significant changes in land and water systems, but has also created new requirements for researching and managing water and land resources, as well as the kinds of institutions needed to manage these resources. Moreover, with increasing development, new and unforeseen problems have emerged in the water sector. In irrigation, for example, it was soon discovered that storage and delivery systems do not automatically lead to equitable distribution of water – good management and effective institutions are required. Drainage problems and salinity build-up manifest themselves after delivery of excess supplies and continue to persist, threatening the sustainability of resources. Also, various water uses have begun to interfere with each other. Agricultural, urban and environmental uses have begun to vie for the same quantity of water. Water allocation and re-allocation are burning issues in much of today's world. Important aquatic ecosystems have borne the brunt of much of the water resources development. Protection and restoration of ecosystems are vital in many basins.

It is evident that poverty and water crises cannot be eradicated without scientific research identifying problems and developing solutions. As the water crises are predominantly occurring in developing countries, poverty cannot be combated without the support from developing country scientists. As stated by the Secretary-General of the United Nations, Kofi Annan, the way in which scientific endeavours are pursued around the world is marked with clear inequalities (Annan, 2003). Developing countries generally spend well below one percent of their gross domestic product on scientific research, whereas rich countries devote between two and three percent. The number of scientists in proportion to population in the developing countries is ten to 30 times smaller than in developed countries. As a result scientific breakthroughs are largely created by researchers from developed countries and much of that science neglects the problems that afflict most of the world's population. This unbalanced distribution of scientific activity generates serious problems not only for the scientific community in the developing countries, but for development itself.

Despite the fact that researchers in developing countries receive only a minute fraction of the resources, a significant amount of high quality scientific results are produced. Other positive aspects for the future are the increasing number of universities in developing countries. In Africa for example, the number of universities has increased from approximately ten to nearly 200 during the last 40 years.

Constraints to the capacity for water research as perceived by the researchers

Examples of research conditions have been compiled for six countries and regions with severe water crises where strengthened scientific capacity is an urgent need; Bangladesh, Burkina Faso, Benin, Ethiopia, Swaziland and Central America. Also, an example is given from Jordan, where simple but sufficient solutions have made it possible to solve difficult problems.

Arsenic polluted water in Bangladesh

Prior to the 1970s most drinking water in rural areas of Bangladesh was drawn from surface water bodies or from shallow hand-dug wells (Alam et al. and Ahmed, this report). This water was frequently contaminated with bacteria from sewage systems and industrial plants and the bacterially contaminated water caused wide-spread epidemics of gastrointestinal diseases and other illnesses. Since the 1990s, drinking water supplies are preliminary drawn from ground water sources, which are free from pathogenic micro-organisms. Unfortunately, while the rural people of Bangladesh have developed the habit of drinking tube well water in order to avoid gastrointestinal diseases, arsenic in excess of acceptable limits (0.05 mg/L) has been found in 61 districts out of 64. Moreover, arsenic moves to the food chain through arsenic contaminated irrigation water.

Finding safe drinking water free from arsenic and enough irrigation water for growing more food are big challenges for Bangladesh. National hydro-chemical surveys have studied the spatial and vertical distribution of arsenic in Bangladesh groundwater to identify arsenic free zones. Alternative options for drinking water are arsenic free surface waters, provided that water from these sources is free from pathogenic organisms and other pollutants. Moreover, it has been found that biomaterials such as garlic skin and rice husk can be used as adsorbents for the mitigation of arsenic from water.

It can be generally stated that despite heavy dependence on groundwater in Bangladesh, the resources are poorly managed. One reason for this is that Bangladesh suffers from a shortage of analytical facilities and trained manpower. Further, although the University of Dhaka has been involved in many studies, national researchers have mainly focused on offering local support and a few basic analyses of sediments. Most of the analytical work has been undertaken outside the country in the laboratories of collaborating institutions.

The analytical facilities have been developed, but there are still not enough facilities within the country for analysis of trace elements, radioactive elements and other pollutants. A modern geochemical laboratory equipped with, for example, AAS, ICP, GC-MS, TOC and DOC analysers needs to be developed. Bangladesh would also gain from a facility with MS and LSC for analysis of stable and radioactive isotopes and from facilities with software and compatible hardware for modelling time-trends of arsenic concentrations and possible vertical movements. Moreover techniques need to be developed for groundwater vulnerability assessments, for increased surveillance monitoring and for forecasting of future groundwater qualities and quantities. In addition, research is also needed on existing drilling technologies and the design of wells.

Pesticide polluted water in Burkina Faso

Drinking water is supplied to the 1.5 million inhabitants of Ouagadougou, the capital of Burkina Faso, by rainwater dams, but the quality of this water is threatened by pollutants from urban activities (Bonzi-Coulibaly et al., this report). In the rural areas drinking water is supplied by pumps and wells, but this water may be polluted by the large quantities of pesticides which are used for agricultural activities. Local studies have indicated a risk of soil, water and crop contamination by pesticides. High amounts of pesticides have been found in vegetables and cereals (1-100 mg/kg for cypermethrin and 12-146 mg/kg for deltamethrin). The amounts detected in food often greatly exceed the maximum tolerance limits.

The contamination levels of drinking water and food need to be more thoroughly estimated in national or regional surveys. Unfortunately, the basic infrastructure for performing such surveys is weak in Burkina Faso. For example, the chemical analytical capacity needs to be strengthened. Also, poor local documentation (books and journals) and the infrequency of scientific meetings prohibit the generation of scientific results.

A suggestion has been made to reinforce a South-South partnership between neighbouring countries. Research teams in neighbouring countries could, for example, jointly plan the purchase of a piece of advanced scientific equipment. Samples could be handled from several countries, tests carried out and results communicated. The follow-up indicator of such a partnership would be the number of services provided for other laboratories in the region.

Pesticide and nutrient polluted water in the Republic of Benin

The Republic of Benin annually uses more than two million litres of pesticides (Soclo et al., this report). The pesticides are used particularly in rural zones where cotton is cultivated. Recent studies conducted on the quality of water resources in some agricultural areas and national parks showed the presence of organochlorine pesticides such as DDTs (1.1-100 ng/l), Endosulphan (58.0 – 750 ng/l), heptachlor and others. These findings constitute a serious threat and it should be noted that poison episodes were registered during 1994-2001 in the cotton cultivation regions. The water quality is also affected by nitrogen pollution caused by the use of chemical fertilizers. Measured concentrations of nitrate exceed 30 ppm in most soils and surface waters sampled in the north of Benin. Faced with water shortages during the dry season, rural populations use non-treated water from dams or surface waters from streams or rivers for drinking water. Moreover, the use of pesticides for fishing is a source of surface water pollution. It is assumed that DDT and heptachlor is used by fishermen, who are spreading pesticides on the surface of waters in order to paralyse the fish before catching it.

The capacity to undertake chemical analyses needs to be strengthened since the only analytical techniques available are UV-visible spectrophotometry analyses of nutrients and gas chromatography connected to an electron capture detection system for chlorinated pesticides.

Polluted water in Ethiopia

Water quality conditions of streams, lakes and groundwater are in general not systematically assessed in Ethiopia (Feleke, this report). In addition to water contamination by pathogenic microbes, which is common in Ethiopia, chemical pollution is increasing with industrialization and with the wide-spread use of agricultural chemicals. Some studies indicate that pesticides have been detected in water and that surface water and groundwater are polluted with nitrate and nitrogen containing compounds. Heavy metal pollution from tanneries, battery processes and other industries may also cause damage to the environment. Moreover, the use of insecticides for malaria control is quite common.

In general, oxygen balance, eutrophication, heavy metals, acidification, organic micro-pollutants and nitrates are some of the concerns related to chemical water pollution in Ethiopia. In addition, a survey on fluoride showed that about 60% of the water used for drinking contains fluoride concentrations exceeding 1.5 mg/l.

No successful attempt has been made to remove fluoride from drinking waters. Scientific research is also required in the area of wastewater treatment and reuse, simple community-scale water treatment systems that can be maintained at low cost and human impacts on the interaction between land and water in relation to arid and tropical climates. It is important to establish an information base related to the water quality, to monitor water pollutants, and to develop pollution control strategies.

Although results obtained so far are promising, the progress of research activities is slow. The major factors contributing to the slow progress include lack of adequate funding, shortage of scientific instruments, shortage of spare parts and consumables, shortage of vehicles for fieldwork, and non-flexible yet stringent financial control systems within local governments. Building local scientific capacity through the development of knowledge and approaches based on applied research is very important to strengthen the establishment and continuity of water research activities. The physical research capacity that needs to be built includes equipment and consumables for the analysis of trace pesticides, nitrate, fluoride and other parameters in water. In addition, participation of researchers at international forums, support for supervision of MSc and PhD students, and support for the subscription of international journals is required. Establishment of partnership with on-going research at the international and/or regional centres may also facilitate capacity-building process.

Access to safe water in Swaziland

Swaziland, like other countries in the Southern African region, is dependent on its water resources for sustainability (Simelane, this report). Agriculture is the main economic activity, and it is heavily dependent on irrigation. Yet water resources are scarce and the demand increasing. Moreover, the country has not yet been able to extend sufficient and

safe water supplies to the bulk of the rural population.

Currently many efforts are being made to improve the access to water, but these efforts are hampered by the unsustainability of the water projects. Studies have tried to identify available water resources and to link these to future demands. Studies have also attempted to evaluate the impact of various activities and of climate changes on water resources. An attempt has also been made to study the management of water resources. Still a lot remains to be done in terms of research on water resources, and research is also needed on how the current water projects have achieved their desired objectives.

The scientific capacity to undertake water research is generally low. The research projects have suffered from several constraints, including poor communication between researchers, poor assistance and inputs of other specialists outside the country, lack of travel funds for researchers, lack of equipment and lack of well-trained technicians. Capacity in key research tools like research methodology, GIS, GPS, national maps, quantitative analysis and modelling is lacking.

Reuse of waste water in Jordan

Reuse of greywater (waste water from households) represents the largest potential source of water saving in domestic uses (Bino, this report). It offers an attractive option in arid and semi-arid regions due to severe water scarcity, rainfall fluctuations and the rise in water pollution. Greywater reuse technologies should be cost-effective and appropriate. Moreover, they must meet quality standards to be safe for human contact and consumption of irrigated crops. Unfortunately, in Jordan, guidelines and standards for greywater either do not exist or are being revised or expanded.

In Jordan, on-site greywater treatment methods for single families were investigated with the objective to achieve ease of construction, low operation and maintenance costs and to yield greywater of a quality suitable at least for restricted irrigation. The project resulted in many direct and indirect benefits to the community and the environment. The monthly domestic water consumption decreased by about 30% for all greywater users and the income of the poor increased by, on average, USD 28 per month. Many families started to copy and imitate their neighbours' reuse of greywater. Women in the community benefited most from the project through training workshops, dialogues and learning to manage and build productive gardens. As the project was limited to cost-effective construction and maintenance methods, lack of equipment did not impair the project to any large degree.

Climate changes in Central America

Central America is a highly vulnerable region in terms of climate changes (Arrietta, this report). Certain parts of Central America are facing the probability that as a result of the thermal expansion of water and the fusion of the glaciers, the sea level will rise from ten to 30 cm by the year 2030 and by one meter by 2050. This would lead to the contamination of drinking water, the recession of coasts and wetlands, the loss of fertile land, serial floods, adverse effects on reservoirs in coastal zones, the substitution of ecosystems, the degeneration and impoverishment of the ecosystems, loss of species and, finally, decreasing land capacity. Moreover, an increase in temperature and the duration of the dry season have been identified as probable effects of climate changes, as well as more intense precipitation, an increased risk of droughts and cyclone activity. As a result of these extremes the region is expected to experience increased damage caused by soil erosion, particularly in the coastal zones, floods, landslides, structural damage, mudslides and avalanches, as well as a reduction in crop productivity and in the quality and availability of water resources. Further, there will be an increase of forest fires and damage to coastal and marine ecosystems, as well as a mounting risk of death in connection with an increase in vectors among the population.

Support is needed for the development of knowledge and strengthening research capacity in climate changes. Support is also needed for strengthening research capacity in "integrated water resources management", which can be used to reduce vulnerability and improve efficiency levels in the use of water resources. The support should focus on strengthening the universities so that they can fulfil their responsibility to develop and disseminate knowledge.

General overview

The constraints as they are described here are similar to constraints previously identified by researchers in Africa (Gaillard and Tullberg, 2001). In 2001 IFS undertook a survey of the working conditions of 700 researchers in Africa working in natural sciences disciplines (Figure 1). The results from this study showed that lack of funding was identified as the main constraint to scientific research. The second largest constraint was the limited access to scientific equipment, and the third constraint was poor library facilities or lack of access to scientific literature. Lack of competent technicians and support staff, which was identified as the fourth largest constraint, is related to the lack of functioning scientific equipment. Also, lack of time and scientific isolation were mentioned as constraints.

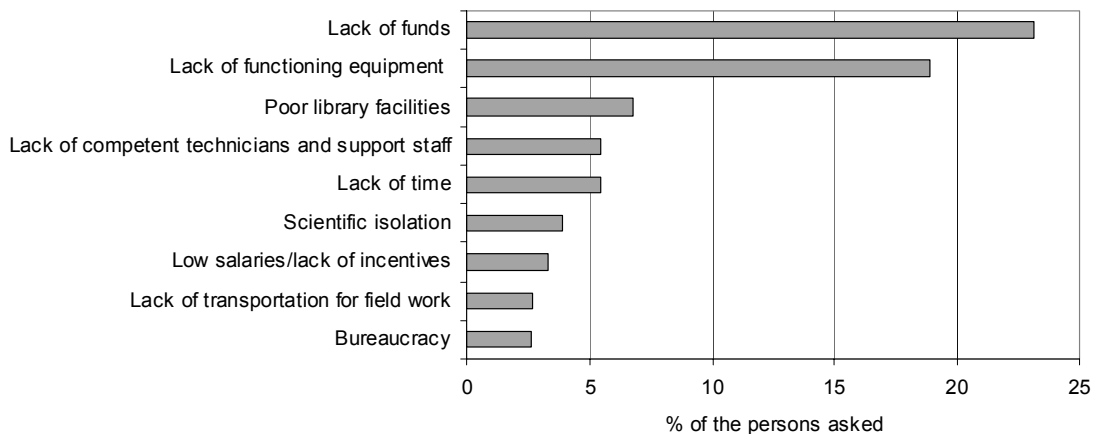


Figure 1: Main constraints to scientific research in natural science disciplines in Africa (Gaillard and Tullberg, 2001)

Actions for strengthening capacity for water resources research in developing countries

The ultimate responsibility for the future of science rests in the hands of national governments, but lack of financial resources makes this very difficult in certain countries. Besides weak finances, developing countries usually have priorities that are not found in the North. For example, in Sub-Saharan Africa, HIV/AIDS and other communicable diseases such as malaria claim thousands of lives every week and absorb large chunks of the health budget. Still many institutes in the developing countries do provide stipends to their researchers, but they are usually not adequate. As the weak scientific capacity in developing countries is closely linked to the economic situation, an improvement of the situation can be expected as the economies recover. Meanwhile, external donors can and should assist developing countries to build up a scientific tradition and a research infrastructure.

At the same time it is generally agreed that the development of country is dependent on scientific research performed within that country. The research policy of a country reflects the extent to which government prioritises science as an integral part of national development. The research policy includes normative issues such as setting priorities for national research, regulating access to international scientific knowledge, and stimulating the scientific profession. It also includes investing in scientific institutions and promoting higher education and research training programmes. The political will is decisive. In countries where there is no proven track record of scientific achievements and where political objectives are short-term, it may be difficult to mobilise political will.

Strengthening capacity requires a system approach

According to the Challenge Programme for Water and Food, capacity can be defined as the ability of an individual

and/or institution to perform functions effectively, in a sustainable manner and in an efficient way (CGIAR Challenge Programme on Water and Food, 2003). Human resources - individual capacities - lie at the heart of all capacity scenarios. Capacity thus has multiple dimensions: financial resources, human resources and overall institutional performance, which in part has to do with functions of the first two dimensions (Molden et al., this report). This implies that capacity is not a passive state but part of a continuing process (UNDP, 1998). Moreover, effective capacity building goes beyond enhancing human resources and enhancing institutional ability to mobilize and use human resources. Empowerment and negotiating skills are also required, and people and institutions must develop the resilience to adapt to a rapidly changing world - the capacity to learn how to learn. Capacity building requires a system approach (Niasse, this report). Besides “strengthened support for the generation and management of scientific and technical knowledge”, “creating mechanisms for consultation between science and policy” is as important

Capacity building can be seen to consist of three basic elements (CGIAR Challenge Programme on Water and Food, 2003):

1. Human resources development and the strengthening of managerial systems.
2. Institutional development, including community participation, and
3. The creation of an enabling environment with appropriate policy and legal frameworks.

Important principles for capacity building include i) local ownership, ii) partnership and iii) responding to demands (Cap-Net, 2002). Local capacity building institutions should be recognised as key players in establishing the core capacity. This is important for the relevance and sustainability of the process. Local capacity building institutions can deliver capacity building services and act as information and knowledge centres. Moreover, partnerships improve capacity building performance by building on the strengths of individual partners. Integrated water resources management, for example, requires a new mix of skills and brings together multiple disciplines across traditional technical boundaries. An important principle is also to respond to local demands. Responding to local demands by identifying and responding to the immediate needs and requirements of a community will increase the impact of capacity building activities.

Scientific capacity components

Scientific capacity relates to knowledge production through scientific research (Ståhl, this report). Human resources, such as competent researchers, can be developed with the help of proper academic studies, training and exposure. When putting the researcher’s skills to work, he or she becomes a critical part of the research capacity at an institute, department, faculty or university. The output is measured in reports, articles, citation indexes, number of successful PhD candidates etc.

Research capacity components include a sound scientific tradition including for example correct scientific methodology (literature searches, appropriate rationales, hypotheses, objectives, materials and methods, evaluations of results and conclusions), peer-review systems of scientific papers, a free academic debate, access to the national and international scientific body of knowledge (through networks, databases, conferences etc.), and administration and management.

Capacity builders should provide the knowledge and the tools relevant to the development process. Only in a few cases is there need for capacity building from scratch. The prevalent academic disciplines are already established in most universities and core elements of scientific research capacity are in place. The issue at stake is to maintain already established research capacity. Staff leaves, equipment becomes outmoded, projects are completed, and funds run out. Management is faced with the task to continuously reproduce existing capacity, to embark on new projects and extend into new research fields. This can be called capacity enhancement and capacity extension. Some institutions have been weakened over the past decade or two and their resources are both run down and underutilized. The task is then one of capacity refurbishment and renewal.

As well as enabling research environments, individual and institutional capacities are prerequisites for the ability to undertake water resources research, research skills required also include interdisciplinary perspectives on problems, the ability to work in multi-disciplinary teams and with communities and policy-makers, and the ability to

communicate results to stakeholders able to take action. Research support institutions have to be ready to deal with new sets of questions that emerge. Resource centres need to respond to the changes in demand for water education, as well as expanding the scientific base.

Addressing the demands expressed by developing country scientists

In terms of manpower, developing countries have young, intelligent and enthusiastic men and women who would like to do research and pursue a research career (Naik and Åkerblom, this report). However, due to the lack of facilities young scientists leave developing countries for the North. The support needed as expressed by developing country scientists themselves includes; i) making funds available; ii) creating access to scientific equipment, scientific literature and the internet; iii) recognising and implementing scientific results; iv) promoting networking and collaboration; and v) creating gender balance among researchers and decision-makers.

Making funds available

The availability of funds has been identified as one of the largest constraints. Funding should be made available on a competitive basis for research programmes so as to stimulate academic staff with post-graduate degrees to continue their scientific career. Research grants can be assumed to have a larger impact on capacity building if they are long-term (5-10 year) and if the projects are contributing to sustainable development.

Infrastructure

Physical infrastructure is usually available in most countries through various institutes of higher education or government facilities (Naik and Åkerblom, this report). However, there is usually a lack of other essential requirements such as capital equipment and consumables. Capital equipment is usually unaffordable both to purchase and maintain, given the national budgets of developing countries whether it is within or outside government systems. Constraints include the logistics associated with the purchase of equipment and consumables since agents/suppliers and backup services (for equipment) are usually difficult to find in most developing countries.

Poor library facilities or lack of access to scientific literature has been identified as a major constraint. Research institutions with a connection to the internet are not only able to access global scientific literature, but can also make their own research results available globally.

Recognition and implementation of successful results

Successful results produced by researchers in developing countries deserve greater public recognition (Öman, this report). Strengthening scientific capacity therefore involves the process of informing the international scientific community about successful results generated in developing countries. Besides informing scientists and other stakeholders world-wide, national scientists, the media, policy-makers and the civil society should be kept informed about generated scientific results.

To strengthen the implementation of scientific results, collaboration is also needed between the researchers and the expected users of the results, including policy-makers, representatives of the local community, and local companies that may develop the research into processes or products. To facilitate the collaboration new interfaces may need to be developed.

Collaboration and networking

Laboratories in some developing countries are isolated geographically or by language (or even political) barriers. The financial cost for exchange of personnel (students and staff) is therefore prohibitive. Participation at regional and international conferences is also important. This allows for exchange of ideas and information and thus helps researchers keep up to date with recent developments and new and future directions of their research discipline.

Formal networks of capacity-building institutions provide an effective strategy for sharing experience and skills and reaching a critical mass of expertise (Cap-Net, 2002). Such networks allow for travel and training within a region and for analysing samples in better equipped laboratories. Formal networking in integrated water resources management

is a relatively new phenomenon that has been emerging especially over the last year (Lendertse, this report). While in 2002 only one such network was operational, namely WaterNet in Southern Africa, in 2003 some 15 country and regional networks have been established and are at different stages of development. One of these, the Regional Network for Capacity Building in Central America (REDICA), covers the Central America Region. REDICA is developing a regional research programme on how to adapt to climate variability and long-term climate changes looking at the exceptional risks water resources in Central American countries are under (Arrieta, this report).

Promoting various disciplines

Certain developing countries lack sufficient capacity in traditional engineering disciplines. As a result, in some regions of the developing world only a small percentage of available water resources are being used. Sub-Saharan Africa as a whole, for example, has only developed about three percent of its water resources.

Besides targeting the skills required for the development phase – engineering and economics – it is important to develop expertise in the areas of management, ecology and social sciences (Molden, this report). To solve problems that emerge during phases of utilization and allocation, a different set of specialties is required than in the early development phases – management specialists to help build appropriate institutions and procedures; social scientists to understand people, their relationships with each other and the environment; and ecologists to understand how changes in hydrology affect ecosystems. Moreover, specialists of the different disciplines should work together and with water stakeholders.

Consultation between science and policy

Creating mechanisms for consultation between science and policy will contribute to better informed water-related decisions and more demand-driven and policy-relevant scientific efforts (Niasse, this report). It is important to note that for these consultations to take place in an effective manner, scientists, policy-makers and representatives of water-user groups need to be able to speak the same language, which requires a minimum amount of shared knowledge. Therefore, government experts and water management institutions (ministries, river basin organisations) as well as representatives of civil society organisations and water users need to be targeted more and more in training programmes and institutional capacity-building efforts.

Creating a gender balance among researchers and policy-makers

Water resources research tends to be the domain of men to the disadvantage of women (Simelane, this report). The number of women researchers can be increased by motivating young women scientists to take on engineering and economic studies. The number of women researchers can also be increased through targeting women scientists to develop the expertise needed for management, ecology and social sciences in the area of water resources. For women to be able to compete, they need training in research methodology and mentoring by experienced researchers. It is also important that the few women who are doing research on water resources are supported.

In order to increase the number of women in education and research it is also necessary to elevate the socio-economic status of women. Girls and women have to be freed from their gender roles of collecting water and firewood, which can be done through appropriate technology and education. Moreover, there is a dire need for research in how women, the main producers of food crops, can access not only domestic water but also irrigation water to produce food and cash crops allowing them income, thus elevating their socio-economic status. There is almost no research on how water resources are managed and shared by different socio-economic groups including gender access and use of water in a country. Gender equity issues are increasingly highlighted in connection with focused research in water resources carried out by women scientists and researchers.

Conclusions

It is evident that poverty can not be eradicated without scientific research identifying problems and generating solutions. As water crises predominantly occur in developing countries, poverty cannot be combated without the support from developing country scientists. As a consequence there is a pressing need for water resources research to be done in developing countries. At the same time the scientific capacity in certain countries is weak and universities and research institutes in many countries perceive a number of constraints. Such constraints include lack of funds,

limited access to scientific equipment, scientific literature and the internet, limited recognition of generated scientific results, limited possibilities for networking and collaboration, and a gender unbalance among researchers and decision-makers.

International aid organisations need to work jointly with national governments and scientists in developing countries to strengthen the scientific capacity to perform water resources research. It is important to note that scientific capacity building requires a system approach consisting of three basic elements; human resources, institutional development and an enabling environment.

Strengthening of scientific capacity in developing countries has already been discussed for many years and actions have been taken; surveys have been carried out and workshops and conferences have been held. Therefore, new initiatives have to be firm and long-term and devoted stakeholders have to be involved already from the beginning.

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Keynote paper

Opening remarks

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Introduction

This is the first time the International Foundation for Science arranges a seminar in conjunction with the Stockholm Water Symposium. We are grateful to the host, the Stockholm International Water Institute (SIWI), for this opportunity. We also want to acknowledge the generous contribution from the Organisation for the Prevention of Chemical Weapons (OPCW), the International Network for Capacity Building in Integrated Water Management (Cap-Net), the Organization of the Islamic Conference's Standing Committee for Scientific and Technological Cooperation (COMSTECH), and the International Science Programme (ISP), which made it possible for IFS to invite the participants.

In this seminar, we will dwell on capacity strengthening in water resources research. This is one of the eight research areas supported by IFS. In this presentation, I will dissect the components of capacity building as they refer to scientific research and then try to apply them to the particular issues and problems we are concerned with here.

Components of scientific capacity

Capacity building is sometimes concretized as equipment, trained technicians and trained researchers. These are indispensable components. However, they have to be set in context. Scientific capacity relates to knowledge production through scientific research. It is a compound concept and applicable at the level of organisation. I prefer not to use the concept at the individual level. Individuals gain scientific competence. Through proper academic studies, training and exposure an individual becomes a competent researcher. When putting her/his skills to work in a research institute, the researcher becomes a critical part of the research capacity at that institute.

The individuals in focus are Masters and PhD students, their teachers and professors. Technicians are also very important in this context. Competent researchers are the carriers of scientific knowledge. Research capacity can be assessed at the organizational level. The organisations in focus are university departments (faculties, the whole university) and research institutes.

The “Humboldtian” ideal is the research university where undergraduate teaching benefits from fresh research insights made by teachers at the home university who are devoted both to teaching and research. Capacity research components include:

- well-trained, competent researchers,
- a research plan, theoretical framework and methodology,
- research equipment, laboratory facilities and other scientific infrastructure,
- access to the international scientific body of knowledge (through networks, databases, conferences etc.),

- administration and management,
- a professional scientific culture,
- funding.

Scientific research capacity defined in this way can also be used at the level of department, faculty and university.

The components include both hardware and software. One cannot say that one of these components is more important than the other. They are all needed. In this context I would like to come back to the role of technicians. Although their work is not scientific per se, they constitute a core group of professionals responsible for scientific instruments. All too often, scientific work comes to a standstill because there is nobody to repair and maintain laboratory equipment.

When the parameters mentioned above interact in a dynamic way, you can say that the department/institute has research capacity in a given field. The output is measured in reports, articles, citation indexes, number of successful PhD candidates etc.

The notion of scientific research capacity at the national level comes very close to research policy. It reflects the extent to which government prioritises science as an integral part of national development. It includes normative issues such as setting priorities for national research, regulating access to international scientific knowledge, and stimulating the scientific profession. It also includes investing in scientific institutions and promoting higher education and research training programmes. The political will is decisive. In countries where there is no proven track record of scientific achievements and where political objectives are short-term, it may be difficult to mobilise political will.

The priorities are reflected in budget allocations. The argument holds also for very poor countries. I do not distinguish between funds emanating from the domestic budget and funds originating from international development co-operation. It would be an indication of seriousness that government authorities are prepared to allocate donor funds for science and research.

Scientific capacity is dynamic

Let us take a look at the setting in an academic establishment. The “normal” situation in research institutes is that research capacity is in place: there are scientists and technicians, the laboratory functions, research questions are defined, projects are being conducted, PhD students pursue their studies and funding is available. The issue at stake then is to maintain research capacity. Staff leaves, equipment becomes outmoded, projects are completed and funds run out. Management is faced with the task of continuously reproducing existing capacity, embarking on new projects and extending into new research fields. I call this capacity enhancement and capacity extension. However, the research capacity of an organisation can be threatened by budget cuts, by competition from other institutions, low productivity etc. Surviving such threats is a measure of capacity resilience. Over the long term the institution must reproduce its capacity. Academic staff retires, a new generation must take its place. Academic reproduction necessitates established post-graduate research training programmes as integral parts of the department.

The above refers to the normal situation at university departments and research institutes in the high and middle-income countries, a bracket to which many of the less developed countries by definition do not belong. Moreover, many of these countries laid the foundations for scientific institutions half a century ago. Universities such as Makerere, Legon, Dakar, Dar es Salaam and Ibadan were famous in the 1960’s and 1970’s.

Scientific capacity is perishable

Capacity *erosion* occurs in many places. Setbacks can appear where you least expect. A well known example is the situation in Argentina, where the conditions for scientific research declined drastically starting in 2001. Over the years, IFS has supported a number of young Argentinean scholars, but in 2001 we decided that Argentina had reached a level of development whereby they should be able to fund research from domestic sources. Some time after our decision however, the economic crisis started to unravel. Now I get e-mails almost daily from desperate

Argentine researchers. Here is an excerpt from one:

“We have done very advanced research within my institution for a number of years and built up several strong research teams. However, the present financial crisis is changing everything. Equipment and supplies can no longer be bought. Research contracts are terminated. Salaries are not paid. Young PhD holders escape abroad. All that has been invested in research capacity is being eroded.”

This is a crisis that cannot be managed at the departmental or faculty level. It is far beyond the power of an individual donor organisation to rectify. It is part of a national disaster.

In the past few decades, research capacity especially in Sub Saharan Africa has been severely eroded. The reasons are well known (declining economies, structural adjustment, destabilisation, conflicts etc).

Nevertheless, only in a few cases is there need for capacity building from scratch. This may be the case in newly emerging research areas like nanotechnology, new materials and genetic engineering. However, the prevalent academic disciplines are established in most universities and core elements of scientific research capacity are in place. The institutions have been weakened over the past decade or two and their resources are both run down and underutilized. The task is then one of refurbishment and renewal.

In countries which are on the threshold of establishing scientific communities, the emphasis on scientific professionalism is of utmost importance. It has been argued that the forces of globalization tend to undermine the relevance of local research, unless the latter sets high professional standards. Research findings of mediocre quality will not be in demand! Hence, the most strategic task is to inculcate a professional spirit into the national scientific community; i.e. high quality doctoral training, competitive research grants, peer reviews, recognition and rewards based on quality research achievements, establishment of professional societies, South-South and South-North links etc. The research culture is extremely important, i.e. the norms and values related to free academic debate and a drive to test hypotheses. A research department where collegiality, curiosity and innovativeness reign will produce interesting research results. A research department which is characterised by rigidity, protocol and hierarchy, will not.

Scientific research capacity for water resources

In the background papers the lack of sophisticated scientific instrumentation and lack of proper training are duly mentioned as impediments to research progress. I agree. IFS is planning a special project to address the need for scientific equipment at selected laboratories in countries where we have many grantees. Dr Öman will elaborate on issues related to equipment policy in her presentation. I will restrict my comments to the developmental context of capacity building.

Unsustainable use of water is the order of the day throughout the globe. Conflicts over scarce water are mounting. Dramatic drops in the water table as well as the seasonal drying up of large rivers before reaching the sea are signs of the unsustainable use and create havoc for millions of people. The developmental potential of water is enormous. Clean drinking water from tap to mouth has the potential of reducing diseases by a magnitude. Water-saving supplementary irrigation has the potential to reduce food insecurity among smallholders by the millions.

It is in this context that scientific capacity-building among the new generation of researchers should be situated. The challenge is to mobilise the potential; a great number of talented and enthusiastic young MSc holders who want to pursue the scientific profession. The new generation demands a meaningful research context. They want to work in teams, they want to network with colleagues internationally and they want to focus their scientific investigation on topics which are relevant for development. The new generation wants to put its scientific energy into a concrete development context. This means interaction with stakeholders such as policy makers, entrepreneurs and end users of the research results. Moreover, the new generation of potential researchers must be assured of a professional career, also outside the academic establishment. The knowledge economy requires scientists in industry, small-scale enterprises, local governments, NGOs and civil society.

Section 1

Researchers from developing countries relating their research to the scientific capacity of their country

*Management of arsenic contaminated groundwater in Bangladesh:
Research needs and capacity building*

Associate Professor Kazi Matin Ahmed

University of Dhaka

Bangladesh

p. 18

The study of the role of arsenic in water resources in Bangladesh

Professor A. M. Shafiqul Alam

University of Dhaka

Bangladesh

p. 22

*Study of water pollution by organic compounds in Burkina Faso:
Evaluation and remediation*

Professor Yvonne Bonzi née Coulibaly

University of Ouagadougou

Burkina Faso

p. 30

Impacts of agricultural pesticide use on the surface water quality in Benin

Professor Henri H. Soclo

University of Abomey-Calavi-Benin

Benin

p. 34

Toxic substances in water in the Rift valley of Ethiopia

Professor Zewge Feleke

University of Addis Ababa

Ethiopia

p. 41

Management of arsenic-contaminated groundwater in Bangladesh: Research needs and capacity building

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Summary

Despite heavy dependence on groundwater in Bangladesh, the resource is very poorly managed. The lack of appreciation for the importance of the vital resource among policy-makers and stakeholders is one reason for the poor state of groundwater management. At the same time there is lack of adequate and requisite analytical capabilities. Tools such as groundwater modelling and vulnerability assessments are not used in groundwater management. This prohibits local professionals from applying their skills in managing the vital resource. Local capacity building in the field of laboratory analysis, use of modelling and vulnerability assessment tools as well as better facilities for training are very important to ensure sustainable development of groundwater resources in Bangladesh.

Introduction

Bangladesh relies heavily on groundwater for water supply and irrigation. Previously, people in the country, particularly in the rural areas, used to drink water from surface sources contaminated with water-borne diseases, which led to many deaths. Groundwater was introduced by UNICEF through hand-tube wells, which resulted into two success stories: Safe water to 97% of the population and self-sufficiency in rice production despite the increase in population. Easy availability of groundwater and cheap drilling technologies made the HTWs very popular, and currently there are more than ten million of these in a country of 130 million people. Introduction of minor irrigation based on groundwater helped in boosting the production of high-yielding rice varieties (HYV), and currently 70% of the irrigation water comes from underground sources. Both these factors have played important roles in social upliftment and poverty alleviation in the country.

Until the early 1990's local people did not know anything about arsenic in groundwater. The recent detection of arsenic above acceptable limits for drinking water has turned one of the success stories into a big worry. Also, the possible entry of arsenic into the food chain due to irrigation with arsenic-contaminated water and the probable role of irrigation in arsenic release have made the sustainability of groundwater-based irrigation questionable. Finding safe drinking water for the millions and enough irrigation water for growing more food are big challenges.

Background

Since the detection of arsenic in 1993, the government, non-government organisations and research institutions have taken up various research projects. The Geology Department at the University of Dhaka has played a key role in the ongoing research on origins, release mechanisms and mitigation of arsenic. After the detection of arsenic in groundwater, one of the most debated issues was its origin. Various hypotheses were put forward involving both anthropogenic and natural causes. Most of those hypotheses were proposed without much evidence or extrapolated to Bangladesh from West Bengal, India. Geochemical evidence found by a joint MSc student project between University College London and the University of Dhaka (Nickson, 1997) was presented in 1998 (Ahmed et al., 1998), which for the first time explained the release mechanism and refuted the widely accepted hypothesis proposed

by Indian scientists. (Nickson et al., 1998) proposed the iron-oxyhydroxide reduction hypothesis in place of the pyrite oxidation hypothesis of Mallik and Rajagopal (1996). The hypothesis explains that groundwater arsenic is mobilised by natural processes, whereby absorbed arsenic is released into the groundwater under strongly reducing conditions (Nickson et al., 2000). Subsequently a series of small-scale studies have been undertaken enhancing the knowledge of arsenic release mechanism and providing guidelines for mitigation of arsenic (Burgess et al., 2002). All these studies include detailed geochemical analysis of water and sediment samples collected from arsenic-contaminated aquifers in Bangladesh.

Sedimentological and petrographic studies of the aquifer materials were undertaken along with the Bangladesh Water Development Board (BWDB), Department of Public Health Engineering (DPHE) and the UNICEF Dhaka Office. Sedimentology and petrography of sediments were studied on samples collected from different parts of Bangladesh. Facies analysis, sieve analysis and optical studies were conducted to describe the sedimentological and mineralogical characteristics of arsenic-contaminated aquifers (Ahmed et al., 2001). The two studies conducted jointly with DPHE and UNICEF involved detailed investigations in two arsenic-contaminated areas. The first study was conducted in NW Bangladesh where geophysical survey, drilling and sedimentological, mineralogical and geochemical investigations were conducted. (GRG, 1998) The second study conducted in the central part of the country involved all above techniques alongside groundwater modelling (GRG/HG, 2002). Both the studies provided useful information for DPHE/UNICEF and helped them in undertaking their mitigation programme.

The study conducted by the British Geological Survey (BGS) in collaboration with the DPHE is considered as the most systematic and informative (BGS and DPHE, 2001). The Department of Geology at the University of Dhaka has played a vital role in the study. The study involved a national hydro-chemical survey enabling us to understand the spatial and vertical distribution of arsenic in Bangladesh groundwater. Detailed studies were conducted in three places to understand the release mechanism, changes over time etc. Detailed geochemical studies on sediment chemistry and isotope geochemistry were conducted. An extensive study to understand the local scale variability and controls on arsenic occurrences is now being carried out together with Columbia University, New York. The study is a comprehensive multi-disciplinary undertaking with three major components: earth sciences, health sciences and social sciences. The Department of Geology is co-ordinating the Earth Science investigations. The study has so far provided useful knowledge regarding the release mechanism and mitigation of the problem (van Geen et al., 2002).

Though the Geology Department of the University of Dhaka has been involved in many studies, the role played by the local researchers was limited to local support along with some basic analyses of sediments. Most of the analytical work has been carried out outside the country in the laboratories of the collaborating institutions.

Capacity building for management of arsenic

Although arsenic management involves various professional groups, the role of the hydro-geologist (geologist) is especially important as the problem is geological and the mitigation, to a large extent, is dependent on proper management of groundwater. However, there are deficiencies in a number of areas of management and there are needs for local capacity building. Areas in which capacity building is most needed are discussed in the following sections.

Geochemical analysis

Accurate quantitative analysis of arsenic in groundwater is the fundamental requirement for understanding the spatial and vertical distribution of arsenic. At the same time it is also important to analyse all the primary health sensitive parameters as there are indications of occurrence of high Mn, B, U etc. (BGS and DPHE, 2001). Since the detection of arsenic analytical facilities have been developed, but there are not enough facilities within the country for analysis of trace and radioactive elements. Also there are reports of the occurrence of organic solvents in the groundwater of Dhaka city, but at the moment there is no facility for detection of such solvents at the moment within the country. Geochemical analyses of sediment samples are also important for understanding the release mechanism, sorption characteristics etc. A modern geochemical laboratory equipped with AAS, IC, ICP, GCMS, TOC and DOC Analyser etc. would be a very important contribution.

Isotope analysis

Isotopes can provide useful information regarding origin and movement of arsenic-contaminated groundwater. The limited application of arsenic by IAEA (Dowling et al. 2002) and BGS has been found to be very useful and there is scope for use of the technique for management of groundwater in Bangladesh. Isotopes have their applications in other issues such as sewerage contamination, surface water/groundwater interaction, origin of entrapped saline groundwater, lateral and vertical movement of groundwater etc. Despite its potential use there is no facility at all for analysis of stable and radioactive isotopes within the country. A stable isotope laboratory equipped with MS, LSC etc. has to be established.

Groundwater modelling

Groundwater flow and contaminant transport modelling are the techniques widely used for groundwater management. In the case of arsenic in Bangladesh, modelling can predict the time-trend of arsenic concentrations and possibility of vertical movement of arsenic from the contaminated shallow (upper) aquifer to currently uncontaminated deeper (lower) aquifer (Cuthbert et al., 2002). Besides arsenic, groundwater modelling can be widely used as a tool for groundwater management. Currently there are limited groundwater modelling skills within the country. Modelling capabilities have to be enhanced by establishing a modelling centre equipped with state of the art modelling software and compatible hardware.

Groundwater vulnerability assessment

This technique is now widely applied in the developed as well as developing countries as a management tool for groundwater protection. The technique is not used at all for groundwater management in Bangladesh. A localised study conducted within the country has been found to be very promising although there are various constraints in conducting such studies (Morris et al., 2000). The technique is unknown to most of the groundwater developers and policy-makers. There is scope for extensive use of the technique for producing national, regional and local level groundwater vulnerability maps.

Surveillance monitoring and forecasting

The current status of groundwater quality and resource monitoring is very limited. There is no scope for surveillance and forecasting regarding depletion of resources or deterioration of quality. The arsenic problem could have been identified much earlier before exposing such a large population to its harmful effects (Ahmed and Ravenscroft, 2000). The limited data collected by organisations like the Bangladesh Water Development Board or Department of Public Health Engineering are not properly stored and interpreted for forecasting about trends of quality. A national surveillance monitoring and forecasting programme has to be designed to address the issues of both groundwater qualities and quantities.

Drilling technology and improved well design

Research has to be undertaken to develop existing drilling technologies, particularly for sampling of sediments and groundwater at the time of drilling. Research is also needed to improve the design of wells, particularly the deep ones, for protecting currently safe aquifers.

Training of professionals

Currently there is a lack of teaching and research facilities in the field of groundwater. Teaching facilities have to be developed for training of professionals with state of the art knowledge and analytical techniques. Teaching and research facilities can be integrated under the same umbrella by establishing a “Centre for Groundwater Studies” within a university. Such a centre can be developed with modern laboratories and field equipments. The centre thus can co-ordinate all groundwater-related research, provide long and short-term training and data, as well as advice on groundwater development and management planning.

Conclusions

Management of arsenic-contaminated groundwater is a real challenge for Bangladesh, which lacks analytical facilities and trained manpower. Groundwater has been a very important element of the socio-economic development of the country and will remain so in the future. In fact it is very likely that the role of groundwater will become more important. The management of groundwater within the country is in a sorry state. It is therefore very important to enhance local capabilities in the field of analysis, modelling, monitoring etc. An integrated research programme has to be undertaken under the umbrella of a “Groundwater Study Centre”.

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Study of the role of arsenic in water resources in Bangladesh

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with

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Summary

Bangladesh has the largest delta in the world, formed by the Ganges, the Bhahmaputra and the Meghna. Together these rivers give rise to large catchments area comprising a total of around 144000 square kilometres spread over five countries, namely Bhutan, Nepal, China, India and Bangladesh. Thus the main water resources of these countries come from rivers estuaries, lakes, canals, ponds and dug-wells, as well as from groundwater. Sadly, in the shallow aquifers of the catchment areas in Bangladesh, arsenic exceeding the acceptable limit of 0.05 mg/L has been found. Water from shallow aquifers has largely been used for irrigation purposes in Bangladesh and it is in this way that arsenic has moved into the food chain (Hasan, 2002, Meharg and Rahman, 2002, Huq, 2002), ultimately affecting human beings. Arsenic-free surface water (like rivers, ponds, lakes etc.) are alternative options for drinking water provided the water from these sources is free from pathogenic organisms and other pollutants. In the dry season, the mitigation of arsenic from tube well water is more or less unavoidable. To allow for arsenic removal of contaminated tube well water, biomaterials with iron chips have been introduced as an absorbent for mitigation. Food samples have also been analysed in order to pinpoint the arsenic content of Hajigonj Thana.

Introduction

Recently two theories about the arsenic poisoning in Bangladesh have emerged. The first theory holds that changes in the geochemical environment brought on by the withdrawal of large amounts of groundwater may have resulted in the decomposition of arsenic-bearing parent minerals. According to the other theory, the reduction of absorbed arsenic contamination in iron oxyhydroxide (FeOOH) and in manganese oxyhydroxide (MnOOH) may be responsible for the arsenic contamination. However, mineralogical identification of the sediment suggests only insignificant occurrences of pyrite, arsenopyrite and other other arsenic-parent minerals, which means that these are unlikely to be the sources of arsenic in the sediments. Further, in some areas excessive amounts of groundwater have been withdrawn for irrigation without traces of arsenic having been found above the acceptable limit (0.05 mg/L) (Khan et al., 2000, Chakraboti 1999, Abul et al., 2001 and Nickson et al., 1999).

Background

Prior to the 1970s most drinking water in the rural areas of Bangladesh was drawn from surface water bodies or from shallow hand-dug wells (Bridge et al., 2000). This water was frequently contaminated with bacteria from sewage systems and industrial plants and the bacterial-contaminated water caused wide-spread epidemics of gastrointestinal diseases and other illnesses. Now, drinking water supplies are preliminary taken from groundwater sources. This water is free from pathogenic microorganisms. Unfortunately, while the rural people of Bangladesh have developed the habit of drinking tube-well water in order to avoid gastrointestinal diseases, arsenic in excess of acceptable limits (0.05 mg/L) has been found in 61 districts out of 64 (BGS, 2000) (Figure 1).

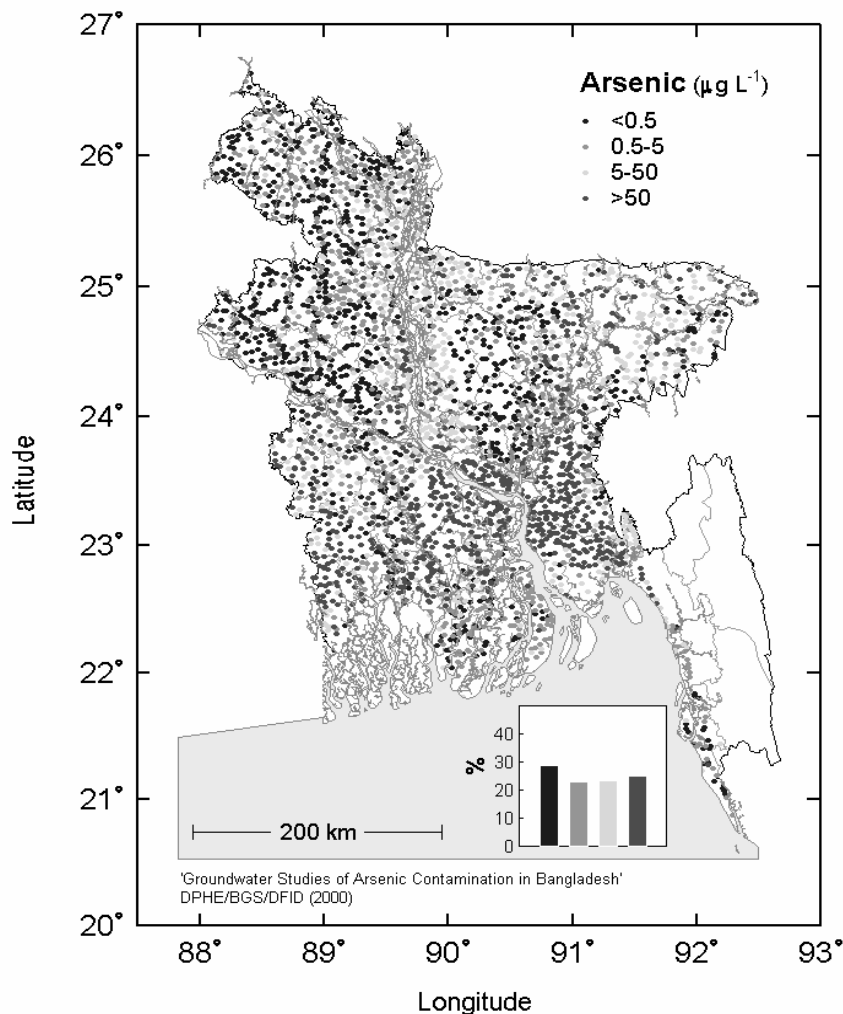


Figure 1: Arsenic in excess of the acceptable 0.05 mg/L limit has been found in 61 districts out of 64

Methodology

For the monitoring of arsenic concentration in selected areas, micronutrients and heavy metals for surface water and mitigated water were stored in polythene containers preserved by HNO_3 (pH 2-3) (Alam et al., 2000). For estimation of arsenic in food samples (Alam et al. 2001, Alam et al., 2002) the $\text{HNO}_3\text{-HClO}_4$ (3:2), the acid digestion method was applied. Finally, arsenic was detected in both water and food samples using the GF-AAS and Ag-DDTC methods (Alam, 2002, Khaliqzaman et al., 1998).

The Hajigonj Thana region, which is located 150 kilometres outside Dhaka, the capital city of Bangladesh, is one of the most endemic areas of arsenic contamination and has been selected for a case study in which the amount of arsenic was measured in well water (Figure 2).



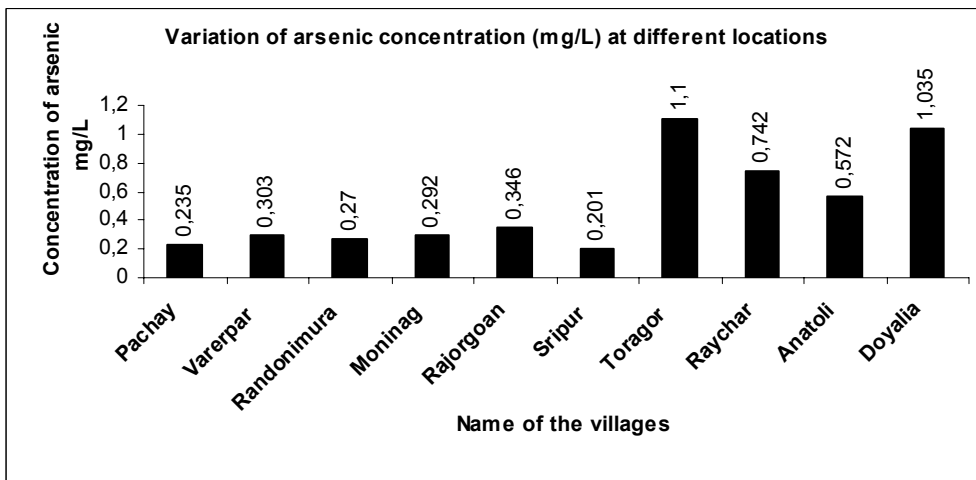
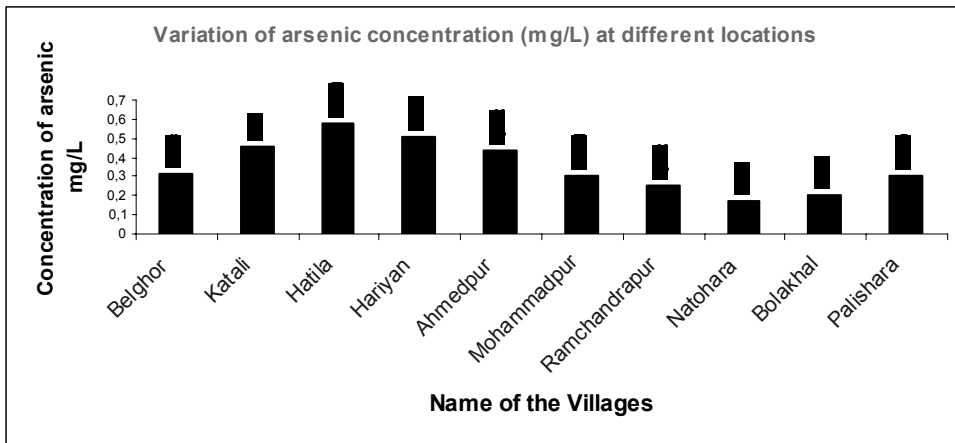
Figure 2: The Hajiganj Thana area selected for a case study

Results and discussion

Measurements from 141 tube-wells in Hajiganj Thana provided the following results: mean 0.507 mg/L, median 0.423 mg/L, mode 0.54 mg/L, standard deviation 0.389 mg/L, variance 0.152 mg/L and range 2.52 mg/L (Figures 3a and 3b). The range of arsenic concentration (2.52 mg/L) indicates that there is an arsenic concentration in a range of between 0.08 and 2.60 mg/L. The mode value of 0.54 represents the highest frequency found it about 8.5% of the values in this distribution. Arsenic contamination may have arisen due to chemical and geochemical changes in the composition of shallow aquifers.

The study found smaller amounts of arsenic in the lower and higher depths of the tube wells. The highest arsenic concentration was in the depth ranges from 60 to 100 feet. This may be because of the large amounts of water withdrawn from this depth (60-100 feet) (Figure 4).

The variations of arsenic concentration in old and new tube wells were also considered. The arsenic contents from older tube wells were relatively lower compared with the newer ones (Figure 5). The explanation for this may be that arsenic has been extracted over a period of several years from geological sediments in older tube wells lowering the concentration of arsenic. In the case of tube wells that are older than 20 years, the low traces are assumed to be the result of the wells rarely being used and that the water thus has stagnated.



Figures 3a and 3b: Examples of average values of arsenic contents in twenty tube-wells in different villages

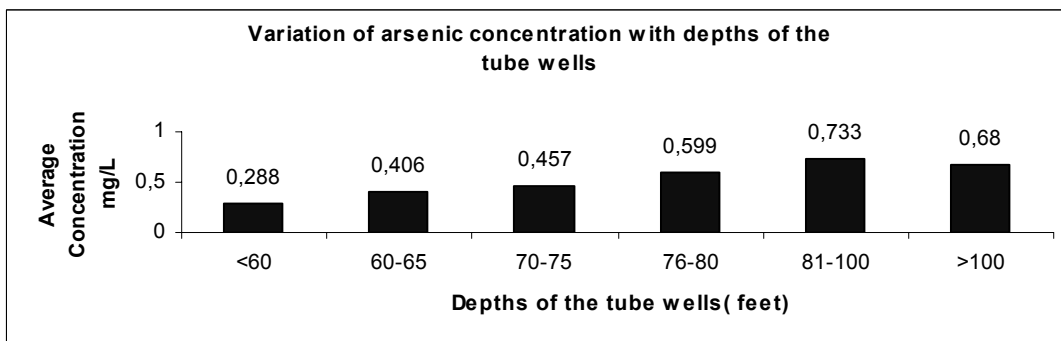


Figure 4: Variations of arsenic concentrations in relation to tube-well depths

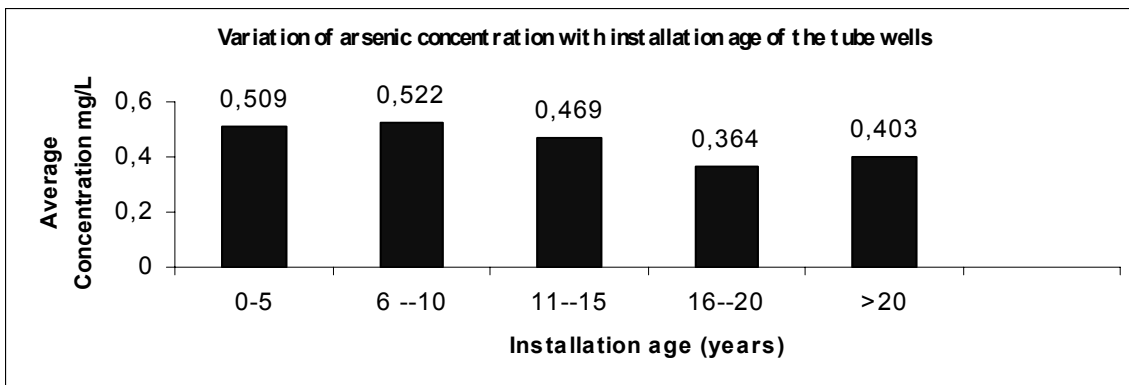


Figure 5: Variances of arsenic concentration in relation to when the wells were installed

Moreover, the study classified arsenic concentrations as follows: very safe level (< 0.01 mg/L), safe level (0.01 - 0.05mg/L), harmful level (0.051 - 0.1 mg/L), dangerous level (0.1 - 0.9 mg/L) and very dangerous level (>1.0 mg/L) (Figure 6). About 89.9% of the wells were found to contain arsenic at levels considered dangerous, 12% of the wells were classified as dangerous and 2.1% as harmful. In other words, very few of the wells delivered safe drinking water.

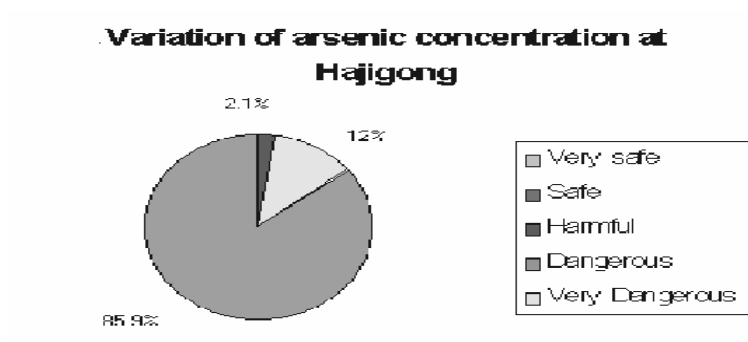


Figure 6: Classification of arsenic concentrations found in drinking water from wells in Hajigonj

A comparison of arsenic uptake in two biomaterials was made, i.e. garlic skin and rice husk. These biomaterials were chosen because of their cost-efficiency for poor villagers, who cannot afford proper filters. The garlic skin was first processed with bleaching powder in order to remove colour and dust. It was then tried out as an absorbent of arsenic in a synthetic 1000 ppb water solution. Its capacity to absorb arsenic was determined after having filtered 10 L synthetic water through a bed lined with garlic skin. One kilo garlic skin managed to absorb about 96% of the arsenic in 10 L of water. The uptake capacity gradually decreased in relation to increasing volumes of water. About 45% of the arsenic was absorbed by one kilo of garlic skin when subjected to 50 L of synthetic water.

The water from the first bed was fed into a second bed containing iron chips. Again, arsenic concentration was measured per 10 L. Measurements of arsenic concentration taken after having filtered through the first 10 L amounted to 10 ± 0.5 ppb, which is an acceptable limit according to the World Health Organization (10 ppb). After 50 L the concentration amounted to 16 ± 0.1 ppb, which is an acceptable limit for Bangladesh (50 ppb).

As for rice husk, after 10 L synthetic water have been filtered through, the arsenic uptake capacity amounted to about 66%. After 50 L, the uptake decreased to 20%. Water from first bed, which was lined with rice husk, was then percolated into a second bed, which contained iron chips. After the first 10 L had been filtered through, the arsenic concentration was measured at was 19 ± 0.8 ppb. The pH of the arsenic-mitigated water was within the range 7.82 to 8.12, and in both cases conductance was 0.34 to 1.8 mS/cm.

A comparison between the uptake capacities of garlic skin and rice husk thus shows that garlic skin is a better absorbent (Figure 7). The arsenic-adsorbing capacity of the -SH group contained in garlic skin is more efficient than the phenolic group contained in rice husk. In addition, sulfur atom in the thiol group, which is another component of garlic skin, was released from the first bed and together with the iron chips formed an iron-arsenic/sulphur (FeAsS) complex. The combination of garlic skin and iron chips proved to be a better absorbent than the combination of rice husk and iron chips.

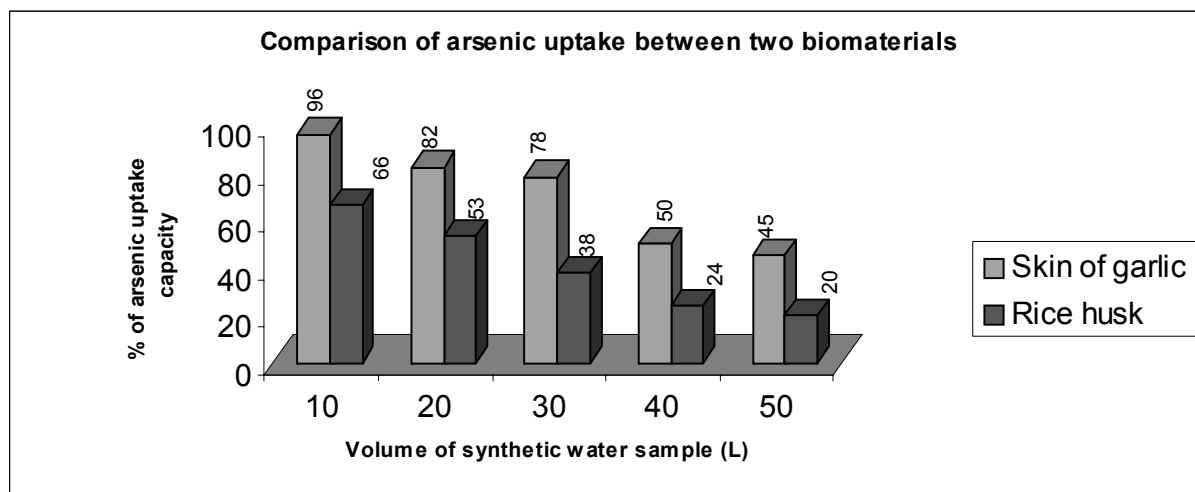


Figure 7: Comparison of arsenic uptake between garlic skin and rice husk

Further measurements were made on toxic metal ions in the surface water (rivers) of Bangladesh (Table 1). Samples were taken for traces of As, Cr, Cd, Pb, Se, Al, Cu, Fe, Mn, Zn from different river waters. Thankfully, the quantities for all these elements in surface water fell below the guideline values assigned by WHO.

Table 1: Average concentration of toxic metal ions in the surface water (rivers) of Bangladesh (N=4)

		As •g/L		Pb mg/L		Cd mg/L		Se •g/L		Cr mg/L	
		Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Buriganga	7.5	12.03 ±1.5	12.40 ±0.6	0.5 ±0.01	8.20 ±0.50	0.50 ±0.02	6.08 ±1.30	5.40 ±0.50	22.90 ±1.20	11.60 ±1.5	4.60 ±1.20
Sitalaykha	7.1	0.66 ±0.1	12.6 ±1.5	0.4 ±0.1	8.20 ±0.03	0.40 ±0.01	4.55 ±0.60	3.60 ±0.40	21.10 ±0.90	5.50 ±1.20	2.10 ±0.30
Karnafully	7.6	6.50 ±0.5	20.10 ±0.5	0.96 ±0.2	10.65 ±0.50	0.40 ±0.03	22.50 ±1.50	4.03 ±0.10	20.80 ±1.50	7.20 ±0.10	40.30 ±2.0
Brahmaputra	7.5	3.90 ±0.6	11.10 ±0.2	0.40 ±0.02	9.60 ±0.60	0.50 ±0.02	2.25 ±0.50	3.80 ±0.80	10.40 ±1.50	5.20 ±0.20	1.0 ±0.02
Jamuna	7.5	4.02 ±0.3	15.5 ±1.5	0.33 ±0.02	11.20 ±1.70	0.80 ±0.1	31.80 ±1.50	3.50 ±0.20	13.06 ±1.30	10.0 ±1.50	4.80 ±0.50

Food and soil samples from Hajigonj were also collected and analysed to determine arsenic contents. The results were given in the form of fresh weight basis. Arsenic was found in high amounts in aium (*Colocasia esculenta*, 0.220 mg/kg) and in lower amounts in potato (*Solanum tubeorsum*, 0.075 mg/kg). Further research work on the food chain will be carried out before any final conclusions are made.

Conclusions

- Not one of the 141 tube-wells in the 29 villages in Hajigonj Thana delivered arsenic-free drinking water.
- Garlic skin has better arsenic uptake capacity than rice husk when used as an absorbent.
- Surface water, i.e. water from rivers, ponds, canals and estuaries can be used for drinking water after having been treated properly.
- Detection and quantification of arsenic content in the food chain in areas affected by high contamination needs to be undertaken in order to establish baseline data for the occurrence of arsenic contamination in Bangladesh.

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Study of water pollution by organic compounds in Burkina Faso: Evaluation and remediation

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with

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Summary

Burkina Faso is a landlocked semi-arid country with a population of about twelve million. Large quantities of pesticides are used in the fields for agricultural activities, especially for cotton cultivation and market gardening. The transportation and deposition of pesticides over great distances is a known phenomena. As is the occurrence of other organic substances, most of which are toxic and most of which have an adverse effect on the environment. Such substances include hydrocarbons, pharmaceutical compounds, PCB, phenols, polycyclic aromatic compounds, fatty acids, phthalate esters, grease, oils from human and hospital waste, and industrial effluent discharges.

R. C. Nébié (Nébié et al., 2002) has measured high amounts of pesticides in vegetables and cereals with the help of HPLC analyses: 1-100 mg/kg for cypermethrin and 12-146 mg/kg for deltamethrin. CPG analyses of a variety of pesticide formulations show that most of them are affected by temperatures and that the contents in active compounds fall under the indicative values (Douvigou, 2002). With the help of HPLC, P. Savadogo has tracked the biodegradation of pesticides used in agriculture in Burkina Faso and has found that ultracide is recalcitrant to anaerobic biodegradation (Savadogo, 2001). These local results prove that soil and water run a real risk of pollution by pesticides and that, in addition, a great number of synthetic organic compounds are negatively impacting the environment and the quality of dams, rain, wells, streams, rivers, lakes and aquatic life.

The aim of our project is to estimate the contamination levels of drinking water in rural and urban areas. For that, pesticides and different kinds of organic substances need to be analysed in water and wastewater. The project should have a multi-disciplinary approach to obtain correlations between pollutant origins, soil characteristics, water characteristics and physico-chemical traces. This workshop will discuss analysis techniques involving classic GC, LC, GC/MS and LC/MS studies as well as how to manage as broad an approach as possible with apparatuses that require as low investment costs as possible.

Introduction

In Burkina Faso, a Sahelian country, water resources are very scarce and there therefore great need for water management in agricultural, pastoral, household and industrial activities. Yet these very activities contribute to pollution in the form of organic and inorganic chemical substances. For example, farmers plant cotton, maize and cabbage next to each other, increasing the risk for pesticides used on cotton spreading to the food crops.

Context

Drinking water for the 1.5 million inhabitants of the capital Ouagadougou is supplied by rainwater dams. The quality of this water is threatened by heavy metals and various POPs stemming from urban activities: households, the national hospital, industries and market gardening. In the rural areas drinking water is supplied by pumps and wells. In Burkina Faso, a significant increase can be seen in the use of pesticides to control insect pests in cotton cultivation

(the main export crop of the country) and in market gardening. To ensure safe contamination levels of food, the government initiated a massive programme of small irrigation in the villages in 2001.

Methodology

The preliminary work was aimed at pesticides, which are the most frequently used Persistent Organic Pollutants (POPs) in Burkina Faso. We studied residues of pyrethrinoids and organo-phosphorous compounds in mass consumption food sampled from markets: fruit, vegetables, cereal. An HPLC analysis was carried out. The biodegradation of the pesticides, which are among the most widely used in agriculture in Burkina Faso (sumithion, decis, ultracide), was done under anaerobic conditions. The quality assessment of six pesticides commercialised by Société des Fibres et textiles (SOFITEX) was done through CPG.

Results

1. Pesticide levels in some food products (Table 1)

One can observe that the amounts of pesticide residuals in these food products are considerable, and that they often greatly exceed the maximum tolerance limits. Also one can note the presence of unidentified compounds.

Table 1: Pesticide levels in some food products

Nr	Food product	Level of <i>pyrethrinoid</i> (mg/kg)	Level of <i>organo-phosphorus</i> (mg/kg)
1	Aubergine	0	0-11.25
2	Cabbage	0.6-33.6	0-1.26
3	French bean (haricot vert)	0-11.5	19.7
4	Sesam	0-1	2-5.8
5	Tomato	0-1.3	0-6.6

2. Study of the biodegradation of pesticides

The degradation kinetics showed that anaerobic biodegradation of 20 mg/l, 50 mg/l and 100 mg/l of *decis* was achieved in 10 days, 30 days and 50 days; biodegradation of 20 mg/l, 50 mg/l and 100 mg/l of sumithion was respectively achieved in 1 day, 25 days and 45 days, and finally, biodegradation of 20 mg/l and 50 mg/l of *ultracide* needs respectively 30 days and 55 days of incubation. Anaerobic biodegradation of *ultracide* in concentrations above 100 mg/l requires more than 60 days of incubation.

3. Analysis of pesticide formulations used in cotton cultivation

The following results were obtained (Table 2). We noted that the concentrations of all pesticide formulations are lower than indicated on the package. The calculated deviations are all higher than levels as authorized by the FAO/OMS joint commission. The deficits can be partly explained by the fact that pesticides are sensitive to heat and in this case have either been subjected to a hot climate or the samples have been stocked in overheated warehouses.

Table 2: Examples of concentrations of commercialized pesticide formulations

Sample	Cypercal P30/200EC	CyperthionP 30/200EC	Polytrine C 230 EC	Concentration (indicated on package)
Concentration g/l of <i>Profenofos</i>	180.18	176.4	184.2	300

Findings

We have made the observation that some pesticides are recalcitrant to biodegradation and it is therefore possible for these substances to enter the groundwater or wash out into surface waters. In other words, pesticides are capable of posing a real threat to water qualities.

Needs analysis for the implementation of a water analysis capacity

1. *The theme at hand, water pollution by POPs, constitutes a first phase of a general diagnose of water pollution.* It is important to provide scientific data on the state of pollution by POPs of waters in Burkina Faso. This research presents a global and multi-disciplinary approach to an evaluation of water pollution by POPs via the setting up of projects. Several domains in the ecosystem (water, soil, agricultural products) are involved in the study together with several different study zones (rural and urban areas). This approach demands a wide range of scientific knowledge. Unfortunately, researchers are more often trained in one single speciality. The poor local documentation (books and journals) and the infrequency of scientific meetings prohibit further the acquisition of scientific education to badly needed.

2. *Partners will benefit from the project through the establishment of local expertise in analysis of POPs in water.* The most frequently used techniques are CPG and HPLC. A perfect command of the heavy equipment involved is called for. Purchase and maintenance costs exceed the budgets of research grants. And as for the equipment itself, several models do not meet the specific needs of water analysis and the necessity of tropicalization.

3. *A South-South partnership should be reinforced between neighbouring countries.* Thanks to the mobility of persons, samples can be transported from one country to another, and two research teams in neighbouring countries could jointly plan the purchase of a piece of heavy equipment. Following the example set by some international organisations such as OMS, regional centres for pathological analysis handle samples from several countries. Tests are carried out, results are communicated. The expansion of the internet has made this system applicable between African countries. The follow-up indicator of such a partnership would be the number of services provided for other laboratories in the subregion. At the same, this would gradually build up a specification list for recipients of equipment grants.

Conclusions

Pesticides are the most commonly used POPs in Burkina Faso. Some pesticides such as *ultracide* are proven to be particularly recalcitrant to anaerobic biodegradation. In many of the various pesticide formulations commercialized in Burkina Faso, there is an underdosage of the active principles. The analysis of pesticide levels in some widely consumed food products has revealed very high concentrations of pesticides and secondary compound residues. Pesticides therefore pose a real risk to the quality of water. The same is true for any POP. These compounds are examined through a multi-disciplinary approach in order to determinate the degree of pollution in regional waters. The lack of equipment for water analysis is a constraining factor in this research.

Identified constraints to research include the lack of pure compounds that can be used as reference material for chemical analyses. Moreover, the researchers need to be multi-disciplinary (i.e., a chemist needs to be familiar with socio-economic aspects). Further, researchers in Burkina Faso prefer to work in industries where salaries are high.

The high cost for chemical analytical instruments is also a problem. GC and HPLC are mainly used to carry out the work and there is only one GC/MS in the whole of West Africa and no LC/MS. When researchers in Western Africa need UV-visible spectrophotometers or FTIR, they have to seek collaboration partners in other regions.

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Impacts of the use of agricultural pesticides on surface water in the north of the Republic of Benin

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Summary

The Republic of Benin does not produce pesticides, but it does import them. More than two million litres of pesticides for harmful insect control are imported and used annually, particularly in the rural zones where cotton is cultivated; cotton is the main cash crop in the country (more than 300 000 tons per year). Between 1994 and 2001 the volume of pesticides used increased from 2,080,000 to 2,317,000 litres per year, and per agricultural campaign the quantities of chemical fertilizers used in these regions increased from 35,300,000 to 68,300,000 tons between 1994 and 2001. Pesticides are not only a threat to the food chain. Faced with water shortages during the dry season (December to June), rural populations use non-treated streaming water stored in dams or surface waters from streams or rivers as drinking water. Recent studies (1998 and 2001) conducted on the quality of the water resources in some agricultural areas and in the protected areas of the Pendjari and W biospheres (national parks) showed a presence of organochlorine pesticides such as DDTs (1.1-100 ng/l), endosulphan (58.0 – 750 ng/l) and others. These substances have the potential to seriously threaten the survival of animals and humans. Add to this the fact that it's not only agricultural activities that have been identified as contaminated by pesticide-ridden water, especially in the North of Benin. Here, the use of such chemicals for paralyzing fish before catching them constitutes a non-negligible source of pollution of surface waters. Many poison episodes were registered during 1994-2001 in the cotton cultivation regions. Water quality is also affected by nitrogen pollution due to the use of chemical fertilizers in agriculture. Concentrations of nitrate have been measured at more than 30 ppm in most soils and surface waters sampled in the north of Benin. Therefore, water quality degradation is becoming a serious problem that needs to be investigated in this part of the country.

Background

The Republic of Benin is a cotton-producing country. It produces between 300 000 and 400 000 tons of cotton a year. In the fight against the unavoidable insects that cause the cotton trees harm, 2.2 million litres of pesticides were imported per year between 1994 and 2001. More than 70% of these chemicals were used in the north region of Benin (Sonapra, 2000). During the same period the quantities of fertilizers used to amend cotton cultivation agricultural soils increased drastically from 35,300 to 68,272,200 tons. In fact, as the soils of hunting zones around the protected areas of the Pendjari and W biospheres (national parks) in Benin are favourable for agricultural activities, farmers prefer to develop their activities (cultivation of cotton, rice, corns etc.) regardless of the regulations governing the protected areas, thus exploiting even the surrounding areas of the national park. During the rainy seasons (June to October) the runoff waters from these agricultural areas flux the parks, including of course water pools and rivers where animals go for water feeding. In addition, people living near the surrounding areas use the surface waters as drinking water sources and water poisoning episodes are often registered in these regions (Karim, 1995 and Assongba, 1996). As is already known, pesticides wreak havoc with the nervous system in the human body when the inhibitory effect of cholinesterases is reversed by the chemicals, causing carcinogenic tumours, mutagenic mutations and teratogenic diseases. Often the fertilizers are not wholly consumed by the plants and a good portion of the chemicals are washed off into runoff waters and discharged in the Alibori, Mekrou and Pendjari rivers and pools.

This contributes to the increase of eutrophication in all the water systems.

Location of the study areas

These figures show the national parks of Pendjari and W, which are located in the North-West of Benin.

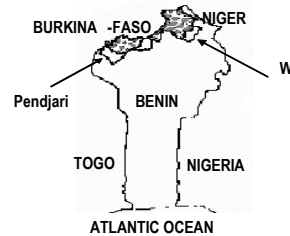


Figure 1: Pendjari National Park

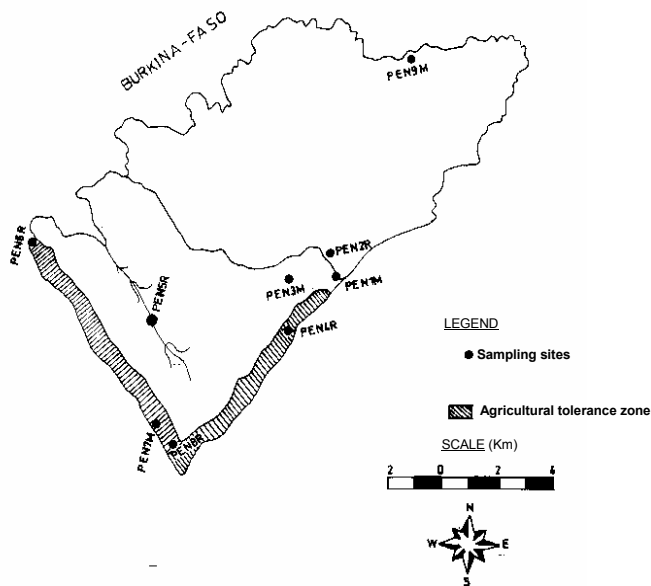
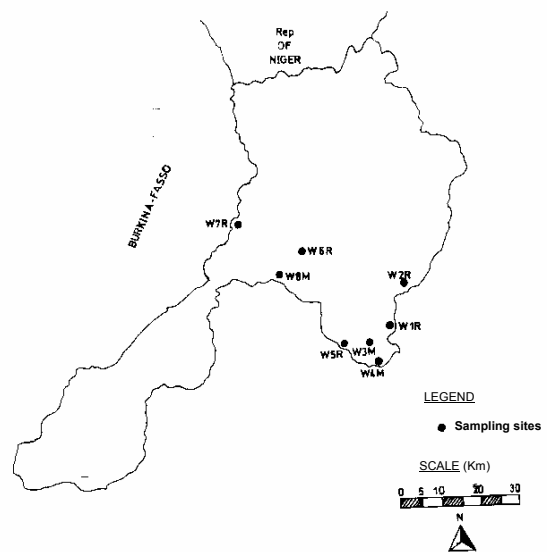


Figure 2: The W National Park



The 568000 ha surface area of the Benin W Biosphere Reserve forms part of the W Biosphere Reserve of the Niger River, which covers the common zone between Benin in one side and the Burkina-Faso and Niger Republics (55.52% of the Niger W Park) on the other side. Two big streams flow across reserve and discharge their waters into the Niger River. The names of the two streams are Mekrou and Alibori. The Pendjari Biosphere Reserve was created in June 1966. It is located in the North-West of Benin between $10^{\circ}30'$ and $10^{\circ}59'$ latitudes north and between $1^{\circ}50'$ and $2^{\circ}04'$ longitudes east. It covers 477802 hectares (Sinsin et al., 2000).

At present these areas offer the richest reserves of faunas in Western Africa in terms of biological diversity. It is characterized by a climate with relatively abundant pluviometry (1000 mm of rain per annum) and a high potential evapotranspiration (1750mm). The hydrographic network of this zone is controlled by the Pendjari river, its affluents and some ponds. In the case of both Pendjari and the complex W of the Niger river, the surface waters, which are flooded by inflows from the cotton cultivation zones where great quantities of agricultural fertilizers and pesticides are used, are the main water supplies for the bordering populations as well as major watering places for animals living in these protected areas. The problem is compounded by the fact that the zones are characterized by water shortages, for which reason the quality of the water resource is doubly important.

Methodology

Seventeen (17) surface water sites were sampled in the two ecosystems of fauna: eight (8) in the W biosphere reserve and nine (9) in the Pendjari. Five water and sediment samples were taken in each site during two campaigns; one during rainy season (September 2002) and the other during the dry season (January 2003). Measured indicators concerning the quality of the water resources turned out as follows:

1. Temperature, pH, conductivity, dissolved total solids (TDS), COD, nutrients (NO_3^- , NO_2^- , NH_4^+ , PO_4^{3-}) in the water samples;
2. Chlorinated Pesticides (DDTs, endosulfan, lindane, dieldrin and heptachlor) in the water and sediment samples.

The analytical techniques used were UV-visible spectrophotometry for the physical chemistry of nutrients (Spectrophotometer SHIMADZU 1601) and gas chromatography connected to an electron capture detection system (HP 5890, Series II) for the chlorinated pesticides.

Results and discussion

Nutrient contents in water samples

Analyses of the data relating to nutrients (NO_3^- , NO_2^- , NH_4^+ and PO_4^{3-}) as described in Figure 3 lead to the following conclusions:

- The nutrient rates are relatively high in the waters in both Pendjari and W. As an example, the nitrate rates are on average 27.18 mg/l for the rivers and 76.14 mg/l for the pools in the W biosphere, and 26.14 and 36.11 mg/l respectively for the rivers and pools in the reserve of Pendjari;
- The concentrations of nitrites and ammonium are on average respectively 0.49 and 4.57 mg/l in W and 0.42 and 6.70 mg/l in Pendjari;
- As for phosphates, the rates are on average 0.73 mg/l in W and 1.08 mg/l in Pendjari;
- The nutrient contents are higher in the rainy season than in the dry season; the relatively higher values of the nutrient contents in water for the entire biospheres, and in particular in the hunting zones close to the bands of agricultural tolerance, should logically have to do with exogenic contribution sources, i.e. such as the use of chemical fertilizers on farms.

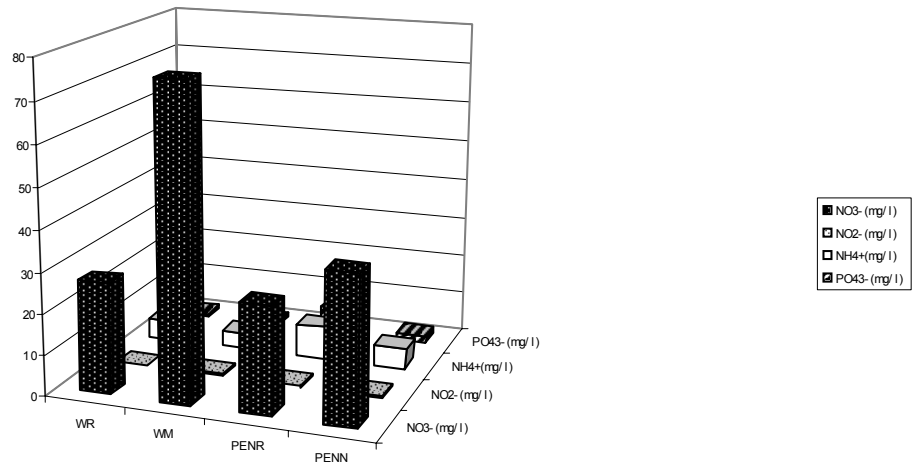


Figure 3: Evolution of nutrients in aquatic systems

Contents of organochlorine pesticides (OCPs) in water and sediments

Figures 4, 5a and 5b give the ranges of concentrations and the distributions of some organochlorine pesticides in water and sediment samples collected from surface water systems of the W and Pendjari biosphere reserves.

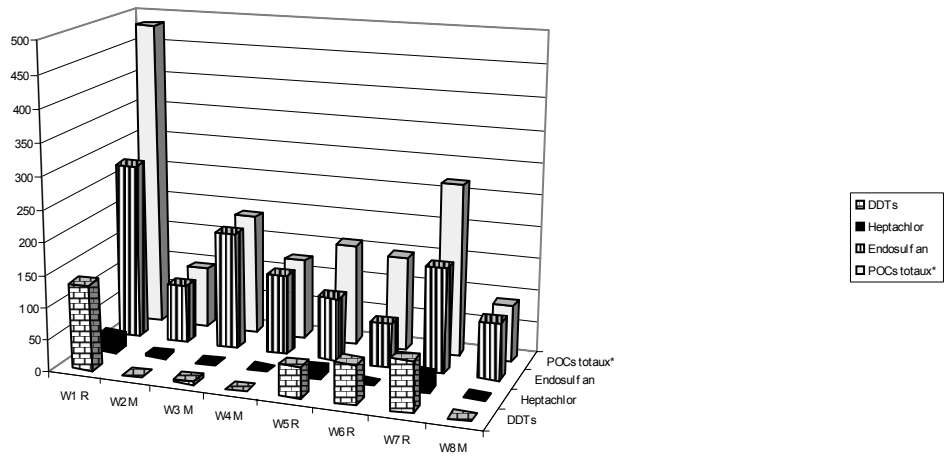
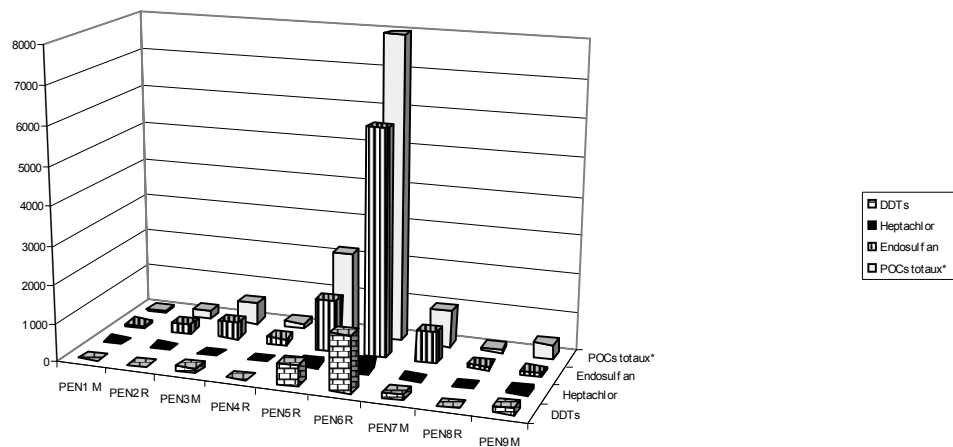
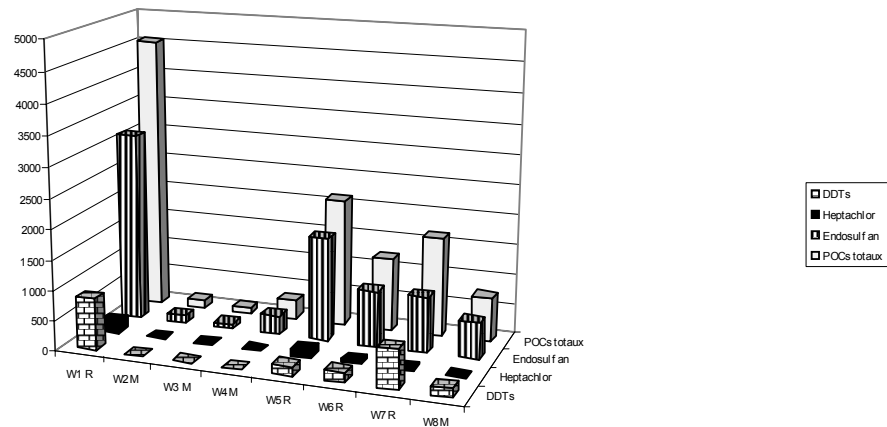


Figure 4: Distribution of OCPs in water of rivers and ponds in W and Pendjari



Figures 5a, 5b: Distribution of OCPs in the sediments of river-sand ponds in W and Pendjari

Summary of findings

- The OCPs are used in the surrounding zones of the two biospheres.
- Three POCs are predominantly used: endosulfan, DDT and heptachlor.
- POCs are more abundant in the rivers than in the ponds.
- Endosulfan is detected in most of water systems, where it appears as the most abundant POC.
- The contents of POCs are higher during the rainy season than in the dry season.
- POCs contents are higher in the rivers than in the ponds.
- Heptachlor and DDT proportions increased in the majority of rivers during the dry season compared to the rainy season, when endosulfan concentrations decreased.
- Apart from occurrence of linden and dieldrin in a few ponds, these two substances appear exclusively in the rivers.

On the basis of these results, certain assumptions have been made

- The prevalence of endosulfan in the majority of the samples shows how abundant and uncontrolled the use of the substance is in these areas for trying to maintain healthy crops, especially on the cotton trees. The existence of endosulfan probably constitutes a fair indication of pollution caused by agricultural OCPs from cotton cultivation areas; investigations carried out near the Agriculture Directory showed that hundreds of thousands litres of endosulfan are annually imported to Benin.
- The higher concentrations of DDTs, particularly in Pendjari rivers, shows the possible use of this chemical product both in Benin and in Burkina Faso;
- The high concentrations of DDT and especially of heptachlor in river waters such as the Pendjari, Alibori and Mekrou rivers, and the increasing levels of this substance during the rainy season shows that DDT and heptachlor is most probably used for fishing: according to the results of the surveys carried out in these zones, the fishermen usually spread pesticides on the surface of waters in order to paralyse fish. Such practices would certainly account for the fact that lindan and dieldrin appears exclusively in the rivers.

Risks related to the use of chemical fertilizers and OCPs

These risks are numerous: they encompass everything from the threat of poisoning the bordering populations to the extinction of species of fauna and flora due to high rates of pollutants in the aquatic ecosystems. Poison episodes are often registered in the Banikoara District near the W biosphere reserve (Lafia, 1996). Indeed, water systems that contain nitrate concentrations higher than 44mg/l, such as W1R, W3M, W5R, W8M, PEN7M and PEN9M, are of poor quality and should not be used for drinking, bathing or leisure, either by human beings or by animals. Waters with contents higher than 100 mg/l, such as in the case of the W2M site, and which continue to be classified as acceptable for use are in fact marked by an excessive nitrogen pollution and are really only suitable for boating excursions;

- The relatively high concentrations of nitrites (higher than 0.1 mg/l) and of ammonium (higher than 4 mg/l) for the majority of the sites indicate pollution and cannot be deemed of adequate quality to be used as drinking water or for the cultivation of fish;
- Concentrations of OCP levels that exceed the acceptable limits as determined by the WHO for drinking water (contents higher than 0.03 µg/l for heptachlor and endosulfan, 0.1 µg/l for DDT) that have been observed in some places confirm the risk of poisoning faced by the bordering populations.

Conclusions

The abundant use of chemical fertilizers and pesticides in the northern areas of Benin has a considerable and adverse effect on the chemical quality of the water resources. There is a definite shortage of good quality water, both for the bordering populations and the wild fauna in the W and Pendjari biosphere reserves. Research has addressed these issues. However, lack of consumables, scientific documentation and limited possibilities for the exchange of studies and findings between laboratories have been identified as significant research constraints.

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Toxic substances in water in the Rift valley of Ethiopia

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Summary

Contamination of water resources (and in particular of drinking water) by toxic inorganic and organic substances is a growing problem in Ethiopia. Our study focuses on the monitoring of water contaminants such as fluoride, nitrate, heavy metals and trace levels of pesticides and the establishment of control strategies including development of treatment processes. The results of ongoing studies are summarized and the type of research capacity that needs to be built is identified.

Introduction

Ethiopia has a population of 60 million with an annual growth rate of approximately three percent. Water demand for domestic, agricultural and industrial purposes is increasing rapidly. Water supply and sanitation coverage extends to only 24% and 12% respectively of the total population. Regarding water supply in urban areas, groundwater and surface water constitute 87% and 12.3% respectively. Groundwater is the major available drinking water source in rural areas. Data on regional groundwater quantity and quality are scarce and combined assessments of the ground and surface water systems have not been made. Growing urban centres have no municipal and industrial wastewater treatment facilities, since the systems are prohibitively expensive. Yet it is becoming increasingly necessary to build out the infrastructure given that estimates suggest a significant increase of industrial water use over the next 25 years, which will lead to even more industrial pollution. The potential impact of agricultural chemicals on the environment may also be a major concern for the rural community.

Emerging issues related to water resources development are health hazards related to declining water quality partly due to inadequate and incompetent management of water resources. Apart from water contamination by pathogenic microbes, which is common in Ethiopia, chemical pollution is increasing with industrialization, not least because of the wide-spread use of agricultural chemicals needed to produce food for the rapidly increasing population. However, there is no information regarding the level of pesticides and other organic micro-pollutants in water supplies. Some studies indicate that certain pesticides have been detected in lakes of the Rift Valley region and that the level of nitrate in groundwater is on the increase. Heavy metal pollution from tanneries, battery processes and other industries may also be causing damage to the environment. In general, oxygen balance, eutrophication, heavy metals, acidification, organic micro-pollutants and nitrates are some of the concerns related to chemical water pollution in Ethiopia. In addition, adverse natural conditions in some cases contribute to the situation. Examples of the latter include areas where the natural geochemical composition of water supplies can lead to severe health impairments such as fluorosis in the Rift Valley of Ethiopia. Maintaining safe drinking water free from chemical contaminants in combination with enough water to supply the population is a challenge. Regulatory measures and capacity building through the promotion of research aimed at water quality issues and future trends are needed.

The purpose of this paper is to summarise the results of ongoing studies on water quality issues, to identify priority research areas related to toxic substances caused by growing anthropogenic influences and identify the type of research capacity that needs to be built or strengthened for such projects to be successful. Our project area focuses on the Rift Valley region of Ethiopia. It is considered that the impact of drinking water quality on public health is cumulative because there are very few rivers and lakes and most of the agricultural and industrial establishments are

concentrated near to these water bodies. In addition, most of the water resources in this area contain high levels of fluoride.

Description of the study area

The Rift Valley region is part of the Great East Africa Rift System and is a long and narrow strip of low-lying plain land between the highlands. It stretches from the north-eastern part of the country to Kenyan border in the south, and divides the highland masses in two; the Central and Eastern Highlands of Ethiopia. There are several streams originating from the highlands on both sides of the Rift Valley that flow into the lakes occupying the low-lying middle areas of the Main Rift System. The depth to groundwater generally varies from 120 to zero metres with tapering elevation towards the lakes. About ten million people live in this area and the region is characterized by scarcity of fresh surface water resources.

The water quality condition of streams, lakes and groundwater has never been assessed in a systematic way. Data compiled by the Ministry of Water Resources only focuses on the analysis of major cations and anions that commonly exist in surface water and groundwater. According to these results, lake and groundwater are characterized by high salinity that originates from natural geological formations. A recent survey showed that about 60% of the water supply used for drinking contains fluoride concentrations exceeding 1.5 mg/l. However, no successful attempt has been made to remove fluoride from drinking waters. As to anthropogenic contamination, the extensive use of fertilizers and pesticides on individual and large-scale state farms within the Rift Valley may have a direct influence on the water quality. The use of insecticides for malaria control is quite common in this region. In addition, the exponential population growth and intensive agriculture along with massive deforestation and the absence of proper forestation practices in the highlands may facilitate runoff to the low-lying Rift Valley. Such impacts of human activities on freshwater lakes have been going on for quite some time in Ethiopia and may have contributed to the continuous degradation of pristine qualities.

The major industries within the Rift Valley include textile, tannery, ceramics, sugar, pesticide formulation and soap that discharge effluents without proper treatment. Industries located in the highlands may also contribute to water pollution in the Rift Valley. Most of the Ethiopian Rift valley lakes are very productive, containing indigenous populations of edible fish and supporting a variety of aquatic and terrestrial wildlife. Some of these lakes are being used for commercial fisheries, irrigation, recreation and other industrial purposes. Human activities may very well be changing the quality of surface water and groundwater resources, but it is difficult to draw such conclusions without available data.

Ongoing research

Fluoride in water

Defluoridation of water by thermally-treated clay: Clay soils and related minerals have been reported as defluoridating materials and offer a major advantage due to their abundance in nature. Clay minerals that are widely abundant in Ethiopia are kaolinite, illite and montmorillonite. Our previous studies using red (kaolinitic) clay soil and its fired products showed that the fluoride absorption capacity is low but quite promising. In this study, the removal of fluoride by thermally-treated clay was investigated. Factors such as thermal treatment temperature, the absorbent dose, the initial fluoride concentration and the solution pH were evaluated. Thermal treatment of clay soil in the temperature range up to 500 °C increased fluoride removal but further increases in the treatment temperature caused a decrease in removal efficiency. The fluoride removal efficiency and absorption capacity of treated clay soil increased with increasing absorbent doses and initial fluoride concentration respectively. Further investigation using thermally-treated kaolinite soil at 550 °C showed that the surface loading needs to be less than or equal to 0.167 to achieve maximum removal efficiency. The absorption isotherm of fluoride in treated clay soil conformed to the Freundlich absorption model. Optimum pH for fluoride removal by thermally-treated clay soil ranges from 5.0 to 7.5. Loss of media by abrasion was minimal. Further investigations will focus on the effect of different cations and anions on the fluoride retention capacity of clay, the affinity of different types of clays for fluoride, characterization of the structure of the clay samples and design of continuous absorption columns for household applications.

Defluoridation using locally produced aluminium sulphate and lime: In this project, the technical and socio-economic feasibility of using locally produced aluminium sulphate and lime for defluoridation of water at small community levels is being evaluated on a pilot basis. The major objective is to pilot low cost defluoridation systems in the target area, thereby reducing the fluoride content to less than 1.5 mg/l in accordance with WHO standard or at a maximum of 3 mg/l (according to experiences made in other countries). Appropriate community support mechanisms that are of use in making such defluoridation systems sustainable and practical in the Ethiopian context will also be developed. The method known as Nalgonda Technique, which comprises the addition of lime, alum and bleaching powder in sequence followed by flocculation and sedimentation, is used. Laboratory batch experiments were conducted using water samples collected from various locations in the Rift Valley regions. The result showed that treatment of water with initial fluoride concentrations exceeding 5 mg/l requires the addition of an alkali to control the pH. Other factors that influence the performance include the composition of the water to be treated, the generation of undesirable substances in treated water such as sulphate, aluminium, calcium ions and other impurities, and the generation of sludge containing fluoride and other substances. Detailed investigations are being conducted to address these issues and to improve the technology.

Defluoridation by electrochemical technique: The disadvantages with alum and lime precipitation are lack of knowledge at the user end when it comes to proper dosages, generation of sludge and the introduction of undesirable substances into treated water. The absorption of fluoride with freshly precipitated aluminium hydroxide in an electrochemical cell, which is generated by the anodic dissolution of aluminium, has been proposed in a few recent studies. In this project the electrochemical behaviour of aluminium electrodes in relation to fluoride removal performance is being investigated using cyclic voltammetry. Elucidation of reaction mechanisms with the aim of enhancing fluoride removal is also part of the study.

Water Pollution by nitrate, pesticides and heavy metals

Pollution monitoring: The extent of water pollution by nitrate and pesticide is being investigated at selected locations in the Rift Valley of Ethiopia. The study is mainly focused on the generation of baseline data that would be useful to assess the extent of water pollution caused mainly by agriculture-related activities. Data is being generated by analyzing groundwater and surface water samples for nitrate, nitrite, ammonium, biological oxygen demand, chemical oxygen demand, dissolved oxygen and other relevant parameters. The results obtained so far indicate that both surface water and groundwater are polluted with nitrogen-containing compounds in urban areas, whereas in some locations in rural areas, groundwater is contaminated by nitrate. Regarding pesticides no data has been generated due to the lack of equipment and chemical reagents. Our further studies will concentrate on generating more baseline data including pesticide residues in order to assess the extent of pollution and the relative importance of various sources of contamination. The idea is to propose possible control measures. Fish as bioindicators of water pollution are being analysed for their heavy metal content. Attempts are underway to identify and quantify bioaccumulating species through speciation studies.

Nitrate and pesticide removal: Experimental investigations will also be carried out to develop nitrate and pesticide treatment processes for drinking water by using materials that are available locally. The development of clean water treatment process for the removal of nitrate and pesticides based on bio-electrochemical techniques and electrocatalysis using zero-valent iron is being investigated. Recently, we proposed a combined bioelectrochemical/adsorption process and a hybrid biofilm reactor for nitrate and pesticide removal.

Research capacity building

Building local scientific capacity through the development of knowledge and approaches based on applied research is very important to strengthen the establishment and continuity of water research activities. The research activities that are being carried out can be used as a basis for further initiatives in water quality studies. In addition, a graduate programme on Environmental Science was launched in 2003, which will be very useful in strengthening research activities and building the scientific capacity of concerned institutions such as the Environment Protection Authority and the Ministry of Water Resources. The type of research capacity that needs to be built at this stage requires equipment and consumables for the analysis of trace pesticides, and nitrate, fluoride and other parameters in water. We also need to facilitate the participation of researchers in international forums, support the supervision of MSc and PhD students, and support the subscription of international journals (Water Research, Water Science and Technology, Environmental Science and Technology). Establishment of partnerships with on-going research at the

international and/or regional level may also facilitate capacity building process.

Water policies and governmental master plans are in the process of being developed in Ethiopia, since the awareness of the water situation is increasing. The researchers try to help the government to develop guidelines, for example by supplying appropriate information. Some of the observed problems are lack of and/or insufficient access to scientific equipment, scientific data, testing programmes, information and networks.

Conclusions

Although results obtained so far are promising, the progress of the research activities is working as planned. The major factors contributing to the slow progress include lack of adequate funding, shortage of scientific instruments, shortage of spare parts and consumables and shortage of vehicles for fieldwork. In addition, although financial control systems of local governments are stringent, they lack flexibility. Our future plan is to further strengthen the aforementioned research activities and other important issues in relation to water resource research in the Ethiopian context. Further scientific research will be required in the area of wastewater treatment and reuse, human impacts on the interaction between land and water in relation to arid and tropical climate, and low cost and simple community-scale water treatment systems. Establishing an information base related to water quality situations that are relevant to current and future development, dissemination of such information, monitoring water pollutants, and assessment of proper pollution control strategies is essential. In other words, the establishment of a well-equipped laboratory dedicated for water research is highly needed.

Section 2

Organisations addressing scientific capacity building in developing countries

Water resources research in Swaziland

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Third World Organization for Women in Science (TWOWS)
and the Department of Geography, Faculty of Science, University of Swaziland
p. 46

*Capacity building for improved water management in Africa: Breaking the vicious cycle
through effective linkages between sciences and policy*

Dr Madiodio Niasse

The World Conservation Union (IUCN) - West Africa
p. 51

Greywater reuse: A sustainable water resources management approach

Dr Murad Jabay Bino

the Inter-Islamic Network on Water Resources Development and Management (INWRDAM)
and the **OIC Standing Committee on Scientific and Technological Cooperation (COMSTECH)**
p. 54

*Strengthening research in integrated water resources management
in the Central American region*

Dr Lilliana Arrieta

Regional Network for Capacity Building in Central America (REDICA)
p. 62

Networks as instruments for scientific capacity building

Mr Kees Leendertse,

International Network for Capacity Building in Integrated Water Management (Cap-Net)
p. 69

Promoting basic scientific research on water in Southern Africa

Dr Yogeshkumar Naik,

Dept of Environmental Science and Health, National University of Science and Technology, Zimbabwe
and Dr Malin Åkerblom,

International Science Programme (ISP)
p. 75

Building water management research capacity in developing countries

Dr David Molden,

International Water Management Institute (IWMI)
p. 79

Support to scientific capacity through the strengthening of infrastructure

Dr Cecilia Öman

International Foundation for Science (IFS)
p. 85

Water resources research in Swaziland

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Summary

The main objective of this paper is to present research activities related to water resources in Swaziland, and describe the scientific capacity of the country to undertake research on water resources. In the second section of the paper an attempt has been made to introduce the country in terms of its location, climatic conditions and water resource provision and use. The third section reviews water resource endeavours in the country focusing on what has been done within the University and the Department of Geography, Environmental Science and Planning. The fourth section establishes scientific research capacity in water resources. The focus here is on what has been done up to now and what is being done at present, as well as current research attempts. Research capacity has also been evaluated in terms of gender, focusing on women's abilities. Finally, the last section draws conclusions on water research activities in the country, highlighting the scientific capacity in strong, weak and nonexistent areas. An attempt has also been made to establish why this capacity is weak in some areas, how it can be strengthened and which water resource areas need to be focused on for future research.

Introduction

Swaziland, like other countries in the Southern African region, depends on water resources for its sustainability. Agriculture is the main economic activity, and it is heavily dependent on irrigation. At the same time, water resources are scarce and the demand is increasing. The country has not yet been able to extend sufficient and safe water to the bulk of the rural population. Current attempts to provide water to the rural population are hampered by poor sustainability of the water projects. As such, research, especially on how to provide sustainable water to rural homesteads, is not only crucial but missing.

Current research attempts in water resources are focused mainly on establishing to some extent the environmental impacts of development activities on water quality and quantity. Attempts have also been made to establish which water resources are available, establishing information for management and planning and mapping the impact of climate changes on water resources. There has been very little research on socio-economic issues related to water resources. Also, most of the research attempts have been based on engineering, i.e. trying to work out technical solutions. However, water problems, development and conservation are not solely technical matters. Social and cultural issues have a considerable impact on developments, not least in terms of gender and equality.

Scientific research capacity in water resources research is very low. As most of the water research is based on engineering, women are more or less left out of the equation. Most women are involved in the 'softer' sciences, a pattern instilled at an early stage in their education when mathematics and science are avoided. Further, most research activities are funded by outside donors, who require a high standard of presentation in the research proposals. Since women lack the capacity to write winning research proposals, they are unable to compete favourably. To improve the situation, women need training in research methodology, Geographical Information Systems, remote sensing techniques and modelling. They also need mentoring from experienced researchers, both within and outside the region.

There is a dire need for research on how to provide sustainable water to the rural communities, and how women, who

are the main producers of food crops, can gain access not only to domestic water, but also irrigation water in order to produce crops for domestic consumption and sale. This would undoubtedly elevate their socio-economic status.

Background

Swaziland is located at latitude 25.5⁰ south and longitude 31⁰ and 32⁰ east in the south-east region of Africa. The country has a total area of 17364 sq km with a population of about one million, growing at 2.4 % per annum. Swaziland, like the rest of the Southern African region, is faced with the problem of natural water scarcity alongside the growing demand for water due to population and economic growth.

The country is divided into four distinct ecological zones, the Highveld, Middleveld, Lowveld and Lubombo ranges. All regions experience a distinct seasonal rainfall with most of the rain falling in summer (October to March) and little or no rain during the rest of the year. The climatic conditions range from sub-humid and temperate in the Highveld to semi-arid in the Lowveld.

Due to the nature of the country's climate, agriculture, which is the main economic activity, is heavily dependent on irrigation. Main cash crops in need of irrigation are sugar cane, citrus fruits and vegetables. The irrigation potential of the country is estimated at 90000 ha, of which approximately 55000 ha are already developed under irrigation (Lankford, 2001). The irrigation sector uses approximately 96% of the water, and 90% of this is used by the sugar industry alone. The sugar industry is the major player in the Swaziland economy. It is the biggest foreign currency earner (about 150-210 million US dollars annually depending on the price of sugar), and provides about 17-22% of the total export revenues (SSA, 2001, USAID 2001). It contributes to direct (6000) and indirect (80000) employment and to more than 50% of the total agricultural output, as well as 30% of agricultural employment.

Water use in Swaziland is divided into three sectors, namely irrigation, domestic and industrial. The provision of water, especially to small and medium-scale farmers, needs to be improved for the country to meet its food demand, particularly at the household level. Currently, the government and NGOs are working hard to improve access to safe water. Water-related diseases still prevail. Poverty is also rampant. Over a third of the facilities meant to serve the poor are not functional. This has been attributed to policy weakness and the related problems of inappropriate technology selection and lack of community participation in the full spectrum of water and sanitation. More efforts are now directed at the sustainability of water projects in terms of operation and maintenance, as well as making more facilities available to the rural areas.

There used to be about 505 water projects supplying rural communities in Swaziland. By 1996 however, only 401 of these were still functioning (Knight and Piesold, 1997). Sustainability of water projects is a big problem in the country. There is a need for studies to evaluate the appropriateness of the current water technologies used as well as the manner in which these projects were planned and implemented. It is vital to establish the strengths and weaknesses of these projects and identify, develop and recommend appropriate water supply technologies. Also, the community members could be trained to operate and maintain the water projects themselves.

Water resources research in Swaziland

There have been various studies undertaken within the country. This paper presents only those studies undertaken by the Department of Geography, Environmental Science and Planning at the University of Swaziland. Six studies undertaken between 1999 and 2003 are presented within the context of issues raised by this seminar. The paper also discusses some of the factors which we as researchers from developing countries perceive to be important in strengthening scientific capacity for water resources research.

Environmental impacts of development along the Mbuluzi Drainage Basin (1999)

Funded by the University of Swaziland Research Board

The study was concerned with the impacts of development within the river basin. A multi-disciplinary team undertook field work land use, distribution of settlements and quantity and quality of water resources. Findings revealed that human settlements have increased dramatically over time, and that the basin faces enormous and irreversible socio-economic and environmental problems. Land use changes indicated an increase in the area covered

by natural forests and dams. With regard to water resources, farming activities in the catchments had an effect on water quality due to increased concentrations of suspended solids, dissolved solids, phosphates and nitrates, especially during the rainy season. The study further noted that the water quality was poor and that there was a low level of awareness about the environmental consequences of agricultural practices by the people. Among other things, the study wanted to determine land use changes and evaluate their effect on the environment. There was a need to identify and map the distribution of settlements. These activities could not be done satisfactorily because of the lack of equipment (GIS, GPS and current national maps). These have since been secured through European Union research grants. However, there is still a need for current national maps. Furthermore, the study was unable to include measurements of water quality, which is an important variable in establishing environmental impacts of development activities within the basin. Again lack of equipment and well-trained technicians were identified as constraining factors.

Water resources development in the Mbuluzi River Basin (2000)

The aim was to determine the reservoir capacity of the basin to meet water demands up to the year 2020. It was found that the water demand in 2020 is estimated to be 266898 million m³ per year. The reservoir capacity was found to be low, demanding construction of another water storage facility with a capacity of 120 x 10⁶ m³.

The study had to establish water demands in the basin. To do this, data was required on all the major activities involving water such as for irrigation, livestock and people. The future water demands of these activities had to be projected. There were problems in making projections arising from the lack of sufficient information, especially on acreage under irrigation and possible expansion. This has to do with problems of mapping the areas under irrigation (lack of current maps and mapping ability). As a result, the study had to rely on assumptions and estimates. This severely reduces the value of the research for real life applications which are so vital for the development of the country.

Development of an innovative computer-based integrated water resources management system (IWRMS) for water resources analysis and prognostic scenario planning in semi-arid catchments (2000)

Funded by the European Union

This project was part of a larger regional study within SADC (Swaziland, South Africa and Zimbabwe). The aim was to classify and investigate land use, degraded areas and settlements by means of remote sensing techniques. These involved aerial photograph interpretation and linkage to GIS, the simulation of hydrological and erosion dynamics using a deterministic physically-based ACURU-model enhanced by OM with Graphical User Interface, validating results via remote sensing and developing a GIS-based management decision support system to identify competing stakeholder water demands and to address water allocation conflicts with respect to social economic impacts. The study was multi-disciplinary in nature involving a wide range of researchers. The capacity of the researchers involved was enhanced through working with researchers within and outside the region. However, the capacity of the local researchers lagged behind as effective transfer of scientific knowledge between researchers was not flowing smoothly, especially due to the nature of the research tasks involved. Thus the country still lacks the ability to develop and use its own models.

Environmental sustainability of shared river systems (a joint research venture between Swaziland, South Africa and Mozambique (2001)

Funded by Sida

This study represents an initial phase of a larger planned study between the three countries. The overall goal of the project was to enhance the researchers' capabilities through trans-disciplinary and trans-boundary collaboration and learning as regards the environmental sustainability of river systems. The project wanted to improve the understanding of researchers by focusing on environmental sustainability of river systems, which in turn increased the researchers' ability to contribute to integrated river basin management and come up with further research proposals. A research proposal on the integrated management of shared rivers with a case study of the Inkomati River Basin was produced. The team is in the process of acquiring funding. The overall project was a multi-disciplinary research initiative involving researchers from three countries and was meant to build research capacity in all three, albeit with a focus on Swaziland and Mozambique since research capacity and data availability is considered especially low in these two countries. However, the study suffered from poor communication and the

team was unable to work together. Further, the team lacked scientific skills, especially with regard to resource economics in establishing the value of natural resources related to water. There is a lack of professionals within the region; only South Africa has scientists with proficient training and because the project had funding problems it was difficult to attract heavy-weight scientists. The research also required expertise and equipment for measuring water quality in establishing the “health” of the river; components that Swaziland lacks.

Evaluation of the impact of climate changes on hydrology and water resources in Swaziland (2002-2003 - ongoing)

Funded by Water Research Fund for Southern Africa (WARFSA)

The study aims to determine qualitatively the expected changes on precipitation, evapo-transpiration, temperature, runoff and water resources in response to expected climate change. This is being done for various climate change scenarios taking into account water demands. Further, the study will devise adaptation strategies that will help mitigate the adverse impacts due to climate changes. So far the results of the GCMs have shown that the country will experience high flows during the summer months but that dry conditions will prevail as currently experienced. The results from the individual catchments vary slightly. No significant changes are expected in the Komati basin either during wet or average conditions. The Mbuluzi basin is expected to experience high flows during the summer under average year conditions with no significant differences from the observed flows during winter months. For the Ngwavuma catchment, climate changes are expected to bring less runoff in the catchment under dry year conditions. Based on the results, the team is currently working on the identification of appropriate mitigation strategies to accommodate high flows in the Mbuluzi catchment and lower flows in the Ngwavuma area. This study required the use of simulation models. The project’s researchers did have the capacity to in part handle some of the models, but they need to be assisted by and receive input from specialists outside the country (e.g. South Africa). The problem is that such specialists have limited time due to busy schedules and that there are no real incentives for them to assist. It also places a strain on the project’s expenses since inviting specialists from abroad requires the covering of travel costs. Together, these problems hamper the competitiveness of research proposals generated within the project, especially in terms of applying for and securing grants.

Evaluation of the socio-economic impact of water projects on women’s projects

This project is still at the proposal stage, but it has been favourably reviewed and requests for amendments are currently being addressed. The funding party has already allocated a small grant (US \$2000) for the researchers to meet the WARFSA criteria. This is an example of a project where women researchers are being encouraged to work on gender issues. There is a paucity of research work done by women in the area of water resources. This study identified the ability of the research team to establish the quality of water sources despite the absence of well-trained technicians and supporting staff.

Conclusion

The general conclusion that can be drawn from the presentation so far is that the country and the department has tried to undertake research in water resources in spite of the many problems involved. Most of the studies have tried to establish available water resources and future demand. There has also been an attempt to establish the impact of development activities as well as climate changes on water resources. There is an attempt to study the management of water resources as well as to evaluate the impact of existing developed water projects on development with a focus on women’s development. A lot remains to be done in terms of water resources research. For example, there is no research on whether current water projects have achieved their objectives, yet this is crucial information in the ongoing work of improving efficiency in the use of water resources. There is no information at all on how water resources are managed and shared by different socio-economic groups including gender access and use of water in the country. Such studies are necessary to inform water managers on the status quo as well as on how the issue of equity in water access and use can be addressed. The above concerns, and in particular issues of gender equity, will be highlighted as soon as more research has been focused on this area; research which hopefully will be undertaken to an increasing degree by women scientists and researchers.

The scientific capacity to undertake water resources is as noted generally poor. The picture is even gloomier when it comes to water resources research by gender. This tends to be the domain of the men (particularly water engineers) to the disadvantage of women. The possibility of women to become involved is limited by their inability to write

strong research proposals that are able to secure research funds. This has to do with patterns established already during formative school years and which lead to less illustrious academic careers. Most water-related research tends to be oriented towards engineering or mathematics and other related fields and there are very few women in these fields. The few that have made it into these fields need assistance. Overall, the country's ability to write winning research proposals has to be strengthened. Skills in key research tools like research methodology, GIS, remote sensing techniques, quantitative analysis and modelling is lacking and needs to be built. Although this is a general problem for the country, women are disadvantaged. The disadvantages are generated early on as very few girls are encouraged to enter into the science fields. Efforts should be made to motivate women towards research and careers in the science disciplines so that future water engineers, managers and decision-makers are willing and able to address the gender divide in water relations.

Currently there are many efforts being undertaken to improve access to water, but these are hampered by the inability to sustain water projects. While others are talking of water demand management, the issue here is access to reliable safe water sources. To address this, water supply problems have to be made sustainable. Research on sustainable provision of safe and reliable water resources should be encouraged and its capacity strengthened.

The elevation of the socio-economic status of women is necessary for the introduction of more women in education, in particular in research and science. Girls and women have to be given the opportunity to break free from their gender roles of collecting water and firewood. To empower themselves they need appropriate technology, which has to be purchased, and the means to pay for their education. Women also have to provide food for their families. Women's access to cash and food can be boosted through small irrigation projects aimed at increasing crop production. This is yet another area in which major research needs to be carried out, not only in terms of technological issues but increasingly in the areas of management and decision-making concerning water-related aspects.

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Capacity building for improved water management in Africa: Breaking the vicious cycle through effective linkages between science and policy

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Summary

This paper explains how challenges facing the continent in the water sector require substantive increases in investments in capacity building. It also observes that efforts being made are trapped in a vicious cycle that weakens the chances of achieving long-lasting results. In order to break this vicious cycle and turn it into a virtuous one, the paper advocates for a system approach to capacity building. By acting at the various levels of the circle (from support for data collection and analysis infrastructures to training of researchers and decision-makers, as well as opening more space for consultation between science and policy), prerequisites can be created for a more policy-relevant approach to water science and improved accessibility of scientific information for decision-makers and water users. In turn this will lead to greater political and public attention and financial support in favour of education and research in the water sector.

Capacity building

The freshwater situation in Africa is characterised by contrasts and paradoxes. While Africa is among the best endowed continents in freshwater resources, its people have the lowest access to clean water for drinking and sanitation, the lowest per capita food production, and the lowest access to other water-dependent services such as electricity (hydropower). More than 40 percent of Africa's population has inadequate access to water as opposed to 15 percent in Latin America and 20 percent in Asia (World Water Council and Global Water Partnership, 2003). Only one fourth of Africa's area for potential irrigation is currently so empowered. Africa's per capita electricity consumption is less than 400 kWh (against a world average of about 2000 kWh), while its installed hydropower capacity amounts to only one percent of its known exploitable potential. While Africa is among the most vulnerable continents to climate variability and change, it is the region where the least investments have been made on water control infrastructures (dams, diversions, irrigation schemes): For example, of the existing 45000 large dams, only 1600 or less than four percent are located in Africa.

In order to speed up Africa's development pace and reduce the currently rampant poverty, unprecedented levels of investments, especially in the water sector, will have to be made. Even in the event of increased financial support from the international community, one critical question remains to be answered: Does the continent have the institutional capacity and internal scientific and technical expertise to conduct these investments so as to achieve the desired development outcomes? If we take, for example, the latter criteria (scientific and technical expertise), we find that Africa lags far behind other regions of the world as reflected by its low ratio of scientists and engineers compared to its population size (UNESCO, 2003). In such a context, increased efforts to train required expertise are of paramount importance. Even if Africa can continue to resort to the world market of expertise to compensate for the deficits of human resources it faces, lessons from the past (in terms of cost, ownership and long-term viability of investments) suggest that sustained significant progress will not occur unless internal human resources are developed at appropriate levels in terms of quantity and quality.

The development of internal human resources of quality in the water sector as well as in others sectors requires a

systems approach to capacity building. Capacity building can be defined as “the sum of efforts needed to nurture, enhance and utilize the skills and capabilities of people and institutions at all levels ... so that they can better progress towards sustainable development.” Its purpose is to empower people to solve their problems, with the specific objective of *improving the quality of decision-making* (UNDP). Capacity building requires therefore an approach taking into consideration the target community, country or region as a whole.

From this point of view, the nature of the problem facing the continent can be summarised as a vicious cycle comprising the following components:

1. *Poor data collection and management systems.* In general the basic infrastructure for water-related information collection and management is absent or obsolete in most of Africa, which means that the basic knowledge base in the water sector is often not of appropriate quality (Uhlir, 2003, and others).

2. *Weak scientific and technical expertise.* This weakness refers to both the number of scientists and in the quality of the work environment.

Considering the above it should, however, be noted that traditional approaches to capacity building consist in tackling these aspects by providing external donor-supported assistance to train scientists and technicians, to provide research grants, to strengthen selected research institutions or to invest in data collection systems (examples of meteorological and hydrological data collection networks). For these reasons there exist enclaves of highly equipped research centres with well-trained researchers in some countries and within some critical scientific domains.

3. *Poor linkages between science and policy.* Regardless of the nature and quality of the scientific and technical knowledge being generated by researchers and research institutions, there is generally a clear separation between scientific knowledge on the one hand and policy-decisions and water management interventions on the other. In other words, water-related decision-making is rarely adequately informed by available scientific knowledge, which means that capacity building (as defined earlier) is not taking place. The lack of effective linkages between science and policy can be explained by a number of inter-related factors, including the facts that: (a) the scientific information that is available in most countries is of poor quality and low credibility; (b) decision-makers and water-users are often themselves not prepared or qualified enough to absorb available scientific information and integrate it in their policy choices and interventions; (c) the information needs of decision-makers and water users are usually not addressed in scientific research efforts as these needs are often not articulated and made available to scientists.

4. *Low level of investments of public resources in water-related scientific knowledge and expertise.* Since available scientific information is either of poor quality or of low policy relevance, decision-makers lack the incentive to mobilise significant public resources with the aim of improving data collection and management systems, strengthening research institutions and improving the quality and quantity of the expertise in the water sector. As long as these different elements continue to feed each other in a vicious cycle, very few long-lasting results will be achieved.

To break the vicious cycle it will be necessary to conceive further capacity building efforts in the context of a coherent and integrated strategy involving, among others, the following dimensions:

A. Strengthened support for the generation and management of scientific and technical knowledge in the water sector

One way of contributing to this objective is by continuing and even expanding current donor-support in data collection and analysis infrastructure, institutional strengthening of research centres, training of experts, funding of research activities, facilitation of networking with other experts in developing countries and in more advanced ones. In these efforts attention should be given to the following areas: (a) water assessments (water audit) taking into consideration the quality and quantity of water availability as well as water demand; (b) water resources development and management options with priority to low-cost solutions; (c) how much water is needed to maintain basic functions of aquatic ecosystems (environmental flow requirements); (d) regional cooperation, which is of critical importance in Africa due to the high level of water-interdependency between countries. Another important way of achieving this objective is to include explicit capacity building components and targets in planned investments in the water sector, especially the water-related Millennium Development Goals. An effective way of guaranteeing appropriate levels of resources allocation for capacity building within these future investments is to

earmark a share of the investments for capacity building.

B. Creating mechanisms for consultation between science and policy

This will contribute to better informed water-related decisions based on scientific support and will lead to scientific efforts becoming more demand-driven and policy-relevant. Very promising results are being observed through regional dialogues on water and climate changes facilitated by IUCN (the World Conservation Union) in various parts of the world over the last few months. These dialogues provide the opportunity to bring together experts and representatives of research institutions on climate issues on the one hand, and government experts involved in climate-change negotiations, civil society organisations and representatives of water-user groups on the other (Bergkamp and Orlando, 2003). It is also important to note that for these consultations to take place in an effective manner, scientists, policy-makers and representatives of water-user groups need to be able to speak the same language, which requires a minimum amount of shared knowledge. Therefore, government experts and water management institutions (ministries, river basin organisations) and representatives of civil society organisations and water users need to be increasingly targeted in training programmes and institutional capacity building efforts.

These suggestions for breaking the vicious cycle are based on the assumption that when decision-makers have greater access to qualified scientific information with which to reach policy decisions, they will be more willing to increase investments of public resources in water-related data collection and analysis infrastructures, in training experts and funding research programmes.

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Greywater reuse: A sustainable water resources management approach

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Summary

The aim of this presentation is to document the experience of the Inter-Islamic Network on Water Resources Development and Management (INWRDAM) in developing greywater (GW) treatment and reuse as a concept of low-cost ecological sanitation solutions and related applications on large scale in Jordan and nearby countries. GW is sewage water collected separately from clothes washing, showers and sinks; water from toilets does not qualify. GW comprises about 60-75% of residential wastewater and when treated can be used in groundwater recharging and landscaping and for the irrigation of certain crops. A case study on GW reuse in Jordan is presented to shed some light on its role in sustainable water management. The role of women in the management of water was emphasized at the Dublin Conference 1992, as was the fact that water is an economic good and a finite resource that should be valued and managed in a rational manner. The study included in this paper shows how current environmental policies should aim to control pollution and to maximize recycling and reuse of GW within households and communities. Public participation in decentralized water resources management offers more options for maximizing recycling opportunities.

Introduction

It is estimated that between 2000 and 2024, the total global average annual water availability per capita will fall from 6600 m³ to 4800 m³. Due to uneven distribution of water resources, some three billion people will live in countries wholly or partly arid or semi-arid with access to less than 1700 m³ of water. Countries or regions are broadly considered water stressed when annual per capita availability is between 1000-2000 m³. When availability falls below 1700 m³ a country is deemed water scarce, and if availability is less than 1000 m³, the situation is considered severe.

Access to fresh water is finite despite the fact that water is a naturally renewable resource (not least through precipitation). Further, access to water is to a significant degree uneven over time and space. In 1989, Falkenmark, Lundqvist and Widstrand ranked countries according to access "per capita annual water resources" (www.watercasa.org). If a country has access to annual water resources of 1700 m³ and above, shortage will be local and rare; for 1000 m³ and below it will have an adverse impact on the health of the population and the economic development of the country; and for countries with access to less than 500 m³, there will be severe constraints on the ability to secure the well-being of the population (Falkenmark et al., 1989). In 1995 INWRDAM published water scarcity data for the 55 Muslim countries detailing how most of these countries fall below the critical availability limit of 1000 m³. Further, ten of the countries had access to less than 500 m³ per capita.

The conventional paradigm of water/wastewater management has been characterized as a supply-driven, centralized and large-scale development. This approach has led to the over-exploitation and depletion of renewable water resources, the mining of non-renewable groundwater resources and the deterioration of water supplies. The collection and disposal mind-set prevailed because it was thought to favour the general health populations. Domestic wastewater is traditionally collected in sewer systems and transported to large central sewage treatment plants.

Treated sewage effluents are discharged into the environment without much direct reuse or recycling. Unfortunately, this creates an endless demand for more and more water which cannot be met with finite surface and groundwater supplies. Water demand management is therefore becoming a must for many countries that face increasing pressure on limited water supplies. The logical outcome is to reuse treated wastewater, most importantly within irrigation since the same water sources can be utilised. Some countries of the Middle East such as Jordan and Israel have already diverted large quantities of fresh water from irrigation to municipal and industrial uses.

Centralized sewerage systems, the hitherto preferred choice for planners and decision-makers, are seldom located appropriately in relation to individual communities and wastewater has therefore had to be transported from scattered communities to centralized facilities. The high cost of conventional sewers is regarded as one of the major constraints to expanding wastewater services to small communities. A World Bank review of sewerage investments in eight capital cities in developing countries found that the costs ranged between US\$ 600-4000 per capita (prices as per 1980) with an annual total cost per household of US\$ 150-650 (Chandrant, 2002). Conventional sewerage systems tend to cost more in small communities. Because of their size and layout, small communities do not enjoy the economies of building large systems. The low population density means that longer sewers are needed to serve each household. The per household cost of the Jordan Valley rural sanitation project was projected at US\$ 2200, four times the average of all urban wastewater projects constructed in Jordan between 1997 and 1996 (Mara, 1996).

Conventional sewerage systems are designed as waste transportation systems in which water is used as a transportation medium. Reliable water supplies and consumption of 100 litres per capita per day (lpcd) are basic requirements for a problem-free operation of conventional sewerage systems. Conventional sewerage is not appropriate for small communities in the Middle East region where water supplies are intermittent and only limited amounts of water are available. By transporting the wastewater away from the community in which it is generated, several reuse opportunities are lost, not least since reuse opportunities in the form of landscaping and agriculture are often located within the community. Recent research and developments in the field of wastewater management suggests that centralized wastewater management is environmentally unsustainable (Loredo and Thompson, 1998).

Greywater reuse

A functional and sustainable wastewater management scheme begins at the household level and is largely dependant on the human component. Only when the outlining of needs and the demand for wastewater reuse systems have been internalized at the neighbourhood/user level will planning and implementation be successfully executed (Hedberg, 1999). Local level support of a treatment and recovery scheme can, in turn, catalyze pro-active institutional and vertical government support. Once the software component has been integrated into the project development, the “hardware” or technological component can act to promote a comprehensive, integrated and sustainable wastewater treatment and recovery strategy for the community - if it is well selected and “appropriate”. Wastewater treatment technologies in the developing world must have one overriding criterion: the technology must be cost-effective and appropriate.

GW reuse represents the largest potential source of water saving in domestic uses. The reuse of domestic GW for landscape irrigation makes a significant contribution towards the reducing the use of drinking water. In Arizona, for example, it is documented that an average household can generate about 135,000 to 180,000 litres of GW per year (Khouri et al., 1994). This illustrates the immense potential amounts of water that can be reused, especially in arid regions like the Middle East and North Africa. Domestic GW reuse offers an attractive option in arid and semi-arid regions due to severe water scarcity, rainfall fluctuations and the rise in water pollution. To ensure sustainable water management, it is crucial to move towards the goal of efficient and appropriate water use. GW reuse contributes to promoting the preservation of high-quality fresh water as well as reducing pollutants in the environment. Meeting different needs with the appropriate quality of water may prove to be economically beneficial and at the same time reduce the need for new water supplies at a higher marginal cost (www.watercasa.org).

Health guidelines

Wastewater treatment for reuse must meet quality standards safe for human contact and consumption of irrigated crops. In most countries, guidelines and standards for GW either do not exist or are being revised and expanded. The most frequent guidelines directing the reuse of GW to a level considered safe for the health of the population are

those outlined in the Engelberg Standards. These guidelines outline acceptable microbial pathogen levels for treated wastewater for reuse in restricted and non-restricted irrigation. Restricted irrigation refers to the irrigation of crops not consumed directly by humans (e.g., trees, fodder crops). For restricted irrigation, wastewater effluents must contain ≤ 1 viable intestinal nematode egg per litre, implying a $>99\%$ treatment level. Unrestricted irrigation refers to the irrigation of vegetable crops eaten directly by humans, including those eaten raw, and also to the irrigation of sports fields, public parks, hotel lawns and tourist areas. The criteria for unrestricted irrigation contains the same helminth criteria as restricted irrigation, in addition to a restriction of no more than a geometric mean concentration of ≤ 1000 faecal coliforms per 100 ml/treated effluent. These guidelines have been introduced to protect the health of consumers eat uncooked crops such as vegetables and salads (Odeh, 2003).

Greywater treatment processes

The daily quantity of GW collected or recovered from a household is usually small. The major difficulty in treating GW is the large variation in its composition. For instance, laundry effluents contain a high concentration of detergents and washed-out dirt and this can double or even treble the organic content of the greywater. Cooking and frying oil and fat in the form of food remains on dishes and cooking utensils are the biggest source of organic pollution in GW recovered from an average family house.

There are a variety of methods that can be used for treating GW rendering it suitable for the irrigation of home garden crops that are not intended to be eaten raw. However, when selecting a treatment method, low costs and a minimal need for advanced technology must be the determining factors. Anaerobic treatment systems, such as up-flow anaerobic sludge blankets or wetlands constructed within confined spaces offer reasonable choices for GW treatment. Anaerobic treatment processes are not affected by wide variations in influent quality or shock loads as are aerobic processes. GW is separated from blackwater and is piped to a suitable point outside the house. A two-stage treatment system comprises oil and grease separation followed by gravity separation of suspended matter is the first treatment stage followed by a biological treatment stage under anaerobic conditions. Sand filtration can be used to remove or capture solids that interfere with irrigation.

The main pollution load in GW is in the form of organic matter and pathogenic microorganisms. GW can contain at least $10^5/100$ ml of potentially pathogenic microorganisms. Stored GW undergoes changes in quality, which includes growth in the numbers of microorganisms according to the limiting factors for each particular microorganism. Research has shown that counts of total coliforms increase from 10^0 - $10^5/100$ ml to above $10^5/100$ ml within 48 hours in stored GW from various sources. Of more concern is the potential infection route that GW provides for viral infections.

It is important that the nutrient resources (nitrogen and phosphorous) be conserved if the wastewater is destined for use in agriculture irrigation. GW reuse in irrigated home gardens in rural areas offers a higher potential of success and public acceptance.

Characterization of raw greywater

The quality of GW is directly related to the amount of water used within the household and it is affected by the occupants' habits, such as bathing, use of disposable or washable diapers and whether the dishes are cleaned manually or in a dishwasher. A flush toilet consumes much more water than the non-flush type commonly used by the rural poor in developing countries and most of the Middle Eastern countries. Highly urbanized and high-income families use much more domestic water than the rural poor. The kitchen is a major source for pollutants in GW, with clothes-washing and laundry coming in second. Some countries enforce regulation that prevents the mixing of GW originating from the kitchen sink with GW from other sources in the house. Soap, shampoo, detergents and cleansing chemicals generally entail a significant increase in the pollution of greywater. Table 1 shows typical GW quantities from different sources within a household. The figures for suspended solids and turbidity are relatively low, which indicates that most of these contaminants are easily dissolved.

Table 1: Average daily water use for a household in a rural area in Jordan (Mara and Cairncross, 1989)

Source	Lcpd
Intake and cooking	10
Kitchen, manual dishwashing	15
Bath/shower	20
Laundry	20
Toilet, non-flush	15
Miscellaneous and irrigation	40
Total	120

The COD:BOD ratio may be as high as 4:1 (varies more than in values reported for sewage), which is mainly due to the use of low biodegradability detergents. COD values varied as much as between 40 to 370 mg/l between sites, with similar variations within individual sites. GW has also proved to be deficient in macronutrients such as nitrogen and phosphorous (Bino and Al-Beiruti, 2000-2003).

INWRDAM experience in greywater treatment

Jordan is one of the ten most water-scarce countries in the world with access to water per capita of less than 200 m³. Jordan is situated in a semi-arid zone with uneven distribution to and variations in precipitation from one year to the next. Rainfall quantities vary from 600 mm in the highlands to less than 200 mm in the eastern and southern deserts, which constitute 90% of the country's surface area. The supply cost of domestic water is high because the main supplies are situated in average more than 100 km away from consumption centres. Domestic water provision in the country is more than 90% and most rural areas are served with piped water and electricity.

With these factors in mind, a INWRDAM research project in GW reuse was undertaken in the village of Ein Al Baida in the Tafila Governorate in Southern Jordan from 2001 to 2003 with funding provided by IDRC. The objective was *"to help the periurban poor in Jordan preserve precious fresh water, achieve food security and generate income while helping to protect the environment"*. To achieve this the following objectives were outlined:

- Increase GW recovery and make it more convenient and safe to handle;
- Minimize environmental impacts associated with GW reuse and determine whether GW treatment is necessary and cost-effective;
- Improve gardening/permaculture practices;
- Strengthen local capacity to safely and efficiently reuse GW and enable women to become better managers of household resources;
- Promote changes in policies to encourage greater GW reuse in Jordan.

Baseline data was collected about domestic water consumption and GW quality as well as the type of crops grown in the area and how willing households were to participate in reuse of greywater. The project involved 23 low-income households, the main high-school for girls and the main mosque. The average family size was 6.2 persons/household and domestic water consumption was 136 lcpd, which is above the national average in Jordan, which is 135 lcpd. This is due to the use of fresh water for the irrigation of home gardens and the watering of livestock.

The baseline data revealed the following:

- The average BOD₅ of raw GW ranged from 300 mg/l to 2300 mg/l due to low water consumption since kitchen sinks were considered a source of recovered greywater.
- The detergent concentration in greywater measured by the methylene blue alkyl sulfonate (MBAS) ranged from 10 mg/l to 300 mg/l.
- Salinity of GW was on average equal to 820 deciSemens/m (ds/m), which is nearly double that of the 450 ds/m value for domestic water supply.
- Average background soils salinity measured as sodium adsorption ratio (SAR) was about two.
- Olive trees constituted the main crop cultivated in home gardens, which were on average 1000 m² large. Further, most families preferred to raise chicken and goats.
- Most households had no religious or cultural barriers against reuse of wastewater and women were willing to learn new methods of irrigation and home gardening.

Women leaders in village communities were identified and received training so that they in turn were able to train other women in such things as how to prevent upstream pollution by using detergents in a more efficient way and by applying better dishwashing practices and permaculture techniques.

On-site GW treatment methods for single families were investigated with the aim of introducing better construction and maintenance techniques at low cost and in yielding GW of a quality suitable at least for restricted irrigation. Two modular treatment methods were developed and field-tested over two years. The first type came to be known as the kit module and consists of two 160-liter polyethylene barrels, whereas the second type, called the intermediate module, consists of four polyethylene barrels, two with a capacity of 160 litres and two with a capacity of 220 litres. The kit module is very simple to construct and can achieve good oil/grease and suspended matter separation and includes sump fitted with a small electric pump for the delivery of GW to a drip irrigation system. The intermediate module consists of an oil/grease separator followed by two-stage gravel (3 cm diameter) media of 220 l each and includes sump fitted with a small electric pump for delivery of GW to a drip irrigation system. A third treatment method was tested that proved suitable for extended families living within compounds of several houses. This method was based on the construction of four concrete compartments below ground level with a total volume of 6.5 m³. The first compartment provides suspended growth of anaerobic bacteria followed by two-stage gravel media beds that provide attached growth conditions, and a final trickling stage filter which functions under aerobic conditions. Figure 1 shows the kit module and Figure 2 shows the intermediate module. The main materials needed for construction are available locally, such as recycled polyethylene barrels, PVC pipes and drip irrigation fittings.

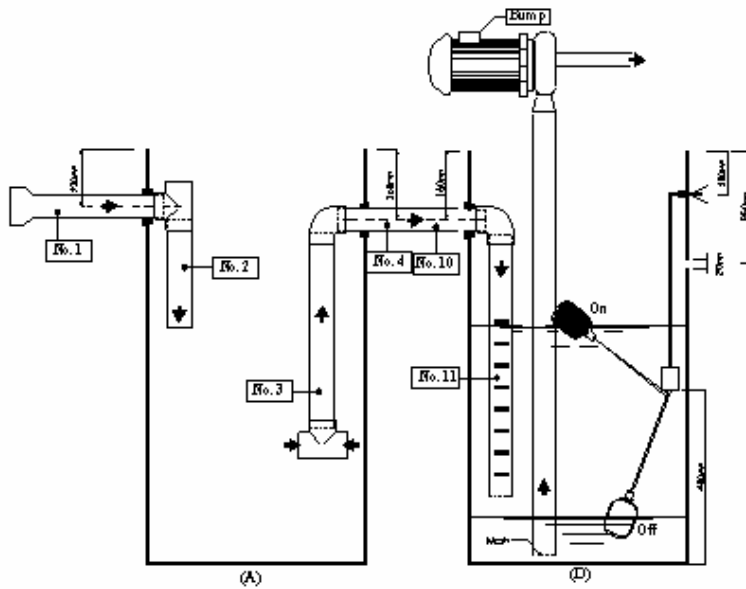


Figure 1: The kit module

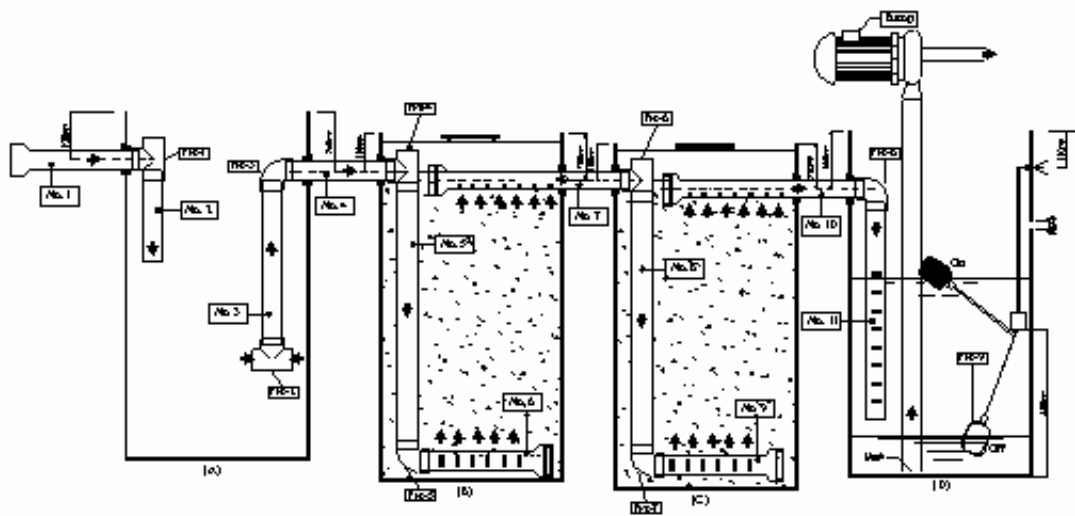


Figure 2: The intermediate module

The GW quality parameters are shown in Table 2. The parameters for 25 users in the project area show the degree of effectiveness in the treatment of greywater. The variation in GW quality was substantial and was affected by how aware the family members were in terms of preventing upstream pollution. The regular cleaning of the oil and grease separator barrel resulted in big improvements in the treatment and reduction of coliform counts.

Table 2: Greywater quality parameters

Sample type	pH	TSS	O&G	BOD ₅	ABS	(FC/100) ^a 10
Raw greywater ^a	6	316	141	1500	101	7
TGW sample 1 ^b	7	42	20	106	20	5
TGW sample 2	6	158	13	680	89	6
TGW sample 3	6	517	50	1011	99	6
TGW sample 4	3	56	5	99	21	6
TGW sample 5 ^c	8	171	8	66	3	4
Average TGW	6	189	19	392	46	5
Percent reduction ^d	-	0.4	0.86	0.74	0.54	-

^aWeighted means of raw GW from households.

^b TGW: Samples 1 through 4 represent treated GW (TGW) for households.

^c Sample 5 represents treated GW from institutional buildings.

^d Rate of change between two means (raw and TGW).

The GW could be used for irrigating olive trees, smooth leave cactus and fodder crops. Monitoring of the impact of GW on soil and plants after two years of application revealed some increase in soils SAR, but it was below levels that have an adverse effect on plant yields. All plant growth rates were improved due to regular complementary irrigation and there was no fecal coliform contamination of crops.

The cost of the kit module for a family of six and including a drip irrigation system for a 2000 m² large garden area amounts to around US\$ 230. An intermediate module for a family of twelve amounts to US\$ 370. A concrete module for 30 persons costs around US\$ 1700, including drip irrigation systems.

Conclusions and recommendations

The project resulted in many direct and indirect benefits to the community and the environment. Women in the community benefited most from this project through training workshops, dialogue and learning by doing and acquired new skills to build a productive garden and management skills. The monthly domestic water consumption decreased by about 30% to all GW users and income of the poor increased on the average **by US\$28 per month** and many beneficiaries had no longer to pay large portion of their meager monthly income to regularly emptying their septic tanks. Many families started to copy and imitate the practice of their neighbors with respect to GW reuse (as practised by the inhabitants in the village of Ein Al Baida.)

The following recommendations can be made regarding the appropriateness of GW reuse technologies:

- The scheme or technology should be a public and environmental health priority, and both centralized and decentralized technologies should be considered.
- The technology should be low-cost and require as little input in the form of energy and mechanization as possible, especially as this also reduces malfunction risks.
- The technology should be simple to operate, adapted to local labour skills, maintained by the community, and should not have to rely on expensive chemical inputs such as chlorine or ozone to meet quality guidelines.
- The treatment should be capable of being incrementally upgraded in line with an increase in user demand and quality standards.

The results of this project convinced Jordan's Ministry of Planning that GW reuse can preserve fresh domestic water, help improve agriculture productivity at the household level and generate income. As a consequence, the Ministry

provided funding for INWRDAM in September 2002 to implement 700 GW units in rural areas of Jordan. This project was successfully completed in June 2003.

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Strengthening research capacity in integrated water resources management in the Central American region

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Introduction

REDICA is a network of Central American Educational Engineering Institutions comprising eleven public and private universities in Panama, Costa Rica, Nicaragua, El Salvador, Honduras, Guatemala and Belize, as well as professional associations. The faculty deans act as contacts and each programme developed by REDICA has a project leader against which the deans work.

We fulfill an important role in terms of capacity and training within academic circles struggling with a region characterised by highly vulnerable climate changes and significant restrictions on water resources due to contamination and inadequate management. To be efficient and to guarantee equity of access, we work with disseminating information to users, academia, researchers and managers of water resources. The supply of information for research is vital in avoiding disasters. Local solutions to natural risks and the handling of climate changes without consideration for the vulnerability of water resources are a source of constant worry that can only be addressed on a well-informed level.

Meeting basic human and ecosystem needs for water in all forms is best ensured by creating prerequisites for the preservation of natural resources. Science and technology in combination with new standards for production and environmental awareness are essential for a more efficient and gentle use of resources.

Strategy for strengthening research in high education institutions

This is a time of transition and the strategies that we try to implement must be thoroughly sustainable with the aim of improving the quality of life. This requires structural changes in the standards of production and consumption as well as in the appropriation of natural resources. Most of all, we need to change how we care for, conserve and use water.

One of the elements of this quality of life has to be the use and conservation of water resources; making available basic sanitation, running water, good and equal access to water resources, and treated sewage sanitation to those who are lacking such supplies. "Water should be a promoting factor of sustainability and peace" (Forum of NGO, 2002).

According to National Wildlife, there is the same amount of water on the face of the Earth as there was 2000 years ago. This means that a limited supply of freshwater must meet the needs of a human population that has tripled in the last century and that continues to grow with the addition of almost 80 million people per year. The demand for water for human uses had caused wildlife and freshwater ecosystems to disappear at alarming rates (www.nwf.org).

With this in mind, we developed within one of our major programmes a strategy for research based on the following ideas:

- Research activities at institutions of higher education play a significant role in the long-term development of the Central American region.

- Research is an important instrument for sharing knowledge on key development issues and adaptation strategies for the management of droughts and floods in Central American countries.
- Water resources management should be based on a participatory and gender approach.
- The efficient use of water resources shall be the goal of our regional research programme.

Central America is a very vulnerable region facing climate changes and scarcity of fresh water. The primary risk is not a quantitative one but one of quality. A complex situation involving different users within agriculture, hydroelectrics, tourists' facilities, ecosystems and drinking water create significant differences between sectors and conflicting interests become political issues. In addition, the region is not only vulnerable in terms of floods, tropical storms and drought, there are now new phenomena carrying new and long-term risks. Landslides are becoming an increasingly difficult and reoccurring hazard and have severely undermined the ability to create a sustainable existence in high-risk areas.

Regional statistics

Between 1996 and 1997, Central America was hit by weather extremes, which produced a severe drought in the region. The devastating Hurricane Mitch unleashed floods the following year. In 1999, there was a second drought, and since then the economy of thousands of rural families, whose have relied on the cultivation of corn, bean and coffee, has been undermined. Clearly, poverty and environmental degradation are closely related and the poor suffer the consequences of environmental degradation the most. The 1992 Hague Report estimates that most poor people live in areas of high biodiversity and fragile ecosystems: 80% in Latin America.

As a region, we are dealing with the high probability that as a result of the thermal expansion of water and the fusion of the glaciers, the sea level will rise from 10 to 30 cm by the year 2030 and by one meter by 2050. Such an ascent would entail contamination of our drinking water, the recession of coasts and wetlands, the loss of fertile land, and increase in serial floods, an impact on the reservoirs in coastal zones, the substitution of ecosystems, the degeneration and impoverishment of the ecosystems, loss of species and, finally, a decline in the capacity of land to sustain life.

According to the definition in the Third Report of the IPCC, we understand adaptation to mean "adjustments in the human or natural systems in response to current or future climate stimulus and its effect, in such a way that damage is minimized and that advantage is taken of the new opportunities created by such changes" (McCarthy et al., 2001).

In regard to Central America, an increase in temperature and the duration of the dry season have been identified as probable effects of climate changes, as well as more intense precipitation, an increased risk of droughts and cyclone activity. As a result of these extremes the region is expected to experience increased damage caused by soil erosion, particularly in the coastal zones, floods, landslides, structural damage, mudslides and avalanches, as well as a reduction in crop productivity and in the quality and availability of water resources. Further, there will be an increase of forest fires and damage to coastal and marine ecosystems, as well as a mounting risk of death in connection with an increase in vectors among the population.

Central America should prepare itself to confront and reduce the risk created by climactic change and climactic variability in order to anticipate and resolve conflicts and incompatible water uses by incorporating policies for sustainability aimed at increasing the participation of and gender equality within the construction of strategies for conservation and integrated water resource management.

Guatemala is to 60% dependent on underground water, Belize to more than 50% and El Salvador to more than 80%. More than 50% of the water used in Honduras and Panama comes from groundwater. The corresponding figure in Nicaragua is 95% and in Costa Rica 75%. The region is in other words vulnerable to climate variability and long-term climate change since the capacity of the water table is directly related to rainfall, according to research done by the Central American Geology Faculty.

- In just one year, 2002, droughts impacted adversely on 625,775 persons in Central America.
- 8,6 million inhabitants of Central America from 122 rural communities are victims of natural disasters.
- Chronic poverty and prolonged droughts have accumulated effects (malnutrition).
- The main threat to water sources is the lack of protection for 75% of vulnerable supply sources.
- 29% of the inhabitants in the region do not have access to safe drinking water.
- 25% of the population does not have a sewer system.
- This percentage increases to 39% of the inhabitants in the rural areas.

REDICA is concerned about gender balance and supports the participation of women in different stages as a members of research groups, at the community level and in the analysing of data. The role of women and NGOs in water management and conservation strategies in developing countries is something that we try clarify for our members, and we lend our support to the construction of indicators with which to measure these important issues. This work is carried out together with the Gender and Water Alliance and Global Water Partnership.

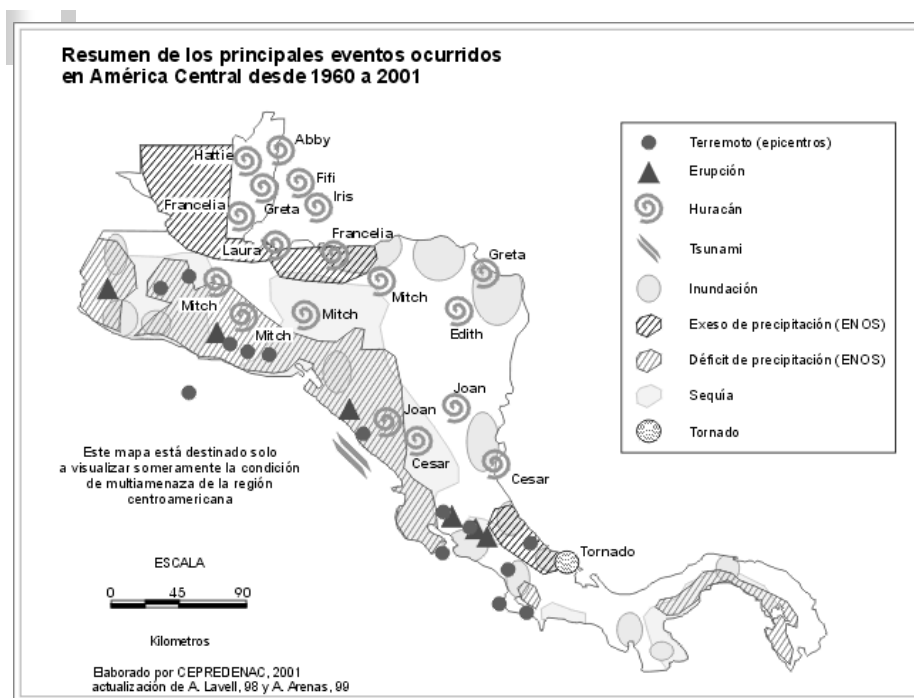


Figure 1: Major natural disasters in the region, CEPREDENAC, 2001

Research as a strategy of adaptation

Research has been identified as one of the most important mechanisms in achieving regional and local appropriation of knowledge, which in turn can be applied to improve the situation of vulnerable communities. Research applied simultaneously in different countries facilitates knowledge ownership and has favoured interpretation adapted to actual situations on in local communities. We believe that research activities in higher educational institutions play a

significant role in long-term development policies and that the assimilation of knowledge reduces the vulnerability of Central America as a region. Research also facilitates the sharing of knowledge within key development issues, such as conditions associated with droughts and floods in the region. Good research planning improves the skills of the researchers; they one the ability to take responsibility for communal projects, which in turn has a multiplier effect. The water sector needs training in research, the mastering of techniques and the ability to enhance skills. The development of scientific knowledge in Central America is important for assessing regional and national needs and risks. Thus support for research should primarily focus on the universities in order to help them fulfil their responsibility to develop and disseminate knowledge.



Figure 2: The Orosi bridge in Costa Rica collapsed under intense rainfall in 2002

Why work at university level

At the beginning of this project we were challenged to improve the capacity to respond to and reduce the vulnerability of the region with the help of the academia. The long-term approach of the International Organization is to process and improve the responsibility and emergency attention for disasters on the national level, but the reorientation of policies and the working out of good implementation strategies takes a long time. We have thus needed to utilise a second group, i.e. new professionals in the region. New graduates are set to become local and national leaders. Our challenge is to raise their awareness about water scarcity and vulnerability already before they come into decision-making positions.

We believe that the universities of the region should:

- Raise awareness in order to reduce the vulnerability, scarcity and pollution of water.
- Identify risks due to the climate variability and long-term climate changes by sector, by resources and by communities.
- Improve the training of new professionals in high technology and modern tools so that they are able to identify future stages.
- Support research in order to further the ability of professionals to take responsibility for the development and dissemination of knowledge.

Research within higher education should:

- Support research capacity building at Central American universities in order to promote conditions (a culture) that encourage professionals and students to utilise knowledge in decision-making.
- The research programme of REDICA will contribute to regional and local developments by using the capacity of universities for the teaching of values, the dissemination of knowledge and the creating of new skills.

Objectives:

- Support knowledge development and strengthen research capacity in Integrated Water Resources Management (IWRM) and climate changes within the university sector.
- Exchange relevant information.
- Forge regional cooperation between members.
- Generate new data that can facilitate comparison between the seven countries of Central America.
- Improve academic quality.
- Enhancement of the gender perspective in scientific research, not only among researchers, but in the communities too.
- Improved the dissemination and use of research results by the authorities.
- Develop a common understanding of the issues and challenges involved in IWRM and Climate Change Adaptation Strategies, as well as for needs involved in Capacity Building in Central America.
- As a network REDICA is able to support its members in using knowledge to reduce water resource vulnerability.

Why a network?

By having established new and better forms of communication and networking, REDICA is able to push to a new level information on how science in the region should be carried out and how that information is shared for common and useful purposes. REDICA is presently developing regional research on how to adapt to climate variability and long-term climate changes. We are also mapping the risks, some of which are exceptional, threatening water resources in Central American countries. Information must be widely disseminated throughout the water sector and users of basin rivers. Network members and REDICA itself can supply the technical advice and regional structures necessary for supporting the research, but we need financing for buying materials, hiring temporary human resources and supporting teachers to interpret the data.

- We need to be able to share relevant information quickly.
- Research capacity in the entire region needs to be improved.
- Support has to be supplied for the use of new technology and the exchange of research in similar areas or within similar themes.
- Access to and regular use of the internet needs to be strengthened so that relevant information and new technology is made available to university members.
- We need to train regional leaders and reproduce workshops at local and national levels.

- Specialised libraries need to be expanded in each of the eleven universities.
- We need to work out a way of making the regional expert database available to researchers.

Last year we produced a guide to summit research projects initiated by REDICA in the following fields:

- Basic Investigation (systematic search for knowledge without necessarily having to produce practical applications of the results).
- Applied Investigation (project-oriented towards practical application).
- Technological Development Investigation (group of activities with the aim of designing, developing, innovating and perfecting prototypes, models, production processes and materials).

Strategies

We understand Integrated Water Resource Management to be a process with the objective of assuring the development and co-ordinated management of water in interaction with other natural, social and cultural systems. IWRM should maximise economic well-being without compromising vital ecosystems.

A successful implementation of Integrated Resource Water Management relies on the generation of detailed information regarding user needs and water availability, information that is not always available in Central America. Thus it is important to support this kind of research and to encourage the standardization of methods for data collection and analysis. Integrated Water Resource Management is a strategy that correctly implemented reduces vulnerability and improves efficiency levels in the use of vital resources, especially in river basins identified as especially sensitive and in the face of climate change and variability. Equity and solidarity should be the guiding principles.

Research 2002

During 2002, research was developed by REDICA members within areas that are of major concern to the association, namely:

- Causes and effects of climate changes in Costa Rica: Increments of the disasters and impact on the availability of water resources.
- Guatemala: Climate changes, impacts on groundwater and repercussions on local development plans.
- Diagnosis of the effects of climate changes in the Pacific coastal zone in Costa Rica and Guatemala.
- User demands on and access to water resources in the Abangares river basin and the sub-basin of Aguas Claras and Gongolona: 25-year projection.

All the above research projects have been financed with the help of UNDP and GWP/Central America.



Figure 3: Gongolona, water intake (UCR study 2002)

New proposals for 2003-2004

The REDICA universities have initiated new research projects in Panama, El Salvador and Costa Rica, one of which is taking a closer look at running water, slides and social vulnerability. The objective of the research is to identify the vulnerability of hydric resources in relation to different types of erosion such as landslides and mud flows since these have an immediate and direct impact on the supply and quality of water resources available to rural communities.

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Networks as instruments for scientific capacity building

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Introduction

Cap-Net is an international network for capacity building in integrated water resources management. It is a UNDP programme and a Global Water Partnership (GWP) associated programme. Cap-Net's direct partners are regional and country level capacity building networks working in integrated water resources management. These networks are mostly composed of capacity building institutions, such as universities and training institutes, but also NGOs, government agencies, private companies, development programmes and others.

Networking for capacity building in integrated water resources management is a relatively new phenomenon that has emerged especially during the last year. Just over a year ago only one such network was operational, namely WaterNet in Southern Africa, whereas today 15 country and regional networks have been established and are at different stages of development. All these networks have different origins and compositions, but have in common the objective of enforcing better management of water resources by ensuring the capacity to do so in a given country or region. The networks therefore mainly focus on delivering capacity building through training and education, institutional strengthening and providing the legal framework within which integrated management can take place.

This new trend towards networking for capacity building offers great opportunities to strengthen the academic basis of the networks' member institutions. Building on the strengths of partners in a network, spin-off effects are created through the exchange of research and activities between members. Information generation and knowledge development is thereby accelerated. Network research programmes and inter-network knowledge exchange are expected to boost local water resources management practices.

This paper examines the characteristics of emerging networks and how they interact with the global network Cap-Net. Strategies in the field of capacity building for integrated water resources management that are developed and adopted by Cap-Net and its affiliated regional and country networks are briefly explained. The development activities of Cap-Net and the networks in the area of research and the way the networks benefit from a common research programme is described in the final section.

Networks

Many regional and country networks for capacity building in integrated water resources management have emerged over the last year or so. There are now some 13 networks affiliated with Cap-Net, each with their own characteristics:

Regional networks

- REDICA - Central American Educational Institutions Network: Strong emphasis on climate change and environmental issues;
- CARA - Central American Water Resources Management Network: Aims to increase the capacity of regional universities;

- LA-WETnet - Latin American Network for Water Education and Training: A network of capacity building institutions and regional organisations who seek to increase IWRM capacities in the region as well as improving access to water and sanitation, all with a focus on equal rights in health and development;
- WA-Net - West Africa Capacity Building Network: A network for regional cooperation among training, education and research institutes and organisations engaged in IWRM;
- WaterNet - Regional network of capacity building institutions with expertise in water resources management in Southern Africa;
- NileNet - a Nile Basin programme for applied training in IWRM that focuses on institutional development and interaction among water professionals;
- NBCBN-RE - Nile Basin Capacity Building Network for River Engineering: A human resources development and institutional development network;
- Awarenet - Arab Integrated Water Resources Management Network: A knowledge development and research promotion network;
- SaciWATERs - South Asia Consortium for Interdisciplinary Water Resources Studies: Aims to improve capacity building within IWRM through education, research and training;
- SeaCapNet - Southeast Asia Regional Network for Capacity Building in IWRM: The objective is to increase access to training and education in WIRM and stimulate regional cooperation and research.

Country networks:

- InaCapNet – Indonesia
- ArgCapNet – Argentina
- MyCapNet – Malaysia

Several other networks are currently being established in, for example, Central Asia, Central and Eastern Europe and the South Pacific.

The networks have different origins. Some are closely linked to GWP regional partnerships, whereas others have developed from relations with international organisations or programmes. The potential they have for improving capacity building in water resources management is now widely recognised since few individual capacity building institutions are able to offer all the skills required and even fewer have experience in achieving an overall approach to efficient water resources management. Networks of capacity building institutions provide an effective strategy for sharing experience and skills and securing the expertise required to address the demanding requirements of reform towards sustainable management of water resources (Cap-Net, 2002).

Some of the networks mentioned have a strong emphasis on applied research related to different aspects of water resources management. Some of the networks receive external support for the development of research programmes and others seek support through local or other international channels. Networks establish partnerships that in turn become powerful tools for building the research capacity so important to forming a scientific basis of benefit to both individual institutions and the network as a whole. Cap-Net therefore supports intra-network and inter-network research activities and assumes a facilitating role in exchanging information on research programmes.

The global network of Cap-Net

Cap-Net consists of an international secretariat based in Delft in The Netherlands and affiliated regional and country networks. As such, Cap-Net is understood as a global network of networks for capacity building in integrated water resources management. The principles that bind the network together work in two ways, first in the form of global level support to regional networks, and second as input from the regions to the global network.

The type of support that Cap-Net provides to the regional networks ranges from technical and financial assistance throughout the take-off phase of a new network establishment to help in organising specific topic-oriented training. Cap-Net also provides appropriate capacity building materials and support for research, development and activities. Networks that want to be affiliated with Cap-Net commit to relaying information on changing demands for capacity development, exchange of experience and provision of capacity building materials both to the global network and other affiliated networks, thus collaborating in regional and inter-regional research.

The global network offers great opportunities both for capacity builders at country and regional levels and for global programmes with the objective of extending awareness throughout entire regions. In this respect, Cap-Net functions as an intermediate and is currently developing a collaborative programme together with IFS for the promotion of research in sustainable management of water resources. Other partnerships have been set up on the global level to strengthen capacity development programmes in the regions and to better adapt programme contents to actual conditions on local levels.

The Cap-Net website is an important vehicle in the communication and dissemination of information to and from regions as well as for sharing capacity building materials. Apart from information on events and news concerning capacity building in water resources management, the site allows for publishing and downloading of courses, resource materials and information on the various networks. The Cap-Net website has become a focal point for capacity building in integrated water resources management for many capacity building institutions and individuals worldwide.

Capacity building

Capacity building is interpreted as the ability of individuals and organisations or organisational units to perform functions effectively and sustainably. This implies that capacity is not a passive state but part of a continuing process and that human resources are central to capacity development (UNDP, 1998). Capacity building consists of three basic elements (Alarts et al., 1991):

1. The creation of an enabling environment with appropriate policy and legal frameworks;
2. Institutional development, including community participation; and,
3. Human resources development and the strengthening of managerial systems.

How capacity building supports the transformation to IWRM is depicted below. The individual and institutional capacities as well as the enabling environment are prerequisites for the implementation of IWRM. They provide the frameworks for institutional and human resources development adapted towards a practical implementation of IWRM. Capacity builders (institutions as well as materials) should provide the knowledge and tools relevant to the development process.

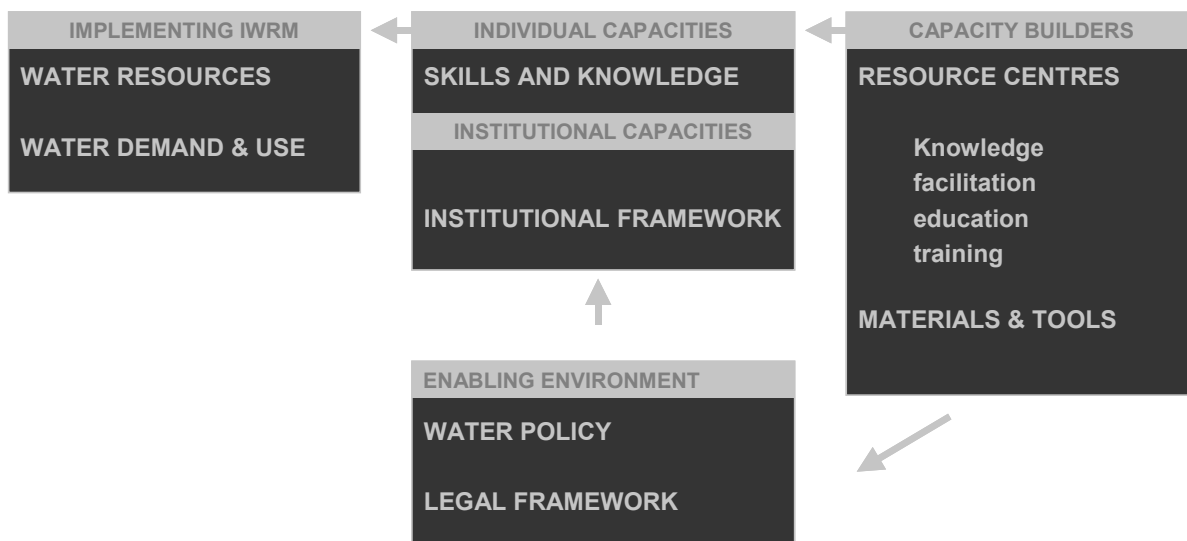


Figure 1: Water sector capacity building

Networks affiliated with Cap-Net share a vision for capacity building based on three principles (Cap-Net, 2002):

1. *Local ownership* of the capacity building process improves awareness and sustainability.

Without recognition of local capacity building institutions as key players in establishing the core for sustained delivery of capacity building services and their roles as information and knowledge centres, external interventions will have problems in achieving an impact in the long run. By anchoring the process in local institutions, capacity building services will both strengthen their responsiveness to local needs and gain insight into their own capacity constraints.

2. *Partnerships* improve capacity building performance by building on the strengths of the individual partners.

Integrated water resources management requires new mixtures of skills and brings together multiple disciplines across traditional technical boundaries. Few institutions are able to offer all the knowledge required for successful IWRM capacity building, for which reason partnerships are a viable option as they build on the collective strengths and capacities of the members. Because the partners are able to complement each other, they become essential tools in ensuring that capacity building demands on IWRM sector reforms are met.

3. *Responding to demand* ensures that capacity building activities have an impact.

Capacity building service providers should be encouraged to adopt a more demand-driven approach and identify the immediate needs and demands of communities and how best to respond to these. When a local capacity building institution fails to engage with the water management implementing agency, the institution is often perceived as unable to deliver the goods, which leads to a lack of confidence both within and for the institution. Taking a responsive interest in capacity building, on the other hand, guarantees an immediate impact.

These principles should not only apply to programme development within the networks, but should also be considered in decision-making processes at both the local and the international level.

The three principles are equally relevant for training and education programmes. Applied research needs to be locally embedded to have an impact on the management of local water resources. The best way of developing adequate research programmes in a multi-disciplinary environment is to build on the scientific strengths of a network's individual members.

Strengthening research

The global paradigm shift towards integrated resources management puts heavy pressure on capacity building and applied research development. Resource centres need to respond to the changes in demand for water education and expand the scientific base necessary to deal with the situation.

The challenge for meeting changes in water management from a sector-based to an integrated approach is to adapt research and education programmes accordingly. The integration of water management requires a multi-disciplinary and multi-sector approach towards scientific capacity development. Networks of capacity building institutions will be instrumental in the development of research programmes with the aim of creating and delivering complete packages.

Capacity building networks can be seen as instruments for scientific capacity building in integrated water resources management because:

- They have the ability to together address salient issues in water management in a multi-disciplinary manner;
- They are in a position to provide strong research results by building on the individual research strengths of the members;
- They are likely to deliver research that is relevant to local water management issues and respond to particular needs in their respective regions;
- They have access to global scientific developments via their global networks and international organisations.

Cap-Net supports the development of a research programme shared by the affiliated networks in various ways:

- *Research information databases*

Cap-Net assists regional and national capacity building networks in IWRM in the development of regional and national research information databases within member capacity building institutions. The creation of databases for research information will not only help the network to collect and disseminate information on research programmes between the members, but will also provide insight into the research activities of partner networks.

- *Inter-network research programme*

On the basis of global research priorities and information collected in connection with research programmes undertaken by network member institutions, an inter-network research programme is being developed. The programme will combine the various skills and experiences of different network members and it is hoped that teachers and researchers will be given the opportunity to interact. It will also contribute to a better understanding of salient water management issues under different circumstances.

- *The Cap-Net – IFS programme*

A joint project has been developed by IFS and Cap-Net to promote research for sustainable management of water resources. The purpose of the programme is to identify and support young promising researchers in the area of water resources, and to establish regional research programmes. The networks have a distinct role in the implementation of the programme in terms of assessing research priorities and reviewing applications for scholarships, as well as promoting the research programme on the regional level.

Cap-Net's support for network researching will provide the scientific foundation required for the networks to deliver adequate and responsive capacity building for better management of water resources.

Conclusion

This paper describes the potential that capacity building networks have in the scientific development of integrated water resources management. The principles that are applied by Cap-Net as well as by the affiliated networks form an adequate and relevant framework for scientific capacity building. The understanding is that the sharing of research and the mutual building of knowledge within integrated water resources management will make the networks stronger as well as improve the performance of individual members.

A network is more than the sum of its contributing elements. The exchange of information and knowledge between members and networks allows for the development of joint research programmes that build on the strengths of the members while promoting multi-disciplinary and multi-sector research. When translated into water resources management activities, such programmes ensure a holistic and integrated approach. In other words, the capacity building networks become instrumental in finding responses to the paradigm shift towards integrated water resources management.

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Promoting basic scientific research on water in Southern Africa

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Introduction

As we know, it is imperative to preserve available water resources in drought-prone countries in regions such as Southern Africa. A sustained programme of monitoring water quality is essential and this requires continued and sustained input of financial resources and planning.

Several organizations are funding projects that address these issues, such as the International Foundation for Science (IFS, Sweden). IFS is well-known in developing countries for providing grants in several disciplines of research including water resources and aquatic resources. Summarised below are requirements for the successful promotion of basic scientific research on water in Southern Africa and a list of constraints. The latter can be seen as having a restrictive effect on research in general.

Requirements

- Trained manpower
- Infrastructure
- Capital equipment
- Consumables
- Networks

Constraints

- Funding for Manpower
- Training
- Exchange

1. Manpower: Developing Countries (DCs) usually have a source of manpower in the form of young, intelligent and enthusiastic men and women who want to undertake research and pursue research careers. Where training is lacking, it is usually down to a corresponding lack in funding. As a consequence, in order to promote their research these young men and women have to go abroad, thus sapping the manpower in DCs. The few who try to remain in their home countries soon find the shortage of functional facilities too constraining and are under constant pressure to abandon native research projects for projects in Western countries. One way to retain enthusiastic researchers is to provide adequate stipends which may not match those provided in the West but suffice for local conditions. Although many DC institutes provide stipends to young researchers, they are usually not adequate. It would therefore be useful to establish grants aimed specifically at post-graduate students.

2. *Infrastructure:* Physical infrastructure is usually available in most countries through various institutes of higher education and government facilities. However, other essential requirements such as capital equipment and consumables are usually lacking.

3. *Capital equipment:* In order to conduct thorough research on water quality a vast array of equipment is needed such as GCs, HPLCs and ICPs. These cost thousands of euros and are thus difficult to *both purchase and maintain* given the national budgets of developing countries irrespective of whether funding is provided within or outside government systems.

4. *Consumables:* Consumables can be acquired from local resources but there is never enough and most consumables therefore need to be imported from Europe. This requires foreign currency, which is either unavailable or cannot be afforded.

5. *Networks:* In Europe and North America scientific communities have ample opportunities to interact, share information and do collaborative research. In contrast, laboratories in Southern Africa are isolated geographically or by language (or even political) barriers. The financial cost for exchange of personnel (students and staff) is therefore prohibitive.

International Science Programme (ISP)

The International Science Programme at Uppsala University is a programme that was started over 40 years ago. Initially providing travel and staff exchange opportunities between DCs and Sweden, it has gradually evolved into an organisation that provides long-term funding to recognized projects in the poorest countries in Africa, Latin America and Asia. Projects are supported only after consultation with local project leaders able to present a clear picture of their project's aims and objectives and who apply basic sciences to local problems. In addition, grant applications must be well thought-through and professionally presented. ISP is divided into three sections: IPICS, IPPS and IPMS for chemistry, physics and mathematics respectively.

ISP's main objective is to identify potential projects for long-term support, i.e. projects that can supported over a period of ten to 15 years. Allocations are granted for three-year periods with renewals based on satisfactory progress. Annual awards are in the region of US\$ 30000 a year. The long-term aspect allows for a more confident planning of future activities within a project. By international standards the level of funding is low, but it is generous considering the limitations of local universities and institutes.

One of the most important features of the projects is what is known as sandwich-type PhD programmes for which projects of local concern are identified and then developed with the help of Swedish collaborators. ISP plays a crucial role wherever possible in the identification of suitable collaborators in Sweden/EU. Sandwich PhDs are extremely useful for developing countries. Traditionally staff development programmes under which young graduates are sent abroad to acquire their PhDs have resulted in very few, if any, of the researchers returning to their home countries. In contrast, sandwich programmes enable students to familiarise themselves with local problems in the very regions where they aim to undertake research, allowing them to build up knowledge and identify constraints on site. In Sweden, they work on their projects by acquiring new technology in the process which they then introduce back home. With the help of the project leader, Swedish collaborators and ISP grants, researchers are able to determine and fund necessary equipment and set it up locally. Further, students within sandwich programmes develop a strong affinity with their research groups and institutes or countries and do not experience the frustrations of their Western-trained counterparts upon returning to a DC. This is important, not least because sandwich programmes enforce the transfer of technology from EU countries to DCs. Grantees value this aspect of the ISP programme as it builds capacity locally both in terms of infrastructure and human resources. ISP also stays in regular contact with their projects, often on site. Project leaders do not have to operate in isolation and useful formal and informal discussions help them focus on the objectives of the project as well as on how ISP staff is doing in order to appreciate current and often unique local problems and constraints. Constraints include the logistics associated with the purchase of equipment and consumables since agents/suppliers and backup services (for equipment) are usually few and far between in DCs.

Part of ISP's approach is to take good care of students who visit Sweden. Usually matters such as accommodation and transport have been taken care of by the Secretariat before the arrival of new participants. The aim is to achieve

as smooth and trouble-free an induction period for visiting students as possible so that they can concentrate on achieving the objectives of the programme, i.e. those of training and research.

ISP encourages participation at regional (preferably) and international conferences for the exchange of ideas and information, allowing researchers to keep up to date with recent developments and future research orientations. In addition, participation enables networking, i.e. excellent opportunities for the informal build-up of contacts, which in turn facilitates the build-up of more formal networks. Happily, a number of networks that focus on different issues have already been established in the region. Although a network dedicated to water research alone has not yet been set up, ISP supports networks that directly or indirectly deal with water research, such as:

1. African Network for the Chemical Analysis of Pesticides (ANCAP) - Tanzania
2. Network for Analytical and Bioassay Services in Africa (NABSA) - Botswana
3. Southern African Regional Co-operation in Biochemistry, Molecular Biology and Biotechnology. (SARBIO) - Zimbabwe
4. Southern and Eastern Africa Network of Analytical Chemists (SEANAC) - Botswana
5. The Africa Branch of The Society of Environmental Toxicology and Chemistry (SETAC) - South Africa
6. The Network of Users of Scientific Equipment in Southern and Eastern Africa (NUSESA) - Zimbabwe

Travel and training within a region are rendered easier with the help of such networks both for experts and for students and technicians, who not least are given access to laboratories with sufficient equipment for analysing samples. This limits the need to send students/technicians to Europe or America for further training and reduces the risk of researchers running out of steam. Also, funds are provided for consumables needed for training.

IPICS and basic water research

The International Programme in the Chemical Sciences (IPICS) has a number of projects in DCs, spanning from physical chemistry to molecular biology. Among these are projects dealing with food chemistry, plant chemistry and environmental chemistry. Recently there has been increase in the identification and support for projects that address issues of water and water pollutants. Currently, four projects are underway in various countries in Sub-Saharan Africa that address issues of water pollution and drinking water quality, two of which are on pollution of aquatic resources by pesticide pollutants. In Africa, which has many agro-based economies, such projects are particularly important in that they address issues of local concern.

IPICS provides grants for projects already underway and for projects led by project leaders with at least some research experience. IFS also plays a useful role in the development of research on water, particularly in a project's start-up phase. IFS provides small grants of about US\$ 12000 over three years, which can be renewed twice. Such grants allow for young post-graduates to begin a career in water resources and aquatic resources (among other disciplines). Although the grants are competitive, they provide sufficient resources to start a pilot project which, if successful, can apply for renewals. The aim is to accumulate a reasonable amount of data that can attract bigger funding. In the process the grant also allows for the training of undergraduate and post-graduate students, providing the funds are used judiciously. This allows organisations such as IPICS to build on work already carried out by IFS and select successful projects for future support.

One of the authors of this paper has experience as an IPICS project leader, one project of which focuses on aquatic toxicology whereas others involve measurements of pesticides and metal residue levels in dams around Bulawayo, the development of biomarkers of pesticide pollution, and identification of endocrine disrupters and genotoxic agents in industrial waste water. The project leader was fortunate in that IFS provided funds for consumables for the initial phase of the research on water pollution and that the project already had access to existing resources. Thereafter, IPICS stepped in with funds for infrastructure, i.e. a spectrophotometer, a centrifuge and a number of other laboratory items. Thanks to two additional grants from IFS, three undergraduate student projects materialised and we

were able to train a technician. A renewal grant provided consumables for a dedicated student to complete her MPhil and she is now considering doing a PhD. Things really took off when IPICS began to support the project. Since 1999, and more emphatically since 2001, the provision of substantial resources has allowed for the initiation of the three previously mentioned projects, all of which are studying issues of water pollution. A Swedish collaborator has been appointed and we expect to establish more contacts in the future depending on our needs.

To summarise: Ideas and manpower are available in DCs but for several reasons (most of which are political) some DCs do not provide adequate financial resources for researchers in their own countries. Most DCs usually prioritise issues that Western countries do not have to deal with. Sub-Saharan Africa, for example, is battling HIV/AIDS as well as other communicable diseases such as malaria, which claim thousands of lives every week and absorb large chunks of the health budget. DCs are therefore in dire need of outside help from organisations such as Sida, SAREC, ISP and IFS who can help identify projects worthy of support and who are able to offer such support on a long-term basis.

Building water management research capacity in developing countries

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Introduction

The last 50 years have witnessed enormous changes in the way people use water for productive and economic purposes. Between 1950 and 2000, the world's population increased from 2.5 to 6.0 billion. Concurrently, there was a ten-fold increase in the number of large dams, from 4270 dams to over 47000 (ICOLD, 1998). Water withdrawals have jumped from 1360 cubic kilometres to 4000 cubic kilometres (Shiklomanov, 2000). Agricultural withdrawals have increased from 1080 to 2600 cubic kilometres (Shiklomanov, 2000), while cultivated land expansion has increased at a much slower rate from 1063 million hectares to 1360 million, demonstrating the important role additional water has played in agricultural production. Water resources development has not only led to significant changes in land and water systems, but also to the skills required for researching and managing water and land resources, and the kinds of institutions required for managing these resources. Is there adequate capacity to effectively respond to these changes?

Starting from the beginning of modern water development and large-scale irrigation in the mid-19th century, the human capacity to drive these changes required skills in civil engineering, agronomy and economics. Skills were needed to construct massive and complex civil works such as dams, water treatment and water distribution systems. Economists helped to figure out what kind of investments would yield the best return for society, and agronomists provided management practices and crop breeding techniques to increase yield with more fertilizers and water. A remarkable achievement has been the doubling of food production in the last four decades, outpacing population growth.

But with increasing development, new and unforeseen sets of problems emerged in the water sector. Malnutrition and poverty persist. In irrigation, it was soon discovered that storage and delivery systems do not automatically lead to equitable distribution of water – good management and effective institutions are required. Drainage problems and salinity build-up manifest themselves after delivery of excess supplies, and continue to persist, threatening the sustainability of resources. Various water uses began to interfere with each other. Agricultural, city, and environmental uses began to vie for the same quantity of water. Water allocation and reallocation are burning issues in much of today's world. Important aquatic ecosystems have borne the brunt of much of the water resources development. Protection and restoration of ecosystems are vital in many basins. One researcher (Zhu, 2003), writing about the Yellow River, stated that "For years we tried to protect people from the river, and now we are protecting the river from people." All of these changes have correctly led to the call for integrated water resources management (IWRM) that recognizes the linkages between various water uses. The question is whether there is adequate capacity to really perform IWRM the way it should be.

This paper provides a conceptual background to the need for changing capacity requirements for IWRM. Based on this background, water resources capacity building needs are identified. IWMI's capacity building programme is highlighted as a case study, and we then make some concluding remarks.

The need for adaptive capacity

Changes in water use can be illustrated by conceptualizing phases of river basin development (Molden, 2002). In its most basic form, water scarcity is a situation where people have difficulties getting access to water for drinking or growing crops. As a reaction to water scarcity, people tap basin water resources. Hydraulic structures, ranging from simple stone and wood diversion structures to complex dam, canal and drainage systems supply water from stream flow for drinking and industrial supplies, and for agriculture. Rain-fed agriculture converts land use from its previous cover (forest, grassland) to cropland, impacting the previous hydrologic regime and, as a consequence, ecosystems dependent on that regime.

At any particular time, the available water supply is limited by the installed hydraulic structures and land placed under cultivation. When demand exceeds this available supply, one response is to provide more either by expanding hydraulic infrastructure or by expanding rain-fed agriculture. This supply approach is ultimately limited by the amount of land and water resources within a basin, the technical and economic limits we have in abstracting this supply (it would be difficult to divert the entire Amazon), ecological thresholds beyond which ecosystems cannot sustain land and water use practices, and societal demands.

A typical pattern for river basin development is as follows. Over time, more water is made available for human uses from stream flow or groundwater by building structures (dams, diversions, groundwater pumps). After a new dam is built, it takes time to deplete all available water by converting it into evaporation. Populations grow, wealth rises and demand increases until depletion reaches the available supply, when possibly another structure is built. Similarly, conversion of land to rain-fed agriculture yields more water (directly from rain) for agriculture. Three important phases of river basin development are implicit in the above discussion.

1. Development

In this phase, the amount of naturally occurring water is not a constraint. Rather, expansion in demand drives the construction of new infrastructure and expansion of agricultural land. Institutions are primarily engaged in expanding facilities for human use.

2. Utilization

Significant construction has taken place, and now the goal is to make the most out of these facilities. Water savings and improved management of water deliveries are important objectives. A common phenomenon during this phase is the growth in the amount of reuse either through drains, downstream diversions or groundwater pumps that ultimately deplete more of the available supplies. Institutions tend to be concerned with sectoral issues such as managing irrigation water or managing drinking water supplies. The creation of the International Irrigation Management Institute (IIMI), for instance, was in response to the perceived need to improve management of irrigation systems, especially new ones that were constructed in the 1950s to the 1980s.

3. Reallocation

When depletion approaches the potential utilizable water, there is limited scope for further development. We refer to this as a “closed basin” (Seckler, 1996). Efforts are placed on increasing the productivity or value of every drop of water. An important means of accomplishing this is to reallocate water from lower to “higher value” uses. Reallocation of water to achieve both sustainability and equity among competing demands becomes a major issue. Institutions are primarily involved in reallocation, conflict resolution and regulation. When resource depletion outstrips sustainable limits, environmental restoration becomes an important agenda item.

In the case of closed or closing basins, inter-basin transfers can provide relief. A south to north diversion of water from the Yangtze to the Yellow river basin currently under construction could provide some relief to the highly stressed North China Plains. There are other responses though – such as limiting or managing demand for water, or reducing agricultural use of water. National policy responses include providing other non-agricultural employment or importing “virtual” water (Allan, 1998) in the form of trade in commodities into the basin. How societies respond to the crisis of overexploited resources is one of the critical water resource management questions of our times.

Water management concerns differ depending on the phase of basin development as illustrated in Table 1. Institutions have to adapt to meet these changing concerns. For example, interest may shift from constructing facilities to better management of supplies. As basin closure approaches, however, demand management becomes a critical concern. At any phase, though, there could be overlap with another. For example, even in the development phase, managing demand could be a concern, especially when depletion approaches available supplies. The following sections describe how capacity requirements vary as per phases of development. “Capacity” has multiple dimensions: financial resources, human resources and overall institutional capacity, which is partly a function of the first two dimensions. In this paper we focus on human resources.

Many of our traditional education programmes have targeted the skills required for the development phase – engineering and economics. There is limited expertise in the areas of management, ecology and social sciences in the area of water resources. Often engineers, skilled at constructing projects, are placed in the role of managing projects, dealing with pollution and negotiating between stakeholders, tasks for which they do not have the appropriate skills. We expect water management organizations with the difficult enough task of distributing water to be able to deal with pollution, or to negotiate water rights agreements. Capacity is often out of step with changing needs.

Table 1: Various dominant characteristics and concerns at different phases of river basin development (adapted from Molden, 2002)

Characteristic	Development	Utilization	Reallocation
Dominant activity	Construction	Managing supplies	Managing demand
Value of Water	Low value of water	Increasing value of water	High value of water
Infrastructure	Installing new structures	Modernization/rehabilitation	Measurement, regulating
Groundwater	Utilizing groundwater	Conjunctive management	Regulating groundwater
Pollution	Diluting pollution	Emerging pollution/salinity	Cleaning up pollution
Conflicts	Fewer water conflicts	Within system conflicts	Cross-sector conflicts
Water Scarcity	Economic water scarcity	Institutional water scarcity	Physical water scarcity
Data	Water data – perceived importance less	System water delivery data important	Basin water accounting data important
Water-poverty concerns	Including/excluding poor in development of facilities	Including poor in O&M decision-making	Loss of access to water by poor
Important skills	Engineering construction, economic project analysis	Management and organization building, organizational procedures, operation and maintenance skills	Social sciences, detailed monitoring, environmental sciences, negotiating skills

Solving types of problems emerging in phases of utilization and allocation requires a different set of specialties than in the early development phases – management specialists to help build appropriate institutions and procedures; social scientists to understand people, their relationships with each other and the environment; ecologists to understand how changes in hydrology affect ecosystems. It also requires a different way of working. Specialists of different disciplines have to work together, and more importantly have to work with water stakeholders. Standard education may provide the disciplinary skills, but other skills of working with communities and in interdisciplinary teams is required.

There is also another dimension. In some regions of the developing world only a small percentage of available water resources have been developed, contributing to under-development, poverty and malnutrition. Sub-Saharan Africa as a whole has developed only about three percent of its water resources. The region lacks sufficient capacity in the traditional development disciplines such as engineering. But it is also important for African countries to develop the full range of modern water resources development and management capacities – the “soft” as well as “hard” disciplines if it is going to develop its water and land in a way that avoids most of the serious consequences of “traditional” approaches.

Building water management research capacity

We use capacity building to refer to both enhancing human resources – individual capacities – and to enhancing institutions’ ability to mobilize and use their human resources. Capacity building requires upgrading of skills in order to handle these various concerns. But effective capacity building goes beyond this. Empowerment and negotiating skills are required in a highly competitive water-world. Who will take advantage of infrastructure projects, and who will be the winners as water is reallocated? People and institutions must develop the resilience to adapt to a rapidly changing world – the capacity to learn to learn. And institutions must be designed in a way that provides incentives and resources to people to achieve their objectives.

Research plays an important role in building the adaptive capacity to manage water resources. Local communities need to adapt quickly to changing situations. For example, irrigation agencies may be required to develop water savings approaches in response to water shortages. Water resource institutions managing or regulating supplies are being reformed. Many construction-oriented agencies are being reoriented to manage river basins.

Research support institutions have to be ready to deal with new sets of questions that emerge. In some cases this is research to help water managers develop solutions adapted to local needs. In other cases, there are generic problems with unclear answers. For example, we just don’t know how to effectively govern groundwater, and serious strategic and well as applied research is required. In other cases, applied research is required for communities to respond to arising problems. Research skills required include interdisciplinary perspectives on problems, the ability to work in multi-disciplinary teams and with communities and policy-makers, and the ability to communicate results to the stakeholders who must take action.

Building water management research capacity requires actions at several levels – within individuals managing water on farms, community-based organizations, water management agencies to manage and regulate shared resources, policy-makers to understand changing situations, and the research community itself. It requires hands-on experiential learning.

IWMI’s strategy on research capacity building

The International Water Management Institute’s mission is: *“improving water and land resources management for food livelihoods and nature”*. To achieve this, IWMI conducts a research and capacity building programme in some 20 developing countries. The research is put into action in five research themes managed through five regional offices across Asia and Africa.

IWMI’s approach is to integrate research and capacity building in its programme. All projects are done in partnership with organizations such as local universities, the NARS (National Agricultural Research Institutions) communities and, increasingly, local NGOs. We see capacity building as a “delivery mechanism” for the knowledge and experiences generated through IWMI projects.

Some approaches that IWMI has put in place include:

- Benchmark basins concept – long-term partnerships (20 years) with NGOs, government agencies and local universities to study water, food and livelihoods situations as a part of IWMI research. These are IWMI’s field laboratories, which typically bring together 15-20 partners in a given basin.

- Including post-doctoral scientists, PhD and MSc students as a capacity building component in many projects beginning at the proposal stage. Some of these students are drawn from water management agencies or national research institutions as a way of strengthening institutional capacity.

The Strategies

- Specifically target interactions with senior policy-makers and members of the development community to take up the knowledge produced.
- Targeting more funds for post-doctoral candidates, PhD and post-graduate students and research assistants.
- Making partnerships the normal way IWMI conducts its business.
- Systematically “translating” the recommendations and benefits of research to a variety of target users.

IWMI has always been engaged in capacity building activities, but initiated a more systematic and ambitious programme as part of its Strategy 2000-2005. At the moment, this programme is being reviewed as part of a strategic planning process currently underway at IWMI.

The programme

IWMI’s capacity building programme calls for action in six main areas:

1. Policy roundtables

IWMI facilitates and contributes to water policy and strategy issues with governments. As an international research institution we are seen as an “honest broker.” IWMI research has produced tools to help developing countries better understand and manage their land and water resources. Roundtable discussions are organized to gain access to senior policy-makers and those responsible for decisions at a senior level and create awareness of water issues and IWMI researched policy options.

2. PhD scholarship programme

This is a major activity through which IWMI builds the capacity of future researchers – PhD students interested in doing research in an area that fits in with IWMI’s research interests. IWMI’s PhD policy is focused on students from developing countries and provides for various forms of student support. The course work is carried out at strategic partner universities and field research is usually undertaken at an IWMI research site as part of its research programme, co-supervised by IWMI scientists. IWMI provides intellectual guidance, research supervision, and some research costs to graduate students whose work closely relate to IWMI’s research interests.

For example, in South Africa IWMI has entered into agreements with the Agricultural Research Council and the Department of Water Affairs and Forestry to co-sponsor employees wishing to pursue MSc or PhD degrees. They continue to receive their salaries and benefits; university fees are either paid by IWMI or there is cost-sharing; and IWMI co-supervises the research and analysis component. This programme is at an early stage but is showing considerable promise as a mechanism for capacity building.

3. Post-doc fellowship programme

IWMI complements its staffing through the competitive recruitment of post-doctoral scientists, a majority of them selected from the South. This is a significant benefit for young, promising researchers from the South who have few opportunities or exposure to do research in a multi-cultural environment.

4. Partnerships with NARS and others

IWMI establishes relationships with NARS including national research institutes, universities, NGOs, private sector, and other institutions implementing water research and development programmes, and offers sabbaticals and fellowships to university staff who may carry out research, or prepare lecture notes and other course material based on IWMI research knowledge. IWMI staff members reciprocate by lecturing at these universities and have their

students involved in IWMI research. IWMI also carries out research projects jointly with developing country universities in a way that supports student research. For example, IWMI and the University of East Anglia are partners with Sokoine University of Agriculture in a Tanzanian river basin that supports 6 PhD students. IWMI provides avenues for the private sector to second their staff to IWMI as visiting scientists for short periods.

5. Workshops

As a part of research projects, training sessions, workshops, seminars and hands-on training are conducted to disseminate IWMI's research knowledge and findings to academics, irrigation professionals, students, researchers and farmers and many others in the field.

6. Linkages

IWMI's programme has been effective for individuals and organizations. But as a stand alone programme it is only a drop in a big bucket. IWMI tries to develop key linkages with NARES, universities and water management organizations to become part of a bigger set of players building research capacity. In Southern Africa, for example, IWMI is a member of Waternet, which is a network of about 40 universities seeking to improve their capacity for providing IWRM training to students.

Conclusions

The world lacks sufficient capacity to adequately carry out the tasks of integrated water resources management. Part of the reason is the rapidly changing nature and needs of water resources management in many river basins in the world. The rate of adaptation has not kept up with needs.

Research done by or in support of people and water management organizations is necessary to adapt to changes. Research capacity is required at several levels to build resilience in water resources systems – from individuals and communities to policy-makers to the research community themselves. IWMI's research capacity building programme aims to work with these players, as well as university, private sector and national research agencies

There are many more players in the field of building capacity for IWRM and several in the field of research. There is a very good argument for making available more resources for capacity building. As a community engaged in capacity building, we can be much more effective by developing key partnerships to carry out such tasks. For example, better linkages could be established between NGOs working directly with numerous communities and research agencies like IWMI and universities. University curricula could be more in tune with local problems and the new scientific skills required, but this requires feedback mechanisms from experiences of those working in the field. Much more could be done in finding practical field-based situations for students. There is tremendous scope for communities to learn from each other in how they can research problems to find solutions.

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Supporting scientific capacity by strengthening infrastructure

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Summary

In the age of the global knowledge economy, the sustainable development of a country is closely linked to scientific research. Nevertheless, scientists in many developing countries experience severe constraints to their research. Funding has been identified as the main problem, followed by limited access to scientific equipment, poor library facilities and limited access to scientific literature. The shortage of competent technicians and time, and having to labour in isolation, are other factors that hamper scientific research.

As a consequence, it is vitally important that national authorities, international aid organisations and other organisations addressing scientific capacity building support researchers in developing countries so that they can carry out high-quality scientific activities. To be successful, new initiatives have to be firm, long-term and involve devoted stakeholders.

This paper also deals with the limited access to scientific equipment endured by researchers in developing countries. Problems involve funding, purchasing, transportation, installation, climate conditions, power supplies, maintenance, servicing, policies and guidelines.

Introduction

Science has contributed immensely to human progress and to the development of modern society, yet, as the UN Secretary General, Kofi Annan, points out, scientific endeavours are marked with clear inequalities depending on where they are carried out in the world (Annan, 2003). Developing countries generally spend well below one percent of their gross domestic product on scientific research, whereas rich countries earmark between two and three percent. The number of scientists in proportion to populations in developing countries is ten to 30 times less than in developed countries. As a result, a large portion of new science in the world is created by researchers from developed countries, and much of that science neglects the problems that afflict most of the world's population. The unbalanced distribution of scientific activity generates serious problems not only for the scientific community in the developing countries, but for development itself.

Despite the fact that researchers in developing countries receive only a minute fraction of the resources, a significant amount of high-quality scientific results are produced. Further, other positive factors prevail. During the last 40 years the number of universities in developing countries has increased. In Africa, for example, the number of universities has increased from around ten to nearly 200.

The major responsibility for the future of science rests in the hands of national governments. International donor organisations can, however, play a constructive role by supporting national programmes to improve research infrastructure. International organisations such as the International Foundation for Science (IFS) strive to at the very least to (i) provide summaries of factors affecting research capacity in developing countries, (ii) address the issue of

and support the provision of properly functioning scientific equipment, and (iii) provide general support to strengthen the capacity for water resources research in developing countries.

Factors affecting scientific capacity

In 2000 IFS undertook a survey of 700 natural science researchers in Africa in order to learn about the state of science and research and the working conditions of the researchers on the continent (Gaillard and Tullberg, 2001) (Figure 1).

In this study a lack of funding was identified as the main constraint to scientific research. The second largest constraint was identified as limited access to scientific equipment, and the third constraint was poor library facilities or lack of access to scientific literature. Shortage of competent technicians and support staff, which was identified at the fourth largest constraint, relates to the lack of functioning scientific equipment. Time restrictions and scientific isolation were also mentioned as constraints.

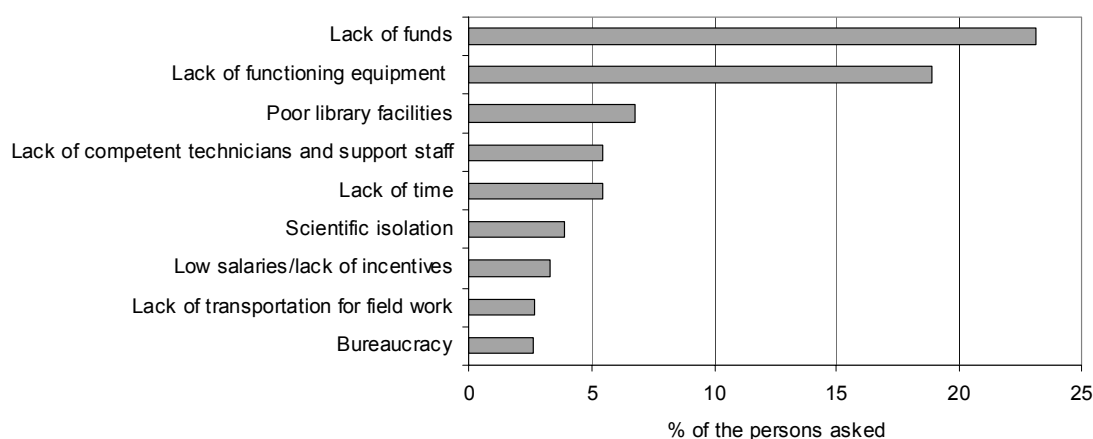


Figure 1: Main constraints to scientific research in natural science disciplines in Africa (Gaillard and Tullberg, 2001)

Availability of funds

The availability of funds has been identified as the major constraint for researchers in Africa. The dearth of funding for research affects young scientists the most as they have not had the chance to establish themselves. Further, the bleak prospects for research funding deter graduates from continuing their research careers. In order to stimulate high-quality research, funding should be made available on a competitive basis for research programmes so as to stimulate academic staff with post-graduate degrees. Research grants can be assumed to have a larger impact on capacity building if they are long-term (five to ten years) and if the projects contribute to sustainable development. It is also important to realise that applicants who have been unsuccessful at securing grants need support in order to improve the conceptualisation and design of their research projects.

Access to scientific equipment

Scientific and technological development is dependent on properly functioning equipment. Trained staff and functioning equipment have been identified as the two most important factors in developing a country's technical level (Selin Lindgren, 2001). Unfortunately, in some countries provisions for the purchasing, servicing and maintenance of scientific equipment are non-existent, which puts a damper on even the most enthusiastic research projects (more details are presented in the next section).

Access to scientific literature and the internet

Poor library facilities and limited access to scientific literature have been identified as main constraints to scientific research in Africa. In 2001, over 50% of the 700 questioned researchers in Africa did not have access to the internet (Gaillard and Tullberg, 2001). In contrast, 95% of scientists interviewed in Mexico during the same year said that they had unlimited access to the internet and that access to scientific literature was only a problem for less than ten percent of them (Gaillard et al., 2001). With vast amounts of scientific literature now available via the internet, connectivity has become imperative for anyone aspiring to scientific research. Research institutions that are connected to the internet not only have the possibility of accessing global scientific literature, but also of making their own research results available globally.

Promoting collaboration

Many researchers in developing countries work in relative isolation. They are marginalised from the international scientific debate and this hampers their productivity. Initiatives promoting collaboration between researchers in developing countries contribute to capacity building. Such initiatives may entail the development of strong networks, the arrangement of scientific thematic workshops, the creation and support of research teams, and sharing of scientific equipment. Mentorship may be an important way of establishing relationships between scientists in the south of Africa as well as between southern-based scientists and northern-based laboratories. In addition, MSc and PhD supervision programmes provide favourable activities for capacity building. A useful method for strengthening scientific capacity is also to support national and regional scientific centres of excellence where basic infrastructure has already been established. Such centres can also act as hosts for researchers within other areas.

Recognition of successful results

Successful results produced by researchers in developing countries deserve greater public recognition. There are a number of scientists that have been doing research for many years, yet they are unable to share their findings and find suitable channels for publishing. Strengthening scientific capacity therefore involves the process of informing the international scientific community about successful results generated in developing countries. This can be done through presentations at international conferences and seminars and through publication in international journals. Besides informing scientists and other stakeholders world-wide, national media, policy-makers and the civil society should be continually updated on generated scientific results. Further, it is also important to get results published in national scientific journals since it is easier for regional researchers to gain access to and exchange knowledge through national publications than via international journals.

Implementation of results

The issue of implementing results is an important one. Collaboration is needed between researchers and end users, including other researchers, policy-makers, representatives of the local community and local companies who are able to develop findings into processes and products. To facilitate such collaboration, it may be necessary to develop new interfaces.

Increased access to scientific equipment

When there is little or no access to functioning equipment, research findings tend to fall below expectations. Whereas a number of laboratories in developing countries are under-equipped, others have used their hard-earned funds to buy capital equipment only to find that for some reason or other they cannot use them. In other cases the experience has been that it is easier to access donor funds for the purchase of new equipment than repair existing pieces of equipment, which is hardly the most cost-effective alternative. The lack of servicing and maintenance also affects the situation in that it is difficult to start-up and maintain the operation of purchased scientific equipment and that many pieces therefore end up unused.

It is therefore essential to initiate firm, co-ordinated and long-term activities aimed at increasing the access to scientific equipment for researchers in developing countries. Important components of such activities include; increasing funding, enabling better pieces of equipment, introducing well thought-through purchasing and transport strategies, ensuring that installations are carried out properly, taking into consideration climate conditions and power supplies, upholding maintenance and servicing, and enforcing policies and guidelines (Öman and Lidholm, 2003). It

is also important that properly functioning equipment is given increased priority at universities and research institution.

Funding

Available funds for purchasing, using, servicing and maintenance of equipment are lacking in the extreme. Every effort should be made to alert politicians to the fact that investing in scientific infrastructure is a necessary precondition for long-term sustainable development. The establishment of national funds for the purchasing, running, servicing and maintenance of equipment would significantly improve the scientific infrastructure. Also, the possibility of attracting private sector funds should be explored for projects of mutual benefit. The funds should be released in a rapid and timely fashion and the process should be transparent. Administrative and financial procedures for the disbursement of funds should be streamlined.

Purchasing

The following constraints have been identified as obstacles in the purchasing of equipment:

- (i) It is difficult to find information on available equipment before decisions on purchases are made. Access to product information as well as more general information about scientific equipment is often lacking. Product information handbooks need to be made easily available for technicians and researchers, and subscription to equipment magazines should be encouraged, especially where internet facilities may be lacking.
- (ii) The high custom duties on equipment, spare parts and related items purchased and imported from abroad is a problem. National governments should be encouraged to waiver custom duties on equipment for research and teaching.
- (iii) Once a purchase has been made, interaction with the manufacturer often comes to an end. The lack of warranties is also a problem. Maintenance contracts and long-term warranty agreements should be negotiated with the manufacturers during the purchase process. Manufacturers offer different kind of support such as demonstration of new equipment, repairs equipment if and when it breaks down, service training for technicians and telephone services which should be utilised. Moreover, scientific equipment should preferably be purchased from manufacturers or suppliers who provide service manuals, sufficient access to spare parts and so on.

Harmonisation of equipment brands

A common problem is that many different manufacturers have supplied equipment to a laboratory as it renders maintenance and repairs unnecessarily muddled. In order to increase the flexibility and interchange of spare parts, the purchase of equipment and other items for a laboratory should be made from a limited number of manufacturers. Even better, countries within the same region should be encouraged to buy equipment and items from the same manufacturers since this would make it easier for the manufacturers' technicians to plan the maintenance of equipment and regularly check in on developments.

Climate conditions and power supplies

By nature, scientific equipment is sensitive to environmental conditions. If a piece of equipment is installed in a location with temperatures and humidity that have an adverse effect on how it functions, research results will at best be unreliable (at worst, of course, it will be impossible to achieve results). Most scientific equipment functions best under temperate conditions, for which reason equipment installed in tropical climates requires special attention. It needs protection from difficult climate conditions such as heat, humidity and dust, yet such protection is often inadequate and the equipment therefore often breaks down. Moreover, most apparatuses required a stable supply of electric power; if the power supply is erratic, the equipment runs the risk of being damaged. Cases of blown fuses, burnt transformers and switching devices are common. Minor as this problem may seem, blown fuses can cause delays, especially if there is no ready access to spare parts. Moreover, units in the hard disk of a computer are often rendered useless by sudden power outages that occur when the computer is up and running. Appropriate infrastructure and premises should be provided to protect the equipment from dust, heat, humidity and unstable power supplies. Provisions should be made for dust-free environments, air conditioning, de-humidifiers and power supply units, including voltage stabilisers.

Installation

The installation of new equipment is not always properly planned. New equipment is best installed by experienced technicians and maintenance and servicing is best undertaken by trained personnel. Ideally a technician should be appointed as responsible for the equipment already during the selection phase as he or she needs to be available when the equipment is delivered for installation. All too often the fact that a trained technician is not on hand to install the machinery has wreaked havoc with what could have been perfectly functional equipment. Further, it takes a long time for inexperienced staff to install machinery, which in many cases has resulted in the expiration of the warranty period before the equipment has been tried and tested to a sufficient degree.

Manuals, spare parts and servicing tools

The lack of user manuals, service and maintenance manuals, spare parts and servicing tools renders the efficient use, servicing and repairing of equipment difficult. A number of items need to be made easily available for technicians and researchers, including user manuals, service and maintenance handbooks, electrical circuit diagrams, spare parts, servicing toolboxes and other test and calibration equipment. Strategies should be worked out for the purchase of items, the ordering of free items from manufacturers, taking inventories of already existing items, and building up a system whereby items are delivered together with purchased equipment for more efficient processing. Technicians should be able to contact their counterparts in other organisations in order to get hold of spare parts, either new or retrieved from obsolete equipment. Photocopies of particular manuals should be made available to colleagues on request. It should be noted here that service manuals for sophisticated computerised equipment are not always provided by the manufacturer since such equipment requires servicing on a level that is beyond technicians other than those employed by the manufacturer.

Career paths and training of technicians

A career profile for technical staff is often lacking and health and safety issues are seldom considered. Technicians are not always offered the training needed to handle the installation, maintenance and servicing of the equipment. Career paths including revised salary scales should be defined for technicians in countries who have not yet done this and safety and health issues should be more strongly enforced. Training and retraining of local technicians and users should be arranged, preferably in collaboration with the manufacturers. The training should be regular, be linked to equipment and facilities already in place and also include information of new technologies. Moreover, trained technicians could train other technicians. As a complement to the training, technicians should be encouraged to attend equipment fairs and exhibitions. In addition, technicians need regular access to the internet, and the use of online advisory websites for consultation would be helpful. The establishment of regional science equipment maintenance centres should be encouraged to minimise duplication of efforts and maximise the use of human and material resources. The levels of expertise required could then be shared and include routine maintenance at the local level and repair and advanced maintenance at the regional level.

Policies and guidelines

It is a problem that policies and clear procedure guidelines for purchase, installation, use, maintenance and servicing of scientific equipment is often lacking. Such policies and guidelines should be developed on the institutional, national and regional levels. Moreover, Standard Operating Procedures (SOP) for the use of the equipment and Good Laboratory Practice (GLP) should be implemented.

IFS support to strengthening capacity for water resources research in developing countries

The aim of the International Foundation for Science (IFS) support programme is to contribute to the strengthening of capacity in developing countries to conduct relevant and high-quality research. To further this goal, IFS supports young scientists in developing country who have the potential to become future research leaders and leading scientists in their nations. The IFS support programme comprises:

- Research grants for the purchase of scientific equipment, expendable supplies and scientific literature as well as funding for field studies.

- Purchasing and delivery of equipment and supplies.
- Servicing and maintenance of scientific equipment.
- Scientific guidance and mentorship to young researchers from well-established scientists.
- Travel grants to attend scientific meetings.
- Access to literature searches and the internet.
- Networking and collaboration between researchers.
- Seminars, thematic scientific workshops and capacity-enhancing training courses.

The research grants provided by IFS amount to USD 12,000 / grant and may be renewed twice. They are intended for the purchase of basic tools needed to conduct research projects, i.e. equipment, expendable supplies, field work and literature. It is essential that research proposals are of high scientific quality and of relevance to the region where they are carried out. Further, they must contribute to strengthening capacity for the sustainable management of biological and water resources. IFS application criteria states that applicants must be young scientists who are embarking on a research career within their native country, which shall also be a developing country, and within which the research work shall be undertaken. Women researchers are especially welcome to apply to IFS. Moreover, IFS supports the development of collaborative research groups in the area of water resources research.

Conclusions

Despite the importance of scientific research for the development of a country, a number of constraints exist within universities and institutions in many countries. This situation has been discussed for a long time and initiatives have been taken to remedy the situation; surveys have been carried out and workshops and conferences have been held. It is therefore concluded that new initiatives need to be well co-ordinated, firm and long-term. It can also be concluded that committed stakeholders have to be involved for new activities to be successfully implemented, and that national authorities, international aid organisation and other organisations addressing scientific capacity building must join forces to be successful.

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The International Foundation for Science (IFS) supports scientific capacity building in developing countries. Established as a NGO in 1972, IFS is today funded by more than 15 donor organisations and has provided over 5,500 research grants and supporting services to young researchers in some 100 countries in Africa, Asia, the Pacific, Latin America and the Caribbean.

IFS identifies promising young scientists working in fields related to the sustainable management of biological and water resources in their early careers and helps them become established and recognised nationally and internationally.

The IFS research grants are awarded through a careful selection process, which relies on a broad network of world-renowned scientists who assess the scientific and developmental value of all proposals. Their feedback and suggestions are provided to all applicants, both successful as well as unsuccessful.

Read more about the IFS granting scheme on www.ifs.se

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