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SuSanA factsheet

Sustainable sanitation and groundwater protection

April 2012

1 Summary

Groundwater is a very important resource for human life accounting for nearly 60% of the world's drinking water supply, while in arid and semi-arid zones this rate may even reach 100%. Groundwater has comparatively low development costs, is a high quality local resource, for which only simple water treatment is necessary, and for small systems requires only simple distribution systems.

Groundwater quality and sanitation are often linked as pollution of groundwater from unsafe household sanitation systems through nutrients, pathogens and organic micropollutants (including emerging contaminants) can occur.

There are many tools to prevent groundwater pollution: land-use planning plays an important role in protecting areas that are vulnerable by restricting the use of these areas. Water Safety Plans can play a fundamental role for communities to protect groundwater quality. In larger frameworks such as transboundary aquifers, Integrated Water Resources Management (IWRM) schemes are required to protect recharge areas, even if they are distant from the points of abstraction.

Sanitation solutions need to be adapted to the regional conditions in order to be sustainable. Accessible and safe sanitation and good groundwater quality are critical elements for sustained growth in developing countries that require policy and legal support systems to remain effective. This includes developing educational curricula (focussing on groundwater and sanitation) as well as institutional capacity building programmes.

Failure to improve general sanitation conditions and thereby contaminating groundwater endangers the economic growth potential of a region. This may impact negatively on the overall economic output due to increasing costs in the health, labour and production sectors. Sanitation and groundwater issues including capacity development need to be addressed on all political levels of government.

2 Why care about groundwater

Groundwater makes up 97% of the world's freshwater (excluding inland ice and glaciers) and is an important source of drinking water. Groundwater accounts for nearly 60% of the world's drinking water supply, while 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, whereas the other 90% is used 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 a more important and efficient form of water storage. Furthermore, the development costs are usually comparatively low; as groundwater is a local resource which normally needs only simple water treatment and for small systems requires only very simple distribution systems. Natural groundwater, unaffected by human activities, is free of pathogens 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 an inevitable key element of sustainable human development.

Figure 1: Unprotected well at close distance of a pit latrine in Lusaka, Zambia (source: K. Mayumbelo, 2006).

3 Introduction to groundwater pollution

Historically it was widely believed that groundwater is generally pure and safe for drinking purposes even without treatment. However, in the past few decades, cases of disease outbreaks due to the consumption of untreated, contaminated groundwater have increasingly been reported. For example, 630 outbreaks were reported in the period 1971-1994 in the USA alone (Craun et al., 1997). Of these, a total of 356 outbreaks were caused by contaminated groundwater systems (i.e. 58% of total waterborne outbreaks), 30% of which were due to contamination of the distribution and treatment system while 70% were due to groundwater contamination. The most common disease in these outbreaks was acute gastroenteritis.

Groundwater contamination occurs when substances are introduced into the aquifer environment due to human activities such as urbanisation, industrial and agricultural development. All of these activities use water and produce wastewater, which may potentially pollute groundwater resources. When the contaminant concentration reaches a certain level the potential uses of groundwater are restricted and 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 localised 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 poorly-designed septic tank systems, poorly constructed pit latrines, leaking sewers, 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 de-icing salts.

In some instances, contaminated groundwater is localised; however, in many cases a single source contamination may spread a considerable distance from the source, depending on the type of contaminant and the hydrogeological conditions.

In areas with human settlements, groundwater pollution should be prevented by 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 contain and sanitise human excreta which contain pathogens in order to prevent the spread of diseases. A sanitation system consists of more than toilets and pits dug in the ground to collect excreta and effluents. It comprises the whole chain of household facilities, collection, transport, treatment and final destination (either disposal or reuse). Each of these components has the potential to cause pollution to the groundwater. In dealing with pollution generated by sanitation systems, the following pollutants are of importance: pathogens, chemicals and organic micropollutants.

4 Pathogenic pollution

Pathogens cause diseases such as cholera, hepatitis A and diarrhoea. In those countries where groundwater is the sole source of drinking water, prevention of faecal-oral transmission should be a highly prioritised public health outcome. 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 types 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). In addition to natural die-off, pathogen removal is also a result of adsorption and filtration through the soil and sub-surface media. A hydrogeologist will be able to estimate the filtration capacity of the media, or alternatively a simple laboratory test can be undertaken to estimate this.

In many European countries source protection concepts have been based on a rule that most pathogens are reduced by 99% within 50 days of transit time in the aquifer. Where drinking water wells are located close to a pollution source (e.g. cesspits without any further treatment), travel times of the groundwater may be much shorter than 50 days. Therefore, water users face increased health risks. It should be noted here that the “99% reduction in 50 days” guiding value should be taken simply as a rough guideline, and actual reductions will depend on the specific context. In fact, important variations exist (Table 1).

Moreover, since the die-off of microorganisms tends to occur logarithmically over time, the complete removal of microorganisms does not only depend on the die-off rate, but also on the initial concentration. For example, when die-off dictates that in 50 days 100 microorganisms die per litre, a concentration of 1000 microorganisms per litre will only be reduced to 10 organisms per litre after 50 days, and therefore, in such case, removal is incomplete.

Reviewing the epidemiological evidence concerning the relationship between pathogen dose and response, the evidence for the most commonly used indicator (*E. coli*), appears significant at doses greater than 10^3 *E. Coli* per 100 ml (Cave and Kolsky, 1999). The significant dose varies widely for different pathogens occurring in human excreta (bacteria, viruses, protozoa, helminths[1]), especially in the tropics. It is estimated that diarrhoeal diseases, resulting from a lack of adequate water and sanitation services, have killed more children in the 10-year period 1992 to 2002 than all people lost to armed conflict since World War II (WEHAB 2002).

The most detailed assessment is the consideration of human health risk targets for a number of microorganisms. The Australian Guidelines for Water Recycling (2006) use disability adjusted life years (DALYs) to convert the likelihood of infection or illness into burdens of disease, and set a tolerable risk of 10^{-6} DALYs per person per year. It is impractical to set human health-based targets for all microorganisms that might be present in wastewater; therefore, the guidelines specify the use of reference pathogens instead: Campylobacter for bacteria, rotavirus and adenovirus for viruses, and Cryptosporidium parvum for protozoa and helminths (Australian Guidelines for Water Recycling from 2006).

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[1] Helminth eggs are usually not an issue in terms of groundwater pollution since they are filtered out in the unsaturated zone (soil).

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 = 10,000 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	<1	100.0	Keswick et. al (1982)
Rotavirus	0.36	<1	100.0	Pancorbo et. al. (1987)
Simian Rotavirus	0.83	<1	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	<1	100.0	Rice (1992)
Faecal coliforms	0.83	<1	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	<1	100.0	Bitton et. al. (1983)
Shigella dysentariae	1.7	<1	100.0	McFeters et. al. (1974)

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 results in a travel time of 50 days. If there is doubt, always use a conservative estimate and account for larger distances. Flow velocities are strongly dependant on local heterogeneity of the aquifer. For instance, safe setback distances[2] may vary from several tens of meters in areas with thick clay cover to 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).

5 Chemical pollution

Beside pathogens, human excreta contain organic matter, nitrogen and phosphorus. Urban wastewater has a high organic content (Figure 2), which is relatively easily oxidised under aerobic conditions. Where the water table is deep, oxygen and micro-organisms in the unsaturated zone of the aquifer may remove (degrade) much of the organic matter.

Below the water table, 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.

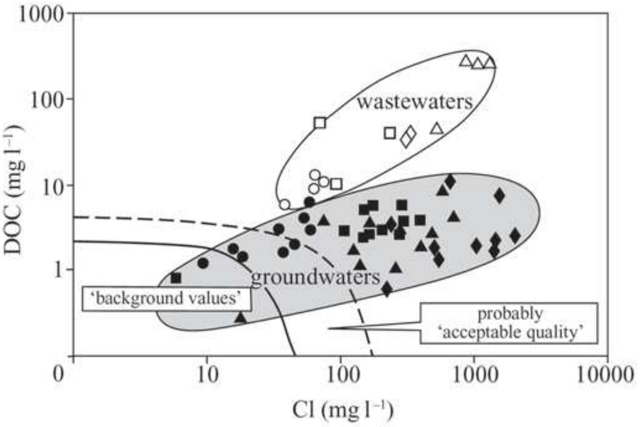

Figure 2: Range of increased chloride and Dissolved Organic Carbon (DOC) concentrations in groundwater from wastewater infiltration research areas (Foster and Chilton, 2004).

The more and more anaerobic (i.e. lacking oxygen) the groundwater environment becomes the more microorganisms are forced to utilise other substances, other than oxygen, for degradation of organic matter and thereby release their metabolism products into the groundwater. This results in a fundamental change in the groundwater chemistry, including increases of dissolved ammonia, manganese, iron, hydrogen sulfide, methane and possibly also metalloid substances such as arsenic.

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[2] A safe setback distance is defined as the minimum distance that a drinking water well must be separated from a pit latrine or septic tank

a) Pollution due to nitrogen compounds

The nitrogen (N) cycle is complex; the predominant wastewater and animal manure related nitrogen form entering the (un)saturated zone from untreated sewage is ammonium while from treated sewage and from chemical fertilisers it is nitrate. The main mechanism for the transformation of N from wastewater that has infiltrated in the soil is denitrification, whereby first ammonium (NH_4^+) from wastewater is oxidised into nitrate (NO_3^-, called nitrification). Then, further in the aquifer, provided that anaerobic conditions prevail, nitrate is reduced into nitrogen gas (N_2, called denitrification), which is stable and ultimately may escape to the atmosphere.

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 guideline value of 50 mg/l. This can be due to fertiliser application or mismanagement of human and animal excreta, but also due 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 three months of age. This was reported in only 2000 cases between 1945 and 1972, most of which were not fatal (Cave and Kolsky, 1999). In the period 1986 to 1996 however, 3,000 babies and young children from Romania’s rural areas were hospitalised with acute infantile methaemoglobinaemia. 3.5% of these cases were lethal (EEA and WHO, 2002).

However the above mentioned number of deaths is still low in contrast to those caused by diarrhoea and associated diseases (Cave and Kolsky, 1999). The actual problem with nitrate in groundwater used as drinking water is its persistence under aerobic conditions; it takes advanced, high cost treatment processes to remove nitrate from contaminated drinking water. Thus long term accumulation should be prevented.

b) Pollution due to phosphorus

The main source of phosphorus in wastewater is inorganic orthophosphate and organic phosphorus. Due to anaerobic digestion, the latter is usually transformed into orthophosphate. Phosphorus transport in groundwater exists[3], however health threats occur only indirectly. Phosphate in aquifers is usually bound to iron-oxides (Dzombak and Morel, 1990) or precipitates as phosphate minerals, like hydroxy-apatite, vivianite, variscite or strengite.

Subsurface transport of orthophosphates has been generally considered negligible because of its high propensity for precipitation and adsorption to the afore mentioned oxides and minerals. However, it is increasingly recognised that phosphorus retention characteristics of soils and sediments vary greatly according to geological and environmental conditions, and are also impacted upon by land use activities such as livestock production, manure application, and sewage sludge disposal (Siddique and Robinson, 2003; Geohring et al., 2001). These activities have been reported to result in high soil phosphorus accumulation and subsequent release of environmentally significant concentrations to subsurface flows as well as to surface runoff.

Such soils have been linked to accelerated eutrophication of freshwater bodies: Phosphate is a limiting factor in algae growth in surface aquatic ecosystems. This means, if there is not enough phosphate, algae growth is reduced, while the more phosphate there is, the more algae growth can take place. Excessive algae growth can lead to the depletion of oxygen from decaying algae, the reduction of fish populations or the predominance of single fish species, and the production of toxins (microcystins) from certain algae species which can impact on human and animal health.

c) Pollution due to other anthropogenic induced pollutants

In some settings, due to the infiltration of wastewater, toxic compounds like arsenic are released. For example, below the city of Hat Yai in Thailand, the increase of arsenic in groundwater 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[4].

Serious and long lasting groundwater contamination is known to result from chemical substances like chlorinated, hydrocarbons, BTEX, polycyclic aromated hydrocarbons (PAH), which are often introduced via leakages or spillage events. Where such industry chemicals are discharged into the wastewater, the drainage system is providing an additional entrance pathway to groundwater.

6 Pollution due to organic micro pollutants

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

Tens of thousands of different chemicals enter sewer systems or on-site sanitation systems and eventually wastewater treatment plants (WWTP) and/or groundwater.

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[3] See: http://toxics.usgs.gov/highlights/phosphorous_migration.html

[4] Arsenic can also occur in groundwater naturally (Bangladesh is a well documented example).

Organic micropollutants are usually quite small (molecular weight predominantly varies between 50 and 1000 Da)[5], therefore regular municipal WWTPs or on-site sanitation systems do not remove these polar persistent organic pollutants.

Pollution of groundwater and drinking water by emerging contaminants is well documented; however human health risks are low in most cases. Many of these contaminants are continuously discharged to the environment, therefore the most important question “Which are the most hazardous or unwanted emerging contaminants?” arises. Definitive answers cannot be given yet. Criteria for answering this question might be related to the ecotoxicological (in aquatic or terrestric environment) and toxicological relevance, the potential to bioaccumulate, as well as the potential to contaminate groundwater and drinking water.

Adverse effects by individual emerging contaminants, like “feminisation” of fish, can occur down to a few ng/L, as reported for 17α-ethinylestradiol and tributyltin. Besides endocrine disrupters, pharmaceuticals (such as carbamazepine, diclofenac, fluoxetine, propranolol) have been shown to cause effects at environmentally relevant concentrations. Current research is providing a growing list of “predicted no-effect-concentrations” (PNEC) which constitute the lowest concentration where a specific emerging pollutant was observed to have an effect on any organism.

7 Protecting groundwater from pollution

The difference between groundwater resources as a whole and the source of groundwater for use can be explained through its management: When groundwater is well managed, the **resource** as a whole is protected for current and future uses; while we protect a currently used groundwater **source** in a defined area with specific and often very specific measures regarding land use.

a) Source protection

The best way to protect groundwater is to prevent contaminants from entering the aquifer which pose 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 contamination, drinking water protection areas are delineated around production wells or springs (see Figure 3). 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 (DVGW 2006):

- 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 pathogens such as bacteria, viruses, parasites, protozoa and worm eggs. Other contaminants which do not degrade during the flow time to the production well are banned from use in this area.
- The outer area protects the groundwater from persistent contaminants like pesticides, radioactive substances or non-degradable chemicals (DVGW, 1995). Where households are located within this zone, their sanitation system should be either an ecological sanitation solution or a system where the wastes are removed from site.

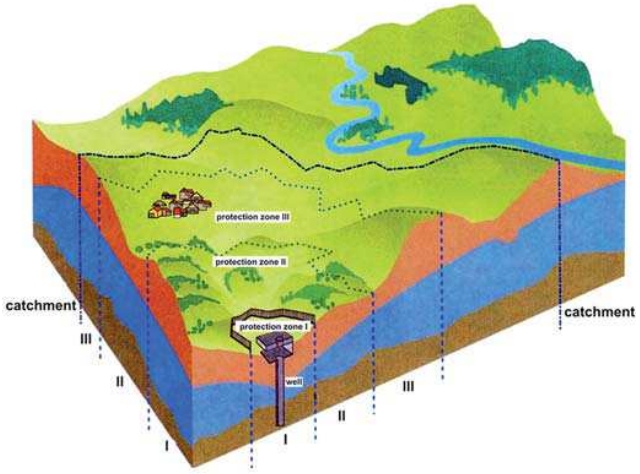

Figure 3: Protection areas in a catchment where the well is in Zone 1 on the left side (source: © Bayerisches Landesamt für Umwelt (LfU))

In villages or towns in developing countries without any water supply or sanitation systems a classification of the three zones is difficult to implement. In such places the citizens regularly obtain their drinking water from local dug wells, springs, nearby streams or boreholes, often polluted by mismanagement of human and animal excreta. Under these circumstances another approach such as developing local Water Safety Plans (WSP) may be implemented. These plans will include approaches for the protection of the water sources used for drinking water, and include developing options for sustainable and affordable sanitation systems which prevent further infiltration of pollutants from human excreta into the groundwater. WSPs also importantly include operational controls, incident and emergency management and importantly treatment.

b) Resource protection

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 prioritise monitoring and protection measures.

Internationally other methodologies have been developed for the same purpose, such as South Africa’s “Ground Water

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[5] The unified atomic mass unit or dalton (Da) is a unit that indicates mass on an atomic or molecular scale.

Protocol" (DWA, 2003) which is a procedure that development and local government agencies are required to follow when planning new sanitation projects. The approach is risk-based, taking into account the contaminant load, the vulnerability of the aquifer, and the strategic value of the aquifer.

c) How to protect the groundwater resource

An integrated water resources management (IWRM) approach is needed in the urban context as it explicitly recognises the complex sets of interdependent 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.

Rees (2006) elaborates that for every setting the different roles which water management organisations might play and the different functions which agencies might perform along water supply chains must be 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, recognises 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 to ensure that decision makers have incentives to take the social costs of their actions into account.

In moving towards an integrated resources protection approach, water uses 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 [Figure 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 intentional trade-offs which usually occur have to be socially acceptable, making multi-stakeholder dialogues an essential component of catchment management.

From the groundwater resource protection point of view, the catchment needs to provide a recharge area which is part of the ecosystem mosaic and free of human activities. Ideally, 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.

8 Productive land use and groundwater protection

If a given area for agricultural production is to be used most efficiently, crop harvests need to be increased by fertiliser application. Local conditions limit the maximum amount of fertiliser that can be applied. This is determined by plant uptake depending on the crop specimen and by effective field capacity depending on the soil type. Fertiliser application exceeding this amount will cause a leaching to the groundwater. Poor timing and inappropriate dosing of fertiliser or application on sandy soil may cause leaching of nitrates into the groundwater.

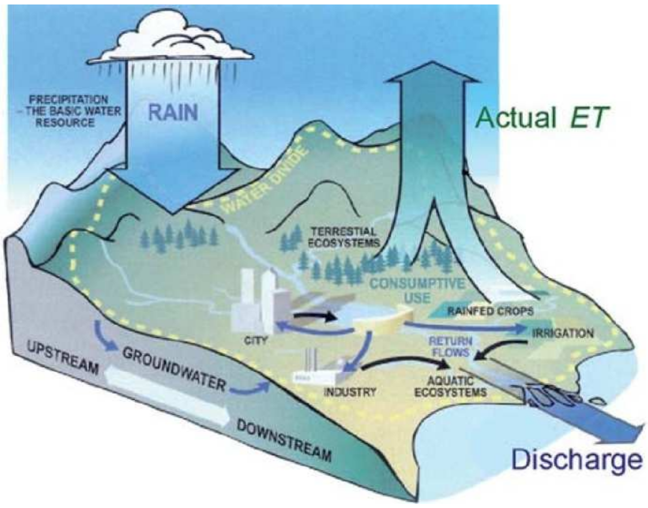

Figure 4: Catchment with its water fluxes (ET = Evapotranspiration, discharge = surface and subsurface outflow) (source: Falkenmark, 2004).

Most synthetic fertilisers consist of a combination of phosphorus (P), nitrogen (N) and potassium (K). While phosphorus and potassium are prone to sorption processes in the soil (so that they become immobile being fixed to organic or inorganic soil matter), nitrogen reaches the groundwater (in the case of leaching) at the same time as the percolating water. Therefore, in order to prevent high nitrate concentrations in groundwater over the longer term and eutrophication of surface waters, regulations on fertiliser application should be developed and enforced. Organic fertiliser, which produces less leakage of nitrate into the groundwater (UBA 2002) is preferred over synthetic fertiliser, and soil should be managed in a sustainable way. Erosion, leakages of nutrients and loss of humus should be avoided.

Figure 5: In densely populated areas infiltration of wastewater threatens groundwater resources in Senegal. Note also the water pipe in the drain which is a common but unsafe practice (source: BGR, 2005).

9 Policy recommendations

The following recommendations were developed by the participants of the international symposium “Coupling groundwater protection and sustainable sanitation” which took place in Hannover, Germany in 2008 (BGR 2008).

- Both, groundwater protection and sustainable sanitation represent basic tasks for all development planning. Every new settlement should take groundwater resources into account and the protection of aquifers should have a high priority. Past planning approaches often failed and innovative sanitation planning including participatory and demand driven approaches should be adopted. Land-use planning, based on a holistic approach and therefore economically, socially and ecologically sound, is required to protect precious resources like groundwater.
- There are a wide range of sanitation solutions available which need to be adapted to the regional conditions 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. Geoscientific aspects have to be considered during sanitation planning, including climate, hydrogeology, soil characteristics and geo-morphology.
- Wastewater is considered a potentially 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 (2006), including the multi-barrier approach; these guidelines and concepts need to be incorporated in practise and imbedded in all implementations.
- 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 arrangements are essential. This includes developing curricula (focussing on groundwater and sanitation) for educational systems as well as capacity building programmes. Neglecting the improvement of general sanitation conditions and thereby contaminating groundwater endangers economic output due to increasing costs in the health, labour and production sector. Sanitation and groundwater issues including capacity development have to be addressed on all political levels.

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Authors and contributors

Main authors:

- Andrea Nick, Federal Institute for Geosciences and Natural Resources (BGR), Germany (andrea.nick@bgr.de)
- Jan Willem Foppen, UNESCO-IHE Institute for Water Education, the Netherlands (j.foppen@unesco-ihe.org)
- Robinah Kulabako, University of Kampala, Uganda
- Dexter Lo, Xavier University, Philippines (d.lo@xu.edu.ph)
- Margriet Samwel, Women in Europe for a Common Future (WECF), Germany (margriet.samwel@wecf.eu)
- Frank Wagner, Federal Institute for Geosciences and Natural Resources (BGR), Germany (frank.wagner@bgr.de)
- Leif Wolf, CSIRO Land & Water, Australia (leif.wolf@sciro.au)

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For questions or comments please contact the SuSanA secretariat at info@susana.org or susana@giz.de. We invite you to join the SuSanA discussion forum: www.forum.susana.org. This document is available at www.susana.org.