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Safe reuse of wastewater and biosolids

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SEAS, RIVERS, ISLANDS
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EUROPEAN PARLIAMENT INTERGROUP
Seas, Rivers, Islands & Coastal Areas

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School of Science & Technology

The Evolution of the research work conducted in relation to the wastewater reuse in agriculture during the period 2004-2021 by the research team of the School Sciences and Technology, Hellenic Open University.

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What is wastewater reuse?

Reuse of treated municipal wastewater for agricultural crop irrigation is a practice of waste disposal.

It contributes to minimizing environmental problems which would otherwise be caused by disposing wastewater in surface waters

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Parameters taken into account for safe reuse of TMWW

The following parameters are necessary for effective reuse:

a- Geological

b-Meteorological

c-Geochemical

d-Socioeconomic factors

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Reuse categories

Treated municipal wastewater can be reused for:

a-Irrigation of agricultural crop

b-Irrigation of landscapes and recreational areas

c-Enrichment of ground water

d-Industrial activities

e-Reformation and protection of problem areas

f-Fire extinguishing

g-Various urban uses (street, car, and toilet cleaning, park irrigation, cooling, etc) as the examples given in the following slides

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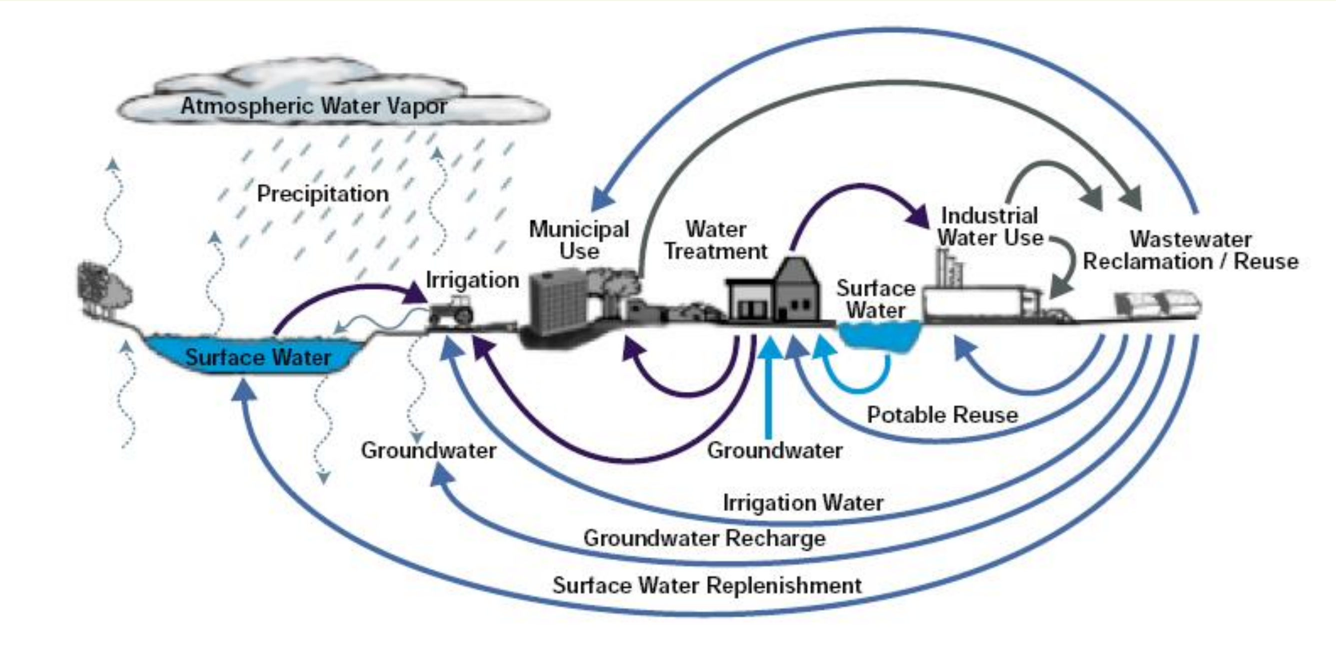
Relation of wastewater reuse to the Hydraulic cycle



The role of engineered treatment, reclamation, and reuse facilities in the multiple uses of water through the hydraulic cycle.

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REUSE

Selection of land area for reuse

The optimal selection of a suitable land area for TMWW reuse should meet the following geochemical and meteorological criteria:

1. Height of annual precipitation
2. Temperature
3. Number, duration and influence of rainfall
4. Evapotranspiration rates
5. Geological and hydrological data such as elevation, topography, slope, ground permeability, water surface collection sites
6. Soil characteristics such as:
   – Mechanical analysis
   – Conductivity, structure, moisture, soil porosity
   – Cation exchange capacity, organic matter, pH, total N & P levels

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REUSE

The wastewater reuse in Greece based on the National Legislation

- According to Greek legislation the wastewater reuse is allowed to be applied only in non food crops

- For the time being the wastewater reuse in Greece is limited and applied only to the non food crops such as cotton, forest nurseries, depleted and decertified soils etc.

- However, **the research work is going on**, studying not only the nonfood crops, but also food plants such as vegetables, and is expected to include field crops and horticultural plantations

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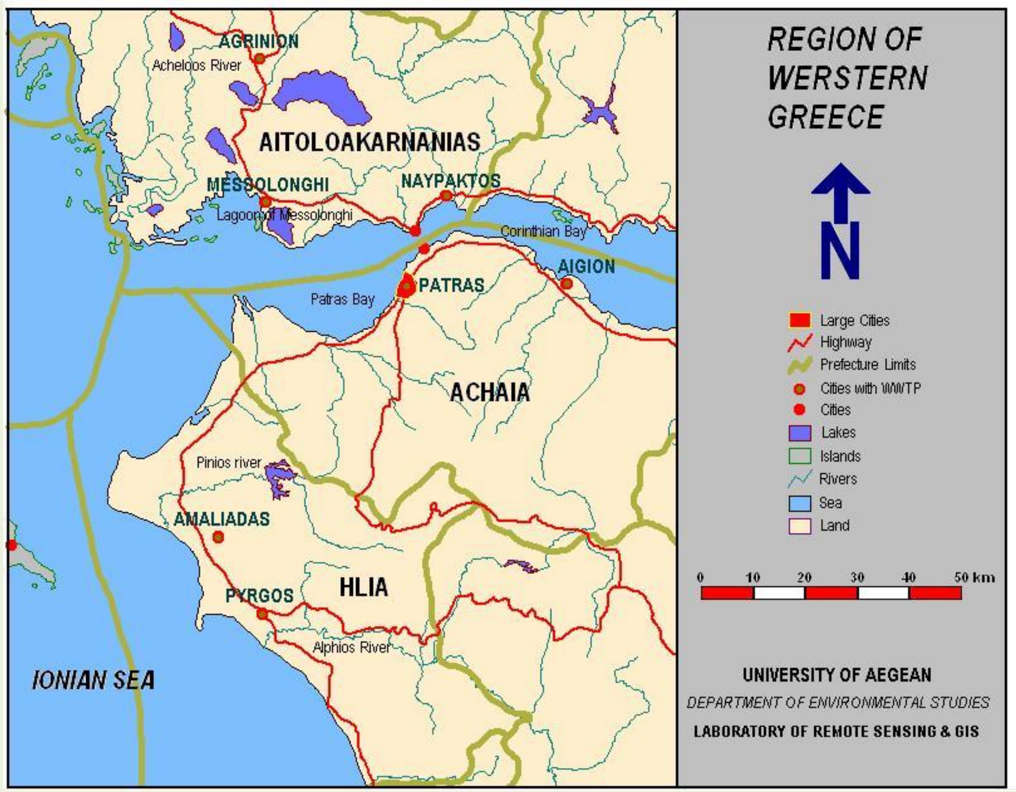
Element		Recommended maximum concentration[a] (mg/l)	Remarks
Li	Lithium	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn[b]	Manganese	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo	Molybdenum	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	Nickel	0.20	Toxic to a number of plants at 0.5–1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd	Lead	5.0	Can inhibit plant cell growth at very high concentrations.
Se	Selenium	0.02	Toxic to plants at concentrations as low as 0.025 mg/l, and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. Essential element to animals, but in very low concentrations.
V	Vanadium	0.10	Toxic to many plants at relatively low concentrations.
Zn[b]	Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH >6.0 and in fine textured or organic soils.

Source: Adapted from Ayers & Westcot (1985); Pescod (1992).

[a] The maximum concentration is based on a water application rate that is consistent with good irrigation practices (5000–10 000 m^3/ha per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3/ha per year. The values given are for water used on a continuous basis at one site.

[b] Synergistic action of Cu and Zn and antagonistic action of Fe and Mn have been reported in certain plants species' absorption and tolerance of metals after wastewater irrigation. If the irrigation water contains high concentrations of Cu and Zn, Cu concentrations in the tissue may increase greatly. In plants irrigated with water containing a high concentration of Mn, Mn uptake in the plants may increase, and, consequently, the concentration of Fe in the plant tissue may be reduced considerably. Generally, metal concentrations in plant tissue increase with concentrations in the irrigation water. Concentrations in the roots are usually higher than in the leaves (Drakatos, Kalavrouziotis & Drakatos, 2000; Drakatos et al., 2002; Kalavrouziotis & Drakotos, 2002).

Wastewater treatment plants of Western Greece



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The scope of research

The scope of the research conducted in the School of Sciences and Technology aims at investigating the problems of wastewater and biosolid effective management, targeting at accumulating relevant scientific data, which along with the experimental results of the international community will be used as a basis for tackling with the various problems related to the wastewater and biosolids exploitation, with the a view to accomplish a real and scientifically based reuse.

More specifically the research will include the following:

a-Study of the treatment methods of wastewater and biosolids

b-Improving the quality of biosolids with physicochemical methods

c-Production of organic fertilizers from prossed biosolids relevant for application to soils for the improvement of their physical and chemical properties

d-Use of wastewater for the fire extinction in urban areas

e-Methods of treated wastewater application in agriculture

f-Processing of wastewater for the production of new products such as biodecomposable bio-plastics

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Computerization of effective reuse of wastewater in agriculture

To accomplish effective reuse of treated wastewater, our research team is working in the preparing of a computer program for the irrigation of agricultural crops and biosolid application in agriculture

The basic purpose of this computer program will be to:

- ✓ supply water to plants
- ✓ supply plant nutrients to crops
- ✓ economize plant nutrients and to decrease the fertilizer cost
- ✓ prevent heavy metal soil pollution, and take necessary measures for the soil protection

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Research conducted during the period of 2004-2021 on the following aspects of wastewater in the School of Science and Technology

1. **Effect of wastewater on growth and development of vegetables** : Allium cepa (onion), Brussels sprouts, Brocolli, Garden red beets, Lettuce, Cabbage, Radish
2. **Transfer factor of heavy metals in vegetables**
3. **Elemental interactions between heavy metals, micro and macronutrients**
4. **Quantification of elemental contribution of interactions**
5. **Heavy metals Soil pollution due toTMWW and biosolid reuse**
6. **Evaluation of the soil pollution by means of the pollution indices**
7. **Calibration of the pollution indices**
8. **Pharmaceuticals in the wastewater and their uptake by plants**.

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Results on Plants heavy metal accumulation

Onion plants accumulated manganese, zinc and copper under the TMWW brussels sprouts accumulated zinc, cobalt, nickel and cadmium under the TMWW.

Copper and zinc increased yield of radish but their accumulation decreased due to the application of zeolite.

Significant accumulation of iron was found in the roots of broccoli and brussel sprouts.

The concentration of cadmium increased significantly in the presence of chloride originating from the disinfection (chlorination) of the wastewater.

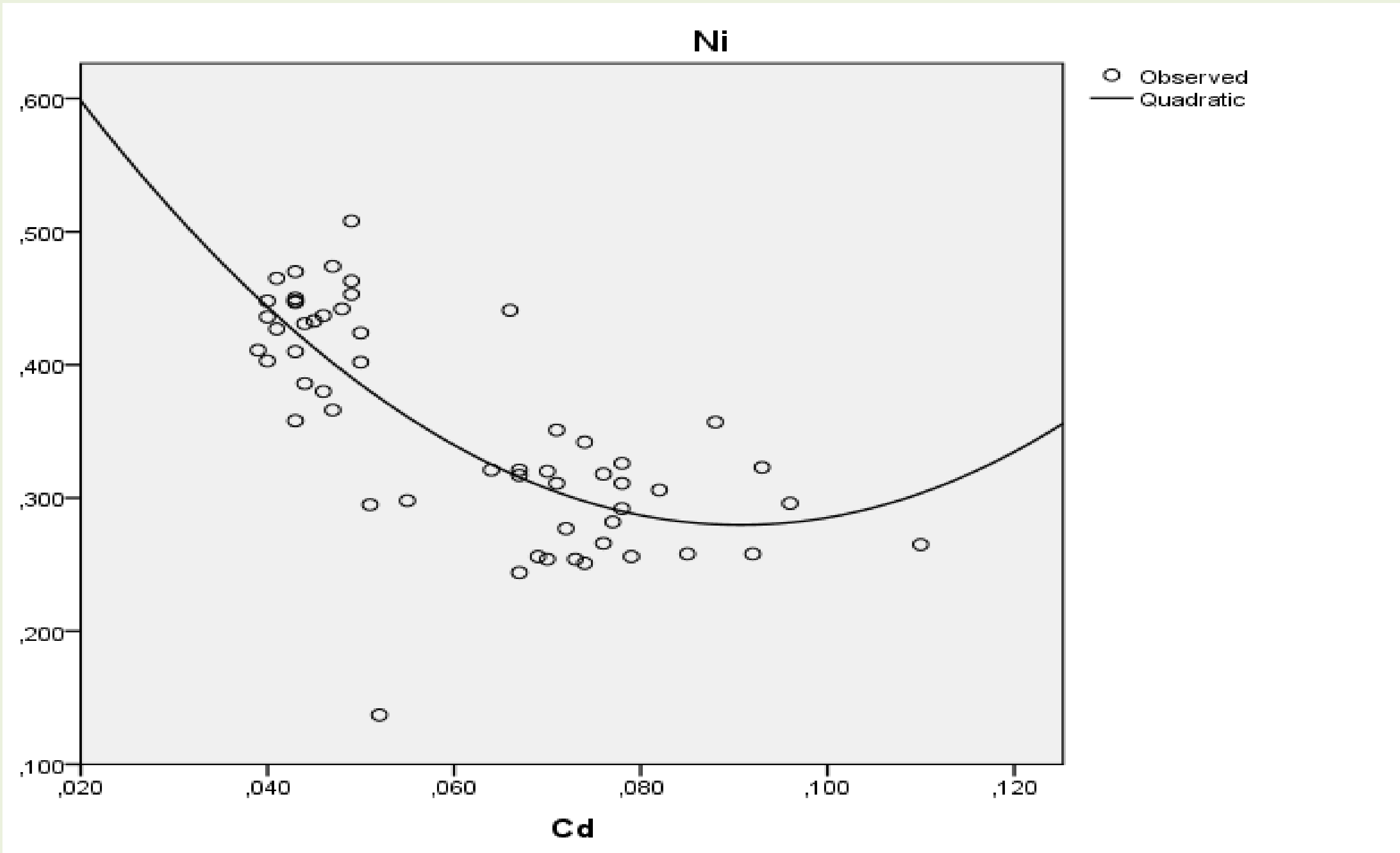
Elemental interactions between heavy metals, macro- and micronutriens and physical and chemical properties of soils in soils

The occurrence of elemental interactions in the soils and plants is an important process which is directly related to soil fertility and productivity.

Consequently, these interactions are directly related to the growth and development of plants because they can either supply nutrients and heavy metals if they are synergistic, or deprive the plants of nutrients to the extent of causing deficiency symptoms and can effectively influence the evolution of the plants.
Hundred of such interactions are taking place in the plants and soils.

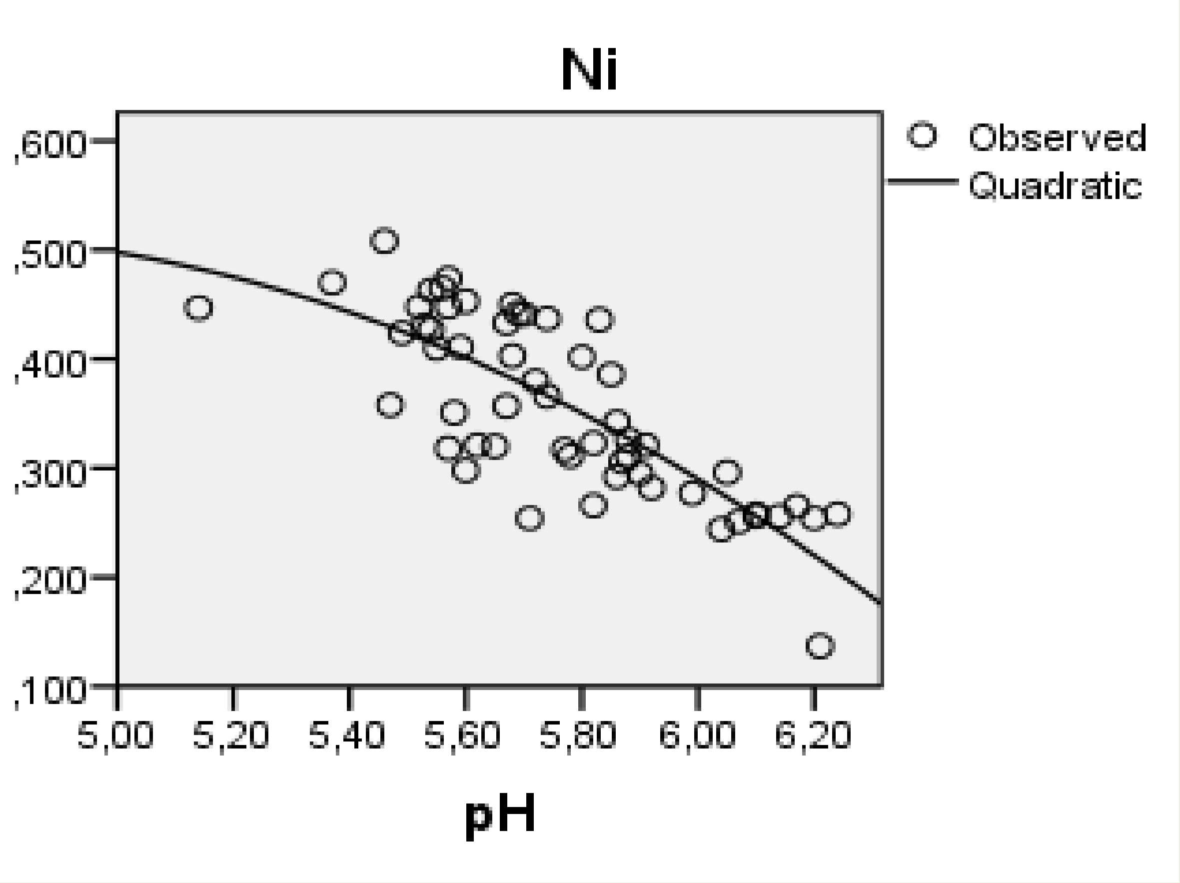
In the following four slides some examples of these interactions are presented.

Antagonistic interaction between Cd and Ni in soils under the effect of sludge



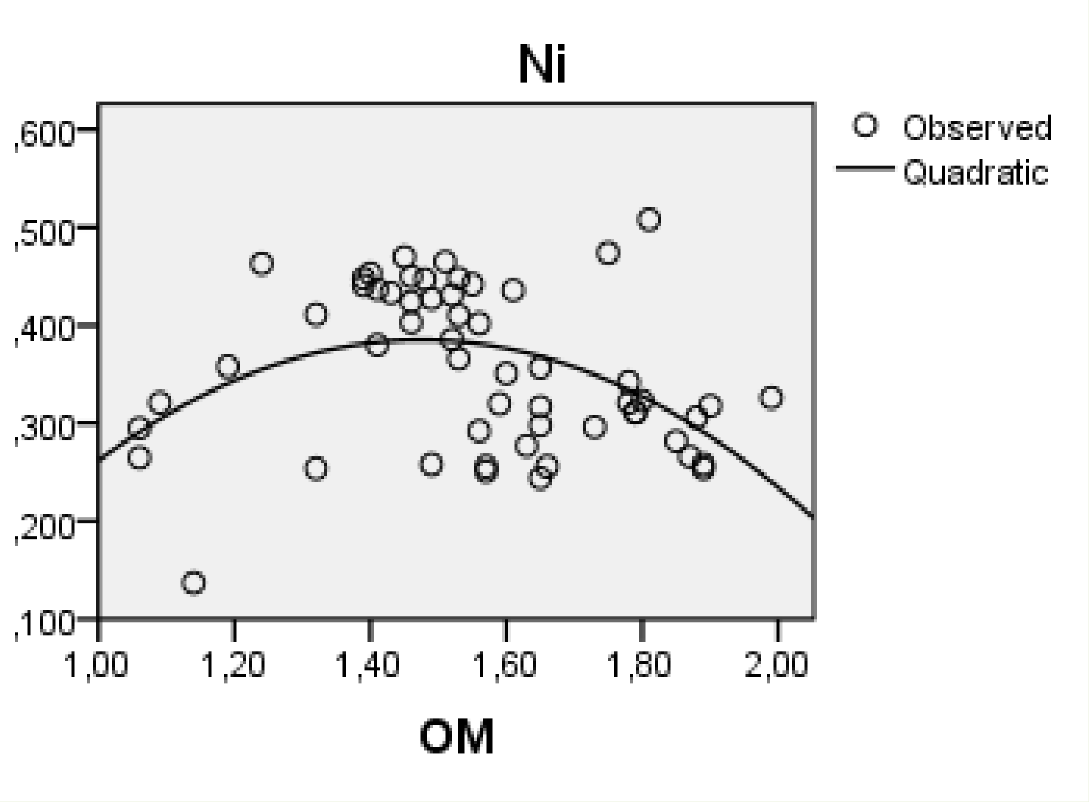
concentration [metal ions/dry sludge] at mg/Kg.

Interaction between pH x Ni in soil under the effect of sludge



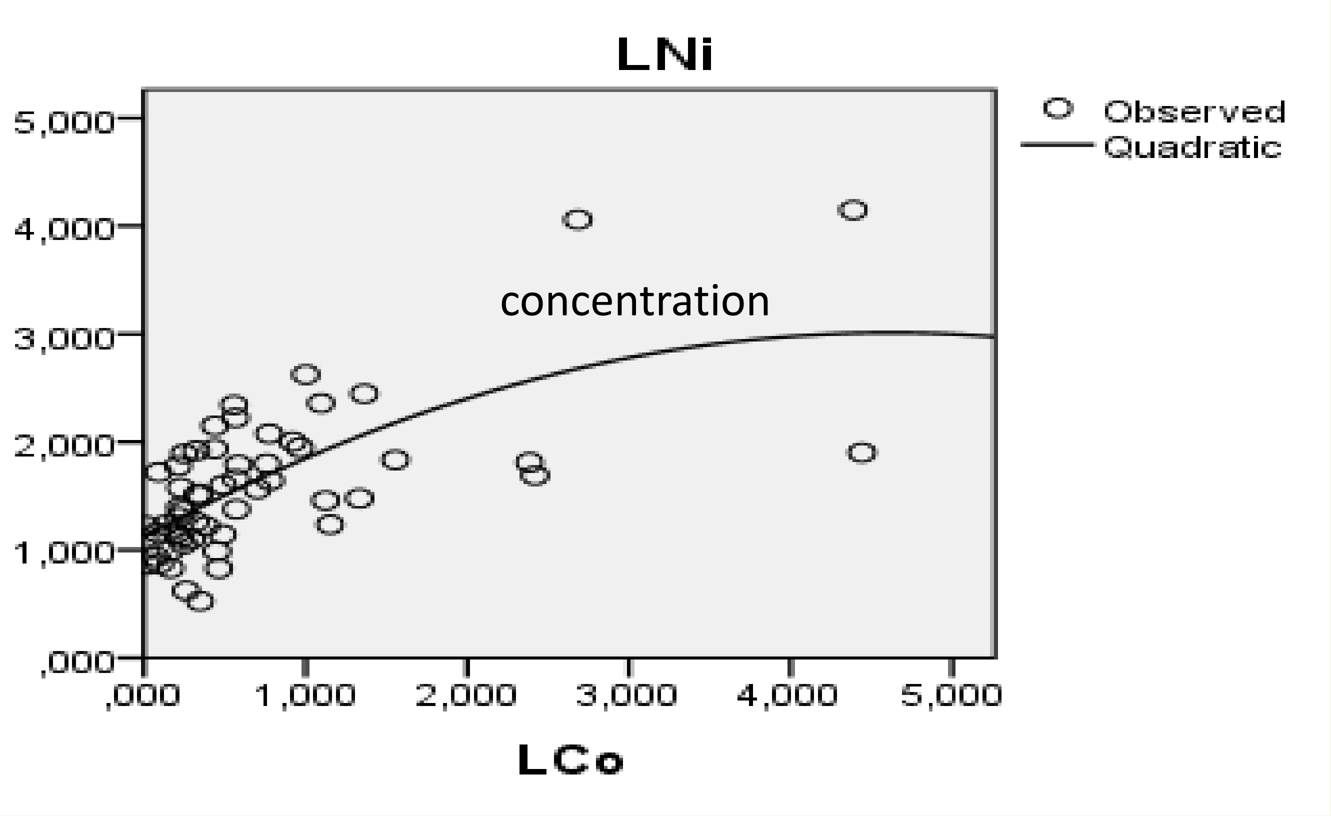
concentration [metal ions/dry sludge] at mg/Kg.

Interaction between Ni x Organic matter in soil under the effect of sludge



concentration [metal ions & OM/dry sludge] at mg/Kg.

Interaction between **L**eaf **Co** x **L**eaf **Ni** in lettuce under the effect of sludge



concentration [metal ions/dry sludge] at mg/Kg

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Quantification of the elemental interactions contribution to soils and plants.

The experimental research on interactions has shown that numerous interactions are taking place in soils and plants, and depending on whether they are **antagonistic** or **synergistic** they contribute positively or negatively *heavy elements, macro- and micronutrients* to soils and plants.
This contribution is calculated as percent of the actual available level of the element level determined by soil analysis by using the following relation:

PEC = (YM-YMN) X100 / (YAM-YAMN)

where: **YM**=maximim theoretical value (mg/kg)
YMN=minimum theoretical value (mg/kg)
YAM=actual maximum theoretical value (mg/kg)
YAMN=actual minimum theoretical value (mg/kg)
PEC= percent elemental contribution

It is noted that the theoretical values are calculated by regression analysis of the actual analytical data.

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Elemental contribution of interactions in heavy metals and plant nutrients

(Plant Biosystems 146 (30: 491-499)

	mg/100grM D.M.
Phosphorus	73
Potassium	642
Calcium	523
Magnesium	80
Manganese	0.88
Zinc	1.26
Iron	0.43
Copper	0.20
Cobalt	0.003
Chromium	0.005
Nickel	0.073
Lead	0.330

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Soil heavy metal pollution

It has been stressed by many authors that wastewater and biosolids in spite of their many advantages, they have also some disadvantages such as these two inputs supply the soil with heavy metals, pharmaceuticals, xenobiotics etc.

Therefore, there is a great possibility that the long term application of wastewater or biosolids may cause accumulation in the soil of heavy metals causing soil pollution with negative effects on the plant growth, surface waters, soil microorganisms, and on the environmental quality.

On the other hand, the continuously increasing irrigation water shortage, a fact that necessitates the wastewater reuse in agriculture, and creates future possibilities for soil pollution and consequently generates conditions for its control.

Evaluation of soil heavy metal pollution

The evaluation of soil pollution is usually done by using the so called pollution indices.

Our research team has produced such indices which have been published in the above publication. These indices can be used in the content of a computer program and can inform the user about the possible creation of soil heavy metal pollution. these indices are given below as follows:

1\N

1- EPI= (M1 X M2 X M3……..MV)

where: **M1 , M2, MV = the metals involved in the pollution EPI**

EPI= Elemental **P**ollution **I**ndex

1/V

2- PLI= (CF1 , CF2, CF3…CFV) (Pollution **L**oad **I**ndex**)**

where**: CF1 , CF2 CFV = C**orresponding **C**oncentration **F**actor of each metal involved in the pollution

Evaluation of soil heavy metal pollution

3- HML=M1 + M2 +M3……MV
where: **M1, M2…..MV= M**etals involved in pollution

4- TCF= (M1+M2+M3…..MV))/ (M1R1+M2R2+M3R3 …….MVRV)
M1, M2, M3…MV= Metals involved in pollution
M1R1, M2R2, M3R3….MVRV – Metal **R**eference **M**etals **V**alues

Calibration of Pollution Indices

To attain an accurate evaluation level of soil heavy metal pollution the indices must be calibrated following the steps mentioned below:

1-Determination of soil heavy metals
2-Calculation the indices values
3-Regression analysis of the indices with the dry matter yield obtained
4-Calculation of the percent plant loss in comparison to the optimum yield in the absence of heavy metals from the soil.
5-A regression analysis is run between the percent loss of the plant dry matter and the pollution indices.

The regression equation which is in turn determined is used to calculate the optimum level of soil pollution classified as optimum, low and high.
These levels correspond to economically acceptable dry matter losses.
The levels of soil pollution which correspond to the above dry matter losses inform us as to whether it is needed to take or not to take the necessary measures to control the possible pollution.

Wastewater Pharmaceuticals Uptake by the plant Beta vulgaris

(Papageorgiou et al., 2018 XENOVAC II)

An experiment was conducted to study the uptake of pharmaceuticals and personal care products (PPCP) by the garden red beet.
The following compounds were found in a wastewater sampled from the WWPP of Amaliada Western Peloponnese.

The main groups of compounds contained in these wastewaters were: ***antibiotics, antifungal, antihistamine, antihypertensive, anti-inflamatiry, beta blockers, insect repellents, muscarinic antagonists, psychiatric drugs, stimulants, and personal care products.***

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Wastewater Pharmaceuticals Uptake by the plant Beta vulgaris

(Papageorgiou et al, 2018 XENOVAC II)

Regarding the antibiotics, the following kinds and quantities were determined:

Antibiotics	Effluent (ng/g)
Azithromycin	220.9
Clarithromycin	104.4
Sulfamethoxazole	18.7
Trimethoprim	29.4

of the seventeen compounds detected in the soil, thirteen were found in the beets.

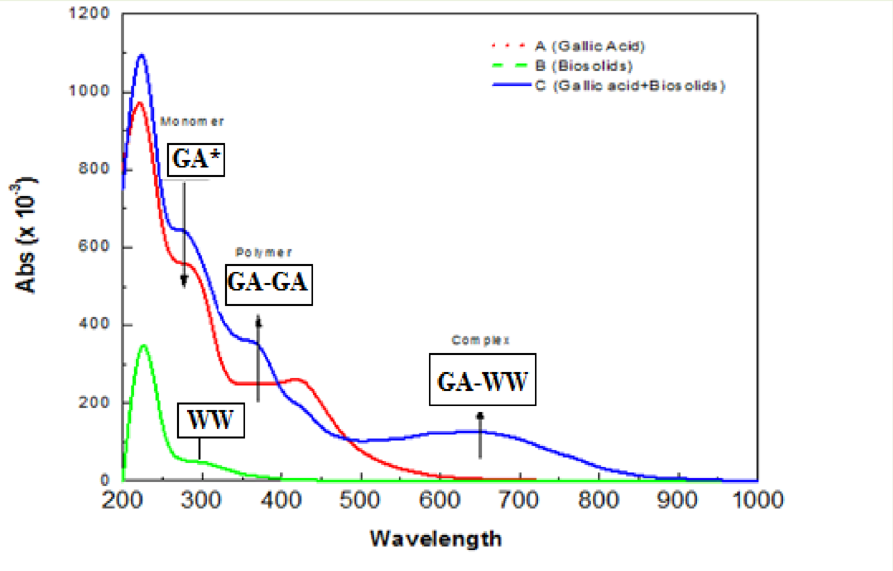
The conclusion of this investigation was that: the ability of beet roots to uptake pharmaceuticals and personal care products depending on the physicochemical properties.

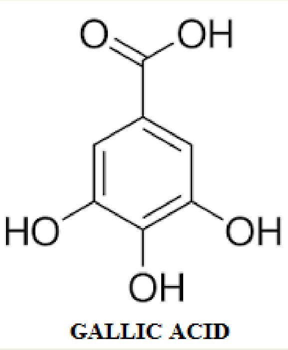
More work is needed and the relevant research work will continue.

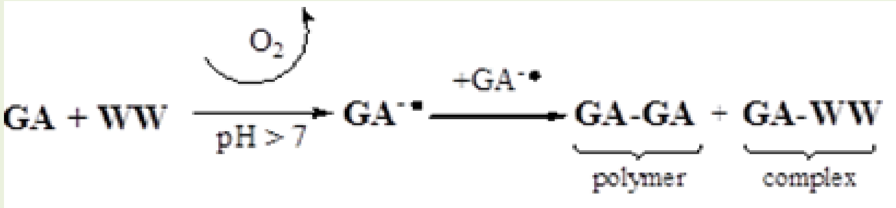
Humification of biosolids by free radical mechanism and compost production for agriculture use

In the context of a PhD dissertation, a complexation mechanism among the organic matrix of the municipal wastewater (WW) and the free radicals of phytochemical molecules (type gallic acid, GA) has been investigated.

A ***proposed*** complexation ***mechanism*** *among GA and WW, under ambient* O_2 *and at pH>7 is:*







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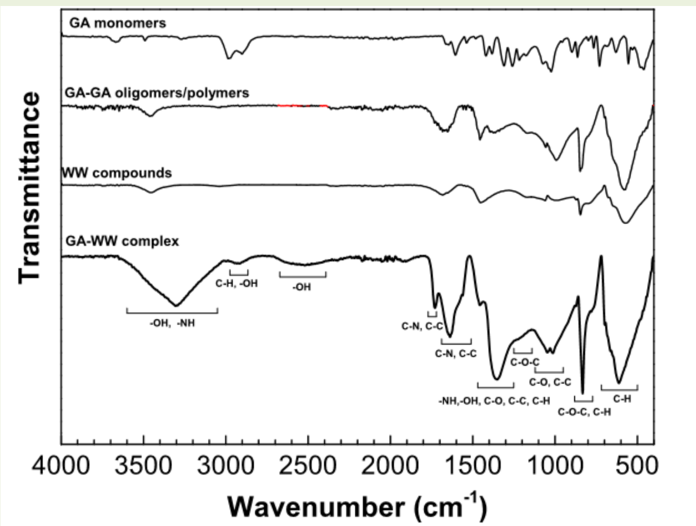
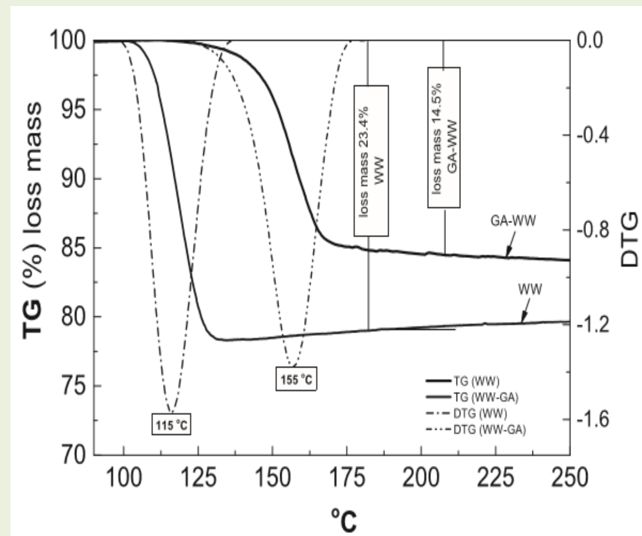
Humification of biosolids by free radical mechanism and compost production for agriculture use

The comparative analysis for WW and GA-WW complex by ATR (Attenuated Total Reflection spectroscopy) and TGA (ThermoGravimetric Analysis) reveals differences due to complexation mechanisms.

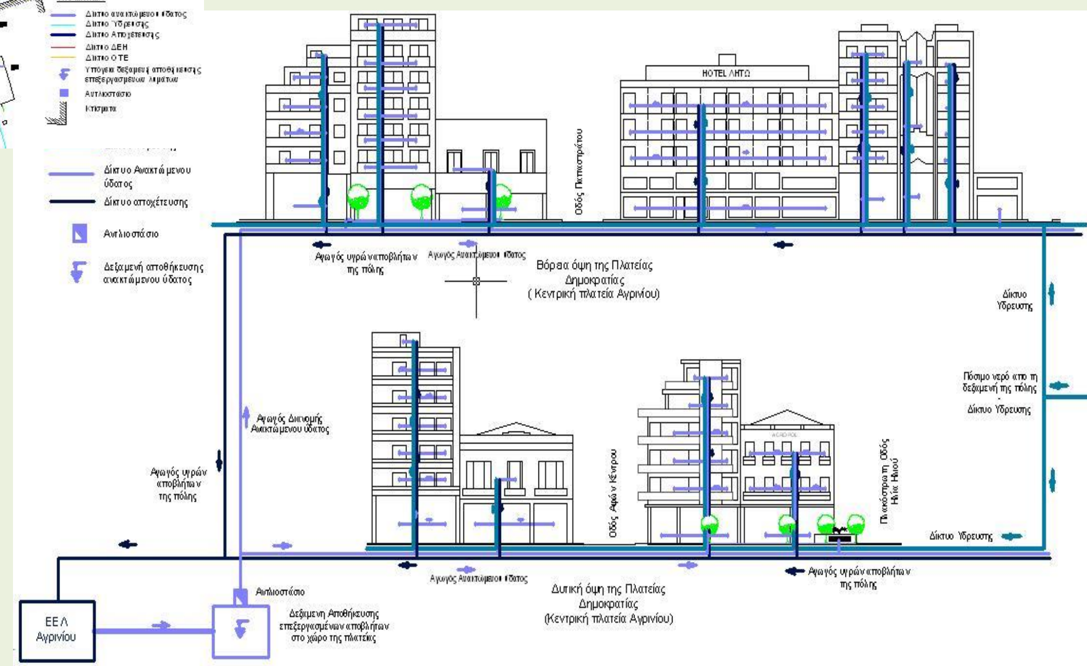




This method compared to the conventional wastewater treatments suggests a novel role of natural polyphenols on the degradation and humification of wastes.

(Giannakopoulos, E., et al. (2017). Oxidation of municipal wastewater by free radicals mechanism. A UV/Vis spectroscopy study. J. Environ. Manage. 195, pp.186-194.)

Planning of TMWW reuse in the park of Central Democracy Square, in the city of Agrinion



Land management planning

Current research work in progress

The current research work presently in progress at the School of Science and Technology includes the following:

- Planning TMWW reuse in the Cities.
- Study of special interactions such as the synergistic Cl X Cd related to human health.
- Investigation on pollution load index and transfer factor of heavy metals and determination of optimum levels for the prediction of soil pollution and plant growth.
- Use of zeolite in wastewater and sludge reuse in plant growth.

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Future research prospects

The research efforts of the scientific team of our school will continue towards facing problems related to the wastewater and biosolid reuse.

It is true that these two inputs are being used in many cases indiscriminately, disregarding the health risks involved due to the anguish of the people to irrigate the crops and produce agricultural products to meet the food needs of the society. Yet, we know that we have not been so far able to free the wastewaters from the health risk involved (heavy metals, pharmaceuticals, toxic compounds, xenobiotics, plastics etc.)

We believe that there is still much work to be done towards achieving as real safe and scientifically based reuse.

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Future research prospects

In this context, we plant to tackle in the near future with the following problems:

1- Further improvement of the pollution indices with the view to accomplish more accurate evaluation of the soil pollution with heavy metals under long term reuse.

2- Optimization of the wastewater and biosolid quality and production of new products such as effective organic fertilizers, biodecomposable plastics from wastewater, and minimization of health risk effect.

3- Control of pharmaceutical uptake by plants by means of relevant processing of the wastewaters.

4- Computerization of the wastewater and biosolid reuse in agriculture.

5- Reuse of the wastewater in fire extinction.

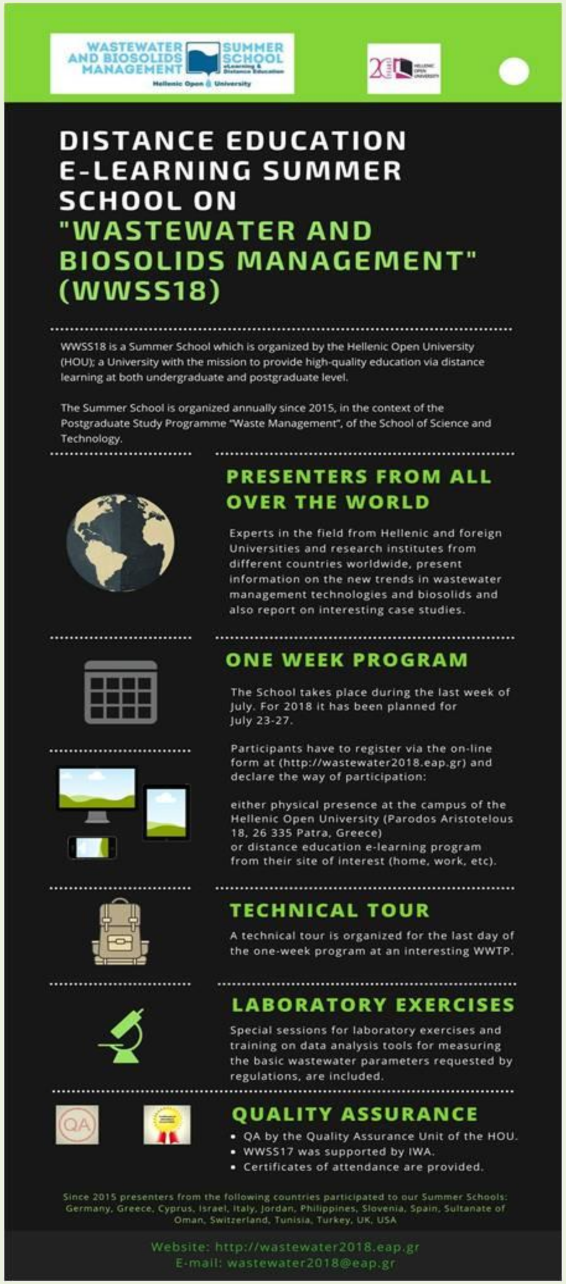
Technical reports

(prepared for various ministries and organizations)

In the context of departmental activities the following reports have been published or are currently being published

1. **Editor: I.K.Kalavrouziotis**, 2017, "Wastewater and Biosolids Management", IWA Book, **ISBN13:** 9781780408224.
2. "An expertise study for combating the irrigation of crops problem in the prefectures of Argolida and Lakonia by TMWW reuse (Management Service of Enterprising Progress in Rural Development and Reform 2000-2006).
3. Regional Planning for the safe reuse of TMWW and sludge produced by wastewater biological processing plants (WWBPP) in soils and crops of Western Greece, municipality of Agrinion, Greece.
4. Technical report for setting the boundary limits and functional status of wetland in the area of Mesokambi Antiniou, municipality of Antirion, 2007-2008.

Distance education & e-Learning…



Research Team

Laboratory of Sustainable Waste Technology Management

- **Prof. Dr. Ioannis Kalavouziotis**
- **Dr. P. Kokkinos**
- **Dr. Dimitris Papaioannou**
- **Dr, Aris Gkolfinopoulos**
- **Dr. Kostas Kollyropoulos**
- **Prodromos Koukoulakis (MSc)**
- **PhD candidates**

- Ekavi Isari MSc

- Ilias Karachalios MSc

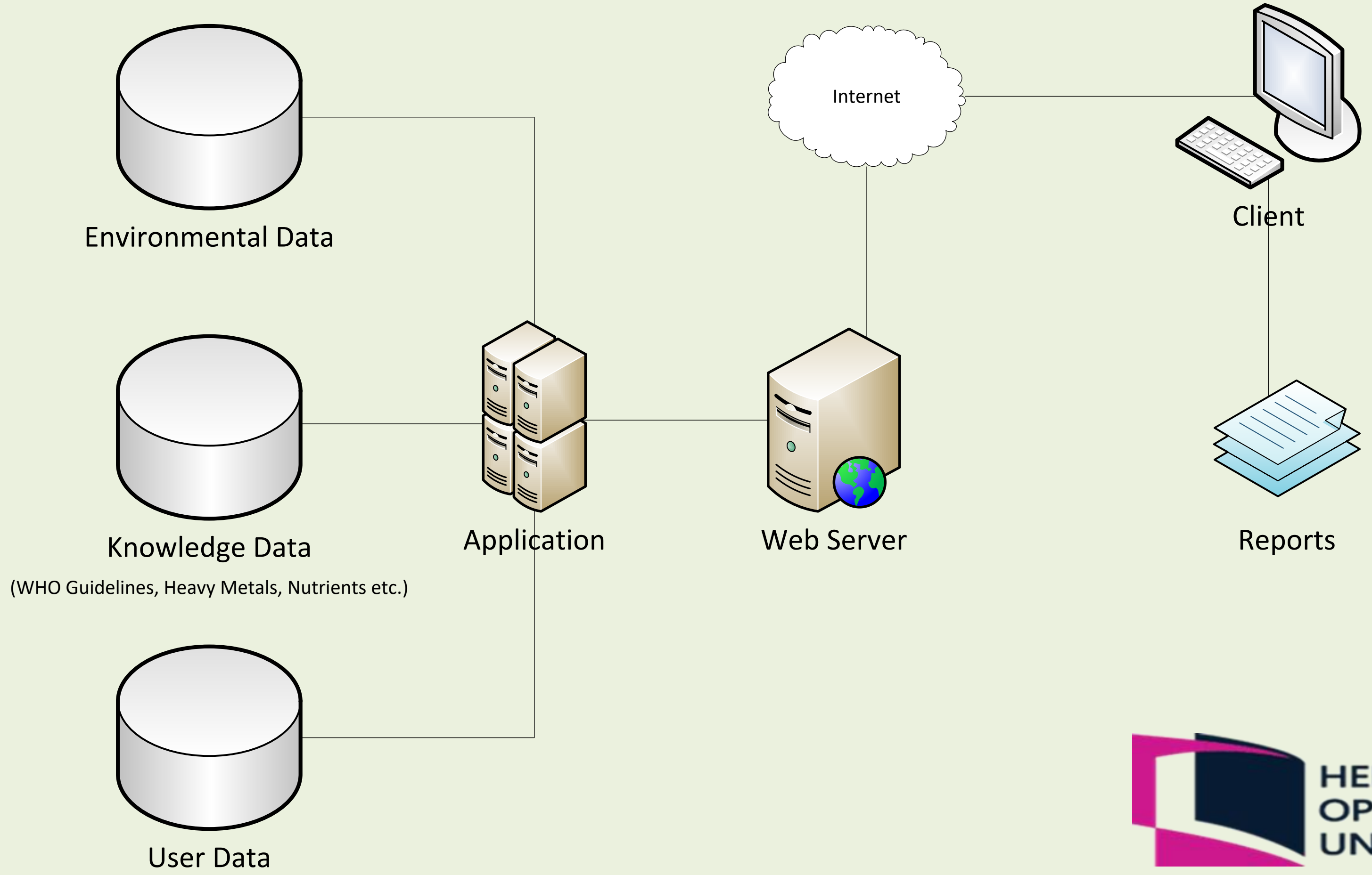
-Sotiris Michalopoulos

-Noni Amplianiti

We collaborate with the following labs

- Geochemistry lab, geological University of Patras, Prof. Varnavas
- Soil research lab, ΕΘΙΑΓΕ, Thessaloniki
- Department of Health Sciences, University of Patras
- Department of Irrigation, Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC)**,** (Spanish Council for Scientific Reseach)
- Department for Information Technologies of Inductive Modeling, the International UNESCO Center of Information Technologies and Systems of the National Academy of Sciences of Ukraine
- University of Aegean, Topographic mapping lab, Prof. Hatzopoulos
- Technical University of Braunschweig, Institute of sanitary and Environmental Engineering, Prof. Dr. Thomas Dokhhron
- Istanbul Technical University, Civil Engineering Faculty, Environmental Engineering Department, Turkey

DSS for Wastewater and Biosolids Reuse



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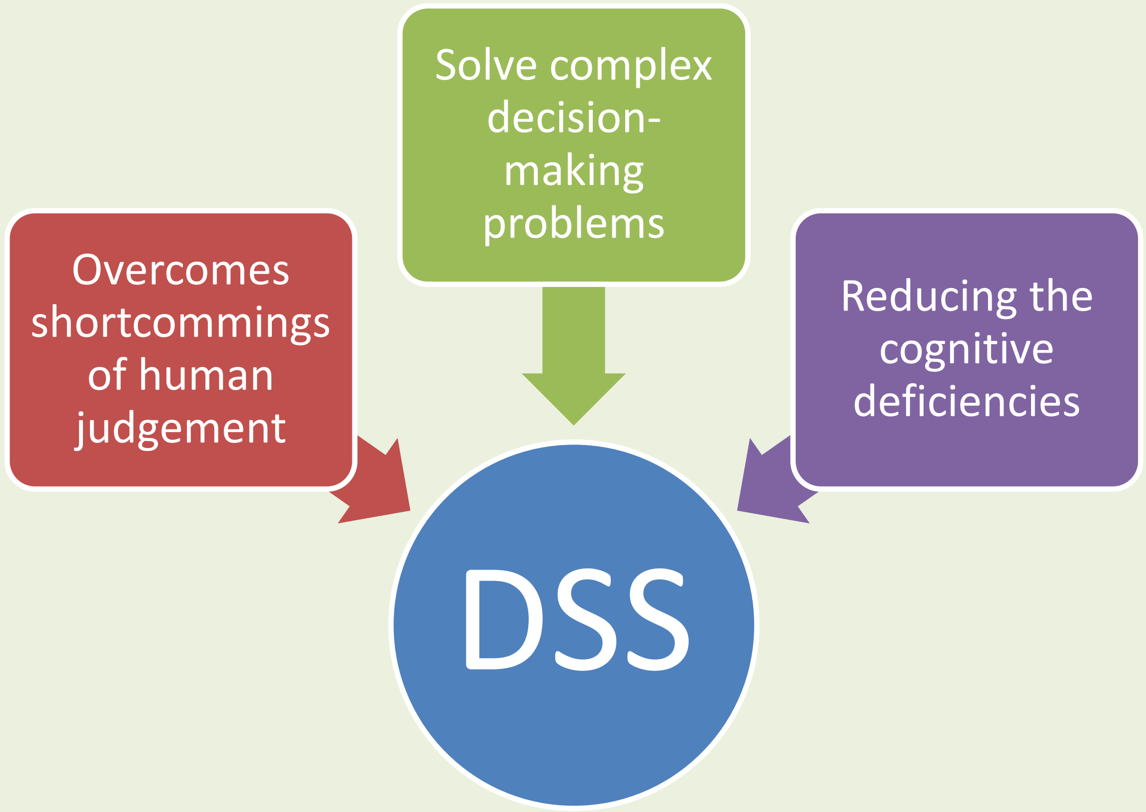
DSS for Wastewater and Biosolids Reuse



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Advantages

- transparent decision-making
- concrete and productive management strategies
- definite and clear cut decision mechanisms

Capability of processing, large sets of data efficiently and effectively

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The main aim of the DSS

Increase

- agricultural production

Reduce

- fertilizer usage & cost

Improve soil

- fertility
- productivity

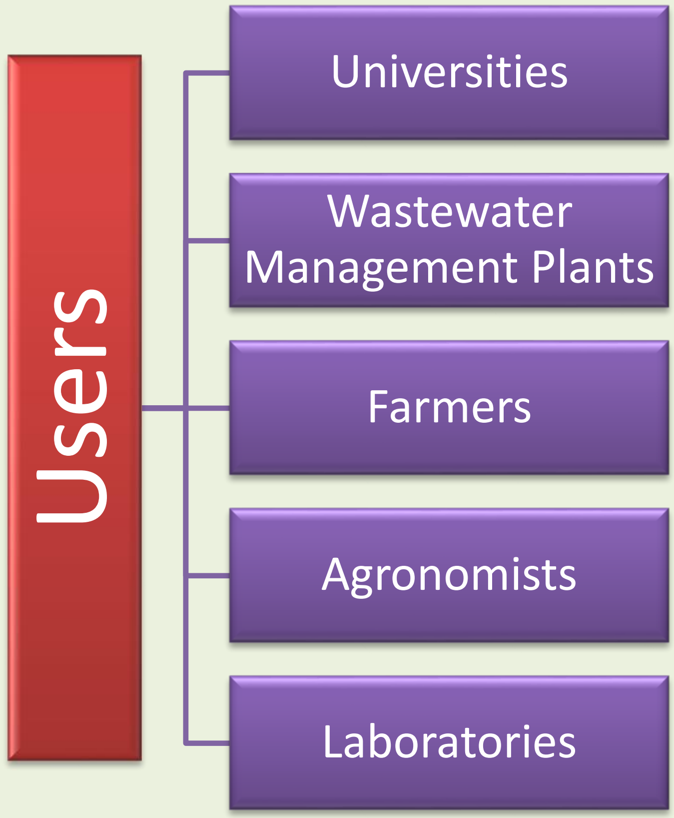
protect the environment from the accumulation:

- heavy metals in soil and plants
- huge quantities of wastewater and sludge

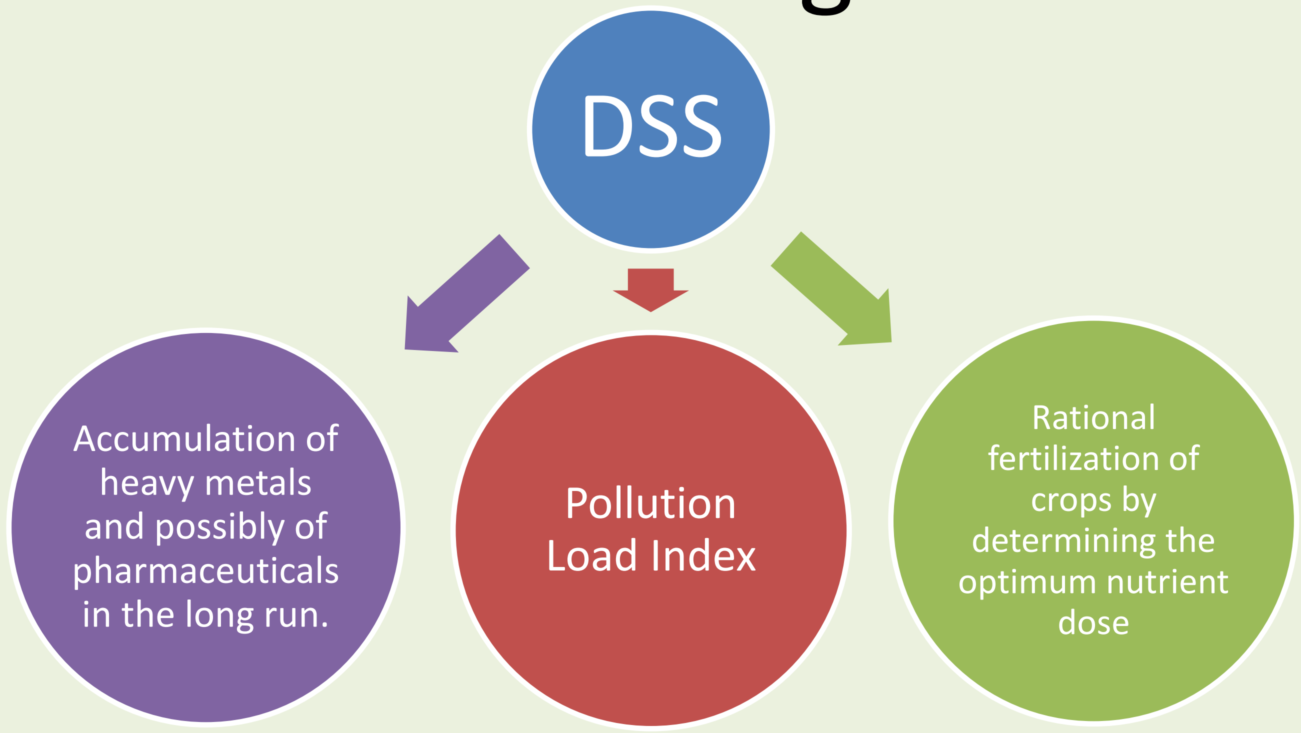
The ultimate objective of the DSS are:

To utilize the treated wastewater and sludge.	• In the context of a rational crop fertilization program.
To alleviate the pressure exerted today on the environment and on the surface waters.	• Reducing the accumulation of sludge and wastewater that are flowing unutilized into lakes and seas.
To reduce the demand of natural irrigation water.	• Providing a solution for the annually observed increase in the use of natural irrigation water that causes severe problems, and permanent headache to the government authorities.

Potential users of the DSS



The software calculates the following:



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DSS for wastewater and sludge reuse

- The system is using web technologies that makes it easy to be used in an interactive mode.
- It emphasizes flexibility and adaptability to accommodate future changes in the environment and the decision making approach of the user.
- The system is being tested and so far it seems to function properly and effectively.

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Cooperations

China

Southeast University

Jordan

Al-Balqa Applied University, Chemical Engineering Department

Spain

Dpt. of Irrigation, Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), National Council for Scientific Reseach, Murcia

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THANK YOU FOR YOUR ATTENTION!