SAFE USE OF WASTEWATER IN AGRICULTURE: GOOD PRACTICE EXAMPLES AND FUTURE RESEARCH NEEDS

PROCEEDINGS

Lima, Peru, 24-25 February 2016

UNITED NATIONS UNIVERSITY

UNU-FLORES

Institute for Integrated Management
of Material Fluxes and of Resources

Proceedings

Safe Use of Wastewater in Agriculture: Good Practice Examples and Future Research Needs

Hiroshan Hettiarachchi (UNU-FLORES)

24-25 February 2016
Lima, Peru

Co-Organised By:
UNU-FLORES (Dresden, Germany)
United Nations Environment Programme (Nairobi, Kenya)
IPES – Promoción del Desarrollo Sostenible (Lima, Peru)

Funded by:
German Federal Ministry for Economic Cooperation and Development (BMBF)

Federal Ministry
for Economic Cooperation
and Development

UN environment

IPES
PROMOCIÓN DEL DESARROLLO SOSTENIBLE

The views expressed in this publication are those of the presenters at the workshop. The presenters are responsible for ensuring that all figures, tables, text, and supporting materials are properly cited and necessary permissions were obtained.

United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES)

Ammonstrasse 74, 01067 Dresden, Germany
Tel.: + 49-351 8921 9370
Fax: + 49-351 8921 9389
Email: flores@unu.edu

Editorial Assistance: Arjun Avasthy, Atiqah Fairuz Salleh (UNU-FLORES)
Design & Layout: Claudia Matthias (UNU-FLORES), mybluepencil
Cover Image: gameanna/shutterstock (ID: 131796455)
Photo Credit: IPES
Print: Reprogress GmbH
Print run: 300

ISBN: 978-3-944863-64-1
e-ISBN: 978-3-944863-65-8

This publication should be cited as:
Hettiarachchi, Hiroshan. 2017. *Safe Use of Wastewater in Agriculture: Good Practice Examples and Future Research Needs*. Proceedings, Lima, Peru, 24-25 February 2016. Dresden: United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).

Background

Wastewater irrigation has become commonplace in some parts of the world mainly due to scarcity of water available for agricultural purposes. Wastewater reuse presents a new opportunity but it also presents potential risks especially related to human health and the environment. The process of wastewater use in agriculture, and especially safety aspects of it have not been well organised in many countries yet. This is more prevalent in the developing countries and regions. To address these issues, there is a need for new institutional arrangements and more skilled and trained human resources.

In 2011 seven UN-Water Members, Partners, and Programmes led by the UN-Water Decade Programme on Capacity Development (UNW-DPC) joined efforts to address these capacity needs of countries with regard to the safe use of water in agriculture (SUWA). Between 2011 and 2013, these capacity development activities brought together 160 representatives from 73 UN Member States from Asia, Africa, and Latin America. During these events there was a clear request from the participants for continued support with capacity development and training to address the technical, institutional, and policy challenges posed by water reuse. This workshop in Lima, Peru organised by the United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) is a direct response to such requests.

Sharing information between countries/regions on "good practice examples of safe water reuse in agriculture" was one of the important suggestions made by the participants in the previous activities during its first phase. This was the primary objective UNU-FLORES wanted to meet with the Lima workshop. During the workshop the attendees were given an opportunity to learn from a number of case studies from the Americas, Asia, and Africa. These case studies provided the attendees with a platform to engage in a fruitful discussion to identify the knowledge gaps in SUWA-related activities where there is need for further research.

Table of Contents

1. Introduction

The workshop was opened with welcoming words by **Ms Noemi Soto** (Executive Director, IPES) and **Mr Luis Marka** (Director General of Deputy Ministry of Water Resources and Irrigation, Bolivia). An opening speech was delivered by **Prof. Dr Hiroshan Hettiarachchi** (UNU-FLORES). At the end of his talk, he also briefly explained the objectives, format, and content of the event. **Dr Birguy Lamizana** (UN Environment) gave a presentation on the history of the safe use of wastewater in agriculture (SUWA) efforts citing examples and accomplishments.

In the subsequent sessions following the introductory presentations, participants presented "Good practice examples of safe water reuse in agriculture" from their countries, commenting on the respective national status regarding wastewater treatment and its use in agriculture; regulations and implementation of guidelines; technical, institutional, and policy challenges; current steps and approaches of the government related to wastewater management and reuse; and possible solutions to make use of wastewater safer and productive. These case studies were presented in three separate thematic sessions: (1) Success Stories; (2) Health and Environmental Aspects and; (3) Policy and Implementations Issues. In each session, presentations were followed by a discussion on the same theme. The discussions covered a wide spread of different areas, ranging from unsafe practices in some countries to formulation of respective national policies.

In the afternoon of Day 1, all participants were given an opportunity to visit the Huáscar Wastewater Treatment Plant in Lima as the field visit component of the programme.

2. Session 1: SUWA Success Stories

The session began with a few remarks from Prof. Dr Hiroshan Hettiarachchi on the objectives of the workshop. He also emphasised on the importance of involving all stakeholders of wastewater use including policy/decision makers to make the research agenda efficient and meaningful. He also briefly talked about the challenges posed by the technology and financing aspects. The presentations in Session 1 were moderated by **Dr Walter Betancourt** and a few interesting success stories were presented by Dr Olfa Mahjoub, Dr Mohamed Helmy Rady Hussian, Mr Uttam Raj Timilsina, and Prof. Julio Moscoso Cavallini who presented case studies from Tunisia, Egypt, Nepal, and Peru respectively. The following subsections provide a brief introduction to each of them.

2.1 Good Irrigation Practices in the Wastewater Irrigated Area of Ouardanine, Tunisia

***Dr Olfa Mahjoub**, National Research Institute for Rural Engineering, Water and Forestry (INRGREF), Tunisia*

The reuse of treated wastewater (TWW) for irrigation in the Ouardanine area dates back to the 1990s. In the early 2000s, farmers have claimed for the installation of a filtration device at the treatment plant outlet to remove suspended solids. Later, the government constructed a storage basin and installed a battery of filters upstream of the irrigated area. In open fields, the surface irrigation of fruit trees was replaced by drip irrigation to decrease water consumption, on the one hand, and to reduce contact between practitioners, soil, and fruits with TWW, on the other hand. Restricted irrigation is fully respected by growing only crops that are allowed by the regulation, such as fodders and fruit trees. In order to benefit from the nutrients available in TWW, a nursery was established for the production of various kinds of plants that represent a valuable economic benefit.

Despite the substantial progress, farmers are unable to value the nutrient load brought by TWW yet. As for the health aspects, vaccination is assured regularly neither by the public health services nor by farmers themselves. The latter state that they have mastered the situation with no accidental contamination reported. The cessation of irrigation before harvesting is difficult to respect since peach fruits are highly demanding of water in the late growing season. Consequently, an appropriate post-harvest handling of fruits is put in place to protect consumers. The role of the extension services is also sought to improve efficiency.

2.2 Wetlands Technique for Safe Use of Wastewater in Egypt

Dr Mohamed Helmy Rady Hussian*, Water Management Research Institute, Ministry of Water Resources and Irrigation, Egypt*

With the gradual increase of water demand and the limitation of water supply, the feasible solution to meet water requirements in Egypt is through the reuse of different agricultural, municipal, and industrial wastes. The Egyptian irrigation system is considered a closed system, where different water losses return to the drainage system, as well as a mixed system. This led to an increase in pollution in the drainage water, and it makes its reuse a serious problem. Providing sewage service and water treatment were among the main priorities of the government in recent decades. However, due to the economic challenges, the service did not catch up with rapid population growth. Therefore, it is important to find alternative solutions to mitigate the pollution problem that are economically and technically feasible.

Constructed wetlands constitute a promising technique to face the problem. The technique was applied in Egypt on a large scale in northern lakes and on a small scale in some secondary drains (in-stream wetland). The pilot projects showed very promising removal efficiency for different pollution elements. In-stream wetland does not require additional areas, and as a simple and cheap technique, it could be applied in parallel at different sites, by incorporating non-governmental organisations, with a suitable dissemination and capacity programme, which could result in considerable progress in improving water quality, and help to make the use of wastewater safe.

2.3 Community-Based Wastewater Management System in Peri-Urban Areas of Kathmandu Valley, Nepal

***Mr Uttam Raj Timilsina**, Agriculture and Forestry University, Nepal*

This case attempts to present the trend of wastewater production, management, and use at the community level in the Kathmandu Valley (Kathmandu Lalitpur and Bhaktapur), Nepal. It also presents the current state of policy, technology, and management practices and the institutional arrangements in addressing the development and management of infrastructure and services on wastewater management and the environmental, health, and livelihood consequences emerging from wastewater production and use in peri-urban areas of the Kathmandu Valley. Specific attention has been paid to the agricultural use of wastewater, the impacts on the agricultural production environment, and the people using wastewater in the production of seasonal vegetables and crops.

In presenting the use of wastewater in agriculture, attention has been paid to the existing practices of wastewater use in agriculture by the people of the Khokana community as a successful case study. The case ends with an analysis of the state of knowledge gap in the country relating to the safe use of wastewater and an assessment of the capacity building needs of the relevant institutions concerned with the management and use of wastewater.

The analyses in the case show that the management of wastewater in the country is driven by the notion of wastewater as an 'environmental nuisance' rather than a 'resource' with the potential for safe application in agriculture and non-agricultural uses. This notion is shown to be driven by the prevalence of sectoral and disciplinary approaches in water sector development. The water sector policy environment in the country, legislation, and regulatory provisions, in general, is found to favour the promotion of safe wastewater use while gaps are identified in institutional arrangements and at the implementation level. The gap in the implementation level is noted in terms of separation in the use of wastewater from the design, development, and management of wastewater system and services. The opportunity, however, lies in considering wastewater as a resource and promoting the safe use of wastewater as a means of ensuring and adding to agricultural water security at the local level. The knowledge system in the country and research and development on the wastewater system, practices, and safe use are found to be largely deficient.

2.4 Use of Reservoirs to Improve Irrigation Water Quality in Lima, Peru

Prof. Julio Moscoso, *National University of Agriculture, Peru*

Due to the discharge of untreated domestic wastewater into rivers and the increasing scarcity of water, the use of contaminated water is a reality that urban and peri-urban farmers in areas close to big cities have to take into account. This vicious circle is closed by offering these cities contaminated food that causes serious health problems to the poorest and therefore most vulnerable population. Efforts to achieve the Millennium Development Goals of reducing by 50 per cent the number of people without a supply of safe water and appropriate sanitation by 2015 could increase the problem described above if the treatment of wastewater does not go hand in hand with all these efforts. Meanwhile, there is a need to seek immediate alternatives that reduce the contamination of water used for irrigating agricultural products such as vegetables.

Against this background, the International Potato Centre (CIP) Urban Harvest Programme evaluated the quality of water in the basin of the river Rímac to quantify impacts on irrigation water, soil, and vegetables and to assess a reservoir-based treatment system to improve the quality of water and vegetables produced in the area. Studies carried out between 2005 and 2007 confirmed that irrigation water in this important agricultural area is strongly contaminated with parasites and faecal coliforms. The concentration of faecal coliforms is more than 5,000 times higher than the permitted limits for water used to irrigate vegetables. As a result, more than 30 per cent of these vegetables are not fit for consumption.

2.5 General Discussion on Success Stories of Safe Use of Wastewater in Agriculture

The presentations on SUWA Success Stories were followed by general discussion moderated by **Dr Olfa Mahjoub**. She thanked the speakers for sharing their knowledge through interesting presentations and then opened the floor for discussion by putting forward the following questions:

1. What are actions communities should take to improve the quality of the wastewater they use?
2. What do you see as the most important aspects that helped the communities in the success stories to achieve success? Can the lessons learned be implemented elsewhere?
3. How can we deal with health risks and what are the most critical aspects of them?

The above questions helped the audience put together their thought process and sparked a healthy discussion. The following is a summary of some selected viewpoints/reactions:

Teófilo Monteiro *(PAHO) congratulated the organisations who believe that water treatment is a key issue in sustainable development. To address water shortage issues with wastewater reuse, it is absolutely necessary to improve the levels of treatment of wastewater. At the same time, it is also important to use the treated water as throwing treated water away is a waste.*

Regarding the second and third questions, it is important to discuss the risks, as there are many risks associated with the treatment of sewage and reuse. The development of strategies to channel risks is a global strategy; in Peru it has accomplished the Sanitation Safety Plan, which analyses the risks associated with the treatment and reuse of wastewater. This is the way: the use of treated wastewater in agriculture is a positive way.

Claudia Campos *(Colombia) was of the opinion that there is an issue that should be taken into consideration. It is the microbiological studies. Although there is a risk of soil salinisation because of reuse, the most important risk is the risk to health. Would we take risk studies as in the 2006 WHO document, in which the analysis of very difficult species is hard to analyse in the developing countries, in general? Then we have to define which kind of monitoring mechanism is to be recommended. We can measure to see if they are within the permissible concentrations. It is true that following the WHO recommendations is great when you have well-managed treatment systems. Unfortunately, in many countries there are no well-managed treatment systems. Then the question would be: what is the quality we have and how much can we control?*

Mónica Saavedra *(Perú) highlighted the value of wastewater reuse. In Peru there is a specific regulatory framework regarding authorisations for reuse of wastewater for irrigation of parks and gardens, agriculture, and aquaculture. Reuse is a procedure that has to be authorised and controlled, and the risk factors should be considered. Rivers are being polluted by uncontrolled discharge. Therefore, the intervention by ANA (National Water Authority) on monitoring and controlling the discharge is important. PAHO promoted Sanitation Safety Plans that allow a complete mapping from source to actual usage, which allows for discerning the most appropriate technology and lower the cost of treatment. We want to see, from these successful experiences, what improvements can be made in the regulatory framework of the government.*

Carlos Madera (Colombia) stated that there are several things that can be done. One is to work hand-in-hand with farmers as the experience in the case study from Nepal. The small-scale farmers usually adapt easily to the situations that arise, and then continue business as usual. Secondly, we have a problem from the microbiological aspects. Many countries have standards. WHO has guidelines since 1989, PAHO has them since 1985. The real issue is how to enforce, especially with the small-scale farmers as explained before. Large-scale farmers may be able to fulfil strict regulations; but not the small-scale farmers. We need all actors to unite to combat these pollutants.

We are seeing the analysis with new eyes, especially the pollutants, and although our countries have regulations for water treatment, there is no regulation for contaminants. We should not focus only on technology; we have to review what can be done, for example, in the food chain, this process should involve all stakeholders.

Julio Moscoso (Peru) agreed that they are on the same path; the ideal solution is to treat all wastewater to stop polluting water bodies with untreated wastewater. On the other hand, the use of untreated wastewater constitutes a risk; we need to get to some point in the middle, so we must formalise the use of treated wastewater. Therefore the use of multiple barriers makes sense. One way is to change crops, i.e. a barrier may be crop restriction. The WHO Guidelines are not used mainly because they are in English, but it is also difficult to translate them into rules or regulations. That is why it is important to know the risks and their assessment.

Juan Carlos Rocha (Bolivia) believes that the most important things are to have rules, look for feasible and viable treatments, the use of guidelines, and the implementation of these guidelines. The methods of implementing standards do not translate properly, but we can try to simplify regulations or guidelines. On the continent there are many experiences of wastewater treatment at all levels, many of which meet the regulations, but the regulations in his countries are stricter. There are good examples such as Mexico, who can show us the best trends that can be used. Combined with the PAHO/WHO guidelines, we can succeed.

Sergio Rolim (Brazil) said that one of the bad things they do is to copy norms and standards of other countries that are difficult to reach and problems are generated. Regulation must be developed step by step; mandatory reductions are very expensive to implement. For example, for the biological oxygen demand (BOD), there are different parameters you can define according to the site. We must try to whittle on a reasonable basis. In addition, the culture of each country is different; in Brazil the State directs treatment companies, they do not consider reuse and water and soil are being contaminated with wastewater.

María Cicchiti (Argentina) said that it is important to share knowledge. In Mendoza, Argentina, there is agricultural reuse, there is regulation, inspections of wastewater treatment plants are done; but controls and measures are not enforced and must be improved. We must differentiate the use of waters of different qualities, also good experiences for the specific use in specific crops. The population receives very well, the fact that they have to pay for treated wastewater; there is good awareness of the use and payment for use. We must continue studying the rules, the impact on aquifers that may result from wastewater irrigation.

3. Session 2: Health and Environmental Aspects of SUWA

Oral presentations in Session 2 were moderated by **Dr Walter Betancourt**. Case studies from Mexico, Peru, Brazil, and Colombia covering various aspects of health and environmental issues were presented in this session. The case study from Mexico presented by Prof. Christina Siebe captured the attention of all as the wastewater irrigation in Mexico has a history that dates back to the late 1800. Prof. Rosa Miglio from Peru presented the monitoring results obtained and challenges observed during the implementation of a wastewater-related project in Lima. Then Mr Mauro Roberto Felizatto from Brazil and Dr Carlos Arturo Madera Parra from Colombia continued with bringing more health and environmental related issues into consideration during their talks. A brief summary of each talk and also the discussion that took place at the end of the session are presented in the next few subsections.

3.1 Environmental Effects of More than 100 Years of Irrigation with Mexico City's Wastewater in the Mezquital Valley

***Prof. Christina Siebe**, National Autonomous University of Mexico, Mexico*

The Mezquital Valley is a unique example of wastewater reuse due to its size (90,000 ha) and temporality (more than 100 years). In this region much data have been collected by several research groups. The aim of this case is to summarise the main lessons learned. The Soil-Aquifer-Treatment system developed as a consequence of the drainage of the closed basin of Mexico to avoid flooding in Mexico City. It has grown in response to the increase of the city's population and wastewater discharge volumes.

Wastewater is a valuable resource in the semi-arid region north of Mexico City and its reuse enables the production of mainly fodder crops and maize, thus achieving above average yields. We investigated the effects of wastewater irrigation by sampling fields irrigated for different lengths of time, and by repeatedly monitoring single irrigation events. Results confirm that wastewater irrigation leads to a groundwater recharge of 25 m^3s^{-1} (2.16 Mm day^{-1}). Although average maize productivity has increased from 2 t ha^{-1} under rain-fed agriculture to 10 t ha^{-1}, excess nitrogen is applied to the fields and leached as nitrate (up to 108 kg ha^{-1} under maize) or emitted as nitrous oxide (up to 0.34 mg N m^{-2} $hour^{-1}$ in maize fields). Heavy metals accumulate in the first 20 cm of the soil; however their availability to plants is small due to the alkaline pH values and the medium to large soil organic matter contents. Also pharmaceutical compounds accumulate

in the top-soil, and an increase in the presence of antibiotic resistance genes was observed. Furthermore, an epidemiological study was conducted in this area in the 1990s, which indicated a larger prevalence of helminth infections among children in the irrigated area compared with a nearby area under rain-fed agriculture.

Until 2015, only untreated wastewater was applied to the fields, but in 2016 a large wastewater treatment plant will start to operate. We will therefore be able to monitor the changes in wastewater, soil, and crop quality and to evaluate the treatment performance and its effects on public health and environmental processes. Our experimental set-up and the archiving of samples make it possible to investigate the long-term effects of wastewater.

3.2 Water-Sensitive Urban Design for Metropolitan Lima, Peru

***Prof. Rosa Miglio**, National University of Agriculture, Peru*

The Peruvian capital, Metropolitan Lima, with over 9 million inhabitants located in the desert of the Pacific coast is characterised by inequalities in access to basic services such as drinking water and wastewater treatment as well as access to healthy green areas. Lima is one of the Latin American cities with the amount of least green areas per inhabitant (Economist Intelligence Unit 2010). Many public and private green areas in Lima are irrigated either with scarce potable water or with polluted surface water, while the reuse of wastewater remained as low as 10% in 2011 (Kosow *et al*. 2013).

Within the research project LiWa (Lima Water) the Lima Ecological Infrastructure Strategy (LEIS) was developed. Its aim is to integrate landscape and urban planning and design with water management in order to support the urban water cycle – including the reuse of wastewater – and to increase access to public green spaces that perform ecosystem services for the benefit of the communities. At a technical level the use of constructed wetlands appears to be one possible water-sensitive urban design strategy for a dry region such as Lima. They generate green areas by themselves and therefore have a high potential to be integrated in open space design.

In 2013 the "Wastewater Treatment Park – Children's Park", located in the San Martin de Porres district, was built as a recreational area with a vertical constructed wetland treating water from a polluted irrigation channel. The wastewater treatment plant was designed by Akut Peru, and included pre-treatment with bars and settler, and a vertical flow constructed wetland; the plant treats 5.57 $m3d^{-1}$ in an area of 50 m^2 resulting in a hydraulic loading of about 0.11 $m^3m^{-2}d^{-1}$. The polluted water has a variable BOD5 and turbidity with peaks of 15.4 mg/L and 1000 NTU

respectively. Faecal coliforms vary over a wide range from 3x102 to 104 CFU/100 ml; and parasites (Ascaris toxocara) were present.

The National Agrarian University La Molina (UNALM)-Lima conducted monitoring of water quality and social acceptance; the water quality monitoring shows that the water quality after the treatment process is significantly improved, reducing health risks to users of the park and reducing negative environmental aspects such as smell and the presence of vectors of waterborne diseases.

This case described the project, presented the monitoring results, discussed the constraints and challenges of such a concept, and shared the participative approach taken to co-design a water-sensitive urban design project which can create socio-environmental awareness to overcome negative conditions over contested peri-urban areas.

3.3 Water Reuse for Landscape Irrigation and Toilet Flushing in Brasilia, Brazil

***Mr Mauro Roberto Felizatto**, Sanitation Company of the Federal District of Brasilia, Brazil*

The presentation covered a case study of a water reuse project in Brasilia/Brazil, assessing its operational results and economic outcomes. The water reuse experiment took place over 11 years (20002011) at the Wastewater Treatment Plant (WWTP) of the Sarah Hospital Rehabilitation Centre (CAGIF) on the shore of Lake Paranoa. The results achieved by CAGIF: effluent concentrations were able to meet the more stringent standard for water reuse in landscaping irrigation and toilet flushing according to American and Brazilian guidelines, with the exception of the TSS variable, with average effluent concentrations of 7 mg/L, 15 mg/L, 8 mg/L, 0.12 mg/L, and 5.9 mg/L, for BOD5, COD, TSS, TP, and TN, respectively. Regarding microbiological variables such as Total Coliforms and Faecal Coliforms, the final effluent results were always "not detectable". The economic outcomes demonstrate the feasibility of the project over a period of 20 years.

3.4 Productivity of Sugarcane Irrigated with Effluent from the Cañaveralejo Wastewater Treatment Plant, Cali, Colombia

***Dr Carlos Madera Parra**, University of Valle, Colombia*

In Valle del Cauca, southwest Colombia, surface and groundwater is used for sugarcane irrigation at a rate of 100m^3/ton of sugar produced. Preliminary experiments were carried out to determine the effect of irrigation with effluent from the Cañaveralejo primary wastewater treatment plant (PTAR-C) in Cali on the sugarcane (variety CC-8592) yield. Irrigation was applied for one year on a 0.36 ha plot. Two water sources were used: effluent from PTAR-C and groundwater (GW). A random block experiment was conducted to test the effect of irrigation water quality on growth, productivity, and sugar production of the crop.

Results showed that the effluent meets the water quality standards for agricultural use (Ayers and Westcot 1985). In addition, according to the United States Department of Agriculture (USDA) (1954) both kinds of irrigation water were classified as C2S1. Crop growth behaved similar to that expected for the region and variety studied. Productivity variables were slightly above the expected values (145 t/ha sugar cane, 16.9% saccharose, 17.6% Brix grades). We did not find differences among plots irrigated with both water sources. Therefore, it can be concluded that the reuse of effluent for irrigation is viable for crop productivity, but other aspects like soil sodicity indicators must be further investigated.

3.5 Managed Aquifer Recharge Systems for Natural and Sustainable Wastewater Reclamation and Reuse Technology: Health Concerns Associated with Human Viruses

***Dr Walter Betancourt**, University of Arizona, United States*

Managed aquifer recharge (MAR) systems, such as riverbank filtration and soil-aquifer treatment, involve the use of natural subsurface systems to improve the quality of recharged water (i.e., surface water, storm water, reclaimed water) before reuse (e.g., planned potable reuse). During MAR, water is either infiltrated via basins, subsurface injected or abstracted from wells adjacent to rivers. MAR systems represent an attractive option for augmenting and improving groundwater quality as well as for environmental management purposes. However, reuse systems designed for applications that involve human contact should include redundant barriers for pathogens that cause waterborne diseases.

This case covered key aspects of a case study on virus removal at three full-scale MAR systems located in different regions of the United States (Arizona, Colorado, and California). MAR projects may be economically viable for developing countries; however, sustainable management is relevant to successfully maintain the attributes necessary for potable and non-potable water reuse.

3.6 General Discussion on Health and Environmental Aspects

Dr Birguy Lamizana moderated the discussion on the health and environmental aspects of SUWA. She started the first part of the discussion by giving a brief introduction to the green methods of wastewater treatments such as wetlands used in some countries such as Peru. She also put forward the discussion points relating SUWA to water quality, social aspects, benefits and risks, and asked how the balance can be maintained for implementing technologies in different countries/contexts.

The discussion carried forward the highlights from Session 1 of moving towards risk assessment to get better risk management options with most importantly the communication of risks. Agreeing with the point made by Prof. Rosa Miglio,sites for communication of risks associated stood out to be one of the most important aspects. Some of the interesting points made by the attendees on this topic are presented below.

Christina Siebe *(Mexico) began with an important point that the soils in Mezquital Valley in Mexico act as a very good filter and buffer zone. But one cannot expect the same in all other places where SUWA is practised. According to her research findings, knowing the system is very important. With the term system here she refers to the whole land-use system. Therefore, social as well as economic aspects of the whole system should be taken into consideration, i.e., how the system works and how it can be managed. She added that we can manage use of untreated wastewater in irrigation only if we understand the system properly. So it is necessary to have a research linked before making a decision.*

Carrying forward from Session 1, she stated that to better manage the risks we should move towards risk assessment combined with the communication of risks. In Mezquital Valley, they are moving towards use of treated wastewater by introducing plans/research on the ground, which has scared the local people. Farmers have set up committees to reject the use of treated wastewater for irrigation purposes because they think it is not only a loss of nutrients but also a loss of money to pay for treatment and fertiliser. Farmers think that they are resistant to diseases and do not need any treated wastewater.

Carlos Pailles *(Mexico) took the opportunity to bring into consideration the unaddressed issues, starting with integrated management, i.e., considering different aspects simultaneously. He gave an example that the main area occupied by the population in Mezquital has the highest percentage of cancer in the world according to WHO. The reason for this is the improper management of wastewater in irrigation for over a hundred years.*

In this area, the main food is lamb/cattle and about 90% of these animals drink wastewater. While on a visit to a slaughterhouse he noticed the black and swollen livers of the lambs caused by wastewater. The government has considered stopping local cattle slaughtering and started importing cattle. But that is not a solution as when they tried to build a treatment plant for water reuse the wastewater was diverted by local people for their cattle to drink. The social status is negative. By making this point he concluded that indeed it is good for universities and research centres to go further for new findings but there should be public-private partnership for social improvement and for bringing research to the ground and implementing them.

Olfa Mahjoub *(Tunisia) talked about communicating with farmers as they are reluctant to face changes and that is obvious because they are the ones who would suffer if things go wrong. Connecting farmers with different stakeholders is important. She explained how the farmers in Tunisia have set up an association, which helps in capacity building, communicating, and taking the lead in solving the problems. She also said that there is a need for brainstorming and inputs from the bottom are needed for decision makers to facilitate positive outcomes.*

4. Session 3: Policy and Implementation Issues Related to SUWA

Policy and implementation issues were taken into consideration and discussed in Session 3 moderated by **Prof. Claudia Campos**. The presenters were Mr Taziva Gomo, Mr Juan Carlos Rocha, Mr Carlos Paillés, Mr Carlos Foresi, and Mr Luis Marka covering case studies from South Africa, Bolivia, Peru, Mexico, and Argentina, and Bolivia respectively. The presentations clearly demonstrated the importance of the governmental role in the implementation of technology and policies. The success of the projects was not only due to technical applications but also due to better communication, capacity building, and the good monitoring systems. A brief introduction to each case study is provided below followed by a summary of the general discussion that took place after the presentations.

4.1 Government Supported Farmers Utilising Wastewater in Irrigation

Mr Taziva Gomo*, Limpopo Department of Agriculture, South Africa*

In the face of dwindling fresh water resources, wastewater has been used to enhance food production through irrigation. Governments across the world have developed and implemented policies that promote the safe reuse of wastewater, but in developing countries, the lack of resources has hindered the implementation of these policies. In South Africa, the government has provided for the safe discharge of effluent into water sources (National Water Act 36 of 1998) and has also published guidelines and policies that support the reuse of wastewater in irrigation (Government Gazette 36820, Notice 665, September 6, 2013).

This study, which is still in progress, is assessing the effort of the South African government through its various departments in promoting the safe reuse of wastewater along the Chuenes River. The Lebowakgomo WWTP deposits treated wastewater into the Chuenes River. Three farmers along the Chuenes River who have received assistance from government departments have so far been included in this study. The preliminary results show the sewerage treatment plant is operating at 200% of its capacity and does not test the quality of the water released into the river. The farmers are not registered to use the wastewater as required by law and the community does not support the farmers that want to use the wastewater. There is legislation that governs the reuse of wastewater but it is not being enforced.

4.2 Challenges within the Implementation of Water Reuse Policy for Irrigation in Bolivia

***Mr Juan Carlos Rocha**, University of San Simon, Bolivia*

This study is based on the work sponsored by PROAGUAS-COTRIMEX to establish regulations for the reuse of treated wastewater. The presentation covered the stages of studying laws and regulations in force, the control parameters proposal, the relationship with World Health Organization (WHO) guidelines, and the sustainability of applying the regulations via the implementation of subsidies to the irrigation system as a whole. Reference was made to the difficulties encountered at all the stages mentioned and the proposals that have been made to overcome them and reach the stage of formulating the regulations.

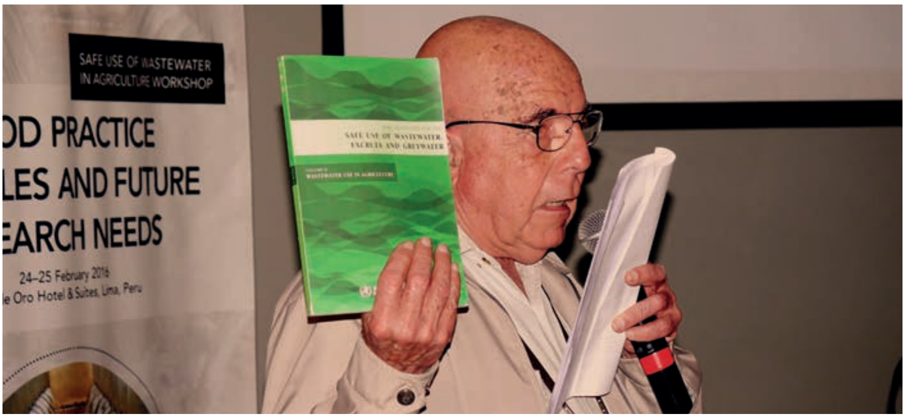
4.3 Council for Certification of Irrigation with Treated Water in Mexico

***Mr Carlos Paillés**, Environmental Trust Fund of Hidalgo, Mexico*

The development of wastewater treatment plants for agricultural irrigation in Mexico and Latin America has taken a long road, starting in Belem, Brazil, in 1999. Implementing more than 30 of them as pilot projects in the states of Oaxaca, Puebla, and Hidalgo, with demonstrative irrigation parcels has not been enough to create replications by the local water and agricultural organisations. The culture of water in the country does not include the importance of the treatment of wastewater.

By 1950 less than 10% of wastewater was treated. By 2000 this percentage had not reached 25%. The concept of the reuse of such water is extremely limited, including Engineering, Agriculture, and Economic Schools. In communities where the pilot projects were implemented, less than 1% of the people, including teachers and government officers, knew about the Safe Use of Wastewater in Agriculture (SUWA).

At the same time, thousands of hectares of agricultural land were irrigated with untreated wastewater with some kind of participation by national and local governments. Prohibition by itself has never worked in the world. In the last 15 years, the Certification of Competences in Mexico has been accepted by workers, farmers, corporations, labour unions, and government agencies as a good instrument to qualify persons in charge of specific activities. The establishment of the Council for the Certification of Irrigation with Treated Water in Mexico intends to promote the day-to-day, person-to-person, acceptance of SUWA objectives.



4.4 Wastewater Reuse in Mendoza Province, Argentina

***Mr Carlos Foresi**, General Department of Irrigation, Mendoza, Argentina*

In Mendoza Province, Argentina, treated wastewater has been reused in agriculture for more than five decades. Factors driving the demand for this resource for irrigation in this region are the infrequent rainfall and aridity typical of a desert.

Situated in central-western Argentina, in the foothills of the Andes, Mendoza records an average annual rainfall ranging from 200 mm to 250 mm depending on the latitude. All human activity and production is concentrated on just 3.5 per cent of its surface area, which covers 148,827 km^2, and around four manmade oases that exploit water from the region's rivers. There is a total of more than 500,000 cultivated hectares where intensive agriculture takes place, the main crop being grapes for wine-making, followed by olive trees, stone and seed fruit, vegetables, forestry, and fodder.

In this context, water resources are in high demand from farmers, especially considering that treated wastewater comes with guarantees regarding quality control and the way it is used, to safeguard against unwanted effects on the soil or crops. Moreover, with this practice the water is treated in effluent purification plants and nutrients are added to the soil, bringing an economic advantage which takes on greater significance in an arid area.

However, what is needed in order to optimise this are the necessary conditions and expertise to maintain the soil's fertility (organic, mineral, and hydrogeological conditions) and to obtain products that meet the health and hygiene standards required by their place of destination, as well as ensuring preservation of the environment, all of which are necessary for wastewater to be used in a controlled manner. To this end, the General Department of Irrigation in 2003 issued Resolution No. 400/03 of the Honourable Administrative Tribunal, establishing mandatory regulations for designated ACREs (Specialised Restricted Cultivation Areas).

A significant percentage of the purification facilities in the province currently provide treated effluents in an ACRE. In terms of surface area, approximately 7,000 ha are irrigated with wastewater in the summer, and consistent with population density, are concentrated mainly on the northern oasis. Eighty-five per cent of this surface area is regularised by law and is managed by its users, with controls from the General Department of Irrigation. What remains is the important task of also regularising winter reuse. In 2006 guidelines and requirements for this are set out in Resolution No. 500/06 of the Honourable Administrative Tribunal.

4.5 Water Reuse for Agricultural Irrigation in Bolivia

***Mr Luis Marka**, Ministry of Environment and Water, Bolivia*

Bolivia has 52.7 per cent basic sanitation coverage, but in many areas there are still no wastewater treatment plants and a large number of the existing ones do not function properly. This results in a potentially major source of pollution. In addition, there are currently no specific regulations for the reuse and management of treated wastewater for agricultural irrigation in place.

The Government of Bolivia is planning and establishing a regulatory framework to solve the problems related to the reuse of wastewater. To date, the only policies present are the Framework Law of the Mother Earth and Comprehensive Development for Living Well which defines guidelines for the treatment of water for extractive purposes, and the Economic and Social Development Plan (PDES) which outlines plans to refurbish and improve wastewater treatment plants with a focus on wastewater reuse.

Since 2009 the Joint Commission has promoted a series of activities aiming at capacity building programmes in Bolivia to define strategies and approaches to the problem of the reuse of treated wastewater for irrigation. These strategies will serve as a guide in developing a programme for the reuse of wastewater for irrigation in Bolivia within the framework of sustainable water management.

4.6 General Discussion on Policy and Implementation Issues

During this final discussion session, the moderator Mr Carlos Paillés straightaway took the opportunity to bring into consideration the unaddressed issues, starting with integrated management, i.e., considering different aspects in one management model. Also, he added that, while it is good for universities and research centres to go further for new findings, there should be public-private partnership for social advancement and bringing research to the ground and implementing them. Prof. Hiroshan Hettiarachchi, Dr Birguy Lamizana, and Ms Natalia Jiménez also brought up key points on the importance of community engagement, system improvement, linking farmers and operators, and on being transparent.

Mr Paillés gave the audience an unusual but effective opportunity to express their final comments, strictly in one minute. Here is a summarised version of the responses recorded:

Juan Carlos Rocha *(Bolivia): Use local measures within a risk management frame.*

Luis Grover Marka *(Bolivia): Promote investigation at local levels based on local needs.*

Carmen Quevedo *(Peru): Develop simplified parameters.*

Julián González (Peru): Consider SUWA throughout the full food chain.

Mauro Roberto Felizatto (Brazil): Support SUWA to reach operational levels.

Uttam Raj Timilsina (Nepal): Propose and combine practical measures in the fields.

Luis Salazar Vega (Bolivia): Include SUWA in water balance of each region.

Taviza Gomo (South Africa): Give priority to stakeholder participation in SUWA.

Rosa Miglio (Peru): Produce good practices on treatment within SUWA context.

Natalia Jiménez (Colombia): Gather research needs for local water policies.

Angela Salinas (Bolivia): Refer SUWA practices to different economic models.

Birguy Lamizana (UNEP): Always consider end users and people's participation.

Isabel Cicchitti (Argentina): Share experiences.

Claudia Campos (Colombia): No to overregulation.

Dirk Loose (SUNASS/GIZ): Consider the options to promote treated wastewater in SUWA concepts.

Olfa Mahjoub (Tunisia): Include SUWA in sustainability of water/soil management.

Carlos Madera (Colombia): Create a cyberspace for farmers for SUWA practices.

Walter Betancourt (USA): Start from zero to present SUWA to local farmers.

Christina Siebe (México): Consider different treatment levels and include an epidemiologist.

Carlos Foresi (Argentina): Try a quality seal on produce.

5. Key Conclusions of the Workshop

The key conclusions made during the workshop are listed below in the respective three categories of discussions.

Session 1: SUWA Success Stories

- We need regulations that are not very restrictive but the ones that are able to implement and enforce easily.
- Treatment should not be too sophisticated, leading to cost prohibition and other issues. The level of treatment should be achievable by the community and should be easy to be implemented on a large scale.
- The role of the community and their involvement is very important. It is necessary to involve them in decision-making, so as to become part of the solution.
- Countries that do not have regulations require examples. Learning from the experience of other countries is the simplest way they can do to start solving their problems.
- Involve researchers in solving the problem.
- We must be proactive in controlling pollution in both the upstream and the downstream.

Session 2: Health and Environmental Aspects of SUWA

- Social aspects are also very important aspects which need to be considered together with health and environmental aspects while moving ahead.
- The level of treatment should be decided based on the end use of the treated wastewater.
- There should be a mechanism to link farmers with the wastewater treatment operators.
- Being transparent in the decision-making and implementation is important to win the trust of the communities.
- Community participation and engagement is crucial to the success of any wastewater reuse projects.

Session 3: Policy and Implementation Issues Related to SUWA

- WHO Guidelines: Develop a practical and useful translated document, at "street language" level, oriented to agricultural and sanitary users.
- SUWA practices: Replicate and disseminate the basic concepts of SUWA practices, oriented to the final and real users of treated wastewaters.
- Technologies: Consider them as part of the solution, not as the fundamental subject, as it has been done in the past 90 years.
- Practices and Barriers (WHO): Support and recommend the use of the Integrated Practices and Barriers as it has been done in specific places, locally experimented.
- Risks management: Teach and demonstrate the appropriate assessment of risk management in the different kinds of health (human, vegetable, environmental, animal, etc.).
- Agricultural productivity: Introduce SUWA practices to increase agricultural productivity, both quantitatively and qualitatively.

ANNEX LIST

Appendix 1: The Field Visit

Participants of the workshop visited the Huáscar Wastewater Treatment Plant in Lima, Peru, on the afternoon of Day 1 of the programme. Some memories captured are presented here.


POLO

Appendix 2: Programme Highlights

Day 1: Wednesday February 24, 2016	
8:30-9 :00	Registration
9:00-15:00	**Welcome Session** Welcome speeches Introduction to the workshop (Hiroshan Hettiarachchi) SUWA history (Birguy Lamizana)
10:15 -10:45	Coffee Break
10:45-11:45	**Session 1 (Presentations): Success Stories** Moderator: Walter Betancourt Presenters: *Olfa Mahjoub, Mohamed Helmy Rady Hussian, Uttamraj Timilsina, Julio Moscoso*
11:45-12:30	**Session 1 (Discussion): Success Stories** Moderator: Olfa Mahjoub
12:30-14:00	Lunch Break
14:00-18:00	**Field Visit** Huascar wastewater treatment plant (managed by SEDAPAL) Parque zonal Huascar (managed by SERPAR)
19:30-21:30	Welcome dinner at Señorio de Sulco Restaurant
Day 2: Thursday February 25, 2016	
9:00-10:30	**Session 2 (Presentations): Health & Environmental Aspects** Moderator: Luis Marka Presenters: *Christina Siebe, Rosa Miglio, Mauro Roberto Felizatto, Carlos Madera Parra, Walter Betancourt*
10:30-11:00	Coffee Break
11:00-12:30	**Session 2 (Discussion): Health & Environmental Aspects** Moderator: Birguy Lamizana
12:30-14:00	Lunch Break
14:00-15:30	**Session 3 (Presentations): Policy & Implementation Issues** Moderator: Claudia Campos Presenters: *Taziva Gomo, Juan Carlos Rocha, Carlos Paillés, Carlos Foresi, Luis Marka*
15:30-16:00	Coffee Break
16:00-17:30	**Session 3 (Discussion): Policy & Implementation Issues** Moderator: Carlos Pailles
17:30-18:00	**Closing**

Appendix 3: List of Participants

Ana Mónica Maria Vargas Suarez
Director of Social Property and Soil Management, Ministry of Agriculture, Colombia

Angela Salinas Villafañe
Consultant, Ministry of Environment and Water, Bolivia

Birguy Lamizana
Programme Officer, United Nations Environment Programme (UN Environment), Kenya

Carlos Foresi
Head of the Mendoza Water Resources Department, Argentina

Carlos Madera
Assistant Professor, University of Valle, Cali, Colombia

Carlos Paillés
Director of Environmental Infrastructure Trust, Valle Hidalgo, Mexico

Christina Siebe
Senior Researcher, Institute of Geology, National Autonomous University of Mexico

David Luis Salazar Vega
Director of Planning and Integrated Water Management, Government of Cochabamba, Bolivia

Dirk Loose
Advisor to the SUNASS (The National Superintendence of Services and Sanitation) supported by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), Peru

Francisco Quezada
Chief of the Wastewater Treatment Plants, Water and Sanitation Service Utility of Lima (SEDAPAL), Peru

Hiroshan Hettiarachchi
Head of Waste Management Unit, United Nations University (UNU-FLORES), Germany

Jorge Arroyo
President, IPES – Promoción del Desarrollo Sostenible, Peru

Juan Carlos Rocha
Lecturer, San Simon University, Bolivia

Julio Moscoso
Professor and Regional Consultant for Domestic Wastewater Management, National University of Agriculture, Peru

Julián González
Management Consultant, Program for Modernization and Strengthening the Water Sector and Sanitation (PROAGUA II), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Peru

Luis Briceño
Coordinator of Environmental Projects, IPES – Promoción del Desarrollo Sostenible, Peru

Luis Marka
Director General of Irrigation, Deputy Ministry of Water Resources and Irrigation (Ministry of Environment and Water), Bolivia

María Claudia Campos Pinilla
Professor, Pontifical Xavierian University, Colombia

María del Carmen Quevedo Caiña
Department of Environmental Quality, Ministry of Environment, Peru

María Isabel Cicchitti Leániz
Director of Water Quality Control, General Department of Irrigation, Mendoza, Argentina

Mauro Roberto Felizatto
Sanitary Engineer, Sanitation Company of the Federal District of Brasilia, Brazil

Mohamed Helmy Rady Hussian
Secretary General, Water Management Research Institute, National Water Research Center, Egypt

Natalia Jiménez
Environmental Engineer, Department of Integrated Water Resource Management, Colombia

Noemi Soto
Executive Director, IPES – Promoción del Desarrollo Sostenible, Peru

Olfa Mahjoub
Researcher in Water Quality and Reuse, National Research Institute for Rural Engineering Water and Forestry (INRGREF), Tunisia

Rosa Miglio
Professor, National University of Agriculture, Peru

Rosario Luz Cabrera
Department of Environmental Quality, Ministry of Environment, Peru

Saavedra Chumbe Mónica Patricia
Director, Department of Environmental Health (DIGESA), Peru

Sérgio Rolim Mendonça
Chairman of the Paraibana Academy of Engineering, Professor Emeritus of the Federal University of Paraíba (UFPB), Brazil

Taziva Gomo
Agricultural Engineer, Mpumalanga Department of Agriculture, South Africa

Téofilo Monteiro
Team Leader – Regional Technical Team on Water and Sanitation (ETRAS), Pan American Health Organization (PAHO), Peru

Uttam Raj Timilsina
Adjunct Professor of Agricultural Engineering, Agriculture and Forestry University (AFU), Nepal

Walter Betancourt
Fulbright Research Scholar, Water & Energy Sustainable Technology (WEST) Center, The University of Arizona, United States

Appendix 4: Case Studies Presented in Absentia

Varamin Project Wastewater Reuse: Success Story from Iran

Mohammad Javad Monem, Associate Professor, Tarbiat Modares University, Tehran, Iran

Limited water resources, increasing water requirements, and competition over water resource consumption in different sectors have become major challenges. Much has been done to find new sources of water. Population growth and urbanisation have produced more wastewater, which could be considered as a new source of water. This source of water is important for agricultural production, which is the greatest water-consuming sector.

In the past, wastewater was used mainly to increase the fertility of the land. Nowadays the main motivation for wastewater reuse is water shortages. Wastewater reuse in agriculture involves several considerations in terms of the quantity and quality of the wastewater. The impact of wastewater reuse on health, the environment, soil, crop and other surface and groundwater resources should be carefully investigated.

Specific monitoring activities should be taken into account, and high standards for wastewater reuse should be implemented. The economic, social, and agricultural evaluations are important aspects which are central to the investigations. Iran is a water-scarce country, urbanisation is increasing, and its population is growing; therefore, the country is planning for more wastewater reuse in agriculture.

The Varamin irrigation project is a successful example of such a plan. The initial wastewater reuse system was established in 1988. Due to the deteriorating conditions of water shortage, a development plan for increasing the capacity of wastewater reuse is underway that will be completed with the collaboration with the private sector. Presently 120 million cubic meters of wastewater are used in the Varamin irrigation network, which will be increased to up to 280 million cubic meters after the completion of the development plan.

Eco-Friendly Wastewater Treatment for Reuse in Agriculture, India

Ravinder Kaur, Project Director, Division of Environmental Sciences, Indian Agricultural Research Institute (IARI), New Delhi, India

Oxidation ponds or activated sludge processes are the two most commonly deployed wastewater treatment technologies in India. However, these processes are expensive and require complex operations and maintenance. In view of these limitations, constructed wetland technology has been receiving greater attention in recent years.

However, the rate of adoption of wetland technology for wastewater treatment in developing countries has been low due to a general belief that these technologies have large land area requirements. Batch-fed wetland systems with shorter hydraulic retention times (HRTs) have generally been found to translate into smaller land requirements and thus appear more acceptable in developing countries.

Keeping this in mind, a batch-fed (<1-day HRT) municipal wastewater treatment plant with vertical subsurface flow wetland technology and a 1,500-LPD capacity was developed at the sewage plot site of the IARI farm. The pilot plant has been in operation since November 2009 and is being continuously monitored for nutrient/heavy metal (pollutant) mass reduction efficiencies.

The long-term average pollutant mass reduction efficiency of the pilot system illustrated its capacity to reduce wastewater turbidity and nitrate, phosphate, and potassium concentrations by up to 81%, 68%, 48% and 47%, respectively. Planted wetland systems, in general, seemed to have an edge over unplanted ones. Nutrient removal efficiencies seemed to be higher for Phragmites karka-based wetland systems. The Typha latifolia-based systems, on the other hand, were observed to be associated with a higher oxidation potential and thus higher sulphate reduction efficiencies (50.51%). These systems also seemed to be associated with significantly higher Ni (62%), Fe (45%), Pb (58%), Co (62%), and Cd (50%) removal efficiencies.

A comparison of the ecological footprint and sustainability of the experimental wetland systems compared with a hypothetic conventional sewage treatment plant (STP) showed that the experimental wetland systems were 1,500 times more sustainable. Based on these experiences, the technology has been recently up-scaled to a 2.2 MLD horizontal subsurface flow system for treating sewage waters in the Krishi Kunj colony adjoining the IARI campus. The up-scaled system has the potential to irrigate 132 ha of land on the IARI farm.

Accumulation of Heavy Metals in Cereal and Legume Crops through Sewage Water Irrigation and Phosphate Fertilisers

Ghulam Murtaza, Associate Professor, Institute of Soil and Environmental Sciences, University of Agriculture, Pakistan

Food crop irrigation with untreated sewage water is an increasingly common practice worldwide as well as in Pakistan, thus requiring management strategies for safe crop production on contaminated soils. In Pakistan, water availability has declined from 1,299 m^3 per capita in 1996-97 to 1,100 m^3 per capita in 2006 and is projected to fall below 700 m^3 per capita by 2025. Therefore, the irrigation of food crops with wastewater has become an important practice.

A field study was conducted to examine the phyto-availability of three heavy metals (cadmium (Cd), copper (Cu), and zinc (Zn)) in two cereal (wheat, maize) and legume (chickpea, mung bean) crops in response to the application of sewage water or phosphatic fertiliser over two successive years. Five fertiliser treatments, i.e., control, recommended nitrogen (N) applied alone and in combination with three levels of phosphorus (P): half, full, and 1.5 times the recommended P designated as N0P0, N1P0, N1P0.5, N1P1.0, and N1P1.5, respectively.

Tissue concentrations of Cd, Cu, Zn, and P were determined in various plant parts (root, straw, and grains). While maximum biomass production was obtained with the application of P at half the recommended dose, the concentrations of heavy metals in crops generally decreased with increasing P levels. Tissue metal concentrations increased with the application of N alone. Translocation and accumulation of Zn and Cu were consistently higher than Cd.

The pattern of Cd accumulation differed among plant species – relatively more Cd being accumulated by dicots than monocots, especially in their grains. The order of Cd accumulation in grains was maize > chickpea > mung bean > wheat. Mung bean and chickpea straws also had higher tissue Cd concentration above permissible limits. The two legume species behaved similarly, while cereal species differed from each other in their Cd accumulation. Metal ion concentrations were markedly higher in roots followed by straw and grains.

Increasing soil-applied P also increased the extractable metal and P concentrations in the post-harvest soil. Despite a considerable addition of metals by P fertiliser, all levels of applied P effectively decreased metal phyto-availability in sewage water-irrigated soils, and applying half of the recommended dose of P fertiliser was the most feasible solution for curtailing plant metal uptake from soils.

These findings may have wide applications for the safer crop production of monocot species when irrigating crops with sewage water containing heavy metals.

UNITED NATIONS UNIVERSITY

UNU-FLORES

The United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) was established in Dresden, Germany in 2012 with the support of the Federal Ministry of Education and Research (BMBF) and the Ministry for Higher Education, Research and the Arts (SMWK) of the Free State of Saxony, Germany. As part of the United Nations University (UNU), the Institute helps build a bridge between the academic world and the United Nations. UNU encompasses 13 research and training institutes and programmes located in 12 countries around the world. UNU as a whole aims to develop sustainable solutions for pressing global problems of human survival and development.

UNU-FLORES develops strategies to resolve pressing challenges in the area of sustainable use and integrated management of environmental resources such as water, soil, and waste. Focusing on the needs of the UN and its Member States, particularly developing countries and emerging economies, the Institute engages in research, capacity development, advanced teaching and training, as well as dissemination of knowledge. In all activities, UNU-FLORES advances a Nexus Approach to the sustainable management of environmental resources.

Find more information at: **flores.unu.edu**

ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE MANAGEMENT OF ENVIRONMENTAL RESOURCES

United Nations University
Institute for Integrated Management of Material Fluxes and of Resources
Ammonstrasse 74, 01067 Dresden, Germany
Tel.: +49 351 8921 9370 | Fax.: +49 351 8921 9389
Email: flores@unu.edu

@unuflores @UNU_FLORES

flores.unu.edu