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Water quality and sanitation in rural Moldova




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Master thesis in Aquatic and Environmental Engineering
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ABSTRACT

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Because of the impact on human health and sustainable livelihood, the topic of drinking water and sanitation facilities is becoming a seriously discussed issue among international organizations as well as developing agencies in industrialized countries. The importance of water and sanitation management initialized this master thesis.

The aim of the project is to do an assessment of the drinking water quality as well as the sanitation situation in the village Condrita in the Republic of Moldova. This was done by studying the existing water and sanitation facilities, sampling the water, evaluating the reason for the poor water quality and mapping the current situation using ArcGIS. Furthermore, technologies for improving the drinking water and sanitation facilities are suggested.

The work was carried out by doing a literature study on how water sources and sanitation facilities should be constructed in order to ensure people's health and to meet their needs. Geographic coordinates and water samples were collected from twenty-two public wells and springs. Interviews on the water situation and sanitation facilities were performed. Furthermore, water samples were analysed with respect to nitrate, turbidity, electrical conductivity and coliform bacteria amongst others. Pesticide contamination was also taken into consideration when one of the wells was analysed. Water sources were classified as improved or unimproved according to definitions by WHOSIS. Moreover, the DRASTIC vulnerability model was used to evaluate the groundwater susceptibility to contaminants.

In general, the water quality in the study area was poor and measured values of the analyzed parameters exceeded international or Moldovan standards for nitrate, hardness, electrical conductivity and total coliform bacteria. Four wells were contaminated with *E. coli* bacteria. Furthermore, turbidity measurements exceeded Moldovan standards in seven out of twenty-two water sources. No pesticide contamination was detected. Sampled water from the densely populated parts of the village as well as unimproved water sources proved to be of poorer quality. Map results showed that a majority of the groundwater within the study area was subject to a moderate or high risk of becoming contaminated. The current sanitation situation is that most families use simple pit latrines, which are placed far away from the dwelling-houses. Digging a new toilet when the existing one is full is a common practice in Condrita. Hand-washing facilities are seldom placed in proximity to the toilets.

Pit latrines are believed to be the most important source of groundwater contamination in the study area. Other sources are agricultural activities and poor practice when abstracting water from the wells. A feasible solution to improve both the drinking water quality and the sanitation situation would be to install ecosan toilets. Improvements of the well's features that are suggested include construction of an apron slab as well as proper lids for covering the well.

Keywords: Republic of Moldova, groundwater, contamination, nitrate, coliform bacteria, sanitation, ecosan, DRASTIC

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REFERAT

Vattenkvalitet och sanitet på Moldaviens landsbygd
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Tillgång till dricksvatten och bra sanitetslösningar är två viktiga frågor som ofta diskuteras bland internationella organisationer och utvecklingsbyråer. Eftersom dessa två har stor påverkan på både hälsa och hållbart leverne inleds denna examensuppsats med att diskutera vikten av bra vatten- och avloppshantering.

Målet med det här examensarbetet var att utvärdera vattenkvaliteten och de nuvarande sanitetslösningarna i landsbygdskommunen Condrita, Moldavien. Detta gjordes genom att observera dricksvattenkällor och toaletter, provta dricksvatten och analysera anledningen till den rådande dricksvattenkvaliteten samt kartlägga den nuvarande situationen i ArcGIS. Vidare föreslogs nya förbättrande lösningar inför framtiden.

Konstruktioner av vattenkällor och toaletter som kunde uppfylla nödvändiga krav på människors hälsa och andra behov utreddes genom en litteraturstudie. Dessutom genomfördes en fältstudie då vattenprover och geografiska koordinater från 22 kommunala brunnar och källor samlades in. Intervjuer och observationer gjordes för att ta reda på hur vattenkällor och sanitetslösningar i studieområdet hanterades och sköttes. Vattenproverna analyserades med avseende på bland annat nitrat, turbiditet, elektrisk konduktivitet och koliforma bakterier. Spår av bekämpningsmedel analyserades också i en av brunnarna. Vidare klassades vattenkällorna som förbättrade eller oförbättrade, enligt WHOSIS definitioner, och en sårbarhetsbedömning gjordes av hur känsligt grundvattnet var för föroreningar.

I allmänhet var vattenkvaliteten i studieområdet otillfredställande och uppmätta värden på nitrat, hårdhet, elektrisk konduktivitet och koliforma bakterier överskred såväl Moldaviens som internationellt satta gränsvärden. Fyra brunnar visade förekomst av *E. coli* bakterier. Vidare överskreds turbiditetsvärden i sju av tjugotvå vattenkällor men inga spår av bekämpningsmedel hittades. Dricksvatten från både den tätbefolkade delen av byn och de oförbättrade vattenkällorna visade sig vara av sämre kvalitet. En sårbarhetsbedömning visade att det fanns medelstor eller hög risk för att grundvattnet i studieområdet skulle bli förorenat. De flesta familjer i Condrita har en nuvarande sanitetslösning som består av enkla latriner, placerade på bostadshusens tomt. Möjligheter till att tvätta händerna finns sällan i närheten av toaletterna.

De latriner som finns i studieområdet anses vara den största utredda källan till det förorenade dricksvattnet. Andra bidragande källor skulle kunna vara läckage från jordbruk och bristande hygien vid hämtning av vatten i brunnarna. För att förbättra både dricksvattenkvaliteten och sanitetssituationen skulle ecosan-toaletter kunna installeras. När det gäller förbättring av brunnarna föreslås gjutning av nya cementplattor och ordentliga lock för att minska risken för föroreningar.

Nyckelord: Moldavien, grundvatten, förorening, nitrat, koliforma bakterier, sanitet, ecosan, DRASTIC

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PREFACE

This work is a master thesis that comprise of 30 credits within the M. Sc Aquatic and Environmental Engineering at Uppsala University, Sweden. The project was assigned by Borlänge Energi and realized as a minor field study (MFS), supported by Sida (the Swedish International Development Cooperation Agency), in the Republic of Moldova. Supervisor at Borlänge Energi was Ronny Arnberg, and the subject supervisor was Jonatan Strömgren at the consulting company Midvatten AB, Dalarna. The subject reviewer was Professor Allan Rodhe at the Department of Earth Sciences, Uppsala University.

Borlänge Energi is a municipally owned company that delivers services such as district heating, electricity and tap water, as well as running the wastewater treatment plant in Borlänge, Sweden. During the last 20 years, Borlänge Energi has in cooperation with Sida and the Swedish Environmental Research Institute (IVL) had international development projects in several countries such as Chile, China and Romania with the purpose of e.g. developing environmental plans (Borlänge Energi, 2009). Today there is also an ongoing project with Apa Canal as well as the Chisinau City Hall in Chisinau, Moldova. Besides Borlänge Energi, this master thesis was carried through in cooperation with Apa Canal in Chisinau along with the Chisinau City Hall.

In particular, we would like to show our gratitude to the helpful people at Apa Canal Chisinau, without whom the fieldwork could not have been carried out. First and foremost, we thank our supervisor Natalia Vavelschi who not only provided us with huge amounts of helpful information but also arranged our field studies and translated for us in situ. Karolina Postolovskaia was of great help with practical things and an important support throughout the stay in Moldova. We are further grateful for all help from Constantin Becciev, Ivan Burdila, and Arcadie Rusnac, and appreciate the assistance from the laboratory personnel and Judi. We express our gratitude towards the Condrita municipality, for letting us come and study your village; in particular to Tudor for showing us around and guiding us through the village.

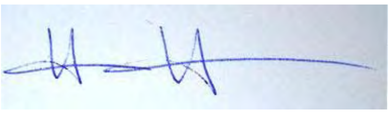
Secondly, Stela Busuioc at the City Hall Chisinau has been of much help during our stay in Moldova. Thank you for finding us an apartment, help with translation as well as field studies and for always trying to answer our questions. Moreover we show great appreciation to the Hifab office in Chisinau. Special thanks are sent to Natalie Tranefeldt who made it possible for us to have an office, desk and wifi, to work at.

Moreover, we would like to express our thanks to Maria Ovii, Tamara Rudenco and Pavel Lacovlev at the Agency for Land Relations and Cadastre of the Republic of Moldova for helping us with information on maps and providing us orthophotos. We show gratitude to Nadia and Sergiu Andreev for taking time to meet with us and discuss the Wisdom organization and ecological sanitation in Moldova. The Swiss Developing Agency further gave us plenty of information on ecological sanitation in Moldova, which was of great help.

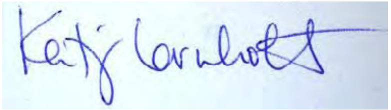
Lastly, we are truly grateful for the assistance back home in Sweden. We appreciate all Skype sessions with Ronny Arnberg at Borlänge Energi, who came up with the idea to make a project about water resources in Moldova. Thank you for solving many practical issues! Our gratitude is shown to Jonatan Strömgren, for all the important advice during this period and for always taking time to answer our emails. We are also thankful for all the input on our master thesis from Allan Rodhe at Uppsala University. In addition, great thanks to the Committee of Tropical Ecology at Uppsala University who made it possible for us to do an MFS.

When working with the thesis, Hanna Hugosson had the main responsibility for chapter 3 while Katja Larnholt had the main responsibility for chapter 2. Chapters 4, 5, 6 and 7 were developed and written by the two of us in collaboration. However, Hanna Hugosson was responsible for the GIS-analyses and Katja Larnholt for the statistical analyses.

Uppsala, February 2010



Hanna Hugosson



Katja Larnholt

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POPULÄRVETENSKAPLIG SAMMANFATTNING

Vattenkvalitet och sanitet på Moldaviens landsbygd
Hanna Hugosson och Katja Larnholt

I en stor del av världen saknar människor tillgång till rent vatten och tillfredsställande sanitetslösningar. Avsaknad av detta påverkar bland annat människans hälsa, levnadsstandard och sociala hierarki. Dricksvattenkvalitet och sanitetslösningar av dålig standard främjar smittspridning och leder till försämrad hygien och hälsa. Som exempel kan nämnas att ca 1,4 miljoner barn dör i diarré varje år. Avsaknaden av centrala vattenledningssystem medför att det går åt mycket tid till att hämta vatten från brunnar vilket leder till mindre tid för arbete och skolgång. Vidare är kvinnor, barn, äldre och handikappade mer utsatta för detta då toaletter sällan är utformade eller placerade utifrån dessa sociala gruppers behov.

Ovan nämnda problematik är utbredd i fattiga områden i utvecklingsländer, främst i Afrika och Asien. I Europa förekommer problemen bland annat i Moldavien, som har klassats som Europas fattigaste land. Moldaviens ekonomi försämrades vid självständigheten från Sovjetunionen 1991. Problemen var störst under 1990-talet även om ekonomin har återhämtat sig något under 2000-talet. Idag lever ca 25 % av Moldaviens befolkning i fattigdom, vilken är mest utbredd på landsbygden. Majoriteten av landsbygdsbefolkningen saknar tillgång till rent vatten och tillfredsställande sanitetslösningar. I de flesta byar används grundvatten som hämtas från enkla brunnar eller källor. Toaletter består i regel av en grävd grop i marken med en täckande betongplatta att stå på. Dessa toaletter innebär problem om näringsämnen läcker från gropen ner till grundvattnet samt kan leda till förorenat brunnsvattnen på grund av bristande handhygien vid hämtning av vatten.

I många utvecklingsländer är investeringar i vatten- och sanitetslösningar inte prioriterade då det anses vara dyrt. Men det faktum att rent vatten återfinns i rika länder medan det saknas i fattiga kan på ett sätt ses som bevis på att tillgång till rent vatten minskar fattigdom. Vidare visar rapporter att det både är direkt och indirekt ekonomiskt lönsamt att investera i förbättrande lösningar. Genom att anställa lokala entreprenörer för uppförande och underhåll av vattensystem och sanitetslösningar gynnas den lokala ekonomin direkt. Indirekt lönsamhet visar sig i minskade hälsoproblem, minskad dödlighet och mer tid för arbete och skolgång.

Syftet med den här studien var att utvärdera och kartlägga vattenkvaliteten och sanitetssituationen i en by på Moldaviens landsbygd. Detta gjordes genom att provta brunns- och källvatten samt intervjua bybor under en fältstudie. Intervjuerna syftade till att få information om vattenkällans utformande, hur vattnet togs upp och hanterades samt hur man hanterade mänsklig urin och fekalier. Denna information användes till att förklara orsaken till rådande grundvattenkvalitet. Vidare gjordes en bedömning av risken för att grundvattnet skulle förorenas.

Vattenproverna analyserades med avseende på flera indikerande parametrar såsom nitrat, klorid, mängd lösta partiklar i vattnet (turbiditet), elektrisk ledningsförmåga (konduktivitet), förekomst av bakterier och bekämpningsmedel. Analysresultaten visade på höga halter av nitrat och bakterier vilket även tidigare studier av grundvattenkvaliteten i Moldavien har hittat. Däremot återfanns inga spår av bekämpningsmedel i grundvattnet. Den elektriska ledningsförmågan var hög vilket tyder på mycket lösta salter i vattnet. Detta är mindre bra om vattnet används för bevattning av grödor eftersom det kan leda till fysiologisk torka, dvs. att växten inte uppfattar att det finns tillgängligt vatten för upptag. Ungefär 40 % av vattenkällorna i studieområdet kunde klassas som oförbättrade enligt definition från

WHOSIS, och dessa vattenkällor kunde sannolikt inte förse befolkningen med tillfredsställande dricksvatten.

Angående sanitetssituationen visade det sig att den största delen av befolkningen i studieområdet använde enkla utedass som bestod av en grop i marken, täckt med en platta att stå på och en skyddande byggnad omkring för avskildhet. Vatten och tvål att tvätta händerna med fanns sällan att tillgå i närheten av utedasset, vilket innebar att risken för smittspridning var stor. Vidare innehåller urin mycket kväve (som kan ombildas till nitrat i marken) som har stor benägenhet att läcka till grundvattnet. Givet de höga nitrathalterna i grundvattnet och vetskapen om att de flesta invånare i studieområdet använde sig av dessa enkla utedass, drogs slutsatsen att utedassen i största sannolikhet var orsaken till nitratföroreningarna. De bakterier som påvisades i grundvattnet antogs bero på bristande hygien och hantering vid hämtning av vatten i brunnarna/källorna.

En lösning till att förbättra vattenkvaliteten och sanitetssituationen är att använda en ekologisk sanitetslösning, vilket innebär att mänsklig urin och fekalier anses vara en resurs istället för oanvändbart avfall. En passande sådan lösning i utvecklingsländer skulle kunna vara en torrtoalett där man separerar urin från fekalier. Urin och fekalier innehåller mycket näringsämnen som, efter att det blivit hygieniserat, kan användas till gödsel vid odling av grödor. Hygienisering innebär att bakterier, virus och andra skadliga organismer dör. Den största vinsten med en sådan urinseparerande toalett visar sig i ökad avkastning från åkrarna där man använder gödslet. Andra fördelar beskrivs som förbättrad hälsa (då fekalier hanteras efter hygienisering), minskad påverkan av föroreningar i grundvattnet samt ökad bekvämlighet för användaren (toaletten luktar mindre och kan placeras i anslutning till bostadshuset).

I kombination med ovanstående lösning skulle de existerande vattenkällorna kunna förbättras genom att de skyddas, t.ex. genom att cementera runt, samt placera ett lock på, brunnen. Ett annat alternativ är att samla in regnvatten. Dessa förbättringar skulle kunna genomföras utan allt för stor belastning på ekonomin i varje enskilt hushåll.

Slutligen bedöms det som troligt att föreslagna lösningar skulle kunna implementeras i studieområdet.

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ACRONYMS AND DEFINITIONS

CIS	Commonwealth of Independent States
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EC	Electrical Conductivity
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GC-MS	Gas chromatography-mass spectrometry
JMP	the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation
MDG	Millennium Development Goal
NTU	Nephelometric Turbidity Units
PEP	Poverty-Environment Partnership
Sida	Swedish International Development Cooperation Agency
SuSanA	Sustainable Sanitation Alliance
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
VIP	Ventilated Improved Pit
WHO	World Health Organization
WHOSIS	WHO Statistical Information System

Basic sanitation is by the United Nations Millennium Project's Task Force on Water and Sanitation referred to as "*the lowest-cost option for securing sustainable access to safe, hygienic and convenient facilities and services for excreta and sullage disposal that provide privacy and dignity while ensuring a clean and healthful living environment both at home and in the neighbourhood of users*" (WHO & UNICEF, 2006).

Excreta Human waste, such as urine and faeces.

IDW Acronym, which stands for Inversed Distance Weighted. Mean value interpolation method, which assumes that data closer to the given interpolated points are more important, hence given more weight, than data further away.

Orthophoto Aerial photograph with the properties of a map.

Raster file A grid of x and y coordinates.

Safe drinking water is according to the definition by WHO (2004), drinking water that "*does not represent any significant risk to health over a lifetime of consumption*". Further, WHO (2009c) states that a safe drinking water source should be suitable for all domestic purposes such as house holding, drinking and personal hygiene.

Sanitation On the WHO website one can read that "*Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces*" (WHO, 2009c).

Sustainable development The concept was created and presented by The World Commission on Environment and Development (1987) in the Brundtland report. The report, also known as *our common future*, defines sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

1 INTRODUCTION

Safe drinking water and basic sanitation are two connected pivotal needs for human well-being. The quality of drinking water is jeopardized by human waste, which contains bacteria and nutrients that may contaminate the drinking water sources if these and the sanitation facilities are not managed properly. Poor sanitation facilities also increase the risk of spreading diseases. People with insufficient access to potable drinking water, i.e. consuming contaminated water, may suffer from illnesses on a short as well as long term basis. Besides health aspects, collecting water from decentralized drinking water sources (wells or springs) is time-consuming and leaves less time for education and labour. Women and children are in particular exposed to this. Fighting these facts will increase the possibility to reduce poverty.

According to statistics of the World Health Organization (WHO), as many as 1.1 and 2.6 billion people lacked access to improved water sources and improved sanitation respectively in the year 2002 (WHO, 2009a). A majority of people with insufficient potable water or sanitation facilities live in Asia or Africa. In Europe, problems for instance occur in the Republic of Moldova. Sida has classified the Republic of Moldova, in this report referred to as Moldova, as the poorest country in Europe (Sida, 2009).

The Moldovan economy has suffered since the independency from the Soviet Union in 1991. During the 1990s, Moldova experienced an economical crisis and had to apply for enormous loans in order to survive. In 1999 two thirds of the national budget was only for paying interest, one factor leading to the gross domestic product, GDP, being reduced to one third. During 2000 to 2005, GDP increased by 43 percent and poverty decreased by half. Today, about one fourth of the population is considered poor and poverty is greatest in rural areas (Ministry for Foreign Affairs, 2006).

Among other things, the Moldovan economy was severely affected when Russia banned the import of Moldovan wine in 2006. Moldova also suffered consequences from not being able to use the free trade agreement with Romania and Bulgaria when these countries entered membership in the European Union, EU, in 2007 (Ministry for Foreign Affairs, 2006). Although economy has recovered since 2000, Moldova is still considered a lower middle income country (Sida, 2010). Consequently, emigration is an existing problem where about 20 % of the Moldovan working-age population live in Russia or EU countries (Per Lindberg, pers. comm.).

Due to the economical status of the country, funds to improve the water and sanitation situation are insufficient. One way to improve the financial situation could be to enter the EU. During the past years the Moldovan government has increased the cooperation with EU in order to approach a membership in the future. Either by entering EU or just negotiating about membership, Moldova would have the possibility to participate in projects and thereby obtain economic support through co-financing (Ronny Arnberg, pers. comm.). Since 2007, Moldova receives financial support from EU by taking part in a four year long strategy which aims to stabilize and increase the economic growth as well as to improve the capacity of the public administration. Sida and other organizations cooperate with Moldova in order to approach an EU membership. The work is done within several sectors such as (Sida, 2009)

- energy efficiency and sustainable use of energy
- democratic leadership in the society
- development of the rural areas.

This master thesis pays attention to the latter of the mentioned EU goals: development of the rural areas.

1.1 AIMS AND SCOPE OF THE STUDY

The aim of this study is to map the drinking water quality and sanitation facilities in a rural village in Moldova. The assessment investigates whether or not the water quality and sanitation facilities are satisfactory. Moreover, a vulnerability study is done using the DRASTIC model to evaluate the potential of groundwater pollution in the study area. If the water quality proves to be insufficient, the reason for this should be investigated, and solutions for improvements suggested. The improving solutions are formed with respect to sustainability, economical as well as simplicity aspects.

The study is focused on the following questions:

Water quality

- Is the drinking water fit for human consumption?
- Does land use in the surroundings of the water source, depth to the water table or construction of the water source affect the drinking water quality?
- Is the area vulnerable to contamination of the groundwater?
- Is the groundwater suitable for irrigation purposes?

Sanitation

- Is the current sanitation system sustainable?

These questions were approached by doing an interview study of the villagers in addition to observations and measurements in situ during the period of September to November 2009. A literature study was performed in parallel to this.

1.2 THESIS LAYOUT

The thesis begins with a literature study of the current situation on water access and sanitation, in general and in Moldova. Focus is put on the importance of improving water and sanitation facilities in developing countries. The study also looks into drinking water as well as sanitation from a sustainability point of view. Chapter two aims to give a glimpse of the situation and the study is motivated with this background information in mind.

As a developing country that receives financial support Moldova needs to form the developing work in a sustainable way. This means that the development must be formed in such a way that not only the present but also the future generations in Moldova can benefit from the improvements that are made. Chapter three gives information on sustainable water sources and sanitation technologies that are suitable in rural developing areas. Common sources of drinking water contamination are discussed as well as how to avoid contaminations, i.e. protecting water sources by proper maintenance and construction. Chapter three also reveals a range of water quality indicators, which are used for determining water quality. Thereafter follows chapter four, which gives a closer description of the study area as well as methods used for assessing the current water and sanitation situation.

Chapter five reveals the results from the assessments of the study area, which are discussed in chapter six. In addition, possible improving solutions are brought to light. Finally, the outcomes of the master thesis are concluded in chapter seven.

Definitions and acronyms used in the report are briefly explained and displayed in the beginning of the thesis.

1.3 COLLECTION OF BACKGROUND DATA

Data for the literature studies in chapter two and three in this report, which functioned as background information to this study, were mostly assembled on the Internet. For this purpose, web sites, internet-based articles as well as statistical databases were used. Some information was also found through contacts with organizations working with matters linked to this study. Information on ecosan work in Moldova was given by Swiss Developing Agency as well as Wisdom organization. An educational field visit to Causeni, a town in Moldova where an ecosan pilot project has been carried out, was further given by Wisdom.

2 BACKGROUND ON WATER AND SANITATION

In this chapter the significance of water and sanitation issues are brought to light. International goals are discussed in addition to reports on the current situation on access to improved drinking water and sanitation. Improving these matters is not only united with public health improvements but also with economical and social benefits.

The water in Moldova is of varying quality, showing contamination of coliform bacteria, nitrate and sulphate amongst others. In general the water is hard with high measurement values of electrical conductivity. Pesticides have also been detected in sampled water.

The urban population of Moldova is often connected to sewage systems, while only a few percent of the rural population have sewage systems. Pit latrines are the most common sanitation system in rural communities.

In order to access safe drinking water, protection of the watershed as well as correct handling of the abstracted water is required. Sanitation facilities should meet the requirements of the user, such as preventing spreading of diseases as well as being socially and economically acceptable.

2.1 THE IMPORTANCE OF SAFE WATER AND SANITATION

With a large number of people in the world lacking access to safe water and basic sanitation, the United Nations Development Programme (UNDP) took action in year 2000 by forming the Millennium Development Goals (MDGs). These include eight different goals that touch upon issues such as eradicating extreme poverty, achieving universal education, combat diseases and ensure environmental sustainability (UNDP, 2009). The MDGs aim to reduce the population without sustainable access to safe drinking water and basic sanitation by half between 1990 and 2015 (WHO & UNICEF, 2006). Reports on the current situation show that there is a large difference in coverage of water and sanitation facilities in the world, not only between countries but also between urban and rural communities. Moldova had a relatively good coverage compared to other developing countries in the world.

Benefits from improved drinking water and sanitation facilities include reduced poverty and health costs, less unemployment and more time for labour and school attendance.

2.1.1 Reports on water and sanitation

Statistics show that the coverage of people with access to improved water sources differs greatly over the world. In 2002, a majority of the inhabitants in Latin America, northern Africa and western Asia was covered, whilst the sub-Saharan region had very little coverage. Rural areas are to a great extent less covered than urban and what is more, of all the people with access to improved water sources only a small part are connected to piped water systems. This should further be subject to improvements in the future (WHO & UNICEF, 2006).

In total, only 59 % of the world population had access to improved sanitation in 2004. Once again, the sub-Saharan region was the least covered area (37 %) while western Asia and the Commonwealth of Independent States (CIS) both had coverage of more than 80 %. Similarly as for the water situation, rural areas were less covered than urban. When looking at the future, the rural population is likely to decrease as urbanization takes place causing the amount of unserved urban inhabitants to increase. Still, current trends indicate that the rural population without access to basic sanitation will be twice the size of the corresponding urban population in 2015 (WHO & UNICEF, 2006).

The MDG objective is to cut the proportion of unserved residents by half. The different world regions have different professional and economic capacities to improve their situation, causing different targets to be set for the different regions. The Republic of Moldova is member of the CIS that needs at least 96 % coverage of improved water sources and 91 % coverage in basic sanitation in order to reach the MDG target of halving the population without access (WHO & UNICEF, 2006).

In 2006, 85 % the rural population in Moldova had access to improved drinking water sources and 73 % to improved sanitation. In total (rural and urban areas) the coverage in Moldova was 90 % for improved drinking water sources and 79 % for improved sanitation in the same year, meaning that an increase of 6 as well as 12 percentage points would be required in order for Moldova to contribute to CIS reaching the target. Larger efforts will be required in the rural areas (WHOSIS, 2009a).

2.1.2 Benefits of improved water and sanitation

Investments on water and sewage are in general not prioritized locally because it is considered expensive. The challenging words by The Poverty-Environment Partnership (PEP) state otherwise, which is that "*investing in water is not a drain on the national exchequer, it positively contributes to it*" (WHO, 2009b). The quote is taken from the report *Linking poverty reduction and water management*, in which PEP seeks to give an understanding of why water management is such an important thing to improve. Firstly, the report states that improved water management is essential for reaching all of the MDGs and that it contributes to all goals either directly or indirectly. Secondly, as the quote implies, investing in water management is profitable whether on large or local scale. Not only will it reduce poverty but also make a positive impact on the country economy, especially if local entrepreneurs are hired. The report refers to several studies made on economical benefits that will arise from investing on improved water and sanitation and they all show benefit-cost ratios higher than one. As a result of improved health and domestic access to piped water, benefits include reduced health costs, decreased mortality rates in addition to advantages of more time for labour and increased school attendance.

Hence, improving drinking water facilities and quality as well as sanitation facilities reduces poverty, inequality and enables the local community to develop. Approximately 25 % of the population in Moldova lives in poverty (Sida, 2009), which is why improvements in the fields of water and sanitation are needed for a positive development of the society to take place.

2.2 WATER IN MOLDOVA

The drinking water quality in Moldova varies greatly depending on where it is abstracted (in villages, forests or close to agricultural land). Reports show that the drinking water is often contaminated with a large number of coliform bacteria (including *E. coli*) as well as high concentrations of nitrate and sulphate. In addition, the Moldovan water is often very hard. Pesticides have been traced in sampled water from wells in the vicinity of agricultural land. Residuals of pesticides are believed to origin from the extensive use of such chemicals during the time when Moldova was a part of the Soviet Union.

The World Bank (2008) reports that a majority, about 60 %, of the Moldovan population lives in rural areas or small towns with little or no access to potable drinking water. Further, the water resources in Moldova reach only 300 m^3 per inhabitant and year. The World Bank states that with less than 1000 m^3 per inhabitant and year, large deficiencies in water are implied. The average water consumption in Moldova is about 163 litres/cap/day although it is often much lower than this, especially in rural areas where it can be as low as 20 litres/cap/day (The World Bank, 2008).

The annual average precipitation is 600-650 mm in the centre and north, and 500-550 mm in the south and southeast (Republic of Moldova – Official website, 2009). The location of Moldova and the larger rivers in the country are displayed in figure 1.

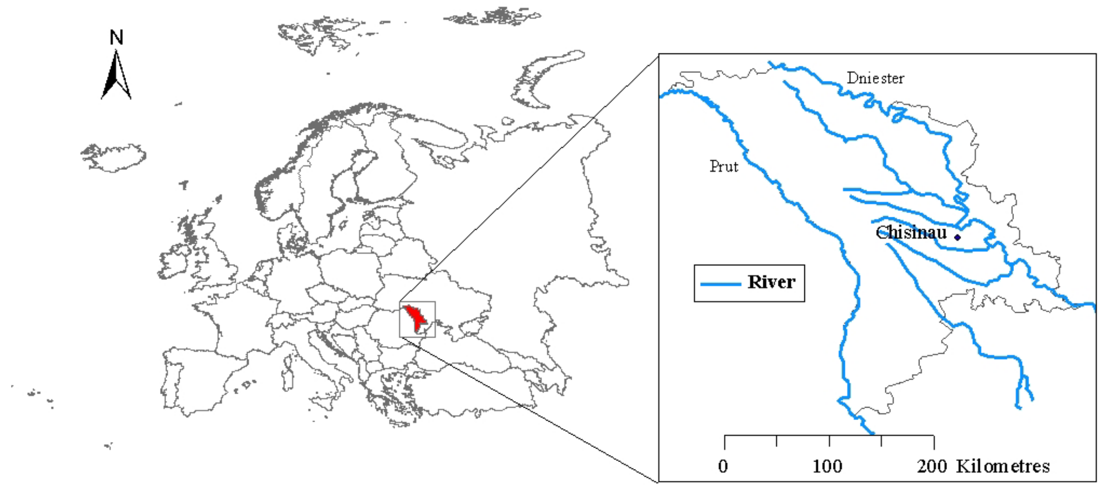

Figure 1 Location of Moldova and main rivers in the country.

2.2.1 Drinking water quality in Moldova

About 70 % of the population in Moldova use groundwater as a drinking water supply; however, the source only represents about 15 % of all the abstracted water in Moldova. Water taken from groundwater sources (wells and springs) are of varying water quality. The remaining part of the Moldovan population is supplied by surface water but the sources are in general polluted and treatment not up to the mark. Drinking water quality suffers from presence of coliform bacteria as well as high concentrations of nitrates, sulphates, chlorine, fluorides, iron and minerals. In addition, the hardness of the water is high. A study showed that coliform bacteria were present in 16 % of all sampled drinking water in rural areas, while 7 % of all samples had contents of faecal coliforms (The World Bank, 2008).

General indicators of water contamination

In a groundwater assessment in two study areas in western Moldova, Melian et al. (1999) found high measurement values for several parameters in sampled groundwater from shallow wells. Amongst others, average measurement values of *E. coli* bacteria, hardness, nitrate and sulphate exceeded present WHO standards. In addition, at least one water sample showed measurement values above standards for ammonia, chloride and nitrite. The electrical conductivity range was 287-6650 µS/cm at temperatures of 10.4-20.7 °C. Melian et al. found that contaminated groundwater sources were mostly situated inside, or close to, villages. Concentrations in water samples from wells in agricultural areas were seldom higher than in areas with no farming. Consequently, Melian et al. concluded that contamination from agricultural activities was not a major threat at the time. Important sources of groundwater contamination were “*earth toilets*”, solid-waste landfills, livestock and poultry yards amongst others.

Pesticides

Pesticides have been used in Moldova for many years leading to accumulation in the soil as well as pesticide residuals being stored in the country. In the publication *Obsolete (lethal) Pesticides, a ticking time bomb and why we have to act now* (Vijgen & Egenhofer, 2009) the authors address the problems brought to countries of the former Soviet Union, the Southern Balkans and the new EU member states by obsolete pesticides. The report refers to the book *Pesticides: The chemical weapon that kills life (The USSR’s tragic experience)* by L.A. Fedorov and A.V. Yablokov, and declares that today’s problems with obsolete pesticides originate from the 1950s and 1960s when pesticides were handed to farmers of communist countries without charge. This was done in order to increase the agricultural yield but led to overuse as well as inadequate handling of left over pesticides and package material. As a consequence, present problems with obsolete pesticides in the mentioned countries have arisen. Hence, obsolete pesticides refer to chemicals that can no longer be used due to age or other reasons, meaning that such problems address the storage rather than the use of pesticides. According to the North Atlantic Treaty Organization, approximately 7000 tonnes of obsolete pesticides or similar chemicals are stored in the Republic of Moldova (NATO, 2009).

The European Environment Agency document *Groundwater quality and quantity in Europe* (1999) shows that DDT, GCCG-a,b, and Phozalon have been reported as some of the most critical pesticide substances found in groundwater wells in Moldova. Neither the reason for this classification nor the prevalence of the substances are revealed, although other European countries define their most critical substances as those with annual mean concentrations exceeding 0.1 µg/L (European Environment Agency, 1999).

According to Melian et al. (1999), trace concentrations were found for a number of pesticides (DDE, atrazin, metaphos etc.) in samples from shallow groundwater wells. The wells were situated in the vicinity of where pesticides were stored as well as downstream agricultural lands and vineyards. Melian et al. stressed that the detection capacity of Moldovan laboratories was not sufficient at the time; hence, trace concentrations could in fact correspond to higher concentrations of pesticides in the sampled water.

In Moldova, pesticide concentrations in groundwater and soil could originate from neighbouring countries, brought to the area by air or surface waters. Obsolete pesticides that are stored in a non-safe way might also be a contamination source due to leakage.

2.3 SANITATION IN MOLDOVA

The World Bank (2008) states that sewerage connections can be found in all municipalities and towns in Moldova, although only 63 % of the urban population are connected to such a system. Even worse, less than half of the rural communities are connected to sewerage systems. Rural sewerage systems have in general simple constructions that have deteriorated since the time of installation. Commonly, wastewater treatment plants do not function satisfactorily and are, due to financial problems, often abandoned or not maintained properly (The World Bank, 2008). In 2005, only 4 % of the rural population had a sewerage connection. Around 60 % of the rural dwellers used improved pit latrines, meaning that the latrines were constructed in such a way that faeces were separated from human contact. In addition, 10 % of the rural population used composting toilets, also considered improved. The remaining part of the inhabitants in rural communities used unimproved latrines such as an open pit or a pit latrine without a slab (Childinfo – Unicef, 2010).

2.4 SAFE DRINKING WATER AND SANITATION

As discussed above, the importance and the requirement of safe drinking water and proper sanitation are great. Ensuring safe drinking water does not necessarily require high levels of technology; instead, it can be achieved with careful planning and awareness of protecting as well as handling the water. Sanitation facilities also need thorough planning in order to function satisfactory and provide the user with what the user requires. Sanitation systems need to be constructed with respect to health, environment, financial and socio-cultural aspects and to comprise of a suitable technology that can be maintained within the local community. If considering these aspects, it is likely that a sustainable sanitation system can be established.

2.4.1 Safe drinking water

It is essential for a community to have safe water. Groundwater has a natural level of purification but if water sources are not managed properly the water quality will deteriorate and safe water will not be provided. The importance of protecting communities' water supplies is discussed in *A Community Guide to Environmental Health* by Conant & Fadem (2008). According to the authors, protecting groundwater is achieved by the following:

- *Practicing sustainable farming*. Large amounts of extracted water, which for instance are intended for irrigation use, must be brought back into the hydrological cycle if groundwater levels are not to become seriously low.
- *Protecting the watershed*. This is done for instance by managing water sources properly, which includes keeping the water source from contaminants both on-site as well as after collection. Water collected from simple dug wells are often contaminated through the bucket or when handling and storing it at home.
- *Building and using safe toilets*. To use a safe toilet means that human waste is disposed in such a way that groundwater contamination is avoided. Human excreta should also be disposed with a safe distance to food or water aimed for human consumption.

2.4.2 Sanitation

When making a Google search on "sanitation" the search result reaches about 11.8 million different hits, which implies that sanitation is a seriously addressed issue. Results commonly stress public health through expressions like disease, human waste and personal hygiene (Google, 2009). Besides safety against diseases, Conant & Fadem (2008) mention four other reasons for why people require better sanitation, toilets in particular. These include privacy, comfort, cleanliness and respect. That is, the toilet should have a proper shelter that is large enough to stand up in. It is also more likely that people will use a toilet that is clean, within a close distance from their houses and where they can sit or squat comfortably. Moreover, the owner may gain respect from visitors if he or she has a toilet that is well looked after.

A sanitation system consists of a chain of solutions including construction of toilets, collection of human waste, maintenance of the system and reuse of waste. A sanitation system should preferably be sustainable so that future generations can use the natural resources (safe water, nutrients in the soil etc.) to the same extent as the present population.

Definition of a sustainable sanitation system

If to be considered sustainable, the sanitation system should meet the following five criteria emphasized by the Sustainable Sanitation Alliance, SuSanA (SuSanA, 2009).

Health and hygiene: This is to ensure public health by preventing the spread of pathogens and harmful substances in the whole sanitation chain (from the toilet to treatment and disposal or reuse of the waste). Public health should be considered in the local village as well as in downstream areas.
Environment and natural resources: Natural resources, such as energy and water that are required during construction, maintenance and operation of the sanitation system should be considered. Emissions resulting from these activities should be taken into account. This aspect also deals with the degree and effects of recycling waste as well as minimizing the need for non-renewable resources e.g. by producing renewable energies such as biogas.
Technology and operation: This involves the degree of functionality and simplicity of which the local community can construct, run and monitor the sanitation system. This includes the whole sanitation chain from collection and transportation to treatment and disposal of the waste. The criterion also accounts for the system's ability to persist when exposed to water shortages, flooding, storms etc. Moreover, the technical part of the sanitation system should be flexible enough to be able to adapt during development in the demographic and socio-economic environment.
Financial and economic issues: What are the costs for each household or the local community during construction, maintenance etc. of the sanitation system? Direct costs like these must be related to benefits and external costs. Benefits include improved health, new employments and increased agricultural productivity from use of recycled fertilizer amongst others. External costs could comprise of environmental pollution.
Socio-cultural and institutional aspects: The sanitation system should meet demands for local customs, convenience, privacy as well as equity between gender and groups of different social status. It should also be designed with respect to the legal framework of the community and in such a way that food security is ensured.

Few sanitation systems are believed to fulfil all criteria. Still, the importance of these criteria lies in pointing out a direction in which to work while constructing and evaluating sanitation systems. It is vital to understand that there is no sustainable sanitation solution that works everywhere. Instead each sanitation solution should be chosen according to local regulations as well as environmental, technical, economical and socio-cultural circumstances (SuSanA, 2009).

3 THEORY

Water sources are subject to contamination through leakage from soil, runoff, air pollution and anthropogenic activities amongst others. Groundwater and rainfall collection are two suitable drinking water sources in rural developing areas since budgets generally are low, and treatment of surface water is expensive. Groundwater is commonly abstracted from dug wells and springs, which need to be constructed and maintained properly in order to provide safe water. Nitrate and bacteria from untreated human waste, i.e. excreta, that leak to groundwater is a common reason why the quality of drinking water is bad in rural developing areas. It is therefore of utmost importance to treat excreta properly. The most suitable technology for treatment on a small scale is the urine-separation dry systems, based on financial, hygienic and environmental aspects amongst others.

To supervise how far developments have reached on the MDGs on water and sanitation, water sources and sanitation facilities can be classified as improved or unimproved. The classification is based on a selection of features. Water quality guidelines such as bacteriological, chemical and physical parameters decide whether the water quality is sufficient. Pesticides are considered separately due to the special characteristics of such substances. In addition to sampling the water specifically, vulnerability assessment on potential groundwater using the DRASTIC model can indirectly indicate the water quality.

3.1 DRINKING WATER SOURCES IN RURAL DEVELOPING AREAS

In general, groundwater, surface water and collected rainfall can all be used as drinking water sources. All water sources may, however, not be suitable to use in rural developing areas. Sources that are particularly suitable in rural developing areas and recommendations on how to keep water sources free from contamination are discussed in the following sections. In comparison, Moldovan regulations on well construction are presented.

3.1.1 Groundwater vs. surface water and rainfall collection

There are three main water sources that can be used for drinking water: groundwater, surface water and rainfall. *Groundwater* is formed either by rainfall or surface water that infiltrates and percolates the ground. In addition, groundwater can form by lateral flow and water transport from one aquifer to another. If the aquifer is linked to surface water, groundwater can form by water flowing from the surface water when groundwater is taken out of the aquifer (Grip & Rodhe, 2003). Groundwater has a natural level of purification since bacteria can be removed through filtration in the percolation process, depending on the permeability of the soil. *Surface water*, such as rivers and ponds, can also be distributed as drinking water. The quality of the water is usually bad due to pathogens and bacteria that are allowed to grow in such environments. Therefore, pre-treating the surface water is necessary. *Rainfall collection* is a third alternative that is very useful if no other safe drinking water sources are available (Skinner, 2008).

What source is to prefer in rural developing areas where budget and know-how is low?
As long as the water source provides water with adequate quality, any of the above water sources can be used. Nevertheless, according to Skinner (2008) there are advantages as well as disadvantages to consider when distributing drinking water on a small scale. *Groundwater* has two great advantages; the natural level of purification and it is often available all year round. On the other hand, abstracting groundwater from wells requires a lifting device. It is easier and cheaper to collect shallow groundwater than groundwater from deep aquifers;

however, shallow groundwater can easily be contaminated by surface runoff polluted by latrines or other sources of pollution. Using *surface water* as a drinking water source is not recommended by Skinner since the water is most likely affected by contaminants from untreated sewage water, agriculture or landfill leakage. Treatment is necessary but expensive and requires knowledge; hence, two major disadvantages when it comes to managing water sources in developing areas. *To collect water from rainfall* and use it as the sole drinking water source is only appropriate if there is enough rain during the year to cover the needs. In other words, dry periods make this source unreliable. The rainwater is pure and safe to drink but can easily be contaminated during collection and storage.

For the above listed reasons, abstracting groundwater for drinking water is probably the best alternative in rural developing areas. In addition, rainfall could be collected to cover some of the needs. The rainwater is safe to drink if adequately collected and stored and, furthermore, it makes the burden of collecting water from wells less heavy.

How to abstract and store drinking water

There are two sources from which it is relatively simple to abstract groundwater; namely dug wells (figure 2) and springs (figure 3), which is one of the reasons why dug wells and springs are common water sources in developing areas. The most important features of a well are cover protection (roof, lid) and runoff protection (apron slab), which are needed to keep the water source from contaminations. Important features when protecting springs are spring-boxes and to fence the area surrounding the spring (Conant & Fadem, 2008; Skinner, 2008). Protection features are described in more detail in sections 3.1.2 and 3.4. Requirements on spring constructions are discussed in section 3.4 only.

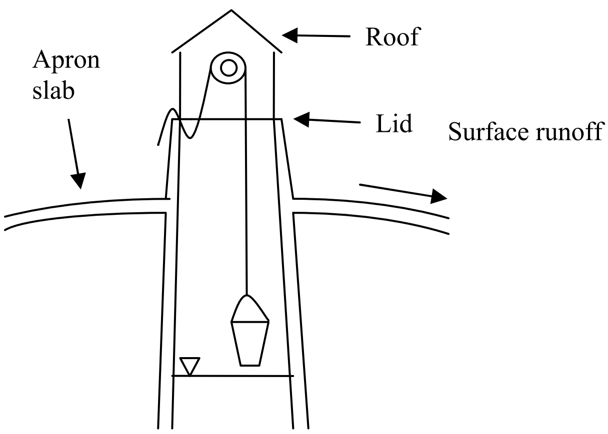

Figure 2 Cross-section of a protected dug well (illustration Hanna Hugosson).

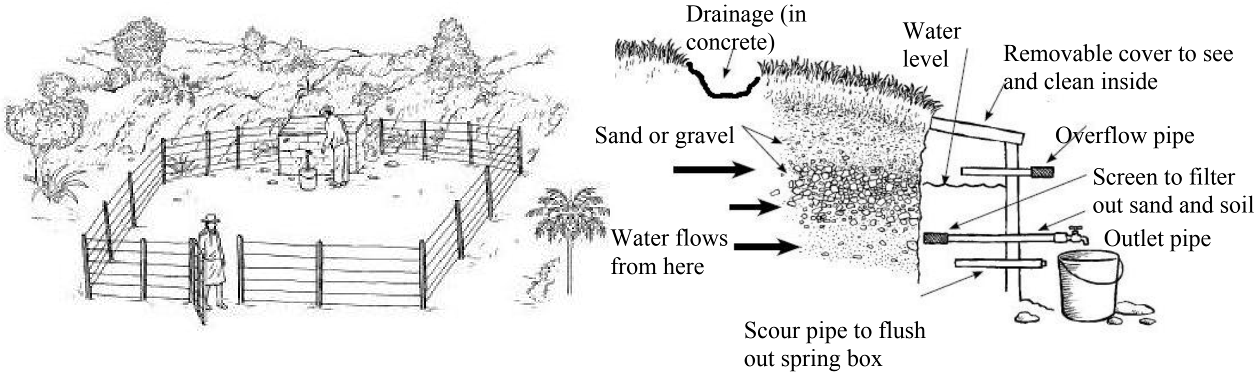

Figure 3 Left: Protected area (fenced) in proximity of the spring (with permission from Conant & Fadem 2008). Right: Cross-section of a spring-box (modified and used with permission from Conant & Fadem 2008).

Rainfall can be collected by various technologies, though the main idea is to gather the rainfall on house-roofs and then lead the water through gutters to storage tanks (figure 4). It is important that roof and gutters are kept clean, which means that any bird spilling and leaves needs to be removed (Conant & Fadem, 2008). The area of the rooftop decides the amount of collected water; one millimetre of rain that falls on 1 m^2 corresponds to 1L of water.

Figure 4 Rainfall collection on rooftop (with permission from Conant & Fadem 2008).

Skinner (2008) and Conant & Fadem (2008) stress the importance of education when it comes to storing abstracted drinking water. Skinner states that "*no matter how much care is taken to produce safe water at the source, it will have been useless if it is polluted afterwards*". To use the right kind of containers is of greatest importance as well as to keep storage containers clean, sealed and away from e.g. light, insects and animals. In particular, narrow mouthed containers (figure 5) are suitable for storing drinking water since the water has to be poured instead of scooped. Hence, contaminants are prevented from entering by for instance ladles or jugs.

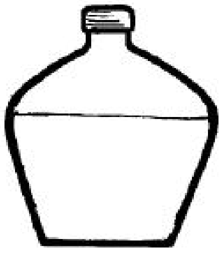

Figure 5 Storing drinking water in narrow mouthed containers prevents from using e.g. ladles or jugs, in other words contaminants are kept from entering the container (with permission from Conant & Fadem 2008).

3.1.2 Protecting a well

Protection of a water source includes both construction and maintenance. The well should be constructed so that surface water is prevented from penetrating the well lining, and so that other contaminants are kept from entering the well. Proper maintenance implies for instance that all human activity and land use that signifies any risks for groundwater contamination should be avoided.

Recommendations in the literature

Skinner (2008) gives recommendations on what features a hand-dug well should have, which are features above ground surface, well lining above water and well lining below water surface.

Features above ground surface. According to Skinner, water should be collected by using collective buckets and rope. Conant & Fadem (2008) add that a chain is to prefer ahead of a rope since it is more hygienic, although more expensive. Furthermore, Skinner states that to reduce risks of contaminations it is important to keep the rope and bucket off the ground. The user should further not be standing on top of the well wall. This is done by securing the rope, hanging the bucket on the winch (if a windlass is used), and constructing a thin headwall (about 1 m high). A cover of impermeable material (concrete or asphalt), i.e. an apron slab, should be surrounding the well on a radius of 1.5 to 2 m to prevent surface water from infiltrating. There should be a drainage channel that leads spill water at least 6 m away from the well to either a soak away pit or a garden, to reduce risk for mosquitoes. The well head should have a cover (e.g. roof or lid) to keep bird droppings from falling into the well.

Well lining above water. To protect water from infiltrating, the well lining should be made out of impermeable material. Below the ground surface, the top 3 m should be covered with clay or concrete to fill any gaps behind the well lining and keep surface water from contaminating the groundwater. Other gaps above the water surface are filled with dug out material.

Well lining below water surface. Both lining and the bottom of the well should be made out of permeable material. Gaps behind the well lining are also filled with permeable material such as small stones and coarse sand.

Apart from well constructions, there are also recommendations on maintenance of a water supply. The well should for instance be emptied and cleaned (removal of sediments etc.) on a regular basis and the well water disinfected after each recharge. Furthermore, Skinner argues that a groundwater source should be kept as far away from possible hazards (latrines, septic tanks etc.) as needed so that the risk for contamination is reduced. To ensure adequate filtration of the water, a minimum safety distance to the well from contaminating sources of 30 m is recommended. The safety distance depends on the depth of the groundwater table and type of soil, i.e. how long it takes for water to percolate to the groundwater in addition to how fast the groundwater travels in the saturated zone. If the groundwater flow can be calculated, the safety distance can be modified either to be larger or smaller. Skinner states that there is a low risk of virus and bacteriological contamination if travel time is at least 25 days, while the risk is very low if it exceeds 50 days. Safety distances are important to consider not only when deciding upon a new location for a water source but also when planning for new establishment in the vicinity of the water supply.

In conclusion, Skinner (2008) states that if a water source proves to be of deteriorating quality it is better to find a new source with clean water than to treat the existing polluted source.

Before looking for a new water supply, however, the possibility of improving the existing source should at first be scrutinized. Improvements are for instance to upgrade from a rope and bucket to a hand pump, or to a windlass (cylinder and winch) or shaduf (a long suspended rod with a bucket at one end and a weight at the other). Hand pumps, windlass and shaduf all improve the hygiene but also results in only one user at a time being able to abstract water.

Moldovan regulations on construction of wells

When choosing a drinking water source there are, according to The Department of State Sanitary and Epidemiological Control of the Ministry of Health of the Russian Federation (1996), some criteria to consider. Firstly, the location should provide a drinking water quality that does not vary too much. Secondly, it should prevent bacteriological and/or chemical pollution as well as water-borne diseases and lastly, contamination should be prevented by adequate maintenance of the water source. Before deciding upon a location, a geological and hydrological analysis should be carried out to provide enough information about groundwater depth and flow direction etc. On-site sanitary conditions need further to be analysed. The water source is for example not to be located any closer than 50 m downhill from existing or possible sources of pollution, such as latrines, cemeteries and storage of chemicals or fertilizers.

Furthermore, the following requirements should be fulfilled to protect dug wells from contaminations:

1. There should be a headwall at least 0.3 - 0.7 m high to protect the well from surface contaminations.
2. The headwall should have a cover.
3. The ground surface surrounding the well should be protected from spill water infiltration by e.g. concrete or asphalt. This apron slab should be 0.1 m thick and protect a radius of 2 m from the well.
4. The well lining should be dense to prevent water from penetrating.
5. Water is to be extracted either manually with a bucket or by pumps. The latter is to prefer from a hygienic point of view.

Moreover, there are regulations on maintenance and operation. Activities such as car washing, watering livestock and doing laundry are prohibited on a radius of 20 m from the well. Every dug well that does not have a pump solution for extracting water should have a bucket for this purpose. It is prohibited to use any other bucket than the one provided or to use private ladles to extract water from a public spring. In addition, the wells should be cleaned at least once a year. After each time the well is cleaned (emptied) or reparations have been done it should be disinfected with chlorine. Cleaning and disinfection should be financed by the local budget or means by private owners. If the well cannot meet standards on sufficient water flow or drinking water quality, it should be liquidated. This should be financed by the owner (The Department of State Sanitary and Epidemiological Control of the Ministry of Health of the Russian Federation, 1996).

As for the consequences if well regulations are not followed, there is a system of fines. Municipal "*sanitary doctors*" from the Centre of Preventive Medicine are responsible for the control of all municipal wells, by sampling and examining sites annually. If water quality in the village should not comply with the standards or the sanitary situation is not satisfactory, "*prescriptions*" are given. The mayor of that specific village will possibly be fined (Natalia Vavelschi, pers. comm.).

The Moldovan regulations do not differ significantly from standards given by the literature study; the suggested features above ground are in general the same. However, suggested safety distances for possible contaminating sources from water supplies are somewhat bigger according to Moldovan standards, 50 m compared with 30 m, which implies a larger safety margin.

3.2 WATER QUALITY INDICATORS

Water quality can for instance be determined quantitatively by sampling water with respect to indicator parameters. In this study, the indicating drinking water parameters can be divided into three groups; bacteriological, chemical and physical parameters. Bacteriological parameters were *E. coli* and total coliform bacteria, while the chemical parameters included ammonia, chloride, electrical conductivity (EC), hardness, nitrate, nitrite, dissolved oxygen (DO), pH and sulphate. Turbidity was the sole physical parameter to be measured. Pesticides were considered separately due to their special characteristics. High contents of salt affect how much water that is available for plants to absorb. Hence, EC is a measure of how suitable the water is for irrigation.

3.2.1 Drinking water

WHO (2004) suggests guideline values for biologically and chemically derived contaminants in addition to physical parameters in drinking water. The primary purpose of the guidelines is to protect public health by improving drinking water sources and making them safe. Therefore, the guidelines are not suitable for industrial waste or protection of aquatic life. Moldovan standards are, furthermore, suggested for all mentioned parameters. The National Board of Health and Welfare (2003) suggest guideline values on parameters such as chloride and nitrate, which can be used as indicators on impact from external sources, for private wells. None of the investigated wells in the study area were private; however, guideline values are still considered valid since it is only for indicating matters. The analysed parameters are described below, while the WHO, Moldovan and The National Board of Health and Welfare guideline values are shown in table A1 in appendix A.

Bacteriological parameters

E. coli. *E. coli* bacteria are normally present in human and animal intestinal flora and the bacteria are harmless in this environment. However, if *E. coli* enters other parts of the human body it will be harmful and cause diseases such as diarrhoea, meningitis and urinary tract infections. *E. coli* is the pathogen that most frequently causes infections in humans and is normally used as an indicator for faecal contamination in drinking water. There are several types of *E. coli*, though only some of them cause diarrhoea. For instance, the most common reasons why infants are hit by diarrhoea are the *E. coli* types EPEC and EAEC (WHO, 2004).

Total coliform bacteria. Total coliform bacteria include different types of bacteria that originate from sewage (faecal bacteria) and exist naturally in the environment. Naturally existing coliforms are heterotrophic with the ability to grow in water and soil environments. Presence of coliform bacteria indicates that water treatment is insufficient (WHO, 2004).

Chemical parameters

*Ammonia (NH_3 and NH_4^+)***.** Ammonia, NH_3 and NH_4^+ (depending on pH-value), occur naturally in groundwater because of leakage from agricultural land, animal keeping, sewage and metabolic processes in the ground. Natural concentrations in groundwater are usually less than 0.2 mg/L. Presence of ammonia in drinking water is not directly a health risk, but it can result in decreased disinfection efficiency and cause unpleasant odour and taste. Certain concentrations of ammonium can give rise to unpleasant taste (WHO, 2004).

Chloride (Cl^-). Drinking water with a high content of chloride is not directly a health risk, although certain concentrations may give rise to unpleasant taste (WHO, 2004). Presence of chloride in drinking water might indicate impact on the water from other sources, i.e. landfills or sewage/surface water (The National Board of Health and Welfare, 2003).

Dissolved oxygen (DO). There is no health-risk coupled to the DO content; however, the parameter indicates ongoing biological and chemical processes in the water. A content of zero DO implies anaerobic conditions, which for instance can result in reduction of nitrate to nitrite (WHO, 2004). In contrast, high DO values enable a positive bacteriological growth rate. Bacteriological growth is further an indication of impact from shallow surface water (The National Board of Health and Welfare, 2003).

Electrical conductivity (EC). The ability of conducting a current through a medium is measured by the EC. As for water, EC is an indirect measure of the salt content or total dissolved solids (TDS). The higher salt content the better the conduction of current (State of California Website, 2009). Salts can either originate from natural conditions, i.e. mineralization in the soil, or human activity. The parameter is relatively easily measured in situ and used as an indicator of drinking water contamination (European Environment Agency, 1999).

Hardness. There is no health-risk linked to hardness, which is caused by dissolved calcium and sometimes also magnesium. Certain concentrations of hardness, pH and alkalinity in the water may have negative impact on water distribution systems. If water is hard, with concentrations of calcium carbonate above 200 mg/L, it can result in scale deposits in boilers and pipe systems. Soft water, with calcium carbonate concentrations less than 100 mg/L, can lead to pipe corrosion due to the low buffering capacity in the water. Furthermore, hard water leads to excessive use of soap and detergents in households (WHO, 2004), which neither is environmentally friendly nor sustainable.

Nitrate and nitrite (NO_3^- and NO_2^-). Nitrate concentrations in groundwater are naturally low, but they can be very high due to leakage from agricultural land and runoff contaminated by human waste after rainfall (WHO, 2004). Nitrate consumption can be a health risk since it, when transformed to nitrite in the body, reduces the capacity of the blood to carry oxygen. This is especially hazardous for infants, young children and elderly. Common health problems due to chronic or large intakes of nitrate are cancer and reduced progress in children's development. If feeding water polluted with nitrate to livestock, losses can take action as harmed vitality and reduced weight gain (Nitrate Elimination Co., Inc., 2009).

Sulphate (SO_4^-). Sulphate in drinking water causes unpleasant taste and if levels are high it can be a laxative to consumers not used to drinking the water, especially infants (WHO, 2004).

pH. When it comes to water treatment pH is one of the most important water quality parameters. Even though pH does not affect the consumer directly it is important, because keeping pH in the right interval ensures the water to be sanitary and clear. Chlorine disinfection is not effective unless pH is lower than 8, but a pH too low makes the water corrosive which affects pipe systems badly (WHO, 2004).

Physical parameters

Turbidity. Turbidity is a measure of suspended particles in the water. High turbidity is caused by particulate matter in the water that either is not filtrated adequately from the source or comes from re-suspended sediment in the distribution system. It is desirable to have a drinking water source with clear water, i.e. low turbidity (measured in Nephelometric Turbidity Units, NTU), since a high content of particulate matter may indicate the water being contaminated. Presence of particulate matter makes disinfection less effective, because the microorganisms can hide inside the particulates and reduce the contact surface between the microorganisms and disinfectant. Changes in turbidity are relatively easy to measure just by looking at the water and consequently turbidity is an important and common control parameter in water treatment processes (WHO, 2004).

Pesticides

Pesticides influence the health of the receiver in different ways depending on the type of pesticide. Some substances affect the nervous system while others may cause cancer. Irritated skin and eyes are common effects of external exposure (U.S. Environmental Protection Agency, 2010). The European Commission's Directive on Drinking Water, 80/778/EEC, allows maximum pesticide concentrations of 0.1 µg/L for individual substances. The total concentration of pesticides may not exceed 0.5 µg/L in drinking water (European Environment Agency, 1999). WHO (2008) presents other guideline values that depend on the actual substance, ranging from 0.03 µg/L to 300 µg/L for aldrin and pyriproxyfen, respectively.

3.2.2 Nitrate in groundwater

High concentrations of nitrate threaten human health and should be avoided. According to the Swedish Environmental Protection Agency (2002), the three main sources of nitrate contaminations are leakage from agriculture, inadequate management of human waste and airborne spreading from e.g. traffic emissions. Information about these sources is given in more detail below, where the Swedish Environmental Protection Agency (2002) was used as reference literature.

Agriculture

Nitrate leaks to groundwater if there are excessive amounts in the soil. Insufficient needs for crops to take up nitrogen or mineralization are generally the reasons for the excessive amounts. Both types of nitrate leakages depend on the soil type. Fine soils, such as clay and silt, are less likely to leak nitrate due to the surface of the soil particles where nitrate ions can attach being greater. In addition, water commonly percolates through larger cracks in the soil, meaning that some parts of the soil will not be in contact with the percolating water. In this case most of the nitrate that is bound to the soil particles are not likely to leak.

During the growing season, crops take up nitrate as nutrients. If the amount of nitrate in the soil exceeds what the crop needs during one season, nitrate will probably leak from the agricultural land. The nitrate will stay in the soil until in contact with soil water, which percolates to the groundwater. Hence, the leakage is enhanced by the amount of rain as well as the amount of manure that is used. The leakage also depends on the type of crop. Crops that can be grown far into the autumn will take up nitrate almost until winter comes and thereby minimize the amount of nitrogen that can leak to the groundwater.

Mineralization of organic nitrogen in the soil is a further source of nitrate leakage to groundwater. The transformation from organic nitrogen to nitrate is done by microorganisms at temperatures above 0 ˚C. Mineralization can only take place in the presence of oxygen. Oxygen deficits are more common in fine soils, meaning that nitrate leakage will be less in these types of soils. If the amount of oxygen is insufficient the microorganisms will denitrify, which releases nitrogen gas instead of forming nitrate.

Sanitation

There are large amounts of nitrate in human excreta. Leakage from pit latrines is considered to be the most critical source of nitrate contamination in groundwater in Moldova (section 2.2.1). In order to eliminate nitrate contamination, the leakage needs to be stopped at the source.

Airborne pollution

Nitrogen compounds from traffic and ammonia from agricultural land may be added to the soil by air and consequently transformed to nitrate in the soil. It is difficult to eliminate contributions of nitrogen from the air.

3.2.3 Irrigation water

High water contents of salts in the soil water may have negative effects on agricultural activity since it affects the ability of the plants to take up water. When the salt concentrations are high the same signal is given as if there would be only small amounts of water in the soil, a phenomenon referred to as physiological drought. Hence, high salt concentrations and EC values increase the risk of reduced crop production. Suggestions for irrigation water quality are shown in table 1 (Bauder et al., 2009).

Table 1 Classes of irrigation water quality, based on electrical conductivity (Bauder et al., 2009)

Classes of water	Electrical conductivity µS/cm
Class 1. Excellent	<250
Class 2. Good	251-750
Class 3. Permissible	751-2000
Class 4. Doubtful	2001-3000
Class 5. Unsuitable	>3001

If class 3 (permissible) is to be used, Bauder et al. states that the unsaturated zone in the irrigated area needs to be permeable in order not to accumulate salts in the plant zone. As for irrigation water, good drainage is needed if using water classified as 4 and 5 (doubtful and unsuitable). Plants irrigated with this water may wither.

3.3 SMALL-SCALE SEWAGE TREATMENT – SANITATION TECHNOLOGIES

Untreated human waste, i.e. excreta, that leaks to shallow groundwater is one common reason why the quality of drinking water is poor in rural developing areas. There are various technologies for treating excreta on a small scale. The technologies can be grouped into the main principles *drop-and-store*, *ecological sanitation* or *flush-and-discharge,* which then are divided into further subgroups (figure 6). In order to choose a suitable technology for rural developing areas several aspects need to be considered, including health, environmental resources, technology, financial and socio-cultural.

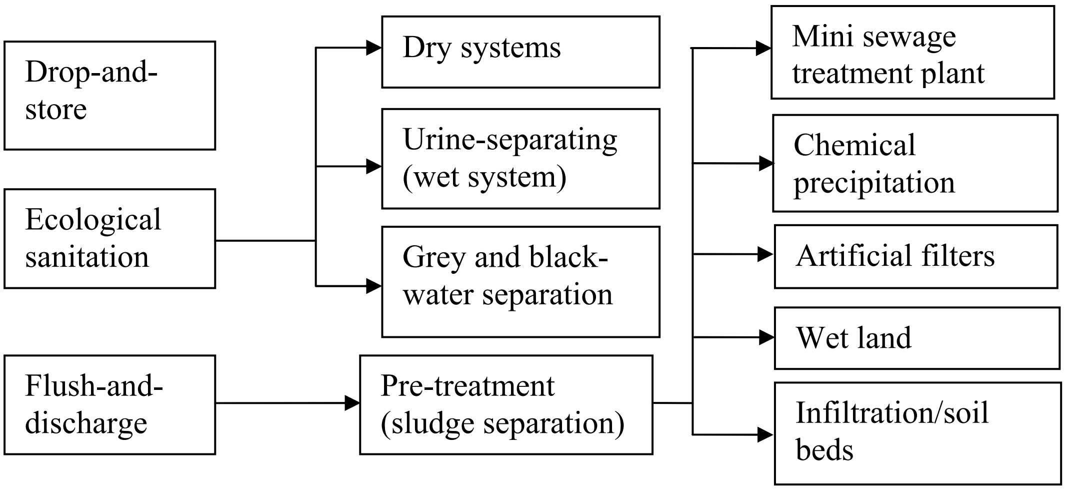

Figure 6 Small-scale solutions for sewage treatment (modified from Palm et al. 2003).

Drop-and-store

The drop-and-store method refers to the dry, simple method of disposing excreta by “dropping” it into excavations. Advantages are the simple construction but the drawbacks are plenty. Drop-and-store toilets represent potential risks for groundwater contamination in areas where groundwater is shallow and are consequently not appropriate in densely populated areas. The soil cannot be too rocky and new pits have to be dug about every year (depending on the load) (Winblad & Simpson-Hebért, 2004). Examples of drop-and-store systems are open pit latrines, improved pit latrines and ventilated improved pit latrines (VIP-latrines) (figure 7).

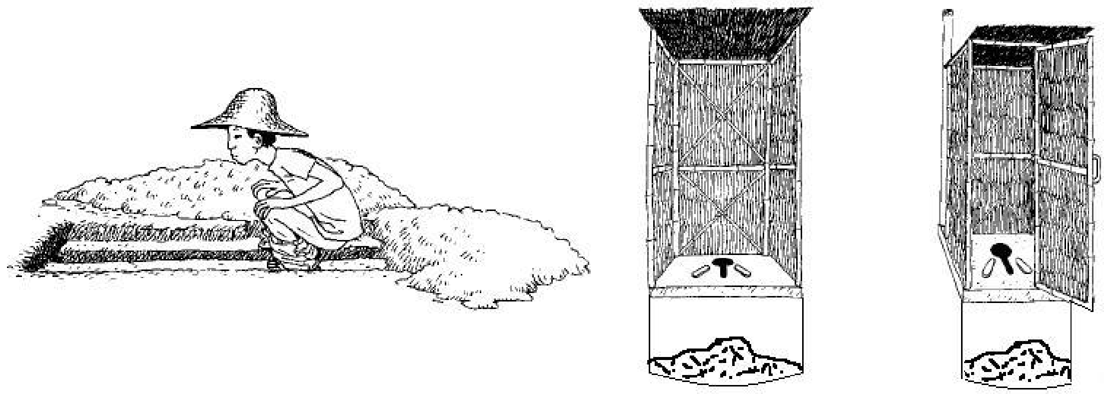

Figure 7 Left: simple (open) pit latrine with no superstructure (left). Middle: improved pit latrine with a superstructure and enclosed pit. Right: VIP-latrine (ventilation, superstructure and enclosed pit) (modified and used with permission from Conant & Fadem 2008).

Ecological sanitation – ecosan

The benefit from reusing human waste as nutrients for cultivation is known as the concept of ecological sanitation (ecosan). Instead of handling excreta and urine as waste, it is considered a valuable resource that increases crop yields as well as closes the ecological loop (Winblad & Simpson-Hebért, 2004). There are several different techniques that include urine separation (dry and wet system) and separation of black and grey water. The urine separation dry system is the only system that does not require pipes and is, hence, the simplest technology.

Flush-and-discharge

The flush-and-discharge systems remove excreta by flushing it away with water to a recipient. Large amounts of water are needed, which in many developing countries is not available due to water scarcity. At the same time, pipes and treatment of the water are required which may be very expensive (Winblad & Simpson-Hebért, 2004).

3.3.1 Suitable systems for rural developing areas – economical aspect

As stated in section 2.4.2, there are several aspects to consider when choosing a sewage system that is sustainable. No system is believed to fulfil all five listed criteria, which is why some of them must be considered more important. In rural developing areas money is probably the most limiting factor, at least if investments are to be done by villagers without co-financing. A small-scale system must therefore be affordable. Palm et al. (2003) showed the costs of installing different sanitation systems in Sweden. The costs were for one household, based on calculations from the year 1999 (summarized in table2). It was evident that a flush-and-discharge system (mixed sewage) was more expensive, mostly because these techniques are more advanced and require an installation of pipes. If taking costs of pipes and labour into count, the cheapest system would be a urine separation dry system. Consequently, which system that is cheapest to choose depends on whether pipes are already installed. The urine separation dry system could be built with more or less advanced features; hence, the costs could be significantly lower than displayed in table 2.

Table 2 Cost range for one household in Sweden for installing ecological sanitation and flush-and-discharge systems (modified from Palm et al. 2003)

	Cost range for one household	**Cheapest system if pipes are installed**	**Cheapest system if pipes are not installed**
Ecological sanitation	950 to 5200 Euro	Grey and black water separation (950 Euro)	Urine separation dry system (2200 Euro)
Flush-and-discharge	2400 to 7600 Euro	Artificial filter (2400 Euro)	Artificial filter (2400 Euro excluding installation of pipes)

Palm et al. listed three criteria to consider when choosing a sewage system, s to minimize spreading of diseases, to economize recourses as well as to minimize the environmental influences. The urine separation dry system was evaluated with these aspects in mind and the conclusions were that

- if composted properly, the spreading of diseases from excreta would be prevented
- the main part of the urine and faeces can be recycled if managed properly
- a dry system gives only small amounts of water as waste, which leads to reduced environmental influences. There may be some emission of ammonia as well as methane (from the composting phase).

The second matter implies that ecosan is a system that requires both knowledge and efforts by the user. If educated, the user will, however, benefit from upgrading from a drop-and-store system (Kvarnström et al., 2006). Urine separation dry systems have not only been cheaper to install than e.g. VIP-toilets, but also contribute to a reduction of environmental contaminations. Further benefits from upgrading to a urine diversion system are described as increased hygiene and health (no contact with the faeces), increased comfort (less odours and located inside the houses) in addition to the reuse of the nutrients from urine.

3.3.2 Ecosan urine separation dry systems – main ideas

According to Esrey et al. (1998) *"sanitation approaches must be resource minded, not waste minded"*, which was the criterion for ecological sanitation. Disease-spreading is a huge problem especially in developing countries; however, by treating and sanitizing faeces (killing the harmful bacteria) disease-spreading is reduced. In addition, sanitizing enables faeces to be recycled and reused, though most of the nutrients are in the urine.

According to Winblad & Simpson-Hebért (2004) there are three main principles for urine separation dry systems, which are *dehydration*, *composting* and *soil composting*. These methods are primary treatment methods and refer to how faeces are dropped and stored. A secondary treatment is needed for all methods in order to completely sanitize the faeces, i.e. make it safe to put on crop fields. Secondary treatment can for instance be done in a garden compost or eco-station. The biggest difference between a garden compost and eco-station is that eco-stations compost with a higher temperature.

Reusing nutrients

Winblad & Simpson-Hebért (2004) give several reasons the reuse of nutrients, such as increasing food production, improving economy (nutrients free of charge instead of buying commercial fertilizers), avoiding contaminations caused by nitrogen leakage, re-establishment of areas that have been subject to erosion. Every year, one adult produces about 400 litres of urine and 25 to 50 kg of faeces, where most of the nutrients are in the urine (4.0 kg of nitrogen, 0.4 kg of phosphorous and 0.9 kg of potassium). In areas where pit latrines are common, large concentrations of nitrogen in the groundwater are most likely found since about 50 % of the nitrogen leaks from the urine. Faeces contain only a smaller amount of nutrients compared to urine (0.55 kg of nitrogen, 0.18 kg of phosphorous and 0.37 kg of potassium). Faeces are still valuable as soil conditioners despite the low quantities of nutrients.

According to Esrey et al. (1998), there are different possibilities to handle urine in households (figure 8). Urine can be manually spread on fields/crops (dilution is needed if spread directly on crops), drained through a soak pit or put on evaporation beds. There are thorough user guidelines for how to sanitize and manage urine and faeces in a hygienic way and what amounts to dilute. When there is no interest in recycling the nutrients, e.g. if no farmland can be found near the user, evaporation beds are a good choice for handling the urine. The urine liquids evaporate on the evaporation bed, which leaves a smaller, concentrated volume of urine to dispose. Urine can also be collected and used on a large-scale level, by commercial farmers.

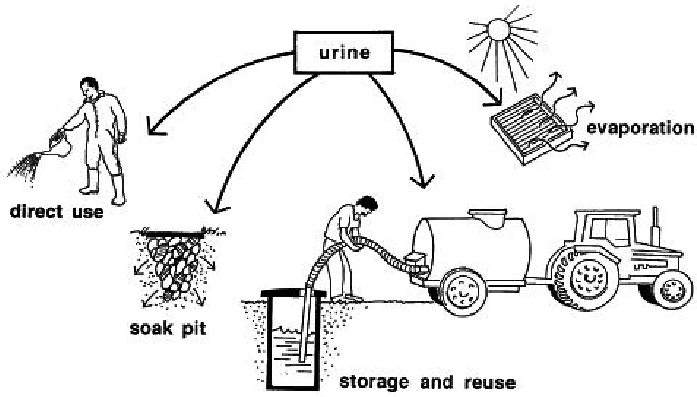

Figure 8 Alternative handling of diverted urine: on crops (direct use), on drainage (soak pits), storage for later collection and evaporation beds (with permission from Esrey et al. 1998).

Main principles for sanitizing faeces

Dehydration means to keep faeces dry by diverting urine to a separate unit from the processing chamber where faeces are kept (figure 9a). After defecation, water absorbing material (such as lime or soil) is added to the compartment where faeces are stored for up to a year. This will reduce odours and partly sanitize the faeces. *Composting* toilets (figure 9b) mix faeces with organic waste from the household and garden. The waste is broken down by microorganisms which in order to function optimally require a special temperature, moisture etc, i.e. some efforts are required by the user to control these. After about half a year the compost material is moved to e.g. garden compost to make it completely sanitized. *Soil composting* means to drop faeces (or excreta) in a composting compartment mixed with larger amounts of soil (figure 9c). This method requires shorter sanitizing time; already after 3 to 4 months the faeces can be moved to secondary treatment. Soil composting is either done in above-ground vaults or shallow pits.

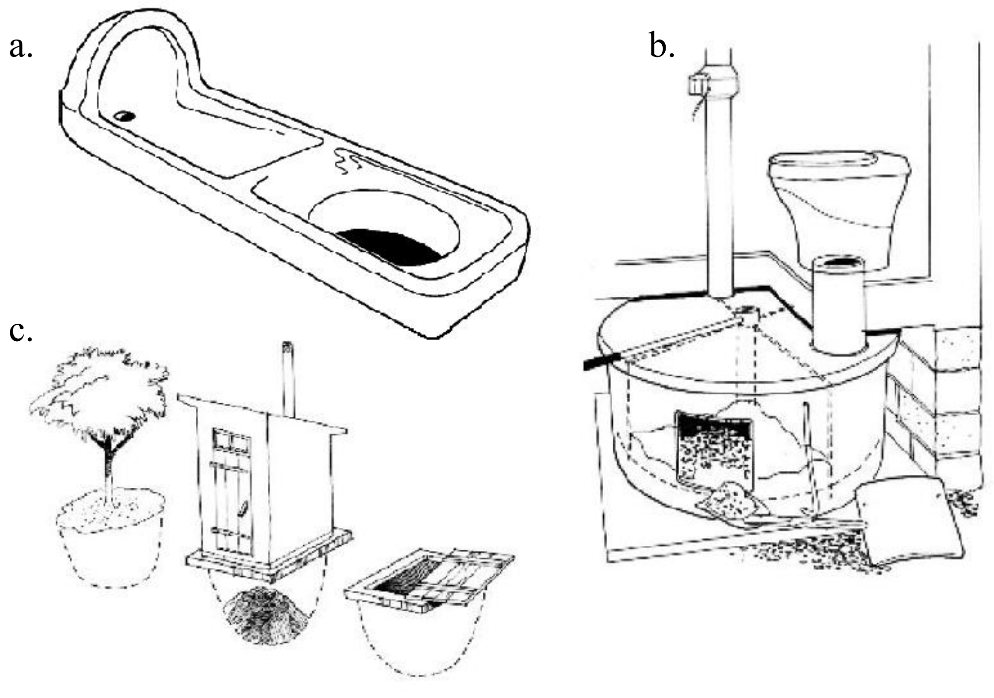

Figure 9 a. Squatting pan for a dehydrating ecosan-toilet (with permission from Esrey et al. 1998).
b. Composting ecosan-toilet with several compartments. **c.** Soil-composting ecosan-toilet (shallow pit) where a tree is planted in the pits (with permission from Winblad & Simpson-Hebért 2004).

3.3.3 Ecosan in practice – dehydrating toilets in Moldova

Wisdom is a non-governmental organization, financed by the Swiss Cooperation Agency (SDC), which has been working with ecosan in Moldova since 2007. Among several different projects, the organization builds ecosan toilets in different parts of the country, educates the population on how to use them and makes surveys on acceptance. Ecosan dehydrating toilets are financed partly by the organization and partly by the household that decide to build the toilet. The cost of one ecosan dehydrating toilet is approximately 10 000 lei (about 560 Euro), including both building material and labour. The cost is significantly lower than the costs displayed for systems installed in Sweden (section 3.3.1). Usually Wisdom and SDC finance the construction material which is about 7000 lei. The remaining 2000 to 3000 lei comprise of the construction work which the households do not pay in cash but in labour, meaning that instead of hiring someone to build the toilet the households build it themselves. The construction work takes at least three weeks (Nadia Andreev, pers. comm.; Sergiu Andreev, pers. comm.).

According to Andreev, N. and Andreev, S., ecosan is a relatively accepted concept in Moldova. It is important to understand the villagers' requisites, however, before trying to implement any solution. Villagers are often keener to understand how ecosan solutions can improve toilet facilities with respect to warmth, comfort, cleanliness and odours than the importance of reusing nutrients. Furthermore, some people may find it hard to imagine that it is possible to have a toilet inside the house at all since existing pit-latrines usually are located far away from the house due to e.g. bad odour.

Ecosan toilets that are built by Wisdom can either be detached or integrated with the dwelling-house, with an indoor entrance. Household toilets are generally built with one compartment, while school toilets normally have two. Toilet bowls are made out of concrete and toilet seats in Styrofoam, which are warm to sit on as well as simple and cheap to construct. Excreta are collected in containers that are dimensioned with respect to how many persons that use the toilet. When one container is full, it is left to stand in the compartment for about one year and is then emptied into a pit or on compost. Since excreta normally are not sanitized until after two years of decomposing, it is important to handle the containers carefully and use gloves and masks. The compartment is ventilated in order to prevent odours inside the toilet. However, ventilation is less efficient during the colder months due to stratified air. Urine is collected in separate tanks and can be used as fertilizer if diluted. Andreev, N. and Andreev, S. recommend a dilution of one part urine and three parts water, or one to seven. Fertilizer use cannot exceed 2 L urine/m^2/year to keep nitrates from accumulating in the soil. The villagers are educated on how to calculate what amounts of urine that can be used during one year.

An ecosan toilet from one of Wisdoms pilot projects is displayed in figures 10-13, where the ecosan toilet building was attached to the main house (figure 10). On the right hand side of the house one can see the ventilation pipe that removes odour from the compartment where urine and faeces are collected. A closer view of this compartment can be seen in figure 11 where the blue tank at the back collects urine, while faeces are collected in the black container. When the black container is full it can be shoved to the back of the compartment where decomposition can be completed. Figure 12 displays a urine separation toilet seat in Styrofoam and figure 13 a ceramic urinal.

Figure 10 Ecosan toilet built with support from Wisdom (photo by Katja Larnholt).

Figure 11 Compartment underneath the toilet. Urine is collected in the tank connected to the hose and faeces in the black container (photo by Katja Larnholt).

Figure 12 Urine separation toilet with a Styrofoam seat (photo by Katja Larnholt).

Figure 13 Toilet and urinal (photo by Katja Larnholt).

3.4 IMPROVED AND UNIMPROVED DRINKING WATER AND SANITATION

To supervise and quantify progresses on the MDGs, the definitions *improved* and *unimproved* water and sanitation was created. Improved water sources are, according to WHO Statistical Information System (WHOSIS) definition (2009b), "*the types of technology and levels of services that are more likely to provide safe water than unimproved technologies*". Improved sanitation facilities are defined similarly as "*the types of technology and levels of services that are more likely to be sanitary than unimproved technologies*". It is believed that access to improved drinking water and sanitation is pivotal for human health. Examples on improved and unimproved water sources and sanitation facilities are displayed in table 3.

Table 3 Improved and unimproved water sources and sanitation facilities (WHOSIS, 2009b)

	Improved	**Unimproved**
Water source	Household connections	Unprotected wells
	Public standpipes	Unprotected springs
	Boreholes	Vendor-provided water
	Protected dug wells	Bottled water
	Rainwater collections	Tanker truck-provided water
Sanitation facility	Connection to public sewers	Public latrines
	Connection to septic systems	Open latrines
	Pour-flush latrines	Bucket latrines (with manually removed excreta)
	Simple pit latrines	
	Ventilated improved pit latrines	

What is the difference between improved and unimproved water sources and sanitation, i.e. what criteria do water sources and sanitation facilities need to fulfil in order to be improved? The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) discusses the definitions in the document *Core questions on drinking-water and sanitation for household surveys* (JMP, 2009). The survey material is intended for collection of accurate data on how drinking water is collected as well as sanitation, in order to determine different household needs.

Similar to the recommendations in section 3.1.2, JMP mentions two criteria for protected wells:

1. Runoff water protection
2. Cover protection

If a dug well only fulfils one of the above-mentioned criteria, it is defined by JMP as an *unimproved dug well*. As JMP does not mention any criteria on the well cover, it is assumed that it should be a lid. Lids protect against both bird droppings and animals from entering the well while a roof only partly protects from bird droppings. However, a well that fulfils the first criteria of runoff water protection and has a roof instead of a lid will, in later chapters, be referred to as a *partly improved source*.

JMP moreover defines an *improved spring* as a spring that is kept from external sources of contamination, such as runoff and bird spilling. Improved springs should have spring-boxes, as shown in figure 3 (section 3.1.1). The spring-box that encloses and protects the water source should be made in concrete or some other impermeable material. *Unimproved springs* are unprotected (lacks spring-boxes) and are open to exposure of external contaminations.

Besides from keeping water sources safe from contamination, access to improved water supplies should be sustainable. The concept of *sustainable access* includes environmental and functional divisions. Environmental protection emphasizes that more water should not be extracted than what is available. Functional sustainability refers to how water is supplied as well as water management. Bottled water and tanker-truck provided water are for instance not considered improved as these sources cannot fulfil a sustainability criterion. In addition, safe water should be accessed within one kilometre from where the user lives and the available amount of water should be at least 20 litres/cap/day (WHOSIS, 2009b).

Improved sanitation facilities should be constructed in such a way so that excreta are separated from human contact. According to JMP, the facilities should have a solid platform, be raised from the ground surface to prevent surface water from entering the pit, and be easy to clean. Needs are done either by sitting or squatting.

3.5 VULNERABILITY ASSESSMENT OF POTENTIAL GROUNDWATER CONTAMINATION

In addition to sampling water with respect to water quality indicator parameters, it is possible to evaluate groundwater quality by doing vulnerability assessments. Vulnerability assessment on potential groundwater contamination can be done by several methods and the choice depends on the available amount of data.

3.5.1 Vulnerability assessment methods

Vulnerability assessment methods can be divided into empirical and numerical. Empirical methods are often the better choice when the user has small amounts of data. Vías et al. (2004) and Draoui et al. (2007) compared several methods when studying aquifers under Mediterranean climatic conditions. Some of the mentioned methods were AVI, which is a numerical method, and GOD as well as DRASTIC (empirical methods). The AVI method requires information on hydraulic conductivity as well as geological layers, while GOD requires data on groundwater occurrence, depth to groundwater as well as lithology (rock type and features). Hence, thorough pre-studies in situ or access to large amounts of data are needed if the AVI and GOD methods are to be used for vulnerability assessments. In comparison, the DRASTIC method is based on seven parameters but can be modified to fit the user and study area.

3.5.2 The DRASTIC model

The DRASTIC model was introduced by Aller et al. (1987), with the objective to find a relatively simple method to evaluate potential for contamination of groundwater in different locations. DRASTIC is an acronym that includes all model parameters: <u>D</u>epth to water table, net <u>R</u>echarge, <u>A</u>quifer media, <u>S</u>oil media, <u>T</u>opography, <u>I</u>mpact of the vadose zone and hydraulic <u>C</u>onductivity. The model was designed for these seven parameters because of their accessibility; they can be found in several different literature sources or be estimated (Aller et al., 1987). Internationally, the DRASTIC model has been recognized and broadly used for vulnerability assessments, especially when performing studies on large areas where studies in situ may be expensive and time consuming. Nevertheless, the DRASTIC model is not intended for replacing field studies. The DRASTIC model is based on four assumptions: the contaminant is introduced at the surface of the soil, is transported into the groundwater by precipitation, has the mobility of water and the evaluated area is 0.4 km^2 or larger (Aller et al., 1987).

When making a vulnerability assessment through the DRASTIC model, each parameter is valued by the user. Valuation should be done in line with guidelines, but there is room for personal opinions as well. Advantages in model simplifications imply drawbacks when it comes to accuracy. The model has been criticized in several articles, which were summarized and briefly reviewed by Panagopoulos et al. (2006).

The major points of criticism were:

- Weighing several different parameters into one index, such as the DRASTIC index, may result in some important parameters being suppressed while other less important are given too big weight.
- Selection of parameters is qualitative and not quantitative.
- Model accuracy is difficult to verify since it would require large scale trace experiments over a long period of time to get a response from the system.

Furthermore, the DRASTIC model does not consider the two factors land use or human activity (Aller et al., 1987) that, indeed, are likely to affect groundwater contamination.

It has been argued whether the DRASTIC model can be used if data on some parameters are missing. For instance, as discussed by Gomezdelcampo et al. (2007), the model can be used with significant results even if hydrological data are insufficient. This is a great advantage since hydrological data can be very difficult to find.

4 METHODS

A study area was chosen and an assessment of the current situation on water quality and sanitation was carried out in cooperation with Apa Canal. Water samples were taken and observations and interviews were made in situ. A few wells were sampled a second time because of their levels of contamination. To confirm any results and gain understanding on the living standards of the local inhabitants, villagers were interviewed about their water and sanitary conditions and habits.

Results from the water sampling sessions were analysed statistically and visualized in ArcGIS. In order to evaluate the potential of groundwater contamination in the study area, a vulnerability assessment study was performed using the DRASTIC model.

During the visits to the study area, data were collected qualitatively (interviews and observations) as well as quantitatively (water samples, measurements of water levels, GPS-positions etc.). Geological information was given by an employee at Apa Canal in Chisinau. Orthophotos for the mapping section was provided by the Agency for Land Relations and Cadastre of the Republic of Moldova.

4.1 THE STUDY AREA

The study area was chosen according to several criteria. Firstly, the village should not be too large with respect to the spatial area or inhabitants as the sampling sessions and over all work would go beyond the capacity of this study. Secondly, the area was to be located in the vicinity of the capital Chisinau as the laboratory that would analyse the water was situated there. Thirdly, it was important that maps covering the village and its surroundings were available. The village Condrita was believed to fulfil these criteria and was therefore chosen in consultation with Apa Canal.

Condrita is situated about 25 km west northwest of Chisinau municipality at 47° 03 N and 28° 34 E (figure 14). The village is located at an altitude of around 130-230 metres above sea level and covers an area of 3.4 km^2. Deciduous forest surrounds the municipality, which generally consists of agricultural land. The population in Condrita reaches approximately 700 people who collect water from 22 municipal wells or springs (Natalia Vavelschi, pers. comm.). In addition, some families have private wells. Condrita is shown in more detail in figure 15.

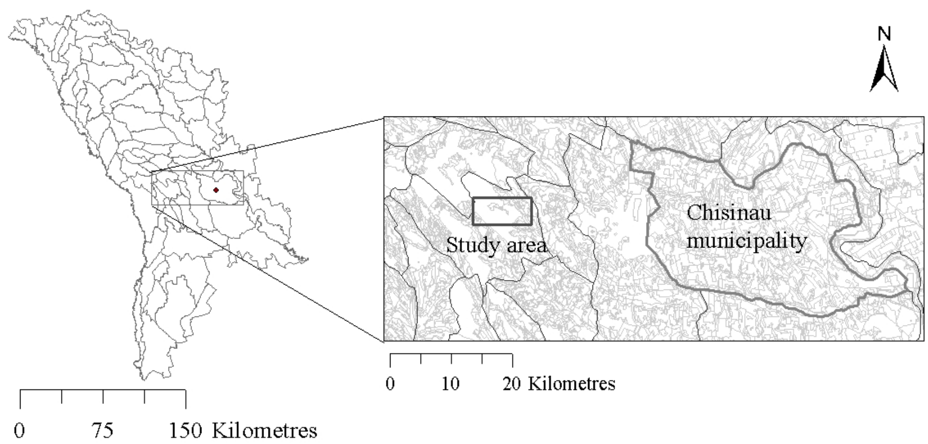

Figure 14 Location of the study area, Condrita, in Moldova.

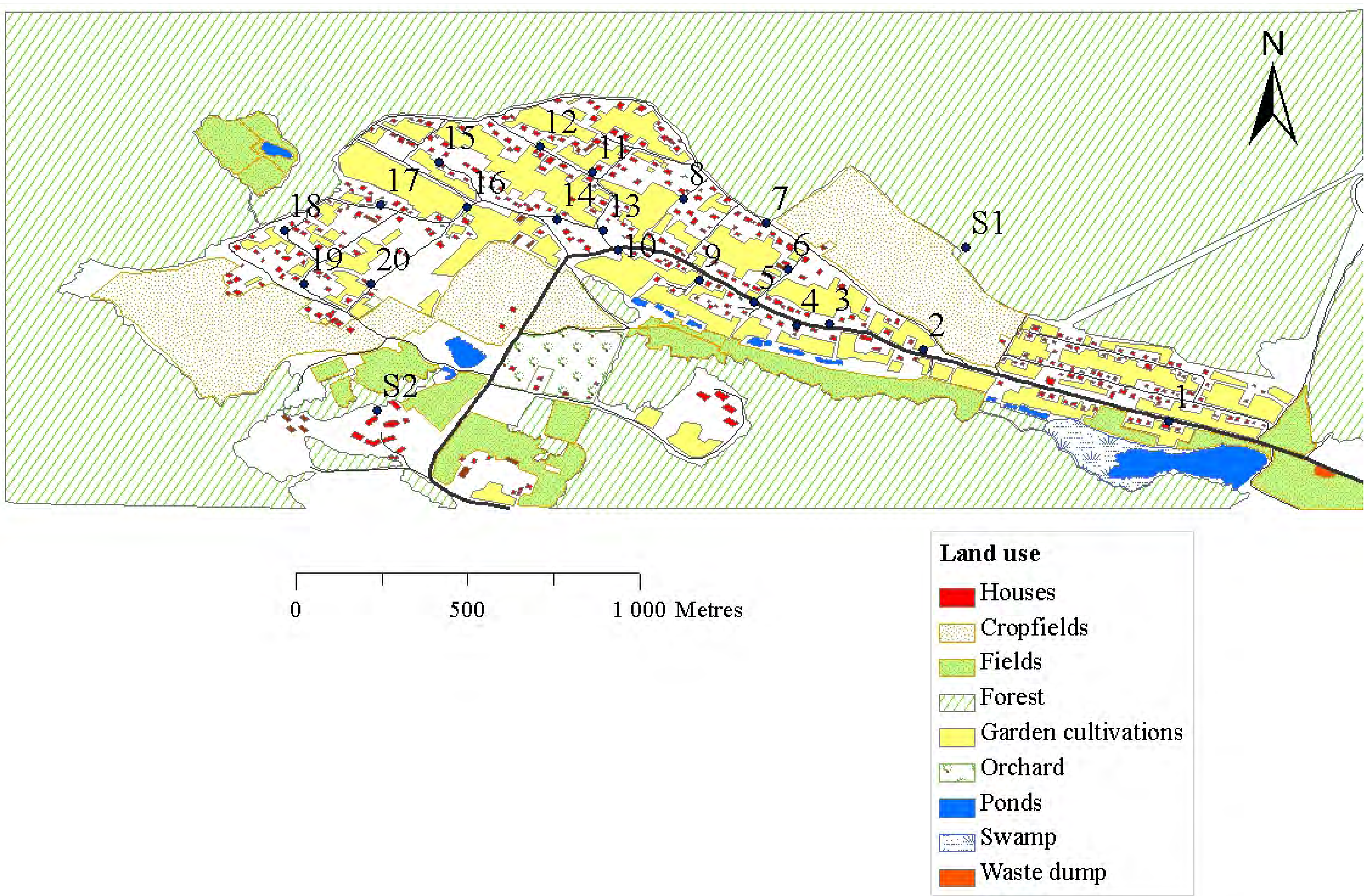

Figure 15 The study area Condrita. Numbers 1 to 20 correspond to all public wells, while S1 and S2 correspond to the public springs.

4.1.1 Population & economy

The main occupation of the villagers in Condrita is farming as most houses have their own yards where different crops are grown. Popular crops are grapes and corn. Crop fields as well as garden cultivations are irrigated partly with surface water (from the ponds) and groundwater from the wells. Animals are commonly kept within the yard of each household where they can move freely around the crops. Several households receive money from relatives that work abroad, which is believed to be the origin of the main income for many families (Natalia Vavelschi, pers. comm.; Igor Casapu, pers. comm.). According to Moldovan regulations, the wells should be cleaned every year. In Condrita, the cost of cleaning the wells is shared among the families that use the particular well (Tudor Zagoreanu, pers. comm.).

4.1.2 Geology and soil

Geological maps were unfortunately not available for the study area due to the fact that this data had been classified as strictly secret. However, it was told that the main soil type in Condrita is grey forest soil (Vasilievici Bugaev, pers. comm.). This soil type belongs to the soil group Phaeozem as classified by the Food and Agriculture Organization of the United Nations (FAO). Phaeozem has further quite similar characteristics to Chernozem, the predominant soil type in Moldova. In Phaeozems, the surface layer (to about 1 m depth) consists of a mollic horizon with plenty of organic matter that is highly saturated with bases. A high base saturation means that there is a high possibility for anions to be adsorbed to the soil particles. Commonly a subsurface argic or cambic horizon lies beneath the mollic horizon. FAO states that cambic horizons are partly characterized by having a texture in the fraction of "*very fine sand*", "*loamy very fine sand*" or finer. It is at least 15 cm thick and has a soil structure. If rocks are present, they should not exist in more than half of the volume of the fine earth. As for argic horizons, these are characterized by high clay content, which is higher than for the layer above. The Phaeozem parent material is made up of unconsolidated material such as aeolian deposits. Because of the soil being permeable and rich in nutrients, Phaeozems are considered to be very suitable for agricultural activities (IUSS Working Group WRB, 2006).

4.1.3 Geohydrology and hydrology

Temperature and precipitation data were not available for the study area, but assumed to be similar as for Chisinau. Values on annual variations were given by Gaisma (2009) as described in figure 16. Furthermore, data on potential evaporation were not available, thus, cannot be shown in this report.

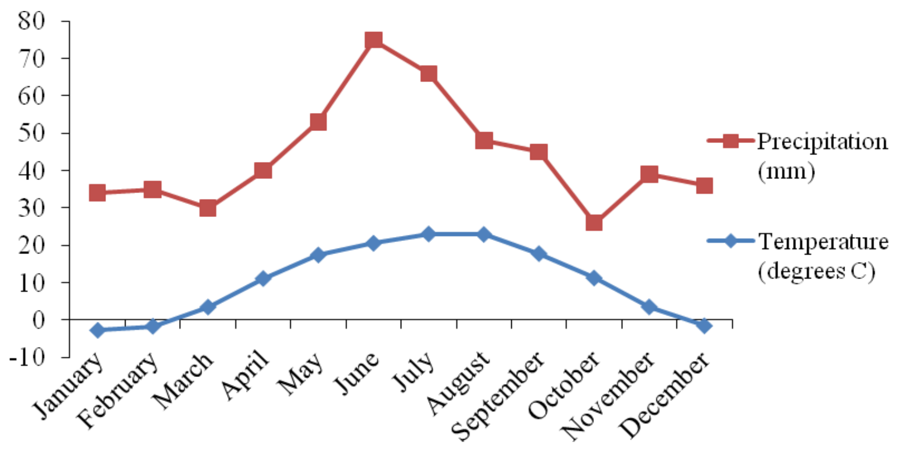

Figure 16 Annual variation of precipitation and temperature in the study area.

The elevation in Condrita varies between 130 and 230 m above sea level (figure 17). There are no natural watercourses in the area; however, there are a few artificial ponds as displayed in figure 17. Through the lowland areas in Condrita there is a concrete drainage channel, which is partly represented by the smaller areas of water in the vicinity of wells 9, 5, 4 and 3. Surface water will runoff to this drainage channel and be lead to the larger pond in the south-eastern part. There is no open outflow from the pond, i.e. either the water infiltrates or evaporates. Some of the water is used for irrigation. The catchment area for Condrita is displayed in figure 18.

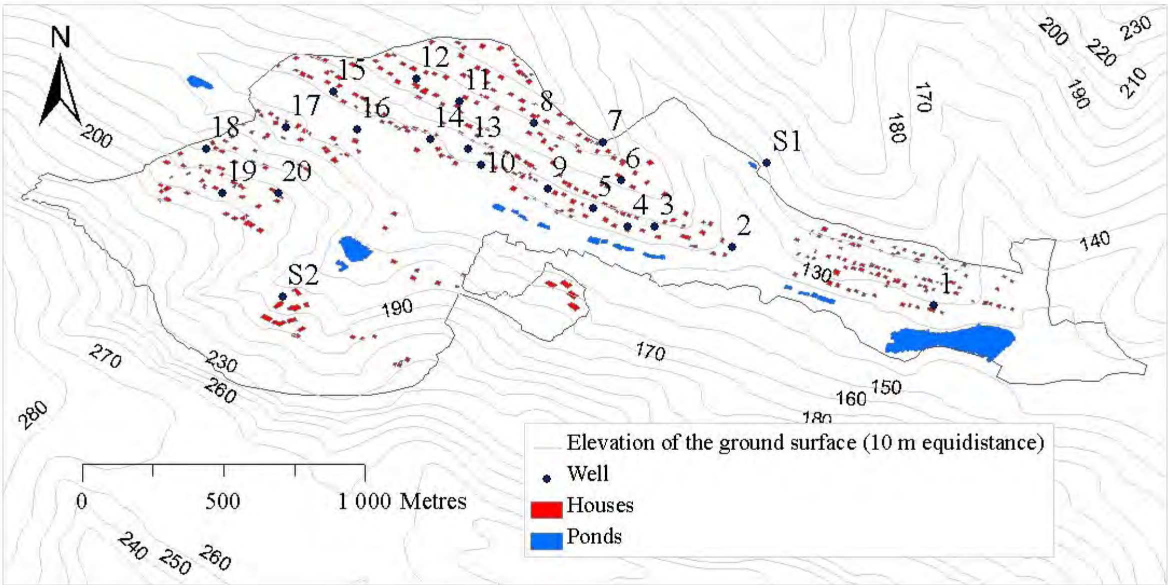

Figure 17 Topography in the study area (altitudes in m. a. s. l.).

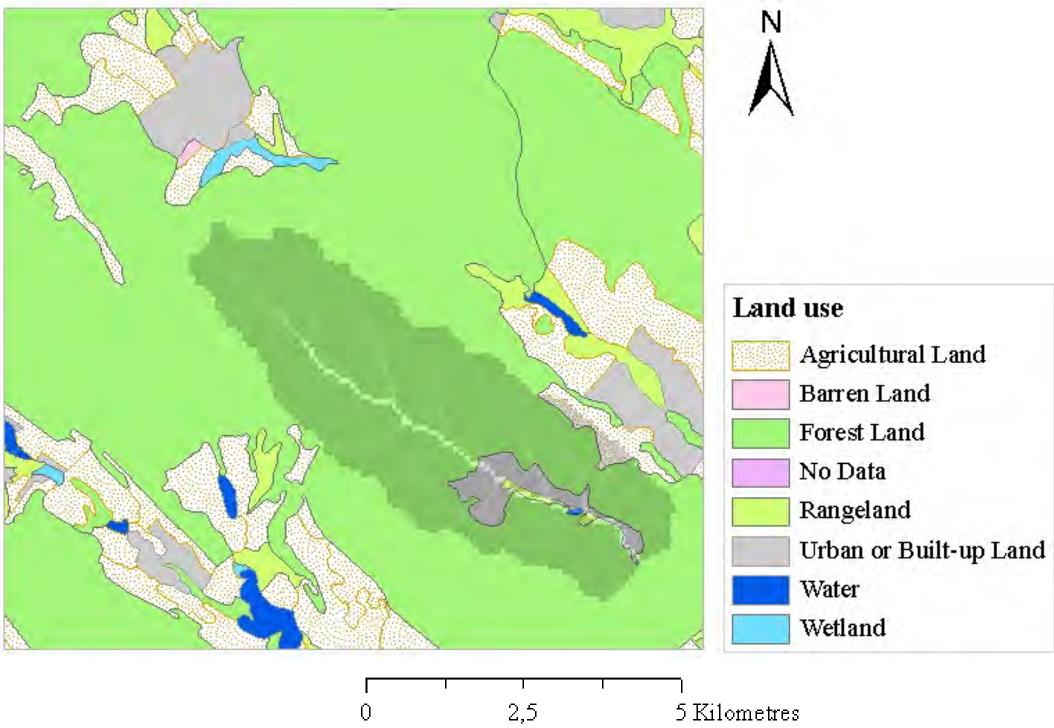

Figure 18 The catchment area (represented by the darker zone) and land use in the surroundings of Condrita.

4.2 ASSESSMENT OF THE CURRENT WATER QUALITY

The purpose of the fieldwork was to

- sample water from wells and springs
- observe the construction of the wells and springs (improved or unimproved)
- observe the surroundings of the wells and springs
- interview the villagers about their habits of collecting and treating drinking water.

The aim of this information was to investigate whether the drinking water was fit for human consumption and to function as a base for giving suggestions on possible improvements.

Since there was not time to finish the sampling of all water sources during one day, sampling took place on several occasions. Due to both time and financial limits only community water sources were studied, i.e. sources located on municipal property and jointly kept. In total, twenty-two different wells and springs were investigated. The wells had predefined numbers (1-20), while the springs were named specifically for this assessment (S1 and S2). Wells and springs in the village were grouped into a north-western and south-eastern part, according to their location. Locations of the water sources are shown in figure 15 (section 4.1).

4.2.1 Fieldwork – Sampling and measurements

On the first day of sampling, Sept 14, 2009, water samples were taken from wells 1-10, 13 and one spring (S1), all of which were located in the *south-eastern* part of the village. Before taking the water samples, the buckets were sterilized and the water in the first two withdrawn buckets was thrown away. When finished collecting water the buckets were attached to the windlass or left standing on the well cover. At each well and spring, samples were collected in two bottles; 0.5 L in a glass bottle for analysing biological activities (coliform bacteria and *E. coli*) and 1.5 L in a plastic bottle for chemical and physical parameters (chloride, nitrate, nitrite, sulphate, ammonium, pH, hardness, DO and turbidity). Water temperature was measured in each well. Furthermore, the coordinates for the wells were collected and observations about the surroundings were made.

On the second day (Sept 16, 2009) wells 11, 12, 14-20 and one spring (S2) were sampled in the *north-western* part of the village. The sampling and field procedure was the same as during the first sampling session. In addition to this, separate water samples that were analysed with respect to EC were taken.

During the third visit (Oct 5, 2009), well 8 that was empty on the first two visits was sampled. Additional water samples were taken from wells that were chosen due to their level of contamination given from the first two sampling sessions. Five of the analysed parameters were considered more important when assessing the water quality; these were chloride, *E. coli*, nitrate, total coliform bacteria and turbidity. Firstly, it was because they are decisive for how the water quality is perceived by the consumer (turbidity). Secondly, the parameters indicate health risks in a short as well as long term basis (total coliform bacteria, *E. coli* and nitrates). Lastly, they imply impact from external sources of contamination (nitrate and chloride). The chosen wells had been disinfected some time after the first sampling session, which was unknown before receiving the laboratory results. However, the second sampling could indicate the disinfection efficiency.

As for the results from the first sampling session, it was further shown that the five chosen parameters as well as hardness exceeded guideline values in several wells. However, hardness was generally high in the area and therefore not considered when selecting wells for further studies. Well water with measurement values exceeding guideline recommendations on at least three of the five chosen parameters were selected. These wells were 6, 7, 12 and 15. Water samples were to be analysed with respect to the same parameters as the first and second sampling sessions; however, EC was only measured once in each well.

During the third visit, separate water samples for the EC measurements were also taken from wells visited on the first occasion (the south-eastern part of the village). Furthermore, water to be analysed with respect to agricultural pesticides were sampled from wells 3, 10, 11, 16 and 19. This selection was based upon two considerations. Firstly, the wells should be in proximity of downstream agricultural land and secondly, the samples should be spread all over the village in order to obtain a general picture of the pesticide situation.

Measuring depths to the water table

During the field studies, the depths to the water table in the wells were measured with a measuring tape. The ground level was measured with a theodolite at nine wells (2, 3, 4, 5, 6, 7, 9, 12 and 15) while a GPS was used for estimating the ground level at the remaining wells and springs. The groundwater levels were obtained by subtracting the depths to the water table from the ground level. A rough assumption was made, that the measured depths to the water table indicated the true groundwater table in all measured wells. This was done without sufficient information on storage capacity, discharge or recharge of the well and may be a source of error.

For the nine wells above, the depths were determined when the measuring tape hit the water surface. The depth to the water table in the remaining wells was estimated by attaching the measuring tape to the well bucket. When the bucket reached the water surface (determined by eye) the distance to the headwall was read. Furthermore, to determine the water depth from the ground surface, the distance from the headwall to the ground surface was measured and subtracted. In order to obtain the groundwater level for these wells, the measured depths to the water table were subtracted from ground elevations collected by GPS. The collected GPS values on elevation were compared to topography data since GPS elevations can differ tens of metres from reality.

4.2.2 Interviews and observations – Drinking water: wells and springs

Questions about the wells were mainly asked to Tudor Zagoreanu, who functioned as a guide during the visits and sampling sessions. Along with Zagoreanu, questions were asked to different dwellers that lived close to the wells or that came to collect water at the wells. Questions that were asked or observations that were made at each well or spring were about

- well or spring construction
- methods to abstract water
- the age of the well or spring
- the amount of families that abstracted water from the well or spring
- water usage
- smell and colour of the water
- the water depth in the well
- water scarcity in the well or spring
- if and what animals that were kept in the vicinity of the well or spring

- the distance between the animal sheds and the well or spring
- the soil type and texture in close proximity of the well or spring
- land use in proximity of the well or spring (agriculture, animal sheds, houses etc.)
- how often the well was cleaned and disinfected .

4.2.3 Sampling, interviews and observations – Pesticides

Given the brief history review on pesticides, it was of interest to look into the possibility that spring and well water in Condrita was polluted with such chemicals. The pesticide assessment was carried out by questioning the guide (Zagoreanu) in addition to sampling water from five wells. The wells were located in the vicinity of agricultural land and situated in a way so that almost the whole village was covered. Questions were asked about if and when pesticides were used, what type of pesticides, where such chemicals were stored and if pesticides were used on agricultural land at present. Within the sampled wells (3, 10, 11, 16 and 19), highest priority was given to number 16. This well was situated in the older part of the village, and, hence, could give information about pesticide use in retrospect. The well was further located in proximity of agricultural land as well as a bus garage, which were possible sources of present contamination.

4.2.4 Laboratory analysis of well and spring water

Drinking water in the study area was analysed with respect to all bacteriological, chemical (except EC) and physical parameters at the Apa Canal laboratory, Chisinau, Moldova. The bacteriological parameters were analysed within 5 hours from the time of sampling. Electrical conductivity measurements were carried out by the authors of this master thesis at the Department of Earth Sciences, Uppsala University, Sweden. The sampled water for EC measurements were stored cold (about 5 °C) for 1.5 to 2 months, depending on the day of sampling.

As for the pesticide analysis, a gas chromatography-mass spectrometry (GC-MS) screening for semi-volatile substances in well 16 was executed at ALcontrol Laboratories, ALcontrol AB, Sweden. Screening for semi-volatile substances was performed in only well due to economical reasons. Further screenings for metals and other chemicals were performed on water samples from all five wells that were chosen for pesticide analysis (section 4.2.1). This was to get a first indication of the water quality, i.e. what substances that were present in the sampled water. The GC-MS screening aimed to specifically investigate the presence of pesticides in well 16.

4.2.5 Statistical analysis on sampled water

A statistical analysis was performed on parameters that were considered important for the water quality in section 4.2.1, namely chloride, nitrate, EC, total coliform bacteria and turbidity. For this purpose, measurement values from the first sampling session were used.

Measurement values were plotted in box plots to show the distribution of data. Records were divided into two parts; one for the densely and one for the sparsely populated part of the village. Sparsely populated areas were defined as the eastern and western parts of Condrita, containing wells 1-5, 16-20 and the two springs. The middle (or northern) part was considered densely populated, comprising wells 6-15. Definitions were made according to what appeared to be more or less populated areas both in situ and in figure 15 (section 4.1). Box plots were also created in order to compare the laboratory analysis outcomes from improved and unimproved water sources.

Linear correlations were studied with scatter diagrams and a Spearman's rank correlation test was performed in order to find out if correlation existed between total coliform bacteria and several physical and chemical parameters. The Spearman's rank correlation test explored the relationship between parameters that did not possess a linear relationship. When using the Spearman's rank correlation test, each value in an interval of measurements received a ranking according to the position in the interval, e.g. the lowest value for each parameter was ranked as number one. The test then showed how likely one parameter value ranking was to answer to a ranking of another parameter value.

4.3 ASSESSMENT OF THE CURRENT SANITATION SITUATION

During the first three study visits, a few toilets were visited to get a general view of the sanitary conditions in the village. An additional fourth study visit (Oct 20, 2009) was performed in order to examine the sanitary conditions in more detail. There was not enough time to visit all toilets in the village, which is why only toilets in close proximity of the wells that were chosen for the second sampling session were visited. Toilet locations were observed and sanitary conditions assessed by interviews as well as observations.

The purpose of this inventory was to see if the location of the toilets or the discharge of grey water and solid waste could have an impact on the water quality in the wells or springs. It was also of interest to see if the sanitary habits were likely to influence the health of the villagers in other ways than through groundwater contamination, for instance by manual handling of excreta.

4.3.1 Interviews and observations – Sanitation

The interview study was concentrated to the households in the vicinity of the four wells that were chosen for the second sampling session. Observations were made and questions asked about

- toilet construction (pit latrine, open pit latrine, flush latrine)
- the amount of people that used the toilet
- the depth of the pit
- if the toilet was moved or emptied when full
- how often the toilet was moved or emptied
- disposal of human waste when emptying the latrine
- handling of human waste
- previous and current location of the toilets
- the distance to public water sources
- treatment and disposal of grey water
- disposal of solid waste.

4.4 MAPPING THE WATER QUALITY IN ARCGIS

To visualize the variations in parameter concentrations some results from the sampling sessions were spatially analysed in ArcGIS.

4.4.1 Coordinate system and data

A Garmin eTrex Legend HCx GPS was used to localize the different wells and toilets in the study area. Coordinates were transferred from the GPS into the computer software MapSource

6.13.7. The coordinates were stored in the GPS as 'degrees, minutes, seconds'; hence, the format had to be transformed into decimal degrees before importing the data to ArcGIS 9.3. For this matter the transformation software CoordTrans v2.3 by Franson (2009) was used. The used projected coordinate system was WGS 84.

4.4.2 Drinking water quality

The five parameters that were considered more important with respect to drinking water quality (section 4.2.1) were chosen to be analysed spatially in ArcGIS. The parameters were chloride, *E. coli*, nitrate, total coliform bacteria and turbidity. Measurement values on each parameter were interpolated using Inverse Distance Weighted (IDW). Total coliform bacteria were measured in numbers/1000 ml; hence, the results were divided by 10 to fit international standards. The interpolation was used for creating layers to spatially visualize the distribution of the parameter concentrations in the study area.

Chloride and nitrate can be assumed to travel large distances if dissolved in the soil water, which is why interpolations over larger distances can be assumed to be true. However, interpolations on bacteria and turbidity would probably not show accurate results because these parameters behave differently from dissolved ions. Bacteria and turbidity are most likely introduced at the wells, bacteria for instance by the bucket when collecting water and turbidity by resuspended particles on the bottom of the well. This means that bacteria and turbidity are significantly lower in the surroundings of the well and, hence, cannot be interpolated. Because of this, only chloride and nitrate were the chosen parameters to indicate the drinking water quality spatially in the study area. However, an additional interpolation was performed to display the drinking water quality for each household. Since the concentrations were for each household (i.e. the interpolation valid for short distances) all five parameters were included.

The parameters were ranged into three classes; fit to drink, permissible and unfit to drink, according to table 4. The classification was based upon guideline values from WHO (2004) and the National Food Administration (2010).

Table 4 Classification of parameters decisive for drinking water quality, based on guideline values (WHO, 2004; National Food Administration, 2010)

Drinking water quality	Chloride (mg/L)	Coliform bacteria[a] (number/100 ml)	*E. coli*[a] (number/100 ml)	Nitrate[a] (mg/L)	Turbidity (NTU)
Class 1: Fit to drink	<100[a]	0	0	<20	<1.5[a]
Class 2: Permissible	>100[a]	1-10		20-50	>1.5[a]
Class 3: Unfit to drink	>250[b]	>10	>0	>50	5[b]

a = National Food Administration (2010)
b = WHO (2004)

Five rasters were created to display the drinking water quality spatially, that is to say one for each interpolated parameter in table 4. Two maps were created by doing overlays of the raster files. Firstly, one map for chloride and nitrate was created and secondly one for all five parameters. The study area was divided into the three classes of quality (fit to drink, permissible and unfit to drink).

4.4.3 Irrigation water quality

According to section 4.1.1, irrigation water is abstracted both from ponds and wells in the study area. Because of limited time the ponds were not sampled. Nevertheless, it was of interest to investigate whether the water in the wells was suitable for irrigation. An analysis in ArcGIS was performed in order to see if the groundwater in public water sources was suitable for irrigation. EC indicates the suitability of the water (section 3.2.3) and therefore EC measurements were used for this purpose. The measured EC values were interpolated in ArcGIS (using IDW) to get the distribution of the EC in the study area. The interpolated values were ranged according to table 1 (section 3.2.3) and reclassified in line with this.

4.5 VULNERABILITY ASSESSMENT

In order to locate areas in Condrita that are more vulnerable to groundwater contamination than others, a vulnerability assessment was performed using the DRASTIC model. A literature study on the model was initially performed, which gave guidelines on how to carry out the modelling. Model data were retrieved during the field study and processed according to the guidelines. Some modifications were at first made on the model to fit the study area. The model resulted in a calculated DRASTIC index, which indicated where vulnerability was low, moderate and high in Condrita. Model procedure is schematically described in figure 19. The guidelines are described in more detail in appendix D, which also gives information on how data were processed in ArcGIS.

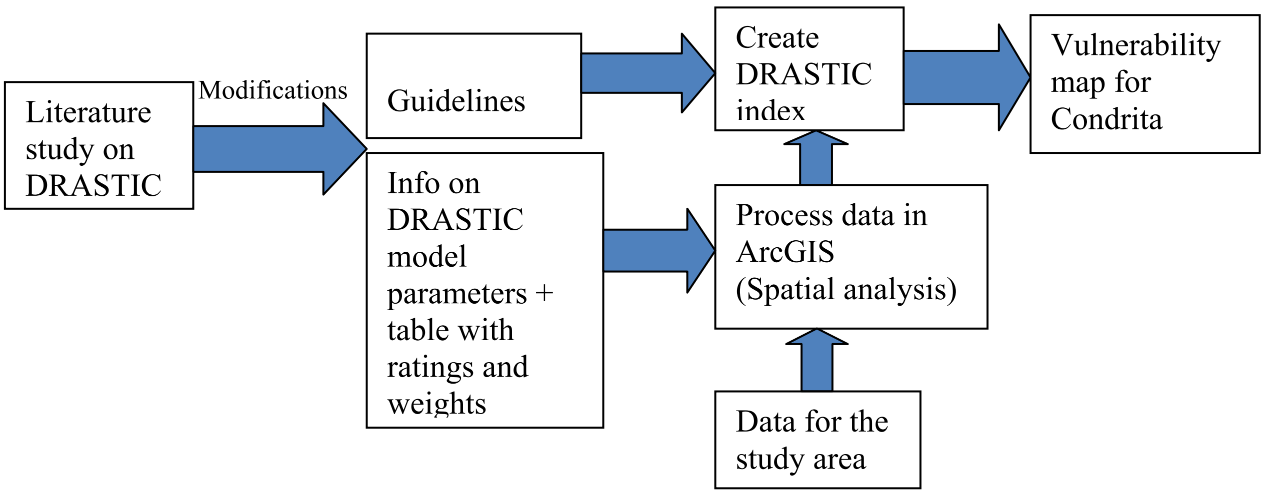

Figure 19 Schematic description on how the work with the DRASTIC model was done.

4.5.1 The DRASTIC model

As for the study area the four assumptions mentioned in section 3.5.2 were considered valid, even though it was evident that some contaminants were introduced in the pit latrines (at some distance below the ground surface) and transported down by urine. Distances from the ground surface to the bottom of the pit fluctuated and were relatively short, which is why the effects were considered negligible and the assumption of introducing contaminants at the surface of the soil valid. Some contaminants may also be transported down by irrigation water or disposed grey water. All these effects should be considered as possible sources of error.

At first, model modifications were made on equation D1 in appendix D by removing the hydrological conductivity parameter and by including land use (equation 1). The DRASTIC model assumes that the model parameters indicate different individual risks for groundwater contamination. All parameters were therefore rated and given weights when adding them together to a modified DRASTIC index. Information on ratings and weights were found during the literature study, gathered in a table and modified to fit the study area (table D2, appendix D). The land use ratings were for instance decided with knowledge gathered from the literature study. After modifying table D2 and equation D1, data were retrieved and stepwise analysed in ArcGIS according to the guidelines found by the literature study. Information on how data were retrieved and analysed as well as how the modelling was performed is described in more detail in appendix D. After all data were processed, a modified DRASTIC index was calculated by equation 1.

$$Modified\ DRASTIC\ index = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + L_r L_w \quad (1)$$

Subscript r = rating, w = weight
D = depth to groundwater table, R = net Recharge, A = Aquifer media, S = Soil media, T = Topography,
I = Impact of the vadose zone, L = land use

4.5.2 Model test

The modified DRASTIC model was tested by checking the correlation between drinking water quality in the study area and the calculated modified DRASTIC index. Land areas where drinking water classified as fit to drink, permissible and unfit to drink coincided with low, intermediate and high vulnerability areas were analysed using an overlay analysis in ArcGIS.

5 RESULTS

The assessment of the drinking water sources showed that approximately 40 % of the wells and springs could be classified as unimproved according to definitions in section 3.4. Nitrate concentrations, turbidity, electrical conductivity and *E. coli* bacteria were above national or international standards in several water samples. Strong linear correlations were found between nitrate and chloride. Moreover, median values of nitrate, chloride and total coliform bacteria were higher in water samples from the densely populated part of Condrita and in water taken from unimproved water sources. No pesticides were detected in the sampled water.

Shallow groundwater is subject to larger risks for groundwater contamination than deeper groundwater. No or little correlation between depths to the groundwater table and nitrate concentrations was, however, shown. Furthermore, no correlation between larger crop fields and high nitrate concentrations could be found. Nitrate concentrations were higher in areas where houses and garden cultivations were more frequent.

The assessment of the current sanitation situation showed that most villagers used simple pit latrines that were placed on their property. The pit latrines were considered improved if excreta were not handled manually.

A GIS assessment revealed that only a smaller part of the study area held drinking water that was fit for human consumption. A vulnerability study using the DRASTIC model further showed that most of the village area comprised of moderate and high-risk areas for potential groundwater contamination.

5.1 DRINKING WATER QUALITY

5.1.1 Wells and springs

The villagers shared water from twenty different dug wells and two springs that were distributed within village area. Some families also had their own wells in the yards. Nine water sources in Condrita were classified as unimproved, eight as partly improved and six as improved.

South-eastern part of the village

When comparing the well and spring features with the criteria on protected and unprotected wells (section 3.4), it was found that four wells (2, 8, 9 and 10) and the forest spring (S1) were considered unimproved water sources. This was because well 8 lacked both lid and roof, while wells 2, 9 and 10 lacked or had a very old apron slab and, consequently, could not meet the criteria on runoff protection. The open spring (S1) was not protected from external contamination and was therefore considered an unimproved water source. Three wells (3, 5 and 7) were found to be partly improved since they were covered with a roof but not a lid. Four of the wells in the area (1, 4, 6 and 13) were improved, and had both runoff protection and a covering lid. Information on well features is given in table 5.

North-western part of the village

When comparing the well features in the north-western part with the criteria on protected and unprotected wells (section 3.4), it was found that four wells (14, 15, 17 and 20) were to be considered unimproved. This was because wells 14 and 20 lacked both roof and lid, while wells 15, 17 and 20 could not meet the criterion on runoff protection. The remaining four dug wells (11, 12, 16 and 19) were considered partly improved because of the fact that they had roofs but not lids. Lastly, spring S2 and well 18 fulfilled the criteria on protected springs and were, consequently, improved water sources. Well 18 was referred to as a well; although, it was built like a spring that transported water through pipes from an old well on a higher elevation (Tudor Zagoreanu, pers. comm.). Characteristics of the wells are listed in table 5.

An example of an improved water source in the study area is shown in figure 20, while an unimproved water source is shown in figure 21.

Figure 20 An improved dug well (including lid, roof and runoff protection).

Figure 21 An unimproved dug well (missing both cover protection and apron slab).

Table 5 Well and spring characteristics in the study area

Well/ spring	Depth to water table (m)	Approx. age (Yrs)	Headwall	Well lining		Well bucket	Enclosure		Lid	Roof	Apron slab		Status of water source
				Concrete	Brick		Partly fenced (>2 sides)	Fully fenced with gate			Good	Cracked	
1	10.3	10	●	●		●		●	●		●		Imp
2	4.8		●		●	●	●			●			Unimp
3	14.5	10	●	●		●	●			●	●		Partly imp
4	14.7		●	●		●	●		●		●		Imp
5	17.0		●	●		●				●	●		Partly imp
6	15.1	22	●	●		●			●		●		Imp
7	22.9	25	●	●		●	●			●	●		Partly imp
8	17.6		●		●	●					●		Unimp
9	14.0	60	●		●	●	●		●				Unimp
10	7.0	50	●		●		●			●			Unimp
11	16.9	50	●	●		●	●			●	●		Partly imp
12	15.2		●	●		●				●	●		Partly imp
13	13.9	12	●	●		●	●		●		●		Imp
14	6.0	50	●		●	●		●			●		Unimp
15	6.7		●	●		●				●		●	Unimp
16	5.8	60	●		●	●				●	●		Partly imp
17	6.1	35	●	●		●		●		●		●	Unimp
18	0	70							Spring box and drainage system				Imp
19	6.4	28	●	●		●				●	●		Partly imp
20	10.1		●	●		●	●					●	Unimp
S1	0								Pipe with an open outlet to a rivulet				Unimp
S2	0	100							Spring box and drainage system				Imp

Imp = improved, Partly imp = partly improved, Unimp = unimproved

5.1.2 Sampling session 1: twenty wells and two springs

Laboratory results showed that high levels of coliform bacteria were found in a majority of the analysed water samples. *E. coli* bacteria were present in four wells at the time for sampling. In general, the hardness and the electrical conductivity in the water were high. Nitrate levels frequently exceeded international guideline values, while most of the chloride concentrations were found to be below standards. Turbidity exceeded Moldovan standards in about one third of the sampled water and the remaining parameters were below guideline values in all the sampled wells and springs. The water temperature was approximately 13 °C in all wells and springs.

Results from the first sampling session are described below and displayed in table A1, in appendix A. In addition, the spatial distribution of the measurement values of chloride, EC, nitrate, *E. coli* and coliform bacteria are displayed in appendix C.

Bacteriological parameters

Bacteriological analysis showed that four wells were contaminated with *E. coli* bacteria. These wells (6, 7, 12 and 15) were also found to have a larger number of coliform bacteria (>1000/1000 ml). In total, about half of the sampled wells were proven to have more than 500 coliform bacteria per 1000 ml.

Chemical parameters

The sampled water was recorded to have a very high hardness with a range of 18-78 °dH, which corresponds to 321-1387 mg/L of calcium carbonate. The pH values were found to vary around 7.4 with minimum and maximum values at 7.00 and 7.90 respectively. Nitrate concentrations of the sampled water were above the guideline value of 50 mg/L that is given by both WHO and Moldovan standards in all water samples but six. Along with the two springs, which had non-detectable concentrations of nitrate, wells 1, 2, 16 and 18 had concentrations below the guideline value. In several other wells, nitrate concentrations were above 100 mg/L, where top concentrations were found at wells 9, 10 and 13 (all exceeding 200 mg/L). Water in all wells but one (well 10) had chloride concentrations below standards. About half of the sampled wells proved to have chloride concentrations above 50 mg/L, and out of these four wells (9, 13, 15 and 17) had concentrations of approximately 100 mg/L. The measured EC in the sampled wells ranged from 733 to 2330 µS/cm. Moreover, nitrite as well as ammonium concentrations were below international and Moldovan standards of 0.5 mg/L for both substances. In addition, DO and sulphate concentrations were beneath given guidelines.

Physical parameters

Seven of the sampled wells had a measured turbidity that exceeded the Moldovan standards of 5 NTU. Among these, well 12 had the top turbidity of 140 NTU, while well 8 had the second highest value (80 NTU).

5.1.3 Sampling session 2: wells 6, 7, 12 and 15

Four wells (6, 7, 12 and 15) were sampled a second time and were analysed with respect to all bacteriological, chemical and physical parameters except for EC. These wells had been disinfected some time after the first sampling. The presence of total coliform bacteria was significantly lower in all four wells compared with the first sampling session and only one water sample showed presence of *E. coli*. Disinfection proved to be efficient for instance in well 15 where, in spite of the high turbidity (140 NTU), coliform bacteria levels were down from 1182 to 111 per litre. Turbidity also decreased after disinfection. Chemical parameters proved to be almost the same as the results from the previous sampling session.

Results from the second sampling session are described below and displayed in appendix B (table B1).

Bacteriological parameters

Well 15 had a low number of *E. coli* bacteria, while all other wells had none. The number of coliform bacteria ranged from 27 to 455 in 1000 ml in comparison to the range of 1182 to 1363 in 1000 ml in the first sampling session.

Chemical parameters

Hardness did not differ too much from the first session; although, the value in well 7 was somewhat higher in the second session. The pH values ranged from 7.15 to 7.70. Furthermore, the concentrations of all sampled chemical parameters in the four wells were approximately the same as in sampling session 1. Two out of four wells had lower DO concentrations than in the last session. All nitrate concentrations still exceeded given standards by WHO as well as Moldovan standards. The chloride guideline value from The National Board of Health and Welfare of 50 mg/L was, just like in the first session, exceeded in all wells but well 6. Nitrite, ammonium as well as sulphate concentrations were below guideline values.

Physical parameters

Analysis showed that all wells but well 15 had a lower turbidity in the second sampling session, while turbidity in well 15 had increased from 0.5 to 3 NTU. Wells 7 and 12 still exceeded Moldovan standards with the values of 50 and 100 NTU, respectively.

5.1.4 Contaminating factors

Nitrate concentrations vs. groundwater table, depths and flow directions

The measured depths to the water table in the wells together with theodolite and GPS measurements resulted in mapped groundwater levels (figure 22) and depths to the water table (figure 23). The measurements are listed in table E1 in appendix E. Groundwater flows from higher to lower potential, i.e. from higher to lower groundwater levels, and therefore groundwater flow directions can be read from figure 22. Flow directions resulting from the theodolite and GPS measurements are represented by blue arrows and differed slightly from what the flow direction would be if only topography was considered (black arrows). This tendency was clearer in the densely populated part of the village. Due to few points of data in the western part of the village, the interpolation is probably not accurate. It would rather be expected that the groundwater elevation would follow the topography in the area.

Figure 22 also displays the nitrate levels in the twenty-two sampled water sources in the study area. The figure shows that the concentrations in the densely populated part of Condrita were lower in wells upstream (12, 11, 8, 7) than downstream. This was, however, not valid for wells 2 and 3.

Depths to the groundwater were mapped (figure 23), which was interesting from a vulnerability point of view since shallow groundwater is subject to larger risks for groundwater contamination. In this study, shallow groundwater was defined as depths to the water table smaller than 20 m. Furthermore, little correlation between water depths and the levels of nitrate concentrations were found. The interpolation is probably not accurate in the western part of the village due to the few points of data in this area. The area with shallow groundwater surrounding spring S2 is possibly larger in figure 23 than in reality.

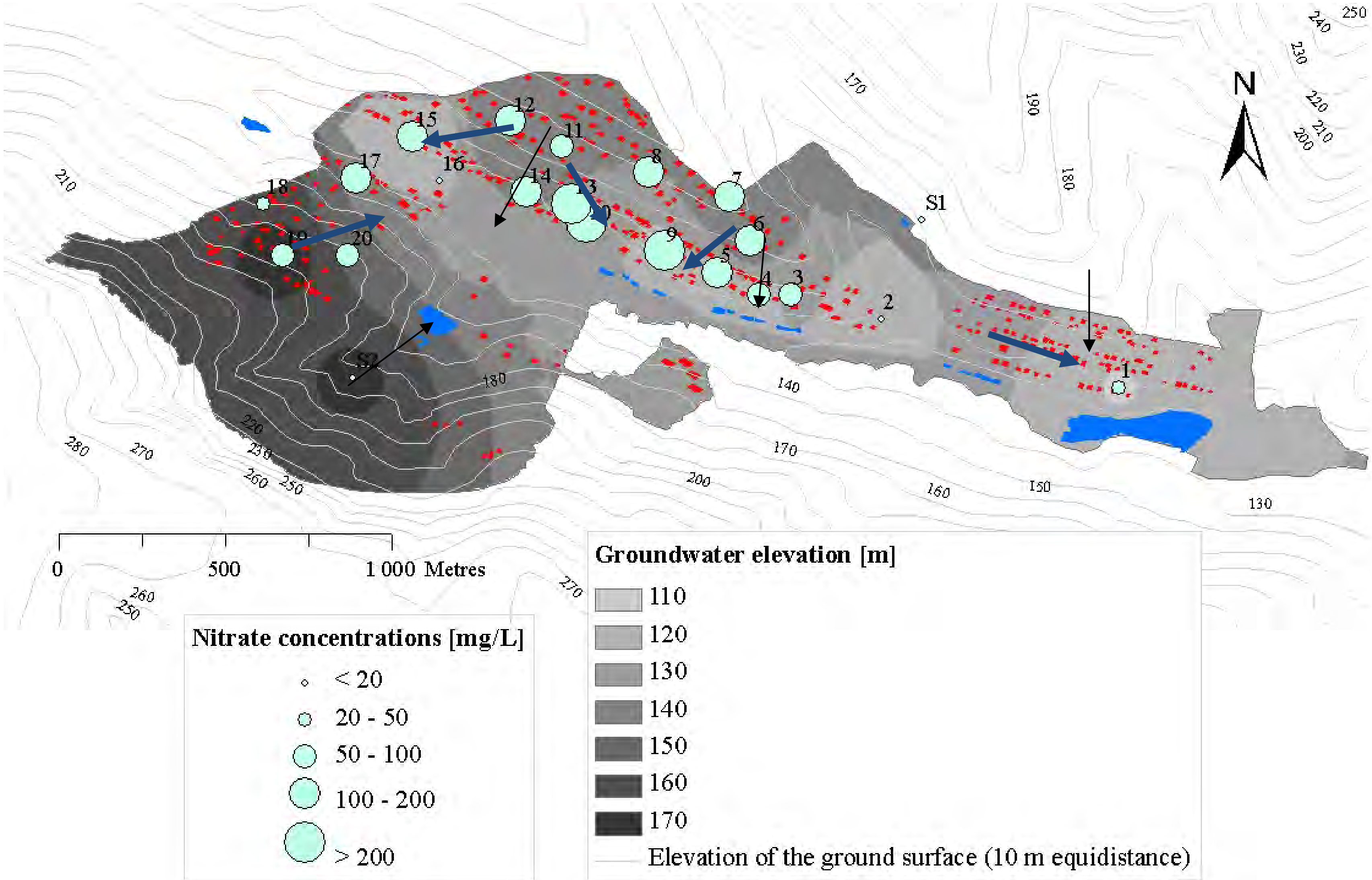

Figure 22 Measured groundwater levels in comparison to topography. The thicker, blue, arrows correspond to the measured flow direction, and the black represent the direction of flow based on topography alone.

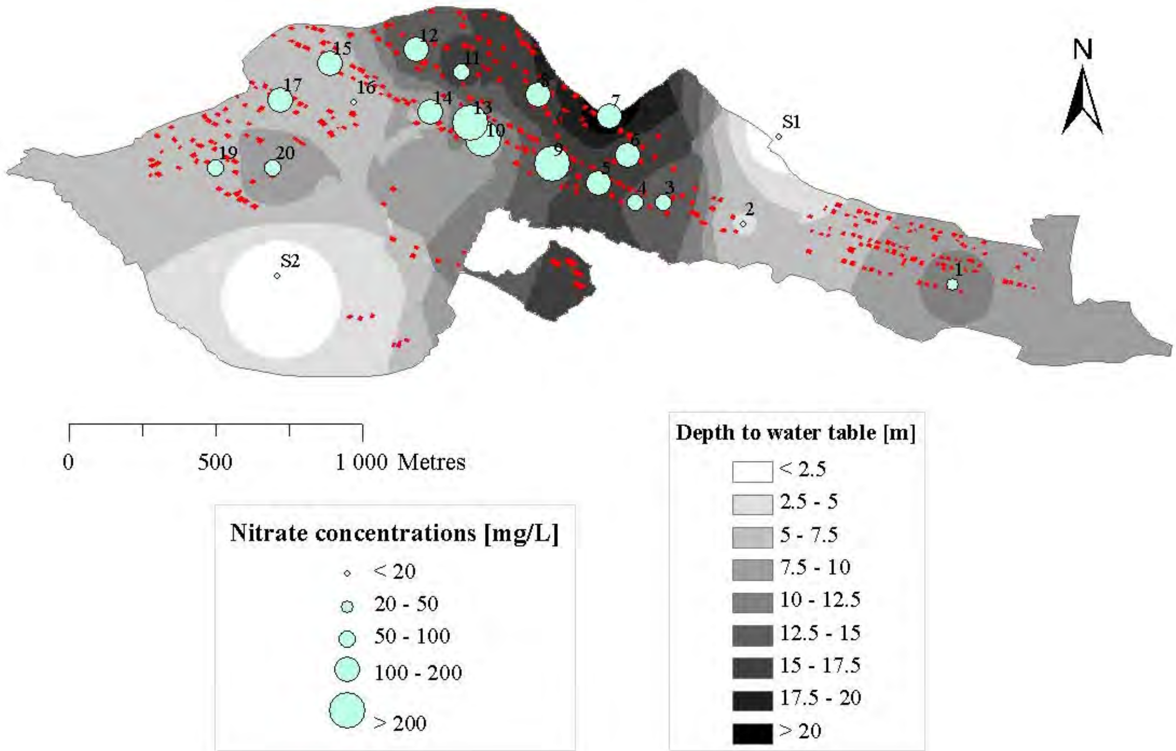

Figure 23 Depths to the water table and sampled nitrate concentrations in the wells.

Nitrate concentration vs. land use

The measured concentrations of nitrate were compared with land use in the study area (figure 24), which showed that the highest concentrations were found in areas with houses and garden cultivations. Little correlation was found between crop fields and high concentrations of nitrate.

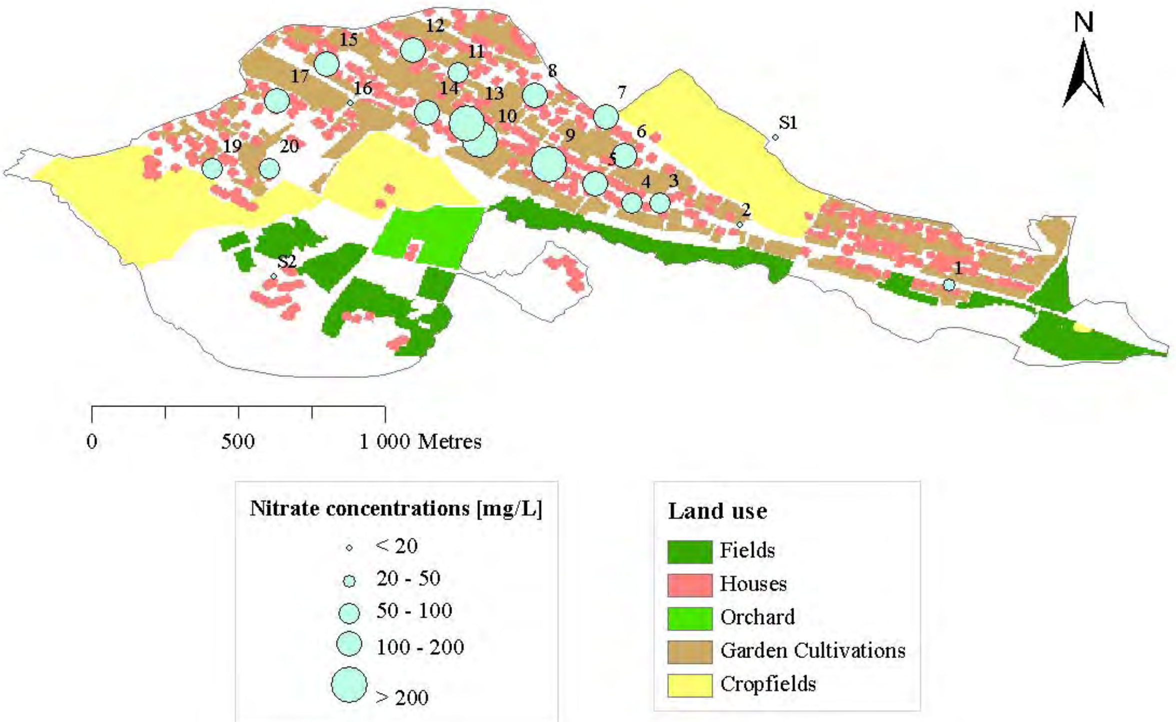

Figure 24 Land use in comparison to nitrate concentrations in the study area.

5.1.5 Pesticide analysis

Due to little information on historical pesticide use, it was unknown what pesticide substances that possibly were present in the sampled water. Therefore, it was difficult to determine any specific parameters to analyse. According to Zagoreanu (pers. comm.), pesticides had not been utilized during the last 50 years. However, Zagoreanu stated that fertilizers were free of charge as well as frequently used during the Soviet period.

No significant concentrations of pesticide substances were found during the analysis of water sampled from well 16, which also confirmed the information on pesticides given by interviews. Neither the screening for metals nor other chemicals showed any significant concentrations.

5.1.6 Statistical analysis on sampled water

The median values of chloride, nitrate, EC and total coliform bacteria were lowest in the sparsely populated parts of the village. In general, both maximum and minimum measurement values were higher for the densely populated areas. The data interval for total coliform bacteria was approximately the same for the two parts of the village. Similar patterns of results were found for improved and unimproved water sources, where the improved sources corresponded to the pattern of the sparsely populated part of Condrita.

High linear correlations between chloride and nitrate were found for both the densely and sparsely populated areas as well as improved and unimproved water sources. Strong relationships were also obtained between EC and chloride as well as EC and nitrate.

The Spearman rank correlation test showed no correlation between total coliform bacteria and physical or chemical parameters.

Distribution of data – Densely compared to sparsely populated parts of Condrita

To show the distribution of data between the densely and sparsely populated parts of the village, box plots were created. In the plot, the box represents the two middle quartiles in the interval of measured values and the horizontal line inside the box indicates the median value. The vertical lines outside the box represent the lower and upper quartile of the measured values within the data interval. Figure 25 shows that median values were higher for both nitrate and chloride in the densely populated part of Condrita. In all cases, measurement values above the median varied more than below the median value. In the dense part of the village all nitrate measurement values exceeded the WHO guideline of 50 mg/L.

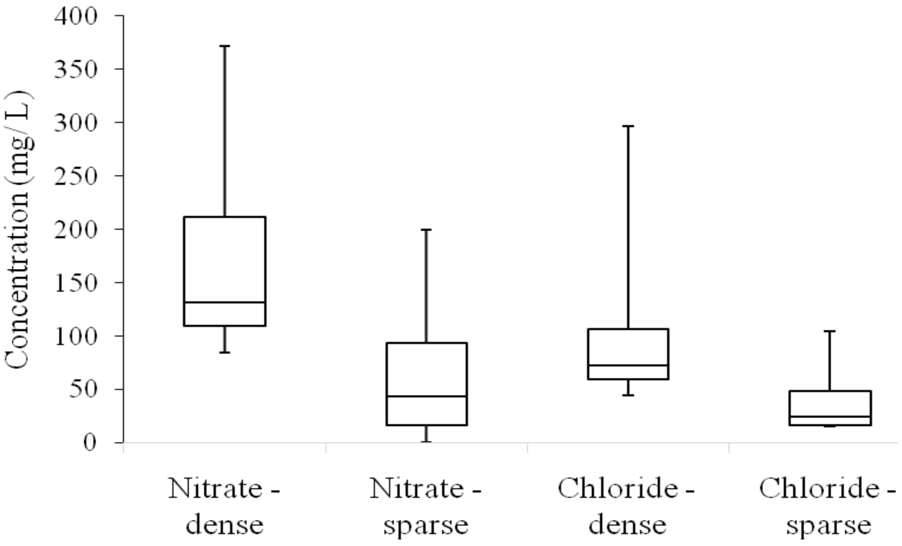

Figure 25 Distribution of data for nitrate and chloride in the densely and sparsely populated parts of Condrita.

Regarding the total coliform bacteria, the data range was quite similar for both parts of the village. The median value for the sparsely populated area was lower than for the densely populated part. Measurement values below the median varied more in the densely populated part of Condrita while the opposite was valid for water samples from the sparsely populated area (figure 26).

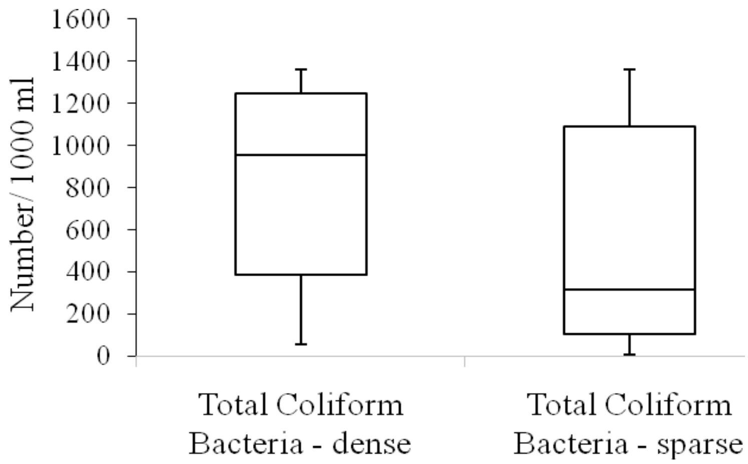

Figure 26 Distribution of total coliform bacteria in the densely and sparsely populated parts of Condrita.

Distribution of data - Improved compared to unimproved water sources

Wells 1, 3-7, 11-13, 16, 18, 19 and the monastery spring (S2) were defined as improved water sources, while remaining wells and the forest spring (S1) were considered as unimproved (section 5.1.1). It was found that the median values for both nitrate and chloride were higher for unimproved sources. The minimum concentrations for each substance were quite similar for both improved and unimproved sources, but the maximum values were higher in the unimproved water sources (figure 27).

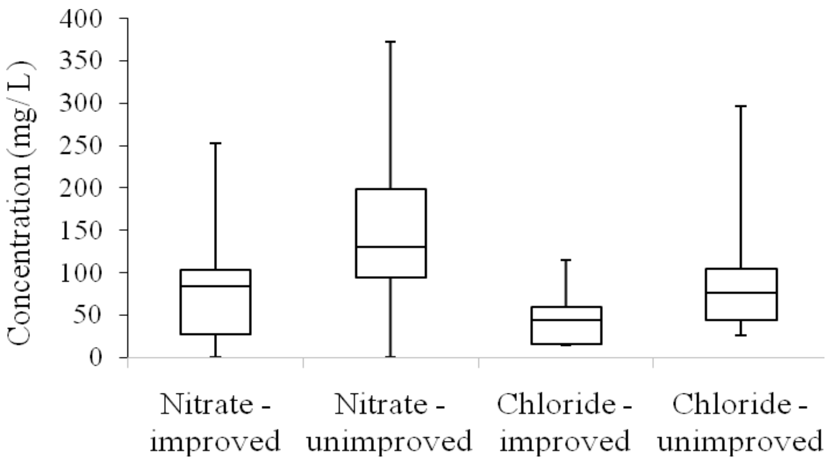

Figure 27 Distribution of data for nitrate and chloride in improved and unimproved water sources.

When it comes to total coliform bacteria, the data range was almost the same for both types of water sources. Of the recorded values, 50 % occurred in the lower fourth of the data range for improved water sources. Almost the opposite situation was found for unimproved constructions (figure 28).

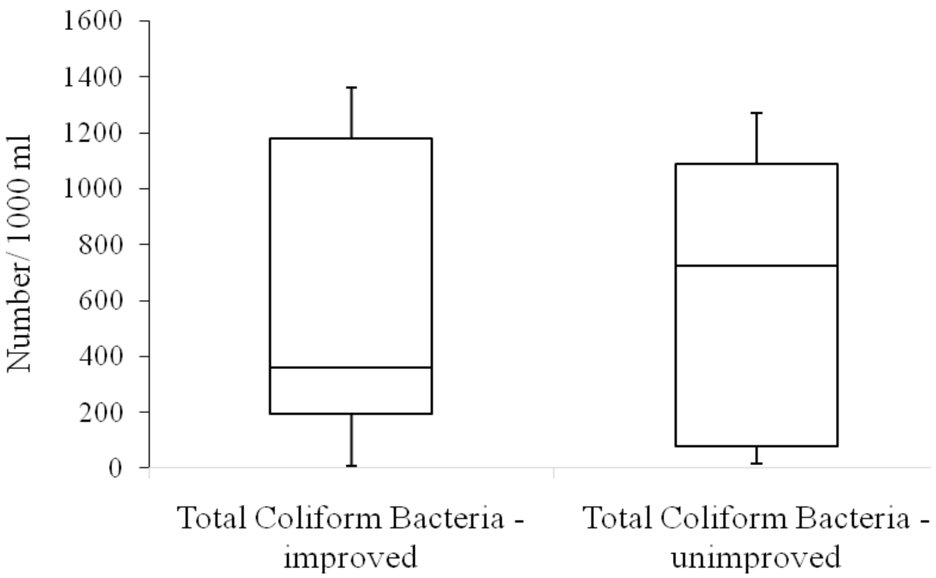

Figure 28 Distribution of total coliform bacteria in improved and unimproved water sources.

Scatter diagrams – Nitrate and Chloride

When investigating the correlation between nitrate and chloride, a high coefficient of determination was found, $R^2 = 0.85$ (figure 29). This indicated that a high level of nitrate was likely to be present if there was a high level of chloride (and vice versa) when looking at a specific set of data. Furthermore, when separating the plots into one for the densely and one for the sparsely populated part of the village a slightly higher coefficient of determination was found for the dense part ($R^2 = 0.87$ compared to $R^2 = 0.83$). The nitrate and chloride scatter diagram for improved and unimproved sources also showed strong correlations. Almost similar R^2-values, 0.89 and 0.86, were found for improved and unimproved constructions, respectively.

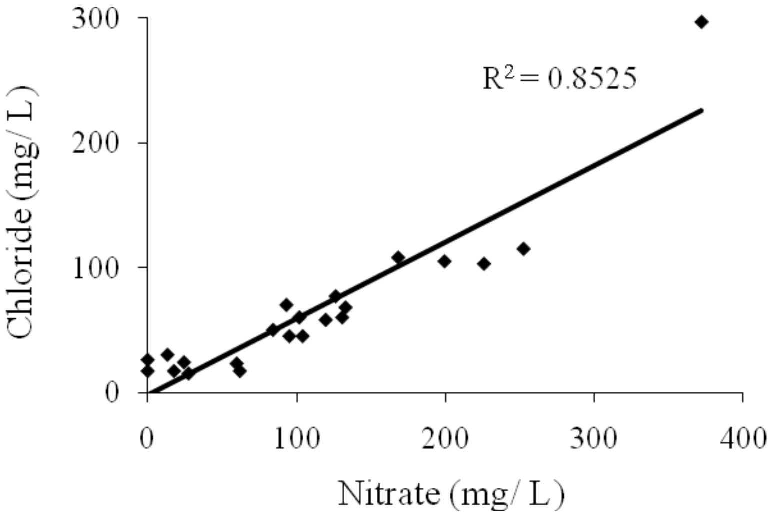

Figure 29 Correlation between the measured nitrate and chloride concentrations.

Scatter diagrams – Electrical Conductivity, Nitrate and Chloride

As discussed in section 3.2.1, EC is a measure of the water's ability to conduct electricity and is enhanced by the amount of salts in the water. Therefore, the correlation between EC and nitrate as well as chloride was considered. A linear correlation existed showing high R^2-values of 0.84 and 0.89 for chloride and nitrate, respectively, as displayed in figure 30. The correlation was not perfect since other dissolved ions also influence the EC.

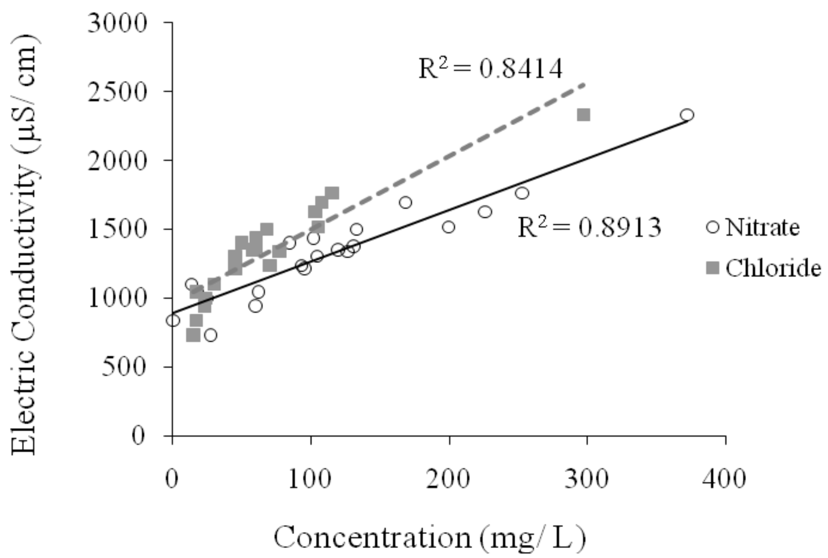

Figure 30 Correlation between EC and nitrate measurements (continuous trend line) and between EC and chloride measurements (dotted line).

Spearman's rank correlation test

The Spearman test showed a weak correlation of 0.25 between the physical water indicator parameter turbidity and total coliform bacteria. The correlation coefficient and degrees of freedom corresponded to a significance level that was well above 5 %, p>0.05. A significance level of more than 5 % (p>0.05) means that the correlation is less than 95 % reliable; hence, the result could be a product of chance.

Little correlation was found between chemical parameters and total coliform bacteria. Since both nitrate and chloride are indicators of poor waste management, it was of interest to evaluate the Spearman correlation between these parameters and total coliform bacteria. The test was also performed on electrical conductivity and hardness compared to total coliform bacteria. The calculated Spearman correlations are presented in table 6.

Table 6 Spearman's rank correlation coefficients between total coliform bacteria and chemical parameters

	NO_3^-	**Cl^-**	**Hardness**	**EC**	**Total coliform bacteria**
NO_3^-	1	0.889***	0.576*	0.904***	0.340
Cl^-		1	0.596*	0.918***	0.261
Hardness			1	0.633**	0.465
EC				1	0.226

n=22 observations for NO_3^-, Cl^- and hardness
n(EC)=20 for electrical conductivity
*p<0.05
**p<0.01
***p<0.001

Results showed that little correlation existed between total coliform bacteria and the chosen parameters. For hardness, a Spearman correlation coefficient of 0.465 was found, which was very close to reaching the significance level of 5 %. However, pair-wise correlations between nitrate, chloride, EC and hardness showed significant results.

5.2 THE CURRENT SANITATION SITUATION

Most households had simple pit-latrines though a few had bucket latrines, which were located in the yards. Number of persons that used each toilet was about 2 to 3 persons. The toilets were commonly placed on a solid platform, either concrete (figure 31) or wooden (figure 32), and they often lacked seats. The pits were enclosed by walls and roofs made out of either wood or metal. The ground surface in close proximity of the toilet was in general covered with concrete.

Figure 31 Pit latrine with a solid platform made out of concrete.

Figure 32 Pit latrine with a wooden solid platform.

Pit depths ranged from 1.5 to 2 m, which implied an adequate distance to the groundwater surface. Some toilets were moved when full while others were emptied on a regular basis. Depending on the load, i.e. the number of people that used the toilet and their frequency of use, the time interval for emptying a toilet was one or two years. The toilet was cleaned when emptied and excreta put on crop fields using buckets. In some yards washing facilities were available, although not in closest proximity of the toilets, while in others facilities were missing.

The simple pit-latrines that could be found in the village were, according to the criteria on improved sanitation in section 3.4, considered as improved sanitation if the pits were not emptied manually. Manual handling of excreta means for instance to empty the pit with a shovel. This method is not sanitary and consequently a health-risk, especially if the faeces has not decomposed properly (section 3.3.2). Bucket latrines and simple pit-latrines that were manually emptied without decomposed faeces were not considered as improved sanitation.

5.3 WATER QUALITY MAPPED IN ARCGIS

5.3.1 Drinking water quality

To visualize the quality of the drinking water in Condrita, analyses and overlays were done in ArcGIS based on table 4 (section 4.4.2). The result showed that only a small part of Condrita could provide water that was fit for human consumption as displayed in figure 33. Chloride and nitrate was used for determining the drinking water quality in the study area since bacteriological parameters as well as turbidity are not valid for interpolation on large distances (section 4.4.2). The groundwater was generally of permissible quality, i.e. chloride concentrations exceeding 100 mg/L and nitrate concentrations of 20-50 mg/L. A smaller part of the study area was classified as unfit for human consumption (chloride concentrations above 250 mg/L and nitrate concentrations above 50 mg/L).

The drinking water quality for each household was determined by combining the measurement values on chloride, coliform bacteria, *E. coli*, nitrate and turbidity. Since distances between the houses and wells were short, all parameters could be included in this interpolation. About half of the households had access to water unfit for human consumption (figure 34). The remaining households had access to water of permissible quality, while a few households had water fit to drink.

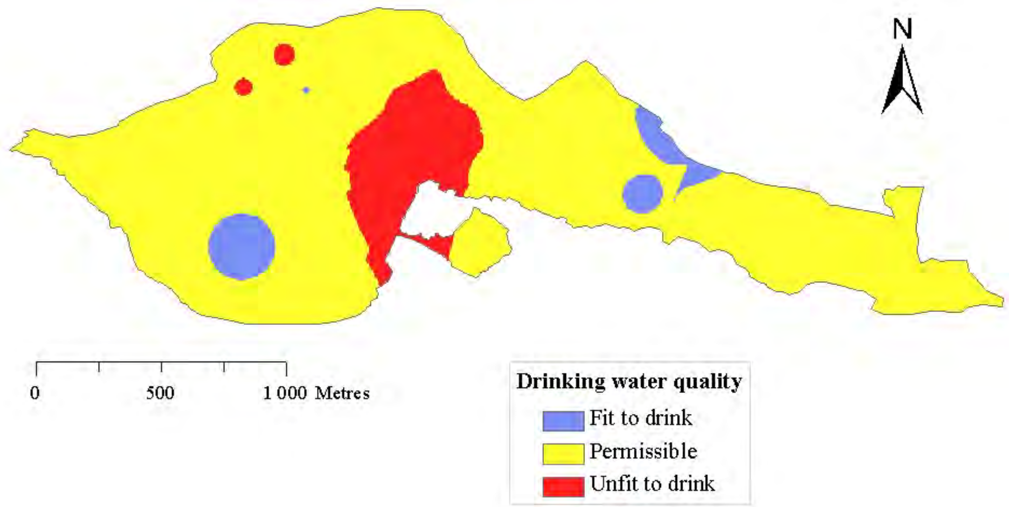

Figure 33 Drinking water quality (based on nitrate and chloride concentrations) in the study area Condrita ranged into three classes (fit to drink, permissible and unfit to drink).

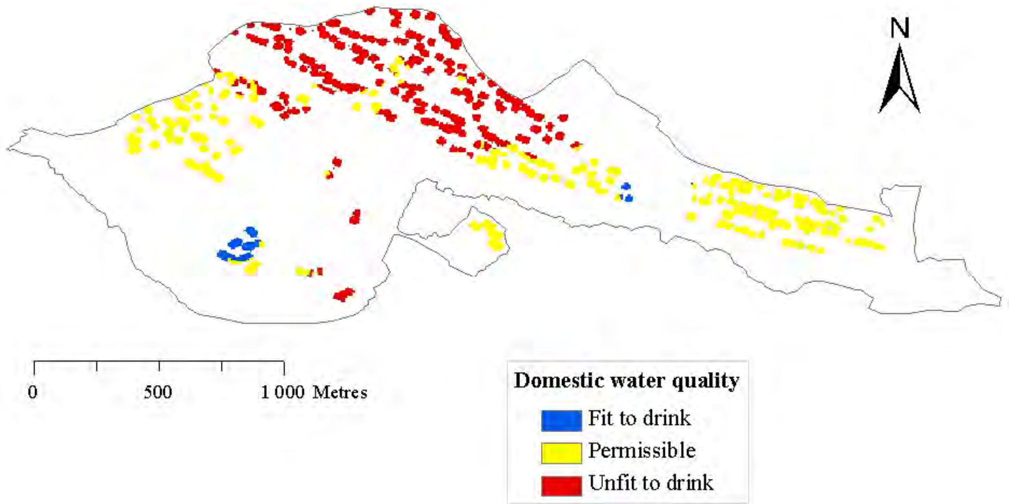

Figure 34 Domestic water quality (based on the parameters chloride, coliform bacteria, *E. coli*, nitrate and turbidity), i.e. households with drinking water classified as fit to drink, permissible or unfit to drink.

5.3.2 Irrigation water quality

The measured EC in the study area was interpolated in ArcGIS to investigate the suitability of using groundwater as irrigation water. The results showed that a majority of the groundwater in the study area, if used as irrigation water, can be considered of permissible quality. Groundwater near well 10 was of doubtful quality if used as irrigation water.

5.4 VULNERABILITY ASSESSMENT

5.4.1 Calculated DRASTIC parameters and modified DRASTIC index

The DRASTIC model calculations gave a modified DRASTIC index that ranged from 108 to 152 (theoretical minimum value was 101 and maximum was 163). The DRASTIC index was divided into 3 classes and reclassified as low (108 to 123), moderate (123 to 131) as well as high (132 to 152) risk areas respectively (figure 35). Low risk areas were mostly found in the forest that surrounded the municipality, while most of the village area was more or less equally covered by moderate and high risk areas.

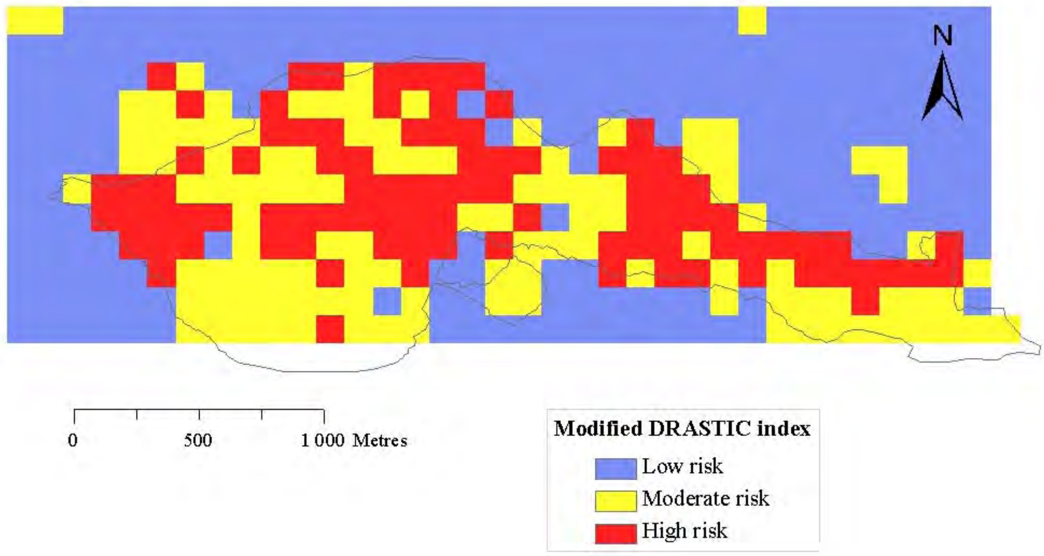

Figure 35 Calculated modified DRASTIC index for the study area.

5.4.2 Model test

The model test showed whether areas with a certain water quality coincided with the different vulnerability areas. Results revealed that no areas with water fit to drink and low vulnerability overlapped. Furthermore, no areas with low vulnerability coincided with areas that held water unfit to drink. Approximately half of the areas with permissible water quality coincided with moderate vulnerability areas, while practically all areas that held water unfit to drink overlapped with high vulnerability areas (figure 36). White areas in figure 36 represent all other combinations of drinking water quality and vulnerability, e.g. water fit to drink and high vulnerability or permissible water quality and low vulnerability areas.

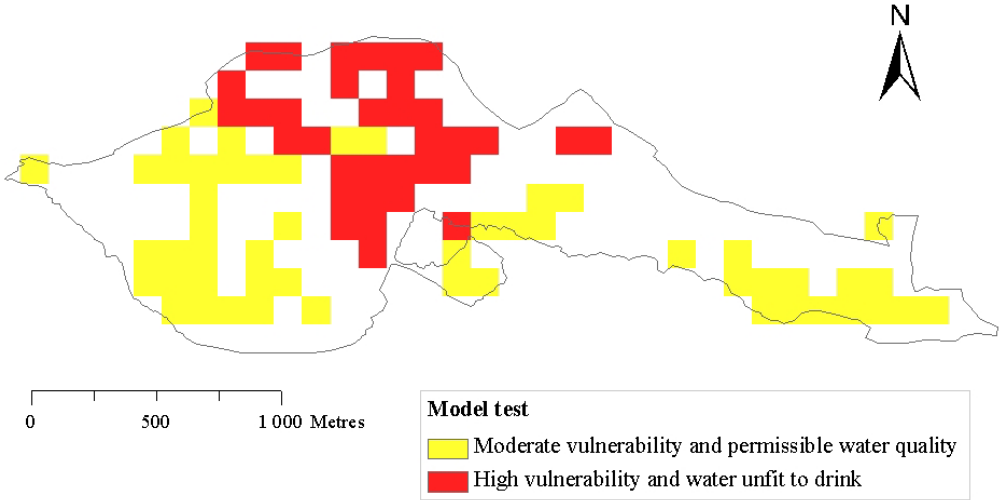

Figure 36 Areas with drinking water quality fit to drink, permissible and unfit to drink that overlapped with low, moderate and high vulnerability areas.

6 DISCUSSION

The drinking water was generally of permissible quality, and improving the situation for the future could be done in several ways. Firstly, a little less than half of the existing water sources were deficient and could, consequently, be improved. Secondly, high levels of nitrate contaminations imply either poor agricultural management or poor latrine management, which should be subject for improvements. It is believed that the most efficient way to decrease nitrate in groundwater is to upgrade from pit latrines to a urine separation dry system.

6.1 THE CURRENT DRINKING WATER QUALITY

The quality of the current drinking water in most wells in Condrita proved to be insufficient. In general, the concentrations of the drinking water exceeded guideline values and were classified as permissible quality or unfit for human consumption. Furthermore, only a few households had access to drinking water that was fit to drink. Consuming drinking water of permissible quality or water that is unfit to drink could on a short-term basis, because of the presence of coliform and *E. coli* bacteria, cause diarrhoea. Risk groups are consumers that are not used to the drinking water in addition to infants and elderly. A large intake of nitrates on a long-term basis could further cause cancer.

No traces of pesticides were found in the sampled water from well 16. Nevertheless, it should be noticed that one sample might not be representative for the situation in the whole village. The result indicated, though, that the groundwater in Condrita was not a health risk to the inhabitants from a pesticide perspective. Oral information was given that no pesticides had been used in the study area for the last 50 years, and that no obsolete pesticides were stored within the study area at present. The information agreed with the laboratory results.

6.2 FACTORS THAT AFFECT THE DRINKING WATER QUALITY

Nitrate and bacteria were the most important contaminators of the drinking water in Condrita. Factors that were believed to contribute to the contamination of the water were land use in the surroundings of the water source, depth to water table and construction of the water source. Nitrate concentrations could originate from agricultural activities, poor sanitation systems and airborne contributions, i.e. different land use. Bacteria were most likely introduced at the water source, when collecting water, i.e. affected by how the water source was maintained.

6.2.1 Land use

Amongst others, land use comprises of human activities such as agriculture, dwelling (including sanitation) and traffic. Contaminators are probably introduced to the groundwater by agricultural and dwelling activities, and therefore land use was expected to be important for the water quality in the study area. Results from the first sampling session showed that the two springs (S1 and S2) overall had much lower measured values than the wells. The location of S1 and S2 are in the outskirts of Condrita, surrounded by forest and areas uninfluenced by human activity. Consequently, measurements from the two springs could be used as background values for unaffected groundwater in the area. Among other things, this means that the natural concentrations of nitrate in the study area are likely to be low and that the occurring levels of nitrate are due to external factors.

Furthermore, concentrations of chloride were above 50 mg/L and nitrate concentrations exceeded 20 mg/L, which implies that the water sources were affected by e.g. sewage, animal dung or surface water. Since concentrations of nitrate and chloride were higher in the densely populated part of the village, human activity was supposed to affect the drinking water quality. Nitrate and chloride concentrations were correlated, which further indicates that human activity affects the levels of contamination. If high concentrations of nitrate were found at the same time as low concentrations of chloride, the nitrate concentrations might have originated from another kind of source. However, the correlation could not establish the extent of the impact from land use, since the linear correlation could depend on a third parameter.

Contributions from agriculture

The inhabitants of Condrita were mainly farmers, who grew crops in their own gardens. For economic reasons it was common to use animal or human faeces as manure for this purpose. A few larger agricultural land areas are located within the village area but it was not told what manures that were used on these crop fields. Larger croplands in other villages were fertilized with artificial fertilizers, spread by machines.

Agricultural land was a possible source of nitrate contamination in wells 19 and 20, as crop fields are situated to the west of these wells. Nitrate concentrations were 62.0 mg/L in well 19 and 92.5 mg/L in well 20, which were lower than in many other parts of the study area. According to the location of wells 2 and 3, the nitrate contamination could have originated from the crop fields situated to the north. Nitrate concentrations in wells 2 and 3 were 13.3 and 59.8 mg/L, respectively, which was lower than in many other parts of the area. It was difficult to conclude to what extent the crop fields affected the nitrate concentrations. However, the fact that there was little correlation between high nitrate concentrations and agricultural land in wells 2, 3, 19 and 20 indicated that agricultural activity is probably not a large contributor to nitrate contaminations in the study area.

Nitrate concentrations were larger in areas where garden cultivations were more frequent, which was in densely populated areas. Conclusions could not be reached on whether the higher levels of contaminations were due to the frequency of cultivations or the likelihood that there were pit latrines located in the vicinity, in each garden.

Sanitation

Correlations between the occurrence of pit latrines and nitrate in groundwater exist. The sanitation system in Condrita was a drop-and-store system, consisting of simple pit latrines. The frequent occurrence of the pit latrines, especially in densely populated areas, was likely to generate a heavy load on the groundwater. The high levels of nitrate in the sampled water were believed to originate from the pit latrines.

Furthermore, it was probable that groundwater downstream of nitrate contaminators (e.g. pit latrines) were affected since dissolved ions can travel long distances in the saturated zone. The groundwater flow probably followed the topography quite well in the western part of the village but diverged somewhat in the eastern and northern parts. The reason for discrepancies could originate from heterogeneities in the soil, but more likely the reason was large volumes of abstracted water in some areas of the village (i.e. lowered groundwater tables). The concentrations of nitrate were higher downstream than upstream in the middle (or northern) part of the village. Different groundwater flow directions could have resulted in other concentrations in the affected wells downstream.

Airborne contributions

The nitrate levels in springs S1 and S2 were likely to represent the contribution from nitrogen transport to the village by air since they were considered uninfluenced water sources. The nitrate levels in the sampled water of S1 and S2 were not detectable. Hence, the area was not likely to be much affected by airborne nitrogen that settled in the soil, which seemed reasonable since the study area was surrounded by forest with little traffic in the vicinity.

6.2.2 Construction and maintenance of water sources

Construction of the water source

No tendency was found for the measured total coliform bacteria, as the data interval was similar for densely and sparsely populated areas as well as for improved and unimproved water sources. The reason for the unexpected behaviour could be that bacteriological contamination has different origins and is not strictly limited to the leakage from pit latrines.

Concentrations of nitrate and chloride were higher in unimproved wells but the correlation could be random because of the few measurement values. Within the densely populated part of Condrita, unimproved wells had higher concentrations of nitrate. As for the springs, the differences in water quality between S1 (unimproved) and S2 (improved) were negligible. Both springs had low levels of contamination, for which the reason could have been that the springs were located in the outskirts of the village with little human activity.

Maintenance

The presence of bacteria in the drinking water indicated faecal contamination in the water sources, which was probably a consequence of poor latrine management and poor hygiene. It is unlikely that the bacteria originated from pit latrines, due to the distance between the bottom of the pit and the groundwater table being large enough. Bacteria that leaked from the pit latrines were hence likely to be filtered in the unsaturated zone. It can therefore be assumed that bacteria were introduced at the wells, e.g. by dirty hands that contaminate the bucket. Other contaminating sources could have been bird droppings or animals (including insects) that fall into the well.

The second sampling showed great disinfection efficiency since both *E. coli* and total coliform bacteria levels were significantly lower than before disinfecting the wells. However, bacteria levels are likely to have increased some time after disinfection since the probable contaminating source (the bucket) had not been removed.

In general, unimproved water sources had drinking water of poorer quality than improved water sources. It can be discussed whether the reason for this tendency was that water sources with adequate water were better maintained or if it was the better construction of the well or spring that generated water of adequate quality. Families in Condrita maintain the water source that they use themselves. The frequency of cleaning and maintaining the well was likely to be determined by each family’s financial situation rather than the current water quality. It might even be likely that maintenance and cleaning was put off if the water quality was perceived as good.

High turbidity values could indicate poor maintenance of a water source since cleaning the well includes removing the sediments on the bottom. A small correlation between turbidity and total coliform bacteria was found during a field study in Peru by Persson (2009), who studied surface water that was distributed in a centralized water distribution system. An explanation to the correlation was the possibility for bacteria to attach to particles in the water. Results from the assessment of the water quality in Condrita showed that turbidity was not likely to explain or predict the amount of total coliform bacteria. The discrepancy between the achieved results could originate from the difference in sampled water (well or spring water compared to surface water). Neither hardness and EC, nor the concentrations of nitrate and chloride could explain the presence of total coliform bacteria. In comparison, Nola et al. (2002) and Lamrani Alaoui et al. (2008) found correlations between Ca^{2+} and faecal coliforms and between EC and faecal coliforms.

6.2.3 Depth to groundwater table

It was expected that the highest degree of contamination would have been found in wells where depths to the groundwater table were small, i.e. short travel times for the contaminant in the unsaturated zone. If this would be the case, the worst water quality would for instance have been found in well 2 (water depth of 2.5-5 m) which held low concentrations. Moreover, some of the most contaminated wells (6, 7, 9, 12 and 13) had water depths of more than 12.5 m. Although being within the range of shallow groundwater, the higher levels of contaminations imply another explanation than just the depth of the water table.

The most contaminated water sources with respect to nitrate (above 100 mg/L) included wells 5-10, 12, 13-15 and 17. The depths to the water table in these wells differed greatly, i.e. high levels of nitrate were found at both small and large depths to the water table. This implies that little correlation existed between depths and concentrations of nitrate. Moreover, the wells were situated in the part of the village that was defined as densely populated. Given the contaminating contribution from land use, it was concluded that the amount of people living close to the wells was a more important factor of contamination than the depth to the water table. In addition, if the depth to the groundwater is small and the well is located in a densely populated area the degree of contamination might be even worse.

6.3 VULNERABILITY TO GROUNDWATER CONTAMINATION

The vulnerability assessment, using the DRASTIC method, displayed areas that were more vulnerable to groundwater contamination than others. A majority of the areas within the municipality was classified as moderate or high risk areas. It cannot necessarily be concluded that the groundwater in these areas is contaminated but if combined with possible sources of contamination, the risk is significant. Managing water sources and latrines properly is for instance important in order to take precaution against groundwater contamination.

6.4 IRRIGATION WATER QUALITY

It was investigated whether the groundwater in the wells was suitable for irrigation use. To avoid the negative effects of salt accumulation that could reduce crop production, the assessment showed that a majority of the water was suitable for irrigation use only if the irrigated soil is permeable. The main soil type in Condrita was Phaeozem, which is a soil with high permeability, meaning that the groundwater might be suitable for irrigation purposes. A small area held groundwater classified as doubtful irrigation water quality. Irrigating crops with water of such a quality may cause the crops to wither.

6.5 SUSTAINABILITY OF THE CURRENT SANITATION SYSTEM

The majority of the families in Condrita had access to improved sanitation and the most common construction of improved sanitation facilities was simple pit latrines. Even though pit latrines were classified as improved, the comfort of using them is not high. Toilets were in most cases placed as far away as possible from the dwelling-house due to bad odour and flies during summer. In winter this placement is inconvenient because of cold weather implying an increased risk of infections (e.g. urinary infection or a cold). Hand washing facilities were (if present) often placed far from the toilets, leading to these facilities not being used regularly. Information from interviews said that it was common that the user would forget to wash his/her hands on the way from the toilet to the wash stand as duties in the yard would come up on the way. The school toilets, which comprised of two unsanitary simple pit latrines, were situated around 50 m from the school building with no hand washing facilities close by. Hence, school children could not wash their hands straight after visiting the toilet and would also risk getting ill during winter.

Most sanitation facilities in Condrita were not believed to fulfil all of the sustainability criteria set up by the SuSanA (section 2.4.2). When it came to *health and hygiene*, the simple pit latrines that were used could not ensure people's health due to leakage of nitrate and the fact that some people came in contact with excreta when emptying the pits. Users did in general not wash their hands, which increased the risk of spreading pathogens. As for *environmental resources* the simple pit latrines did not require much construction material, which could be considered good from a sustainability point of view. Human waste was sometimes recycled and used as fertilizer on crops though the human waste was seldom sanitized before applied as fertilizer. In addition, contaminant leakage from the latrines reduced the groundwater quality. Sustainability could, hence, not be achieved in these aspects.

Sustainable advantages was the simple *technology* and little *maintenance* required by simple pit latrines. The costs of constructing a simple pit latrine was small for the private household, merely consisting of *economic expenses* for construction material and time for labour when digging the toilet. Once construction material had been invested in, it could be reused if the toilet was moved to another place. Maintenance costs comprised of the users' time for cleaning and, perhaps, emptying the toilet. Furthermore, economic aspects of sustainability also consider external costs as well as benefits. External costs were for instance groundwater pollution. Even though the investment and maintenance costs were low, the benefits for the local community were few since this type of sanitation system did not require any local entrepreneurs.

When looking into *socio-cultural and institutional aspects*, the toilets in the study were situated with a minimum distance of 30 m from the communal wells or springs. This was closer than the Moldovan regulations of 50 m but followed literature recommendations. However, the toilets were often uncomfortable, unsanitary with a bad odour and placed far away from the house. None of the visited toilets were constructed so that disabled people or elderly with reduced abilities to move could access the toilets easily. Moreover, women probably experience inconvenience when using these facilities during menstruation.

6.6 HOW TO IMPROVE THE CURRENT SITUATION

The shallow groundwater in the study area was contaminated; hence, the situation needs to be improved. Two ways of improving the drinking water quality is to construct a deeper borehole, i.e. to find a new source, or to improve the existing sources in addition to removing the current sources of contamination. Probable sources of contamination are the existing pit latrines and leakage from agricultural land. Rainfall collection could be implemented as a drinking water source to an increased extent than at present.

When asking about what the development plans were for the drinking water distribution and sanitation the answer in general was that the problem is financial, i.e. there was not enough money to build the required facilities. The cost of a new borehole as well as the required water tower, pump and pipes would be unaffordable for the villagers unless external financing could be applied for. Merely the water tower would cost about 0.5 million lei (about 28 000 Euro) to construct. Access to tapped water would increase the living standards in Condrita and leave the inhabitants with more time left for other duties than collecting water from wells, i.e. improve the local economy indirectly. In cooperation with EU, either through a membership or not, it is likely that funds could be applied for in the future to improve water infrastructure.

However, applying for funds and planning for infrastructure takes a long time, which implies that a centralized system lies far ahead in the future. In the meantime, the current situation should be improved by simple and cheap solutions that can be realized by local efforts. A significantly cheaper, and affordable, alternative than to install a centralized drinking water system would be to improve the eight wells that were classified as unimproved water sources or to install gutters for rainfall collection. Upgrading to ecological sanitation systems would not only reduce nitrate leakage (the environmental effects) but also improve hygiene, comfort and health aspects. In addition, ecological sanitation would give revenues such as increased crop yields.

6.6.1 Improve water sources

Existing water sources

Eight wells were classified as unimproved water sources. Upgrading the eight wells to improved water sources would mean that seven wells would receive lids and six wells a concrete apron slab. The cost of an upgrade includes concrete, material for the lid as well as labour.

Apron slab

The amount of concrete that is needed for one 0.1 m thick apron slab with a radius of 2 m (calculated with basic geometry) is about 2.2 m^3. In Moldova, the cost of concrete is approximately 950 lei per m^3, including taxes (Karolina Postolovskaia, pers. comm.). Hence, to improve one well would cost about 2090 lei which corresponds to about 117 Euro. Labour is not included in the cost.

Lid

A lid to cover the well entrance could quite easily be constructed by the villagers. Construction material could be wood, plastics etc. depending on what material that is available locally. Using local material would keep the costs quite small.

Collect rainfall

Depending on the size of the collecting area (area of the roof), collected rainfall could be enough to cover the WHO recommendation of at least 20 litres/cap/day. A roof of 30 m^2 would for instance collect 18 m^3 of water during one year if the annual rainfall is 600 mm. This amount corresponds to a consumption of about 50 L per household and day. Storing water from rainfall, for irrigation and hygienic needs, is already realized in water scarcity areas in the southern parts of Moldova (Sergiu Andreev, pers. comm.).

The costs of implementing rainfall collection were not calculated. The procedure requires a large storing capacity, e.g. large cisterns, since rain does not fall evenly throughout the year. Many families in Condrita commonly use such cisterns when producing wine; hence, storing devices for rainfall collection are likely to be available locally. Except for storing devices, the only cost of installing the collecting system would in that case be the pipes that lead the water from the roof to the cistern.

Remove or reduce the effects from existing contaminating sources

Nitrate levels in groundwater in Condrita are most likely to originate from dwelling activities (pit latrines) but could also originate from agricultural activities. According to Winblad & Simpson-Hebért (2004), leakage of nitrate from pit latrines is a huge problem, due to the large amounts of nutrients in human excreta. About 50 % of the nitrogen content in urine leaks from pit latrines, which corresponds to 2.0 kg nitrogen per person and year. The pit latrines should therefore be upgraded to urine separation dry systems.

How can nitrate leakage from agricultural land be prevented? The leakage can be minimized by growing crops on the crop fields all year round, thus leaving plants to take up nitrogen during all seasons. For this reason, it is recommended that the fields are ploughed during spring instead of autumn. Further reasons for cultivating the soil when the climate is colder is that microorganisms are less efficient at such temperatures. Soil cultivation increases the amount of oxygen and organic matter in the soil, which enables the microorganisms to increase the mineralization. This effect will be reduced if temperatures are low.

6.6.2 Improve sanitation facilities

To start with, ecosan toilets would prevent the spreading of diseases and accomplish environmental sustainability. Since excreta are kept from entering the soil, leakage of nitrate and bacteria that could contaminate the groundwater (and later be of health risk to the person who drinks the water) is avoided. A proper construction will also keep excreta separated from human contact. Depending on the type of solution, the user might have to move the container where faeces are collected. However, safety can be ensured if the user wears covering gloves. Hand-washing facilities should be located near the toilets. Environmental sustainability can be reached by using locally produced material for construction of the toilets. The risk of groundwater contamination is minimized since excreta are kept from entering the soil. Natural resources are preserved by the recycling of nutrients and the fact that a dry sanitation system uses no water for flushing faeces.

As for technological and financial aspects, sustainability is accomplished with the simple technology of constructing, operating and maintaining ecosan toilets. The user will need to cover the investment costs of construction material of the toilet house and the toilet itself. This can be considered a disadvantage compared to continuing using the existing pit latrine. Still, ecosan toilets are a more sustainable option since, in comparison with other sanitation systems, the installation costs of ecosan toilets suggested buy Wisdom are cheaper. Furthermore, continuing using the present pit latrine is not sustainable when considering the other aspects. From a sustainability point of view, buying locally produced construction material is considered a financial benefit since it supports local manufacturing.

Since leakage to groundwater is avoided with ecosan toilets, the toilets do not need to follow Moldovan regulations on minimum distances to the water source. Hence, institutional sustainability is obtained. The largest improvements, however, are probably achieved since an ecosan toilet enables the sanitary facilities to be connected to the dwelling-house. By doing this, the user may experience the three requirements (besides safety and privacy) mentioned by Conant & Fadem (2008) (se section 2.4.2 in this report), i.e. comfort, cleanliness and respect. Connecting the toilet to the house is also safer as it minimizes the risk for infections during the cold season of the year. Furthermore, the user is more likely to clean a toilet that is easily accessed and having a well-kept toilet may gain respect.

To sum up, installing a urine separating ecosan toilet is a feasible solution for improving the sanitation facilities in Condrita. In addition, this type of solution can meet several of the sustainability criteria set up by the SuSanA.

6.7 DISCUSSION OF METHODS

6.7.1 Interview method

The results from the interviews may be subject to errors since questions were mainly asked to one guide, which could have resulted in the answers not being representative for all villagers. However, additional questions were asked to dwellers when visiting the wells. Using an interpreter during the interviews was of major importance due to insufficient language skills, but could have caused misunderstandings and be further subject to errors.

6.7.2 Sampling method

During the sampling sessions, the water samples from the 22 wells were taken at different days. However, the parameters can be assumed not to differ at such short time differences since no rainfall was recorded during this period of time. The results should thus not have been affected significantly. Furthermore, time and economical limitations made it impossible to sample the private wells in Condrita. It would have been interesting to sample these wells to get more basic data for the statistical analysis.

The chemical analyses done by Apa Canal were performed within reasonable time after the sampling session. Bacteriological analyses were done within 5 hours from sampling. As for the water stored for EC analysis, the storing time (1.5 to 2 months) was not considered too long to change the measured EC since EC is not considered to change much over time.

As for the collection of elevation data with the GPS, data were compared with topography data to rule out any inaccuracies since GPS measurements on elevation can differ tens of metres. In comparison to topography data for this study, the GPS measurements did not differ significantly.

6.7.3 Vulnerability assessment of potential groundwater contamination

When using DRASTIC, deficiencies in input data existed due to the fact that several parameters had to be estimated (e.g. net recharge data and data on the unsaturated zone). This may have lead to errors in results that were retrieved throughout the modelling. The DRASTIC model is empirical, based on subjective decisions by the user on what parameters are more important, and could be subject to further errors. A distributed model that would quantify contaminations was, however, not possible to use, due to insufficiencies in data. The DRASTIC model was therefore a good choice.

Moreover, the IDW interpolations that were done could have lead to errors since the interpolation points were relatively few, and the model itself was based on several assumptions. A different interpolation method may give other results, which could be subject for further studies.

The model test showed the correlation between the modelled vulnerability in the study area and the current water quality. No areas with low risk for groundwater contamination and water fit to drink overlapped. The reason for this was probably that the DRASTIC model assumed that areas outside the municipality boundary were of lower risks and that the water quality was not interpolated for those areas. Furthermore, no areas classified as low vulnerability possessed water unfit for human consumption. The result supported the model approach, which means that areas modelled as low risk areas indeed have low vulnerability. Still, it is possible that areas with low vulnerability could possess water of poor quality if the load from e.g. human activity is heavy enough. The moderate and high vulnerability areas that coincided with permissible water quality and water unfit to drink were further a validation of the model.

6.8 SUGGESTIONS FOR FURTHER STUDIES

The most important measure to take when improving the water quality in Condrita would be to remove the source of nitrate contamination. Ecosan toilets are believed to be a simple and affordable solution for improving both the water quality and the sanitation situation. In order to implement an ecological sanitation system it should be investigated whether the villagers are keen on using the system. Further studies of interest would therefore be to investigate how ecosan toilets could best be installed as well as what would motivate people to upgrade their sanitation system. Since this master thesis has focused on health and environmental aspects, future studies should focus on social, cultural and economical aspects to study the willingness to invest time and money into the construction and maintenance of ecosan toilets.

Furthermore, it would be of interest to learn how the inhabitants' value ecosan toilets in comparison to traditional water toilets. What is their opinion on a dry urine separating system that requires effort to maintain but is much cheaper and more sustainable than a traditional water system? Would the inhabitants regard an ecosan toilet as an improvement worth the effort and are qualities such as safety and cleanliness valued? In addition to these aspects, it would be interesting to study which factors that could motivate sustainable living even though the consequences of non-sustainable living lie far ahead.

Further studies could also consist of performing studies of the water quality in deeper aquifers, with the intention of exploring whether deep groundwater could be suitable as drinking water. If such an assessment were to be carried out, the economical aspects of installing water towers, pumps and pipes would be necessary in order to see if the municipality could afford this type of solution (for instance by co-financing). However, the environmental downside of the pit latrines (leakage of nitrate and bacteria) would still remain unless the possibility of changing the sanitation system was also investigated.

7 CONCLUSIONS

The water quality in Condrita is generally poor. The largest health risk is due to deficient drinking water quality containing nitrate and total coliform bacteria as the most hazardous parameters. No pesticide concentration was detected, which indicated that the health of the consumers is not likely to be affected by such chemicals.

Nitrate concentrations are believed to originate from the simple pit latrines, frequently used by the villagers. The groundwater might be affected by nitrate leakage from the surrounding agricultural land in addition to cultivations in people’s gardens. Nitrate concentrations are higher in the densely populated part of the village and in unimproved water sources.

Bacteriological contamination varies greatly in the village and the degree of contamination could not be explained by the population density or the status of the water sources. In addition, no significant statistical correlations were found between nitrate, chloride, EC, turbidity, hardness and total coliform bacteria. Therefore, it is believed that bacteriological contamination most likely occurred at the well, for instance by abstracting water with dirty buckets or not covering the well with a lid.

Most groundwater sources within the study area are at high or moderate risk of becoming contaminated. Furthermore, a majority of the drinking water quality is not fit to drink; hence, most households in Condrita do not have access to safe drinking water. If using the groundwater for irrigation the quality is mostly considered as acceptable.

A majority of the villagers have access to improved sanitation. Pit latrines are generally placed far from the dwelling-house, often lacking hand-washing facilities.

The most important improvement to be implemented would be to upgrade the current sanitation system consisting of pit latrines. Installing ecosan toilets would be a good and sustainable solution for both the environment and for the health and comfort of the users. Additional possibilities for improving the water sources would be to collect rainfall or improve the construction of existing wells and springs.

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Tudor, Zagoreanu, villager and guide during the field studies in Condrita.
Vasilievici, Bugaev, employee at Apa Canal, Moldova

Appendix A Drinking water analysis results; sampling session one

Table A1 Results from the first sampling session

Well/ spring	Turbidity (NTU)	NO_3^- (mg/L)	NO_2^- (mg/L)	NH_4^+ (mg/L)	Cl^- (mg/L)	Hardness (°dH)	Hardness ($CaCO_3$ mg/L)	O_2 (mg/L)	SO_4^{-2} (mg/L)	pH	EC (µS/cm)	E coli (number /100 ml)	Total coliform bacteria (number/ 1000 ml)
1	**6.5**	24.4	0.005	0.10	24.0	**28.6**	**511**	0.96	52.3	7.90	**1001**	0	**272**
2	0.5	13.3	< 0.003	0.50	30.0	**30.8**	**550**	1.12	87.2	7.50	**1101**	0	**909**
3	1.0	**59.8**	0.030	< 0.05	23.0	**28.0**	**500**	0.96	94.6	7.45	**945**	0	**364**
4	3.5	**93.2**	0.050	< 0.05	70.0	**30.8**	**550**	1.28	70.8	7.55	**1237**	0	**1091**
5	3.5	**119.6**	0.025	0.05	58.0	**39.3**	**701**	1.36	103.7	7.60	**1351**	0	**182**
6	3.0	**104.1**	0.025	0.05	45.0	**29.2**	**521**	1.20	54.7	7.40	**1305**	**7**	**1363**
7	**70.0**	**132.9**	0.050	0.07	68.0	**18.0**	**321**	0.96	100.4	7.65	**1502**	**3**	**1182**
8*	**85.0**	**126.3**	0.025	0.05	77.0	**28.6**	**511**	0.68	80.2	7.65	**1338**	0	**55**
9	2.5	**225.9**	0.020	0.10	103.0	**44.9**	**801**	0.96	112.8	7.70	**1629**	0	**727**
10	**13.0**	**372.1**	0.070	NA	**297.0**	**77.7**	**1387**	2.40	123	7.15	**2330**	0	**1273**
11	0.5	**84.2**	< 0.003	0.05	50.0	**36.5**	**652**	0.80	67.4	7.60	**1401**	0	**198**
12	**140.0**	**101.9**	0.030	0.05	60.0	**43.5**	**776**	1.28	109.4	7.25	**1435**	**13**	**1182**
13	5.0	**252.5**	0.060	0.08	115.0	**50.5**	**901**	0.40	109.5	7.25	**1763**	0	**273**
14	0.5	**130.7**	0.025	< 0.05	60.0	**37.0**	**660**	0.16	62.5	7.35	**1377**	0	**727**
15	0.5	**168.3**	0.050	< 0.05	108.0	**51.0**	**910**	0.88	221.7	7.15	**1693**	**14**	**1272**
16	**8.0**	17.7	< 0.003	0.05	17.0	**51.6**	**921**	0.80	46.9	7.15	**1042**	0	**1364**
17	3.5	**199.4**	0.005	0.05	105.0	**44.9**	**801**	0.24	108.6	7.00	**1519**	0	**1090**
18	0.5	27.5	< 0.003	< 0.05	15.0	**24.7**	**441**	0.16	34.5	7.30	**733**	0	**117**
19	0.5	**62.0**	< 0.003	< 0.05	17.0	**28.0**	**500**	0.16	68.7	7.45	**1047**	0	**1182**
20	2.0	**95.2**	0.150	0.07	45.0	**32.4**	**578**	0.32	100.4	7.50	**1215**	0	**81**
S1	1.5	ND	0.015	0.38	26.0	**23.8**	**425**	ND	36.2	7.50		0	**18**
S2	0.5	ND	< 0.003	0.05	17.0	**21.9**	**391**	0.40	26.3	7.70	**839**	0	**9**

	Turbidity (NTU)	NO_3^- (mg/L)	NO_2^- (mg/L)	NH_4^+ (mg/L)	Cl^- (mg/L)	Hardness (°dH)	Hardness ($CaCO_3$ mg/L)	O_2 (mg/L)	SO_4^{-2} (mg/L)	pH	EC (µS/cm)	E coli (number /100 ml)	Total coliform bacteria (number/ 1000 ml)
WHO (2004)	< 5 (desirable)	50	0.5	35 (1) 1.5 (2)	250 (1)		300 (1) 200 (3) 100 (4)		500 250 (1)	6.5 - 8.5 (4) (5)	250	0	0 in 100 ml
Moldovan Standard (Elena Movila, pers. comm.)	5	50	0.5	0.50	250	5		5	250	6.5 - 9.5	2500	0	0 in 100 ml
The National Board of Health and Welfare (2003)		20 (7)			50 (6)			8.0 (1)(2)(8)					

Bold figures exceed WHO guidelines or Moldovan Standards
ND = Not detectable
NA = Not available
* Samples taken after well was disinfected with chlorine
(1) To reduce taste
(2) To reduce odour
(3) To reduce risk for scale deposits in boilers
(4) To reduce risk for corrosion in pipes
(5) To make disinfection effective
(6) Indicates impact from salt groundwater, sewage, landfill, surface water or road salt.
(7) Indicates impact from sewage, animal dung and other sources.
(8) Indicates impact from shallow surface water.

Appendix B Drinking water analysis results; sampling session two

Table B1 Results from the second sampling session

Well/ spring	**Turbidity (NTU)**	**NO_3^- (mg/L)**	**NO_2^- (mg/L)**	**NH_4^+ (mg/L)**	**Cl^- (mg/L)**	**Hardness (°dH)**	**Hardness ($CaCO_3$ mg/L)**	**O_2 (mg/L)**	**SO_4^{-2} (mg/L)**	**pH**	**E coli (number/ 100 ml)**	**Total coliform bacteria (number/1000 ml)**
6*	1.0	**102.0**	0.065	0.05	40	**28.0**	**500**	0.20	55.5	7.10	0	**355**
7*	**50.0**	**130.7**	0.110	0.05	65	**26.6**	**475**	0.80	98.4	7.55	0	**455**
9*	1.5	**210.4**	< 0.003	0.06	100	**44.9**	**801**	0.18	114.6	7.55	0	< 9
12*	**100.0**	**93.0**	0.050	0.07	60	**42.9**	**766**	1.28	107.4	7.50	0	**111**
15*	3.0	**168.3**	0.030	0.05	108	**49.6**	**885**	0.88	224.0	7.15	**3**	**27**
WHO (2004)	< 5 (desirable)	50	0.5	35 (1) 1.5 (2)	250 (1)		300 (1) 200 (3) 100 (4)		500 250 (1)	6.5-8.5 (4) (5)	0	0 in 100 ml
Moldovan Standard (Elena Movila, pers. comm.)	5	50	0.5	0.50	250	5		5	250	6.5-9.5	0	0 in 100 ml
The National Board of Health and Welfare (2003)		20 (7)			50 (6)			8.0 (1)(2)(8)				

Bold figures exceed WHO guidelines or Moldovan Standards
* Samples taken after well was disinfected with chlorine
(1) To reduce taste
(2) To reduce odour
(3) To reduce risk for scale deposits in boilers
(4) To reduce risk for corrosion in pipes
(5) To make disinfection effective
(6) Indicates impact from salt groundwater, sewage, landfill, surface water or road salt.
(7) Indicates impact from sewage, animal dung and other sources.
(8) Indicates impact from shallow surface water.

Appendix C Sampled drinking water – spatial distribution

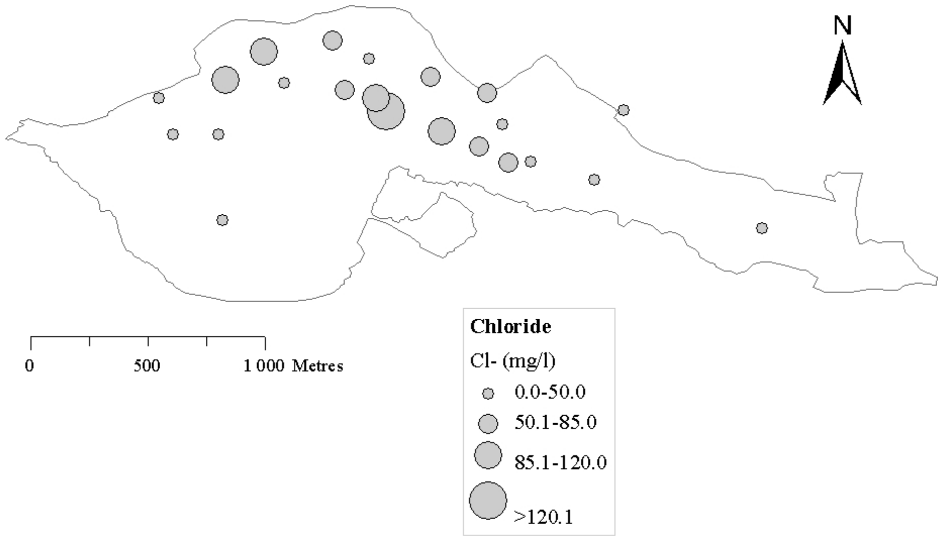

Figure C1 Chloride concentrations in the study area.

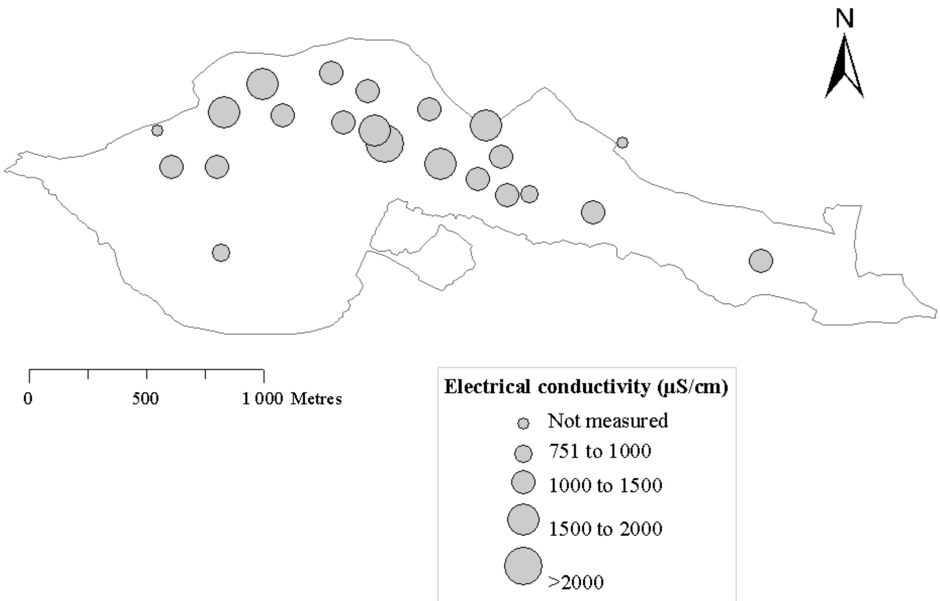

Figure C2 Electrical conductivity measurements in the study area.

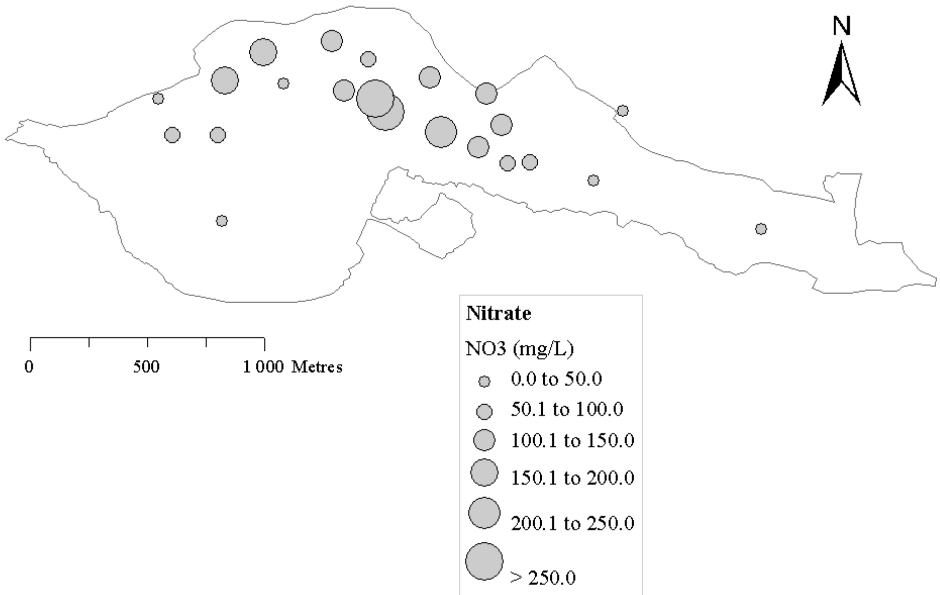

Figure C3 Nitrate concentrations in the study area.

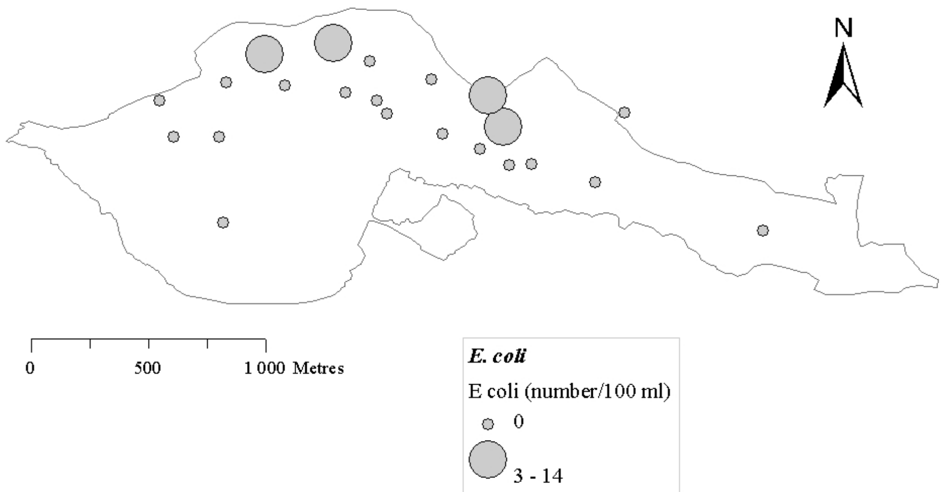

Figure C4 *E. coli* bacteria in the study area.

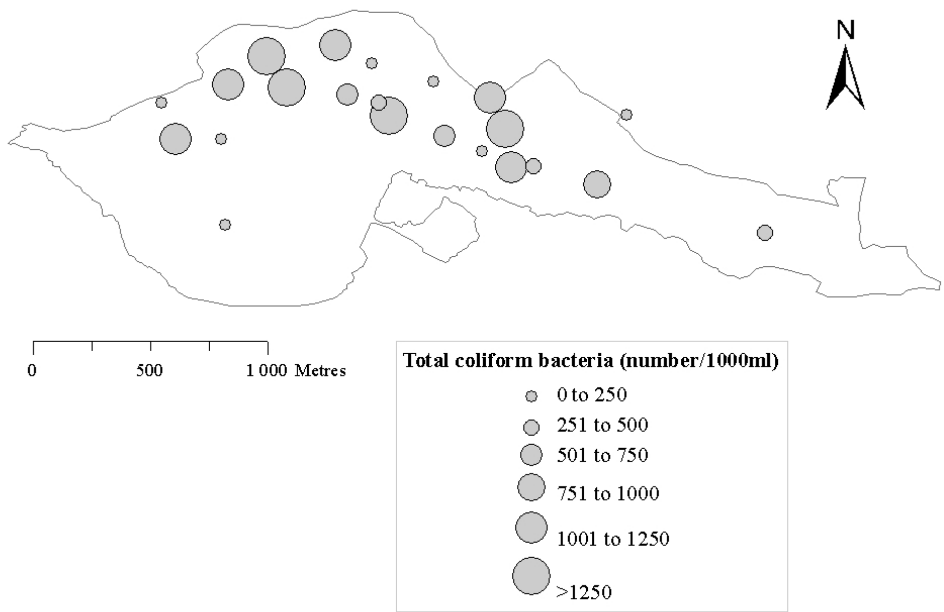

Figure C5 Concentrations of total coliform bacteria in the study area.

Appendix D The DRASTIC model

Table D1 Information on DRASTIC model parameters and methods to retrieve data for this study

Parameters	**Explanation** (Aller et al., 1987)	**Parameter determination** (Aller et al., 1987)	**Method to retrieve data**
DRASTIC			
Depth to water table	Depth to water table is the distance to the groundwater table from the ground surface, hence it is an indirect measure of how long time it takes for contaminants to reach the groundwater. Larger depth corresponds to smaller risk for contamination.	T, C	Interpolation in ArcGIS of measured water tables in situ.
net Recharge	Net recharge is the annual amount of water that percolates the vadose zone per unit area, i.e. the water flow that is available to transport possible contaminants. The higher recharge the higher risk of groundwater pollution, as long as recharge falls under the limit where contaminants start to be diluted.	T, C	Data from FAO Aquastat
Aquifer media	Aquifer media determines the flow through the aquifer, hence the rate to which contaminants travel in the saturated zone. The higher the travel speed, the greater risk for contamination.	F	Interviews in situ
Soil media	Soil media determines the rate of infiltration to the unsaturated zone. Pervious material corresponds to higher risks on groundwater pollution than impervious.	T, C	Observations in situ
Topography	Topography refers to the slope variation in the study area, which determines if surface water infiltrates the ground to travel by gravity to the water table or is more likely to run off. Smaller slope corresponds to higher risk of contamination.	C	Using ArcGIS to illustrate the slope variation (in percent) in the study area
Impact of the vadose zone	Impact of the vadose zone, i.e. the unsaturated zone above the ground water table, is important to consider since it determines if contaminants are absorbed in the media or leak to the groundwater. Pervious material corresponds to higher risks on groundwater pollution than impervious.	T, C	Interviews in situ
hydraulic Conductivity	Hydraulic conductivity is a measure of contaminants travel time to the groundwater table.	T, F	Not included in model
OTHER			
Land use	Land use is important to consider since contaminant concentrations are higher, due to human activity, in some areas than others. Risk areas are for instance agricultural land and landfills.	C	Digitized orthophoto and observations

T = Travel time
F = Flux
C = Concentration

How to model a DRASTIC index

The first step in the DRASTIC model is to range and rate the parameters after their individual risks for groundwater contamination and create rasters in ArcGIS on each DRASTIC parameter. The lowest risk rating is 1 and the highest 10. After rating all parameters, they are added together by equation D1 to calculate a relative DRASTIC index. This is done by doing an overlay of all rasters in ArcGIS. When adding the parameters, each raster is weighted according to a scale from 1 to 5 that measures how important the DRASTIC parameter is in terms of risk for contamination. Ratings and rates that were used in this study are shown in table D2. The final step is then to range the relative index into risk categories such as low, moderate and high risk, for groundwater contamination (Aller et al., 1987). Ranging is done by reclassifying the calculated raster from equation D1.

$$DRASTIC\ index = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \qquad \text{(D1)}$$

Where,
subscript r = rating, w = weight
letters D, R, A, S, T, I, C corresponds to each DRASTIC parameters

Table D2 Ranges and ratings of the modified DRASTIC model parameters used for the study

Model parameter	Range in model	Range according to literature	Typical rating suggested by literature	Rating (R)	Weight (W)	Total weight (R·W)
DRASTIC parameters						
Depth to water table [m]					5	
	0 to <5		NA	10		50
	5 to <15		NA	9		45
	15 to <30		NA	7		35
net Recharge [mm/year]					4	
	118.2	102 to 178	5[A]	5		20
Aquifer media					3	
	Sand		8[A]	8		24
Soil media					2	
	Aggregated clay		7[A]	7		14
	Clay loam		3[A]	3		6
	Muck		2[A]	2		4
Topography [percent]					1	
	0 to <2			10		10
	2 to <6			9		9
	6 to <12			5		5
	12 to <18			3		3
Impact of the vadose zone					5	
	Silt/Clay		3[A]	3		15
hydraulic Conductivity					3	
	Unknown and not included in the model			0		0
OTHER parameters						
Land use type					3	
	Crop fields	Complex cultivations[P]	10[P]	10		30
	Waste dump	NA	NA	10		30
	Garden crop fields	NA	NA	8		24
	Orchard	Olive groves[P]	5[P]	5		15
	Bus garage	NA	NA	4		12
	Houses buffer 10 m	NA	NA	4		12
	Fields	Natural grassland[P]	3[P]	3		9
	Deciduous forest	Mixed forest[P]	1[P]	1		3
	NoData	NA	NA	1		3

A = Aller et al., 1987
P = Panagopoulos et al., 2006

Creating layers in ArcGIS based on the modified DRASTIC parameters

D - Depth to water table

The depth to the water table is equal to the distance from the ground surface to the ground water table. Measurements of the depth to the water table in the wells were carried out in situ, as stated in section 4.2.1. The groundwater table measurements were interpolated in ArcGIS using the Inverse Distance Weight method (IDW). A k-factor of 2 and 10 interpolation points were used. In Condrita, water abstraction in the measured wells was performed using the bucket/windlass method; hence the abstracted volumes were considered negligible. Any water table variations due to extraction of water or insufficient recharge were therefore ignored, and the interpolated water depths were considered valid. Interpolated water depths were reclassified in ArcGIS to rate and range data according to table D2, as shown in figure D1.

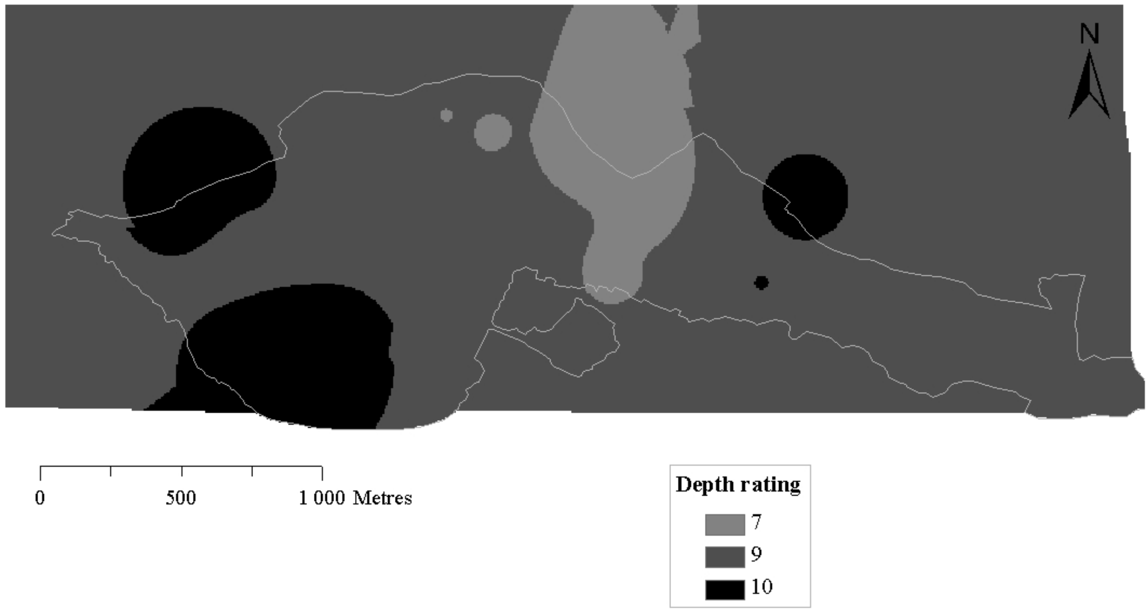

Figure D1 Rating of D - Depth to water surface. The first DRASTIC parameter, which describes what influence distance to the ground water has on potential ground water contaminations.

R - Net recharge

Hydrological data for the study area was unavailable which is why net recharge was assumed to be the annual groundwater production in Moldova, estimated by Aquastat (2009) to 118.2 mm/year. The net recharge value was rated according to table D2 and a layer was created in ArcGIS.

A - Aquifer media

Information on how aquifer media varies spatially in the study area was unfortunately not available, but determined qualitatively by interviews. According to people in the village who were present when digging wells, the saturated zone consists of sand. A raster with information on aquifer media was created in ArcGIS and classified and rated according to table D2.

S - Soil media

Since no geological maps were available for the study area, soil media was to be determined by observations in situ as well as a digitized orthophoto (ARFC, 2009). Twenty wells were visited along with other locations such as several crop fields, one spring located within the monastery grounds and one spring in the deciduous forest. Observations in proximity of these locations showed that the soil media consisted of aggregated clay, clay loam and muck. These media were rated and classified in ArcGIS according to table D2, as shown in figure D2.

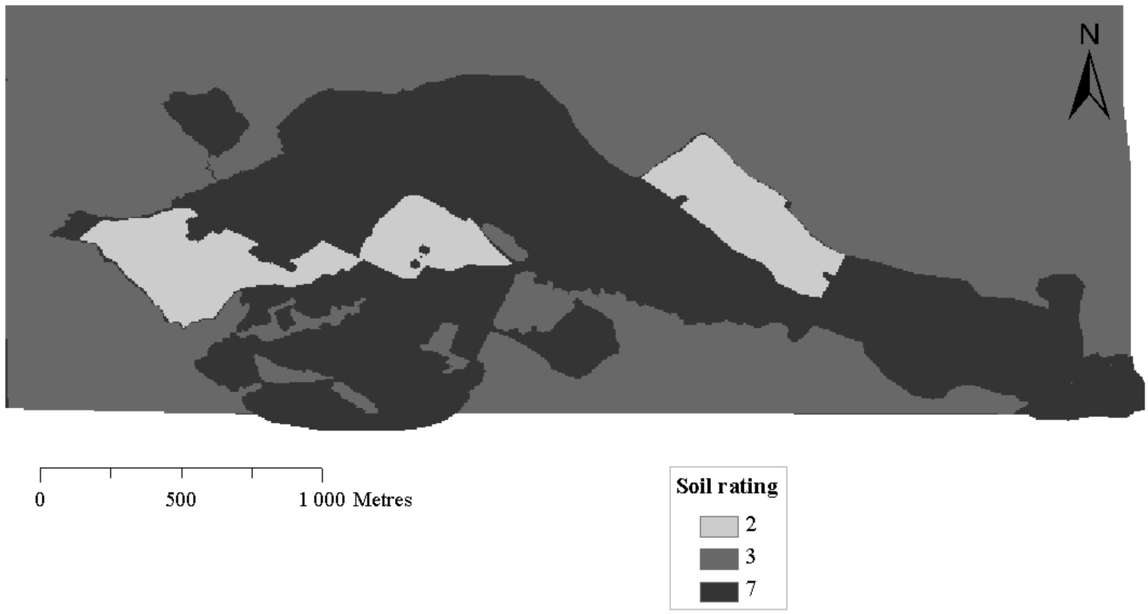

Figure D2 Rating of S – Soil, the fourth DRASTIC parameter which describes what influence the top soil layer has on potential ground water contamination.

T - Topography

Topography in a DRASTIC context refers to the slope, in per cent. Using ArcGIS, a layer on slope variation was created from a DEM-file on Moldova. A raster on slope variation was ranged and rated according to table D2 and reclassified as shown in figure D3.

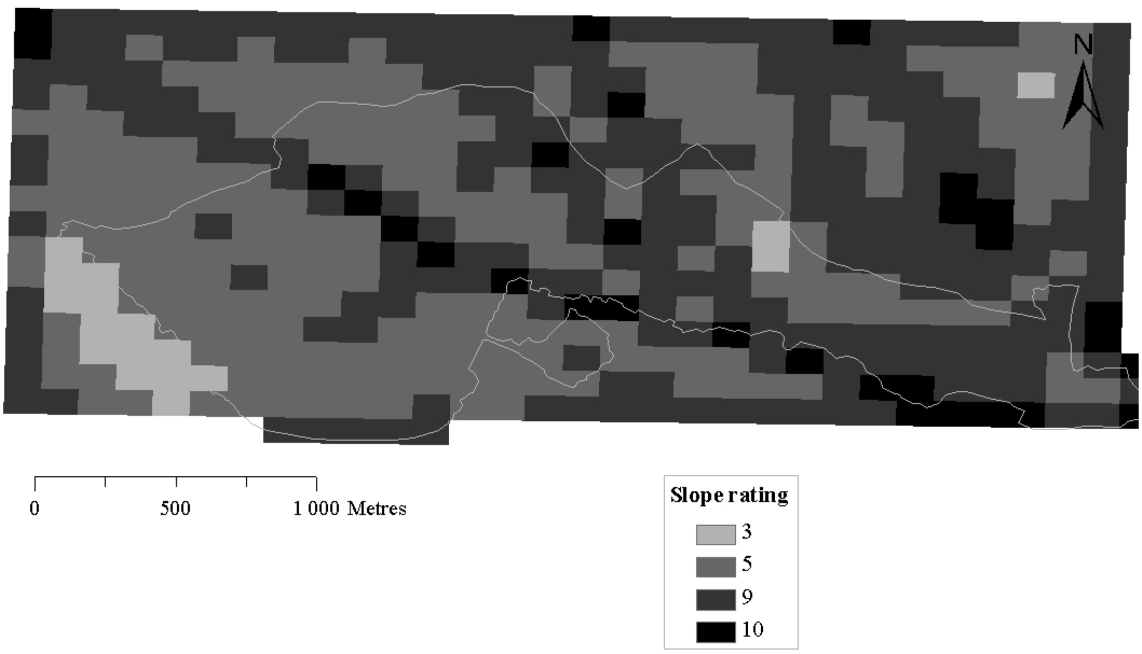

Figure D3 Rating of T – Topography. The fifth DRASTIC parameter, which describes what influence slope variation (in per cent) has on potential ground water contamination.

I - Impact of the vadose zone
No data on the unsaturated zone was available, which is why the parameter had to be determined qualitatively by interviews since there was no time for field measurements. According to people in the village who were present when digging wells, the unsaturated zone consists of silt and clay. A raster on the parameter impact of the vadose zone was created in ArcGIS and classified and rated in line with table D2.

C - Hydraulic Conductivity
By referring to a study in Jordan where hydrological conductivity data were missing, Gomezdelcampo et al. (2007) states that the DRASTIC model can be used with significant results even if hydrological data is insufficient. Furthermore, Panagopoulos et al. (2006) concludes that hydraulic conductivity has little correlation to nitrate concentrations and hence to the level of groundwater contamination. The hydraulic conductivity parameter varies a great deal spatially and is due to variations in pore size in the soil difficult to measure. No hydraulic conductivity data was available for the study area Condrita, hence it was for above stated reasons decided not to include hydraulic conductivity in this study.

Land use and human activity
Land use data was determined from digitizing orthophotos (ARFC, 2009) as well as observations in the study area. A raster on land use was created in ArcGIS and ranged into several categories such as cultivations and developed areas according to table D2. The model distinguishes between crop fields, i.e. larger cultivations with either irrigation systems or tractors to condition the soil, and garden cultivations which are defined as smaller cultivations in the backyard of houses. Categories were partly suggested by Panagopoulos et al. (2006) and partly by the authors of this master thesis, as shown in the table. The layer was reclassified in ArcGIS and rated in accordance to what was suggested (figure D4).

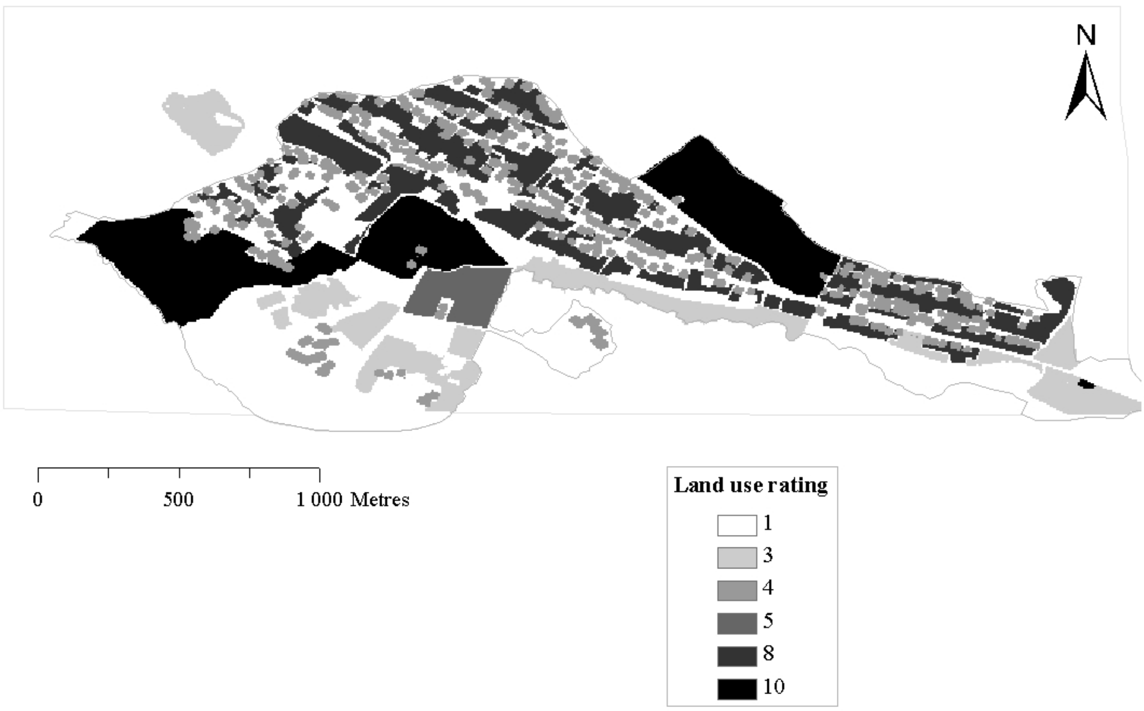

Figure D4 Impact from land use describes the influence the human activity has on potential ground water contamination.

Appendix E List of depth to water table, ground levels and water levels at the wells and springs.

Table E1 The ground level and the depth to the water table in the wells and springs. The water level for each well and spring was calculated by subtracting the depth to the water table from the ground level

Well/ spring	Depth to water table (m)	Ground level (m.a.s.l)	Water level (m.a.s.l.)
1	10.3	130	119.7
2	4.8	132.82 ^{t}	128.02
3	14.5	151.96 ^{t}	137.46
4	14.7	150.68 ^{t}	135.98
5	17.0	152.17 ^{t}	135.17
6	15.1	162.04 ^{t}	146.94
7	22.9	172.00 ^{t}	149.10
8	17.6	168	150.4
9	14.0	152.08 ^{t}	138.08
10	7.0	147	140.0
11	16.9	162	145.1
12	15.2	163.51 ^{t}	148.31
13	13.9	151	137.1
14	6.0	140	134.0
15	6.7	142.57 ^{t}	135.87
16	5.8	136	130.2
17	6.1	156	149.9
18	0	170	170
19	6.4	184	177.6
20	10.1	185	174.9
S1	0	149	149
S2	0	173	173

t = measured with a theodolite

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