sustainable sanitation alliance

SuSanA - fact sheet

Sustainable sanitation & groundwater protection

08/2009

Key take-aways

1. Groundwater is an important resource

Groundwater makes up 97% of the world's freshwater (excluding inland ice and glaciers) and is a very important source of drinking water. In fact, it accounts for nearly 60% of the world's drinking water supply, whereas in arid and semi-arid zones this rate may even reach 100%.

2. Groundwater is a cheap resource

Groundwater is an efficient form of storage, has comparatively low development costs, is a local resource, for which only minor treatment is necessary, and it does not need complex pipeline systems for distribution.

3. Groundwater and sanitation are linked

Pollution of groundwater from lacking or unsafe household sanitation systems can include: pathogenic germs, chemicals and organic micro pollutants (including pharmaceuticals):

A. **Pathogens** (causing diseases such as cholera, hepatitis A, and many more) die off after a certain time in the subsurface. This time is highly dependent on the soil properties and the subsurface properties. The estimation of the minimum distance from a potential pollution source to the water extraction point (i.e. the pump) requires professional experience and knowledge of the subsurface conditions (e.g. between 10 m and 10.000 m), thus: consult with hydrogeologists!

B. **Chemicals**: High organic content (such as from infiltrating wastewater) can lead to dissolution of harmful substances (like arsenic) in the subsurface, polluting the groundwater. Nitrate at elevated concentrations (>50 mg/l), can be harmful to humans, especially babies (so called "blue baby syndrome). Therefore, fertilizer needs to be applied with caution. Long term accumulation should be prevented. Phosphate is the limiting factor in algae growth in aquatic systems. The phosphorus retention characteristics of different soils and groundwater body types vary greatly according to geological and environmental conditions. Some soils have been linked to accelerated eutrophication of freshwater bodies.

C. **Organic micro pollutants** or so called "emerging contaminants" such as pharmaceuticals, estrogens, ingredients of personal care products, biocides, flame retardants or perfluorinated compounds enter sewer systems or on-site sanitation systems and eventually wastewater treatment plants and/or groundwater. Some of them have been shown to cause effects at environmentally relevant concentrations (e.g. 'endocrine disruptors' effect of 'feminisation' of fish).

4. Groundwater pollution can be prevented

The tools to prevent groundwater pollution are manifold: land-use planning plays an important role in protecting areas that are vulnerable by restricting the use of these areas. In more rural settings Water Safety Plans can play a fundamental role for communities to protect their wells. In larger frameworks as in the case of transboundary aquifers, Integrated Water Resources Management schemes need to protect the recharge areas, even if they are far from the points of abstraction.

5. Sanitation must be sustainable in order to protect groundwater

Sanitation solutions need to be adapted to the specific conditions of the regions of concern in order to be sustainable. To fulfil the five sustainability criteria, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and natural resources. Herein, geo-scientific aspects have to be considered during sanitation planning, such as climate, hydro-geology, soil characteristics and geomorphology.

6. Lacking sanitation and polluted groundwater hinders development

Efficient political structures, policies and legal set-ups are essential. This includes developping curricula (focussing on groundwater and sanitation) for the entire educational system as well as capactiy building programmes. Neglecting the improvement of general sanitation conditions and thereby contaminating groundwater endangers the overall national gross product due to increasing costs in the health, labour and production sector. Therefore sanitation and groundwater issues including capacity development have to be addressed on the highest political level.

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1. Introduction: Why care about groundwater?

Groundwater makes up 97% of the world's freshwater and is a very important source of drinking water. In fact, it accounts for nearly 60% of the world's drinking water supply, whereas in arid and semi-arid zones this rate may even reach 100%. Groundwater is a highly valuable resource, which is not only used for drinking water supply purposes but also exploited for agricultural use. In Yemen, for example, only 10% of extracted groundwater is used for drinking water purposes, the other 90% is taken up by the agricultural sector.

Why is groundwater so precious? Compared to surface water bodies, groundwater resources are better protected against pollution and evaporation during dry seasons, therefore they represent an important and efficient form of storage. Furthermore, the development costs are comparatively low, as groundwater is a local resource which normally needs only minor treatment and does not require complex pipeline systems for its distribution. Natural groundwater, unaffected by human activities, is free of pathogenic germs and in many areas free of undesirable chemical substances. In arid and semi-arid countries groundwater is very often the sole resource for agricultural irrigation. All these facts turn groundwater in most areas of the world into an affordable, reliable and inevitable key element of sustainable human development.

2. Groundwater pollution

Long ago it was widely believed that groundwater is generally pure and safe for drinking purposes even without intensive treatment. However, in the past few decades, cases of disease outbreaks due to the consumption of untreated, contaminated groundwater have become widespread. For example, 630 out-breaks were reported in the period 1971-1994 only in the USA (Craun et al., 1997). Of these, a total of 356 outbreaks were caused by contaminated groundwater systems (= 58% of total waterborne outbreaks), 30% of which was due to contamination of the system while 70% was due to groundwater contamination. The most common disease was acute gastroenteritis. Groundwater contamination occurs when soluble or insoluble substances are introduced into the hydrogeologic environment due to human intervention such as settlement, industrial and agricultural activities. All of these use water and produce wastewater, which potentially pollutes groundwater resources. When the contaminant concentration reaches a certain level such that potential use of groundwater is restricted, the groundwater is said to be polluted. There are two types of sources of groundwater contamination which can be classified according to their origin. Single-source contamination can be localized and can easily be identified; whereas contamination from multiple sources or non-point sources is wide in scope and is more difficult to control. The major sources of groundwater contamination are faulty-designed septic tank systems, poorly constructed pit latrines, unsanitary dumpsites, unlined chemical landfills, intensive agriculture and wastewater disposal ponds. Other causes include spills and leaks; mine drainage; poorly constructed or abandoned water, oil and gas wells; and road deicing salts. In some instances, contaminated groundwater travels a distance of less than a kilometer, however, in many cases of single source contaminations have spread beyond ten kilometres from the source.

In areas with human settlements, groundwater pollution should be prevented by proper sanitation systems. The main objective of a sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable, however, a sanitation system should also be economically viable, socially acceptable, technically and institutionally appropriate, and protect the environment and natural resources. The main task of a sanitation system is to sanitize human excreta which contain pathogens in order to prevent the spread of diseases. A sanitation system consists of more than toilets and a simple pit dug in the ground to collect their effluents, but rather comprises the whole chain of household, collection, transport, treatment and final destination (either disposal or reuse). Thus pollution has to be reviewed for all these components. In dealing with pollution generated by sanitation systems, the following parameters are of importance: pathogenic germs, chemicals and organic micro pollutants.

2.1. Pathogenic pollution

In most developing countries where groundwater is the sole source of drinking water supply, prevention of fecal-oral transmission should have top priority. Once pathogens have infiltrated into the groundwater, e.g. through manure heaps, pit latrines, leaking sewerage systems or over-irrigation with untreated wastewater, it takes different amounts of time for different species of pathogens to die off. During this time, groundwater travels a certain distance depending on the permeability of the aquifer (i.e. the groundwater body). Where drinking water wells are located next to a pollution source (e.g. cesspits without any further treatment), travel times of the groundwater will be much shorter than 50 days. In this way, water users face increased health risks. It should be noted here that the '99% reduction in 50 days' rule of thumb should not be taken too seriously. Important variations exist (Table 1). Moreover, since the die-off of microorganisms tends to occur logarithmically in time, the complete removal of microorganisms does not only depend on the die-off rate, but also on the initial concentration. For instance, when die-off dictates that in 50 days 100 microorganisms die per liter, a concentration of 1000 cells per liter will only be reduced to 10 organisms per liter after 50 days, and therefore, in such case, removal is incomplete.

Table 1: Concentration reduction of a number of microorganisms. Die-off rates were taken from literature (based on Pedley et al., 2006)

Organism	Die-off rate (1/d)	Concentration after 50 days (initial = 10000 cells/mL)	Reduction (%)	Reference
Coxsackievirus A9	0.019	3867	61.3	Matthess et al. (1988)
Echovirus 24	0.12	25	99.8	Jansons et al. (1989a)
Hepatitis A virus	0.1	67	99.3	Nasser et al. (1993)
Poliovirus 1	0.48	0	100.0	Keswick et al. (1982)
Rotavirus	0.36	0	100.0	Pancorbo et al. (1987)
Simian Rotavirus	0.83	0	100.0	Keswick et al.(1982)
F-specific RNA bacteriophages	0.025	2865	71.3	Nasser and Oman (1999)
Bacillus subtilis spores	0.14	9	99.9	Meschke et al. (2001)
Cl. perfingens spores	0.071	287	97.1	Meschke et al. (2001)
E. coli	0.083	158	98.4	Schijven et al. (2000)
E. coli O157:H7	0.32	0	100.0	Rice (1992)
Faecal coliforms	0.83	0	100.0	Keswick et al. (1982)
Faecal streptococci	0.066	369	96.3	Bitton et al. (1983)
Klebsiella spp.	0.031	2122	78.8	Dowd and Pillai (1997)
Salmonella typhimurium	0.3	0	100.0	Bitton et al. (1983)
Shigella dysentariae	1.7	0	100.0	McFeters et al. (1974)

Reviewing the epidemiological evidence concerning the relationship between pathogen dose and consumers response, the evidence for the most commonly used indicator (E. coli), appears significant at doses greater than 103 E. coli/100 ml (Cave and Kolsky, 1999). The significant dose varies widely comparing different pathogens (bacteria, viruses, worm eggs, etc) occurring in human excreta, especially in the tropics. The main health risk associated with contaminated groundwater, i.e. diarrheal disease, opportunistic viral infections and other resulting diseases, causes up to 3 million deaths annually.

In this context it must be noted that it requires professional experience and knowledge of the subsurface conditions to estimate the minimum distance in the soil-aquifer system, which warrants a travel time of 50 days. If in doubt, always account for larger distances. Flow velocities are strongly dependant on local heterogeneity of the aquifer. For instance, safe setback distances may vary from several tens of meters in areas with thick clay cover to safe setback distances of more than 5 km in karstic aquifer systems. Also, flow velocities and transport paths may change in connection with strong rain events, especially in karstic systems or fractured bedrock (Hrudey et al, 2003).

2.2. Chemical pollution

Beside pathogens, human excrement contains organic matter, nitrogen and phosphorus. Urban waste water has a high organic content (Figure 1), which is relatively easy oxidized under aerobic conditions. Besides, where the water table is deep, oxygen and micro-organisms in the unsaturated zone of the aquifer may remove (degrade) much of the organic content.

Below the water table, any further degradation (of organic matter) will consume the dissolved oxygen present in the groundwater. The quantity of oxygen dissolved in groundwater is less rapidly renewed than in the unsaturated zone (soil). Thus additional infiltration of organic matter leads to depletion of dissolved oxygen in groundwater by microbial degradation potentially exceeding the limited oxygen supply. The more and more anaerobic (i.e. lacking oxygen) groundwater environment forces microorganism to utilize other substances than oxygen for degradation of organic matter and release their metabolism products into groundwater. This results in a fundamental change in groundwater chemistry, including the increase of dissolved ammonia, manganese, iron, hydrogen sulfide, methane and possibly also metalloid substances such as arsenic.

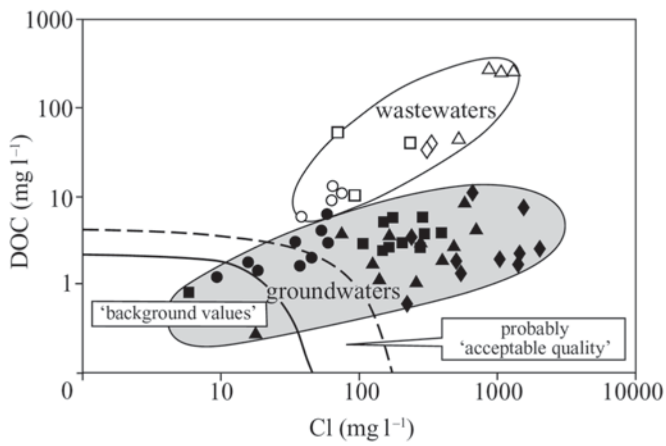

Fig. 1: Range of increased Cl and Dissolved Organic Carbon (DOC) concentrations in groundwater from wastewater infiltration research areas (Foster and Chilton, 2004).

2.2.1. The nitrogen cycle

The nitrogen (N) cycle is complex, but probably the predominant nitrogen form entering the (un)saturated zone is ammonium. The main mechanism for the transformation of N from waste water that has infiltrated in the soil is denitrification, whereby first ammonium (NH_4^+) from waste water is oxidized into nitrate (NO_3^-), and then, further in the aquifer, provided that anaerobic conditions prevail, nitrate is reduced into nitrogen gas (N_2), which is not further modified (stable) and ultimately may escape from the aquifer. When aerobic conditions prevail, nitrate may be the final product, which, at elevated concentrations (>50 mg/l), can be harmful to humans, especially babies. Worldwide, in developed and developing countries alike, many water supply wells show increased levels of nitrate above the WHO limit of 50 mg/l. This can be due to fertilizer application or misman-agement of human and animal excreta, but also to natural conditions.

Nitrate is in itself relatively non-toxic, however, upon ingestion, it is partially converted by bacteria in the mouth to nitrite. The formation of nitrite is especially important as it reacts with haemoglobin, the oxygen carrying constituent of red blood cells, to produce methaemoglobin which cannot transport oxygen (ARGOSS, 2002). Methaemoglobinaemia (also known as “blue baby” syndrome) occurs mostly with children under 3 months of age. This was reported in only 2000 cases between 1945 and 1972, most of which were not fatal. In the period from 1986 – 1996, 3000 babies and young children of Romania’s rural areas were hospitalized with acute infantile methaemoglobinaemia. 3.5% of the cases were lethal (EEA and WHO 2002). Still, this contrasts markedly the above mentioned number of deaths by diarrhoea and associated diseases (Cave and Kolsky, 1999).

The actual problem with nitrate in groundwater/drinking water is its persistence under aerobic conditions; it takes high tech – high cost applications in purification to get nitrate out of contaminated drinking water – thus long term accumulation should be prevented.

2.2.2. The phosphorus cycle

The main source of phosphorus in waste water is inorganic orthophosphate and organic phosphorus. Due to anaerobic digestion, the latter is usually transformed into orthophosphate. Phosphor transport in groundwater exists, (http://toxics.usgs.gov/highlights/phosphorous_migration.html) however health threats occur only in very rare cases. Phosphate in aquifers is usually sorbed to iron-oxides (Dzombak and Morel, 1990) or precipitates as phosphate minerals, like hydroxy-apatite, vivianite, variscite or strengite. The importance of phosphate is that it is the limiting factor in algae growth in aquatic systems. This means, the more phosphate there is, the more algae growth can take place, including the depletion of oxygen and reduction of fish populations, etc. This process is called eutrophication.

Subsurface transport of orthophosphates has been typically considered negligible because of its high propensity for precipitation and adsorption to afore mentioned oxides and minerals. However, it is increasingly recog-

nized that phosphorus retention characteristics of soils and sediments vary greatly according to geological and environmental conditions (matrix vs karst), and are also impacted upon by land use activities such as livestock production, manure application, sewage sludge disposal (Siddique and Robinson, 2003; Geohring et al., 2001). The afore mentioned activities have been reported to result in high soil phosphorus accumulation subsequently releasing environmentally significant levels of this nutrient to subsurface flow as well as to surface runoff. Such soils have been linked to accelerated eutrophication of fresh-water bodies.

In some settings, due to the infiltration of waste water, toxic compounds like arsenic are released. For instance, below the city of Hat Yai in Thailand, the increase of arsenic due to the reductive dissolution of iron oxides is well described (Lawrence et al., 2000). Of the various routes of exposure to arsenic, drinking water probably poses the greatest threat to human health. The international Agency for Research on Cancer (IARC) has classified arsenic as a Group 1 human carcinogen. Its undesirable health effects include skin cancer, cancers in the lung, bladder and kidney, and peripheral vascular disease.

2.3. Organic micro pollutants

Organic micropollutants or so called “emerging contaminants” were recently detected in wastewater and the environment up to several µg/L, although they might have been present already decades (Ternes, 2009). Innovative analytical instrumentation enables the identification and quantification of organic contaminants down to the lower nanogram per litre and nanogram per kg range. Prominent examples of emerging contaminants are pharmaceuticals, estrogens, ingredients of personal care prod-ucts, biocides, flame retardants, benzothiazoles, benzotriazoles or perfluorinated compounds (PFC).

Tens of thousands of chemicals enter sewer systems or on-site sanitation systems and eventually wastewater treatment plants (WWTP), and/or groundwater. And because these contaminants are usually quite small (molecular weight predominantly varies between 50 and 1000 Da), regular municipal WWTPs or on-site sanitation systems do not remove these polar persistent organic pollutants. Contamination of groundwater and drinking water by emerging contaminants is well reported. Because many of those contaminants end up in the environment, one of the most important questions is “Which are the most hazardous or “unwanted” emerging contaminants?”. Definitive answers cannot be given yet. Criteria for answering this question might be related to the ecotoxicological (aquatic, terrestric) and toxicological relevance, the potential to bioaccumulate, as well as the potential to contaminate ground water and drinking water.

Adverse effects by individual emerging contaminants, like ‘feminisation’ of fish, can occur down to a few nanograms per litre, as reported for 17α-ethinylestradiol and tributyltin. Besides endocrine disrupters, also pharmaceuticals (e.g. carbamazepine, diclofenac, fluoxetine, propranolol) have been shown to cause effects at environmentally relevant concentrations.

3. Protecting groundwater from pollution
3.1 Source protection

The ideal way to protect groundwater is the prevention of contaminants, which are a threat to water quality and are hazardous to human health. One practical way to achieve this is land-use planning. In order to prevent groundwater from contamination by substances or organisms hazardous to human health or affecting the water quality, drinking water protection areas are delineated around production wells or springs (see figure 2). Usually, for large-scale drinking water supply, classification of these areas involves three levels of restrictive use, allowing fewer human activities with increasing proximity to the groundwater extraction site.

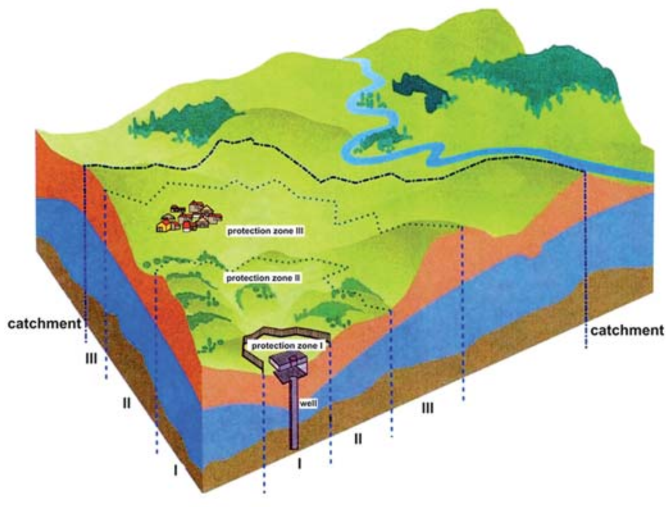

Fig. 2: Protection areas in a catchment (source: BGR).

The first and immediate area is to protect the production wells or springs and their immediate environment from any contamination and interference. The second area is delineated at the line from which groundwater travels 50 days until it reaches the production well or spring. It protects the groundwater from pathogenic microbiological constituents such as bacteria, viruses, parasites and worm eggs. Other contaminants which do not degrade during the flow time to the production well are banned in this area. The outer area protects the groundwater from persistent contaminants like pesticides, radioactive substances or non-degradable chemicals (DVGW 1995).

In villages without any water supply or sanitation system a classification of the three zones is difficult to implement. In such villages the citizens depend on their drinking water mostly on local dug wells or boreholes, often polluted by e.g. mismanagement of human and animal excreta. Under these circumstances another approach such as developing local Water Safety Plans (WSP) has to be implemented. Sustainable and affordable sanitation options must be found which prevent further infiltration of human excreta into the groundwater.

Foto 1: Unprotected well at close range of a pit latrine (by: Kennedy Mayumbelo, Zambia, 2006).

3.2. Resource protection

3.2.1. What to protect

An empirical model to map aquifer vulnerability has been developed by the USA National Water Well Association and the Environment Protection Agency. The DRASTIC approach refers to hydrogeological units incorporating major factors which affect and control groundwater movement (depth to groundwater table, net recharge, aquifer media, soil media, topography, vadose zone media impact and hydraulic conductivity of the aquifer).

These factors form the acronym DRASTIC and give their rated and weighted input to the numerical DRASTIC index (USEPA 1987). This index, in combination with the mappable hydrogeological settings, creates a groundwater vulnerability map. The approach helps to prioritize monitoring and protection measures (EPA 1987).

3.2.2. How to protect

An integrated water resources management (IWRM) approach is needed especially in the urban context as it explicitly recognises the complex sets of interdependency relationships which exist within and between human and environmental systems. One guideline of an IWRM approach is that water decisions should be made at the lowest appropriate scale. The following elaborations are taken from Rees 2006.

For every setting the different roles which water management organisations might play and the different functions which agencies may perform along water provision chains must be found and defined (i.e. from resource management – bulk supply and transport – treatment – distribution – waste/excess water removal). The IWRM approach, when applied in an urban context, must recognise intersectoral competition for resources (physical, social and financial). This involves the creation of an institutional framework within which water relevant roles and functions are performed at an appropriate spatial scale and which helps ensure that decision makers have incentives to take the social costs of their actions into

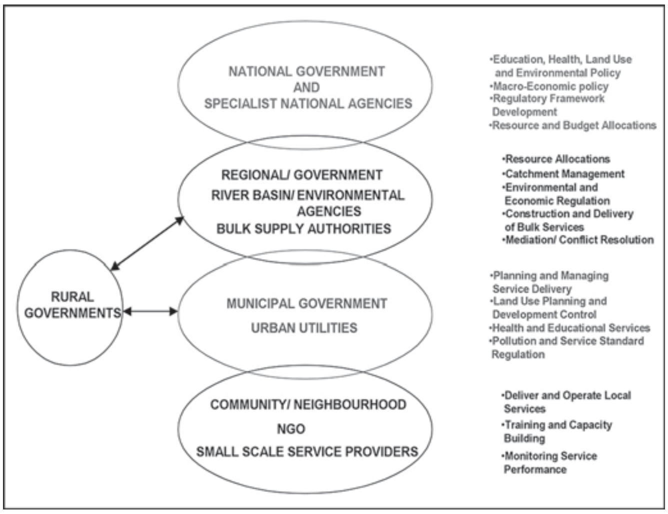

Fig. 3: Division of roles and functions (source: Rees 2006).

account. Figure 3 provides a generalised picture of the broad division of roles and operational functions which could exist between the various ranks of government and governance.

On the way towards an integrated resources protection approach, the uses of water in a certain area must be understood and taken into consideration. One concept is described by Falkenmark (2004): “Human activities and ecosystems depend on the same water, i.e. the rainfall over the catchment (Fig. 4). This makes the catchment a useful landscape unit for an integrated approach where a balancing between humans and nature can be carried out.” A management task is to “orchestrate the catchment for compatibility”. The usually occurring intentional trade-offs have to be socially acceptable, making multi-stakeholder dialogues an essential component of a catchment management.

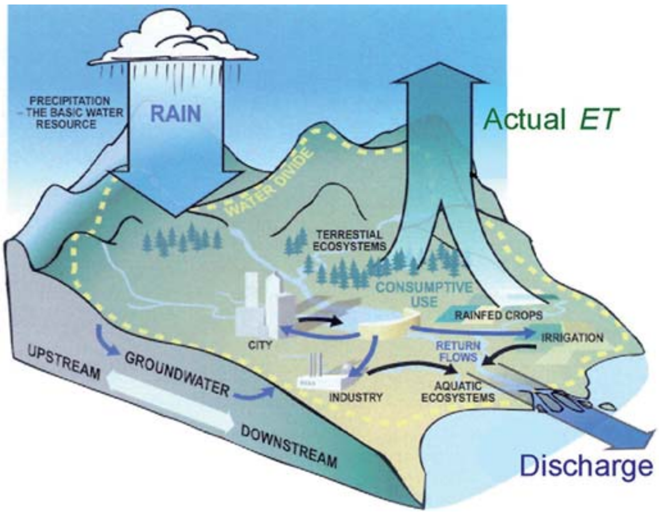

Fig 4: Catchment with its water fluxes (ET = Evapotranspiration, dis-charge = surface and subsurface outflow) (source: Falkenmark 2004).

From the groundwater resource protection point of view, the catchment needs to provide a recharge area which is part of the ecosystem mosaic, free of human activities. The area in which humans consume water for domestic and industrial use should be situated downstream of the recharge area while agricultural activities may lie even further downstream, allowing for use of nutrients from domestic water (and sanitation).

4. Productive land use & groundwater protection

If the given area for agricultural production is to be used most efficiently, crop harvests need to be increased by fertilizer application. According to local conditions, there is a certain amount of fertilizer that is determined by plant uptake depending on the crop specimen and by effective field capacity depending on the soil type – fertilizer application exceeding this amount will cause a leaching to the groundwater. Wrong timing and inappropriate dosing of fertiliser application or application on sandy soil, for instance, may cause leakages of nitrates. Most synthetic fertilizers consist of a combination of Phosphorus (P), Potassium (K) and Nitrate (N). While P and K are prone to sorption processes in the soil (so that they become immobile being fixed to organic or inorganic soil matter), N reaches the groundwater (in case of leaching) within the same time as the percolating water. Therefore, as mentioned before, in order to prevent high nitrate levels in groundwater in the long term and eutrophication of surface waters, regulations on fertilizer application must be regarded. Organic fertilizer, which produces less leakage of nitrate into the groundwater (UBA 2002, 138) should be preferred over synthetic fertilizer, whereas the soil should be managed in a sustainable way. Erosion, leakages of nutrients and loss of humus have to be avoided.

5. Policy recommendations

The following recommendations were developed by the participants of the international symposium “Coupling groundwater protection & sustainable sanitation” taking place in Hannover, Germany, from October 14-17, 2008 (BGR 2008).

- Both, groundwater protection and sustainable sanitation represent basic tasks for every development planning. Every new settlement should take groundwater resources into account and the protection of the aquifer should have high priority. Past planning approaches failed and innovative sanitation planning including participatory and demand driven approaches must be adopted now. Land-use planning, based on a holistic approach and therefore economically, socially and ecologically sound, is required to protect precious resources like groundwater.

- There is a wide range of sanitation solutions available which need to be adapted to the specific conditions of the regions of concern in order to be sustainable. To fulfil the five sustainability criteria, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources. Herein, geoscientific aspects have to be considered during sanitation planning, such as climate, hydrogeology, soil characteristics and geomorphology.

- Waste water is considered a valuable resource; however, its uncontrolled and unregulated utilisation must be prohibited. Guidelines for the safe reuse of excreta and wastewater have been published by WHO (WHO, FAO, UNEP 2006), including the WHO multi-barrier approach; these guidelines and concepts need to be translated into practise and become implemented.

Additionally, the reuse of wastewater, human excreta and greywater in agriculture requires further studies and implementation policies in developing and developed countries.

- Efficient political structures, policies and legal setups are essential. This includes developping curricula (focussing on groundwater and sanitation) for the entire educational system as well as capactiy building programmes. Neglecting the improvement of general sanitation conditions and thereby contaminating groundwater endangers the overall national gross product due to increasing costs in the health, labour and production sector. Therefore sanitation and groundwater issues including capacity development have to be addressed on the highest political level.

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Foto 2: Especially in densly populated areas infiltration of wastewater poses a threat to groundwater resources (by: BGR, Senegal, 2005).

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Box 1: Some useful links for further reading

BGR Symposium on groundwater protection and sustainable sanitation	www.bgr.bund.de/EN/symposium2008
WHO / UNICEF Joint Monitoring Programme	www.wssinfo.org
UNICEF Water and Sanitation Programme	www.unicef.org/wes/
Urban groundwater database	www.scar.utoronto.ca/gwater/IAHCGUA/index.htm
Tutorial in soil physics	http://www.aquarien.com/sptutor/index.htm
Course global water, sanitation, and hygiene	http://www.unc.edu/courses/2007spring/envr/890/003
Sanitation Connection – environmental sanitation network	http://www.sanicon.net/index.php3
IAH -International Association of Hydrogeologists	http://www.iah.org/
IAH - Commission on urban groundwater	http://www.scar.utoronto.ca/~gwater/IAHCGUA/index.htm
Unesco - International Hydrological Programme	http://www.unesco.org/water/ihp/
USACE Engineering Manuals	http://www.usace.army.mil/publications/eng-manuals
The Hydrogeologist homepage	http://www.thehydrogeologist.com
BGS Rock classification scheme	http://www.bgs.ac.uk/bgsrcs
Wilkes University	www.water-research.net
MIT Groundwater Hydrology Course	http://ocw.mit.edu/OcwWeb/Civil-and-Environmental-Engineering/1-72Fall-2005/CourseHome/index.htm
The SWITCH Project	www.switchurbanwater.eu
The AISURWS project	www.urbanwater.de
Early warning network project programme (UNEP)	http://www.unep.org/dewa/water/groundwater/africa/
Cape Cod Toxics Programme site of the USGS	http://ma.water.usgs.gov/CapeCodToxics/
Urban Water at the CSIRO (Australia)	http://www.csiro.au/science/psu9.html
University of Surrey Robens Centre f. Public & Env. Health	http://www.rcpeh.com
British Geological Survey - Hydrogeology Section	http://www.bgs.ac.uk/research/groundwater/home.html
AGK - Applied Geology Karlsruhe	http://www.agk.uni-karlsruhe.de/hydro/
Worldbank - Urban Water Section	http://www.worldbank.org/watsan/urban.html
Poseidon project	http://poseidon.bafg.de
World Health Organisation	http://www.who.int/water_sanitation_health/resourcesquality/en

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