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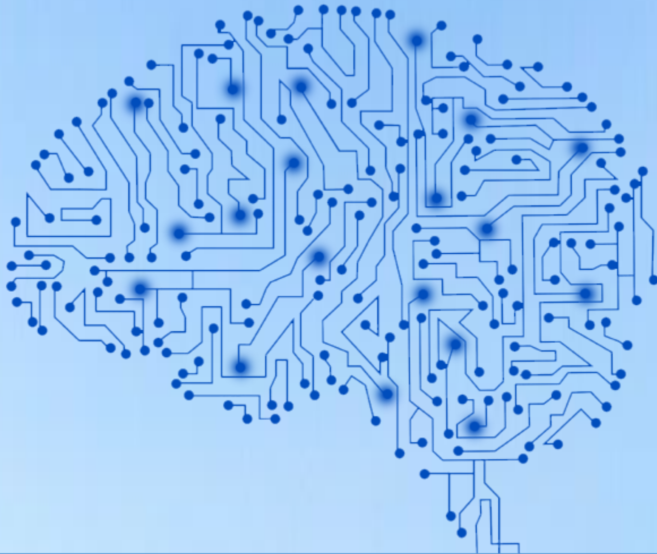
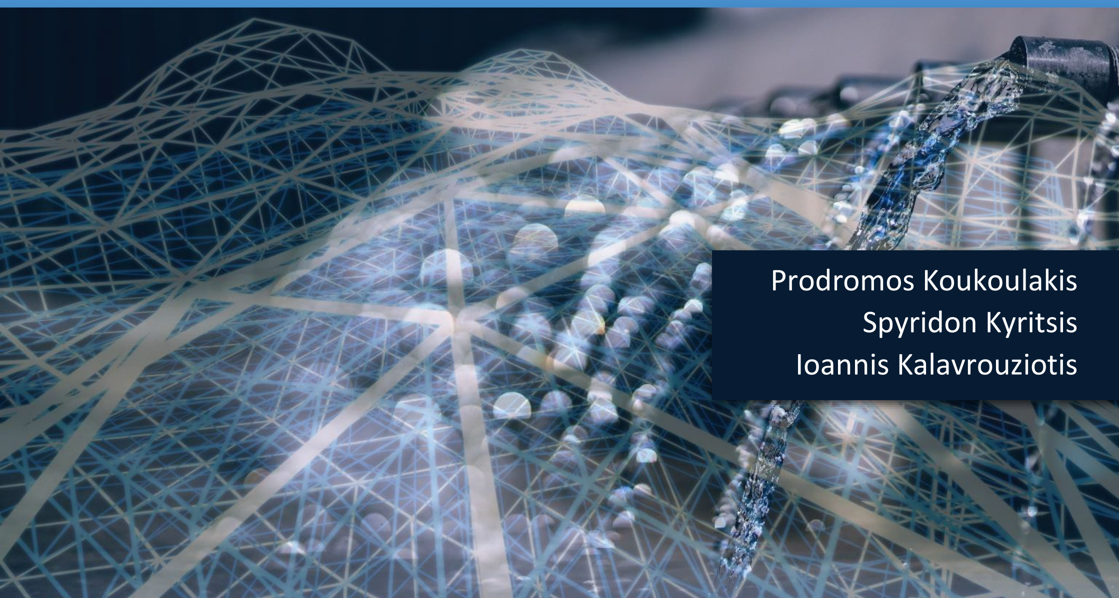


DECISION SUPPORT SYSTEM

FOR WASTEWATER AND BIOSOLIDS REUSE IN AGRICULTURAL APPLICATIONS



Prodromos Koukoulakis
Spyridon Kyritsis
Ioannis Kalavrouziotis

DECISION SUPPORT SYSTEM

FOR WASTEWATER AND BIOSOLIDS REUSE IN AGRICULTURAL APPLICATIONS

Prodromos Koukoulakis, Spyridon Kyritsis and Ioannis Kalavrouziotis

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Decision Support System for Wastewater and Biosolids Reuse in Agricultural Applications

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PART I

DECISION SUPPORT SYSTEM

FOR WASTEWATER AND BIOSOLIDS REUSE IN AGRICULTURAL APPLICATIONS

INTRODUCTION

The decision-making in the case of wastewater and sludge or biosolid reuse in agriculture is beset with a multitude of information. More so, this practice is characterized by an avalanche of data that must be integrated in such a way so as to be studied and lead to relevant conclusions, related to the effect of these effluents of the Wastewater Treatment Plants (WTPs) on the soil and plant systems.

Among the recent developments which have been accomplished in relation to the exploitation of the wastewater and biosolids, the contribution of Computer Science to the treated wastewater and biosolid reuse in agriculture seems to offer an attractive possibility for decision-making in relation to safely reuse of the above-mentioned effluents of the WTPs.

A tool that could offer the possibility of reducing the cognitive deficiencies and to overcome the shortcomings of the human judgment could be an Expert System (ES), a Decision Support System (DSS), which can utilize the capabilities of modern computer hardware to solve complex decision-making problems.

The DSS is able to process a multitude of data, apply rapidly calculations and evaluations on them, leading to solutions of numerous problems evolving in the extremely complex and dynamically changing environment of the soil-plant system. Consequently, the DSS can lead to decision-making, and to effective management of the available resources in a cost-effective manner, securing sustainable fertility, and productivity of soil (Dumitrescu and Chitescu, 2015).

The advantage of the use of the Decision Support System (DSS) is that it offers the possibility of achieving transparent decision-making, which can direct towards the development of concrete and productive wastewater and sludge management strategies, and definite and clear cut decision mechanisms. And in this sense, the DSS could be a desirable tool for accomplishing a safe reuse of these inputs in agriculture. The above achievements can be accomplished by the fact that the DSS can offer the capability of processing, large sets of data efficiently and effectively.

The reuse of the treated wastewater and biosolids can supply the soil with macro and micronutrients necessary for plant growth. Also with toxic heavy metals and some pharmaceutical compounds, which are considered as emerging toxic substances. The effects of these constituents are combined with the existence of soil native plant nutrients and heavy metals, affecting an impact on plant growth and development.

This combination is complex, and therefore human judgment and cognitive capacity are almost impossible to study it effectively in a conjugated manner. Furthermore, the accumulation of the heavy metals in the soil during the long term application of the wastewater and biosolids, and the interactions between the macro, microelements, heavy metals and physical, chemical and biological properties of soil make the problem of their study extremely complicated and challenging. Hence, only a DSS utilizing computer power could be able to integrate all these complicated data and process them accordingly, leading to definite conclusions. Therefore, the conjugation between human judgment and artificial intelligence decision making under such circumstances may be far from optimal and naturally cannot offer effective and clear cut solutions. Obviously, the quality of decision-making is an important factor in the management of these effluents, and therefore the deficiency of the human mind towards effective decision-making in relation to the combination and conjunction of such complex problems has always been the concern of the scientific community.

The current era of technological progress and digitalization has helped to face effectively this human deficiency. Thus, today, there are several decision support systems (DSSs) reported in the literature, focusing on water and wastewater (Almeida et al., 2013; Car, 2018; Hamouda et al., 2009; Hidalgo et al., 2007; Karlsson et al., 2016; Khadra and Lamaddalena, 2010; Oertlé et al., 2019; P. W. Jayasuriya et al., 2018; Rose et al., 2016; Rupnik et al., 2019). Unfortunately, none of them deals with the effect of the reuse on the environment, crop rational fertilization, forecasting possible soil pollution due to heavy metal accumulation, and protection of soil and crops from the toxic effects of these metals. Also, Xie et al (2015) have used a DSS for the remediation of polluted sites

The DSSs reported in the literature examine mainly techno-economical aspects, regarding system planning and designing or cost analysis without focusing on advantages as soil fertility improvement or on fertilizer usage reduction due to nutrients contained in wastewater and biosolids, on soil heavy metal accumulation and on the release of the pressure exerted on the environment by the huge quantities of wastewater and biosolids produced over the world.

Since the basic aim of the safe wastewater and biosolid reuse in agriculture has not been attained so far, in most of the low-income economy countries, it is believed that the existence of a relevant specialized software such as for example a relevant decision support system (DSS) i.e. an expert system, having problem-solving capacity related to the reuse, the DSS could possibly successfully help in the effective control and in as safe as possible reuse in agricultural production, of wastewater and biosolids. The DSS could offer a desirable solution to this basic and highly important problem that concerns all the world. Its main aims are summarized below as follows:

- To reuse the wastewater for the irrigation of crops and biosolids, for the optimization of soil fertility and productivity, minimizing human and environmental risk.
- To enrich the soil with organic matter.

- To supply the soil with organic matter and improve soil structure, water-holding capacity, and increase its resistance to erosion.
- To supply the soil with plant nutrients.
- To improve soil fertility and productivity.
- To optimize the fertilization of crops.
- To reduce fertilizer cost.
- To forecast and prevent soil pollution with heavy metals.
- To optimize crop production quantitatively and qualitatively.
- To protect the agroecosystem from overload with heavy metals and plant nutrients.
- To relieve the environmental stress and the pressure exerted by the huge quantities of wastewater and biosolids produced annually
- To optimize the life quality.

The DSS to be effective must be an expert system capable of accomplishing the following:

- To calculate the optimum nutrient dose for each crop.

- To estimate the nutrient inputs contained in the soil in the form of residual nutrients, in wastewater, and in biosolids.
- To co-evaluate the nutrient losses due to leaching, denitrification, fixation, and removal via crop harvesting.
- The quantity of the available inorganic nutrients contained in the soil, in the wastewater, and in biosolids.
- The quantity of the fertilizer which is to be applied during the different crop growth stages (early growth, flowering, fruit set, etc).
- To guide the user at the proper time (Fall, Winter, Spring), and to help him use the relevant method for the application of fertilizer to crop.
- To calculate the soil pollution index (EPI[1]) (Kalavrouziotis et al., 2012) and to supply quantitative information about the level of soil pollution with heavy metals.

[1] EPI: Elemental Pollution Index

- To determine the quality of the wastewater being used, and to exclude it from reuse if its concentrations in heavy metals are higher than the international standards, or include it in reuse otherwise.
- To calculate the optimum rate of liming material needed to improve a strongly acid soil to the desired pH, for the normal growth of crops.
- To inform the user about the level of soil salinity, which is a very useful information related directly to the plant growth, as the reuse of wastewater and biosolids may often increase soil electrical conductivity.

The DSS must also be friendly to the environment and can function not with only wastewater or only biosolids but also with both of them as well.

Finally, the DSS must incorporate modern technologies with an intuitive user interface, easy to use, even for inexperienced computer users.

The present DSS has been recently developed by the research team of the School of Science and Technology of the Hellenic Open University developed a DSS with the afore-mentioned capabilities, which could be used as a very useful tool in approaching the safe reuse of wastewater and biosolids in Agriculture. In Figure 1 the DSS's architecture diagram of its basic components is reported.

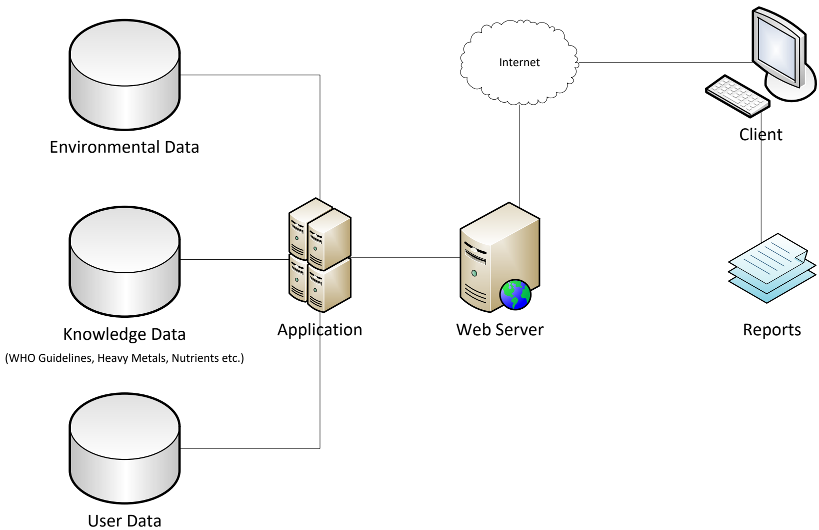

Figure 1. DSS Architecture diagram

The knowledge base of the system contains rules with recommended maximum heavy metal concentrations in wastewater (WHO, 2006). The system estimates the Elemental Pollution Index, before and after wastewater and biosolids application. It can detect highly acidic soils and calculates the optimum rate of liming material needed for the desired pH. Its knowledge base contains a large set of rules to calculate optimum nutrient dose and to provide fertilization advice for every supported crop.

EXAMPLES

To demonstrate the DSS function for the reuse of wastewater and biosolids, the following two examples of reuse are given. First with low nutrient content of treated municipal wastewater (TMW) and biosolids, and second with high nutrient content, respectively. In both examples, the same soil is used, and its analytical data, physical properties, chemical properties, macro-micro nutrients, and heavy metals concentrations, are reported in Table 1 and Table 2.

Table 1. Physical and chemical properties of soil

pH	$CaCO_3$ (%)	Org. Matter (%)	EC (mS/cm)	Clay (%)
7.10	5.00	2.66	0.55	26.00

Table 2. Macro-micro nutrients and heavy metals of soil (mg/kg)

Elements	mg/kg
N	0.00
P	10.00
K	130.00
Ca	775.00
Mg	25.00
Na	15.00
B	0.89
Fe	4.00
Mn	6.00
Zn	0.80
Cu	0.20
Cd	0.01
Co	0.05
Cr	0.00
Ni	1.00
Pb	1.20

EXAMPLE 1

Wastewater and biosolids application to potato crop:

- Application to potato crop of 3500 m^3/ha wastewater of both low plant nutrients and soil heavy metal content, respectively.
- Also of 10,000 kg/ha biosolids, similarly low in nutrient and heavy metal content.
- The physical-chemical and elemental content of the soil are reported in Table 1 andTable 2, and of the wastewater and biosolids in Table 3. These input data are required by the system in order to provide a valid and accurate report.
- The level of the heavy metal soil pollution is evaluated by the pollution indexes of Table 4 and the suggested rational plant nutrient levels and their respective fertilizer quantities in Table 5, in which the guidelines for the effective application of fertilizers to potato crop are also reported in detail by the DSS.

Table 3. Macro-micro nutrients and heavy metals of treated municipal water (TMW) and biosolids (Example 1)

Elements	TMW (mg/L)	Biosolid (mg/kg)
N	0.00	3.50
P	0.10	150.00
K	2.00	120.00
Mg	5.46	35.00
Na	0.00	0.00
B	0.00	0.50
Fe	0.04	150.00
Mn	0.00	35.00
Zn	0.01	20.00
Cu	0.00	6.00
Cd	0.00	0.19
Co	0.01	0.52
Cr	0.00	0.25
Ni	0.05	4.51
Pb	2.74	125.00

Table 4. Evaluation of soil pollution level (Example 1)

Value of pollution index before irrigation with treated wastewater	Value of pollution index after irrigation with treated wastewater	Evaluation of pollution level
0.1698	0.1956	No pollution

Table 5. Rational crop fertilization advice (Example 1)

Nutrient	Dose (kg/ha)	Fertilizer	Guidelines for fertilizer
N	101.28	Dose 1/4 **75.58 kg/ha** Ammonium Nitrate 33.5-0-0 Dose 3/4 **302.33 kg/ha** Ammonium Nitrate 33.5-0-0	1/4 broadcasted and incorporated into the soil at seedbed preparation, 3/4 surface applied beginning at the commencement of the flowering, and continued to the fruit set, in two applications per 10 days interval.
P_2O_5	22.64	**113.20 kg/ha** Simple Phosphate 0-20-0 or **49.22 kg/ha** Super Phosphate 0-46-0	Broadcasted and incorporated into the soil at seedbed preparation.
K_2O	93.02	**186.04 kg/ha** Potassium Sulfate 0-0-50	Broadcasted and incorporated into the soil at seedbed preparation.
MgO	0		No fertilization required for the current year.
Fe	1.12	**18.67 kg/ha** Iron Chelate EDDHA Fe 6%	Applied by spray according to the manufacturer guidelines or broadcasted mixed with one of the above fertilizers.

Nutrient	Dose (kg/ha)	Fertilizer	Guidelines for fertilizer
Zn	1.43	**10.21 kg/ha** Sequestrene-NA_2-Zn 14% or **9.53 kg/ha** Zn-EDTA 15%	Applied by spray according to the manufacturer guidelines or broadcasted mixed with one of the above fertilizers.
Mn	9.8	**30.63 kg/ha** Manganese Sulfate 32% or **27.22 kg/ha** Manganese Sulfate 36%	Applied by spray or broadcasted mixed with one of the above fertilizers.
Cu	1.79	**7.16 kg/ha** Copper Sulfate 25%	Applied by spray or broadcasted mixed with one of the above fertilizers.
B	1.34	**11.65 kg/ha** Borax 11.5% or **6.54 kg/ha** Solubor 20.5%	**Borax:** Applied by spray or broadcasted mixed with one of the above fertilizers. **Solubor:** Applied by spray according to the manufacturer guidelines or broadcasted mixed with other fertilizers.

EXAMPLE 2

Application to potato crop of equal volume and weight to the above quantities per ha of wastewater and biosolids respectively, but of higher content in plant nutrient (Table 6).

- The analytical data of soil is unchanged because the same soil is used.
- The evaluation of the heavy metal soil pollution level is given in Table 7.
- The suggested quantities of nutrients and their corresponding fertilizers, as well as the guidelines for fertilizer application, are reported in Table 8.

Table 6. Macro-micro nutrients and heavy metals of treated municipal water (TMW) and biosolids (Example 2)

Elements	TMW (mg/L)	Biosolid (mg/kg)
N	0.00	3.50
P	1.50	450.00
K	12.50	3333.00
Mg	35.00	309.00
Na	0.00	0.00
B	0.70	0.50
Fe	0.25	121.00
Mn	0.10	43.60
Zn	0.50	70.00
Cu	0.04	29.00
Cd	0.00	0.36
Co	0.01	0.60
Cr	0.00	0.40
Ni	0.04	0.37
Pb	0.19	302.30

Table 7. Evaluation of soil pollution level (Example 2)

Value of pollution index before irrigation with treated wastewater	Value of pollution index after irrigation with treated wastewater	Evaluation of pollution level
0.1698	0.2022	No pollution

Table 8. Rational crop fertilization advice (Example 2)

Nutrient	Dose (kg/ha)	Fertilizer	Guidelines for fertilizer
N	91.06	Dose 1/4 **67.96 kg/ha** Ammonium Nitrate 33.5-0-0 Dose 3/4 **271.82 kg/ha** Ammonium Nitrate 33.5-0-0	1/4 broadcasted and incorporated into the soil at seedbed preparation, 3/4 surface applied beginning at the commencement of the flowering, and continued to the fruit set, in two applications per 10 days interval.
P_2O_5	0		No fertilization required for the current year.
K_2O	0		No fertilization required for the current year.
MgO	0		No fertilization required for the current year.
Fe	0.31	**5.17 kg/ha** Iron Chelate EDDHA Fe 6%	Applied by spray according to the manufacturer guidelines or broadcasted mixed with one of the above fertilizers.
Zn	0		No fertilization required for the current year.

Nutrient	Dose (kg/ha)	Fertilizer	Guidelines for fertilizer
Mn	9.38	**29.31 kg/ha** Manganese Sulfate 32% or **26.06 kg/ha** Manganese Sulfate 36%	Applied by spray or broadcasted mixed with one of the above fertilizers.
Cu	1.59	**6.36 kg/ha** Copper Sulfate 25%	Applied by spray or broadcasted mixed with one of the above fertilizers.
B	0		No fertilization required for the current year.

SUMMARIZING THE TWO EXAMPLES

The values of soil pollution index before irrigation with treated wastewater in Table 7 of example 2 and in Table 4 of example 1 are identical. This was expected, because, the same soil is used, with the same analytical data, physical properties, chemical properties, macro-micro nutrients, and heavy metals concentrations from Table 1 and Table 2, to calculate the value of soil pollution index before the wastewater reuse in both examples.

The soil pollution index after irrigation with treated wastewater in example 2 is slightly higher than the corresponding value in example 1, due to higher heavy metal concentrations in applied wastewater in example 2.

Despite that, in both examples, heavy metal concentrations are below the recommended limits for reuse (WHO, 2006), and no risk for pollution detected by the system during the evaluation of the pollution level.

The summary of the suggested nutrient doses for both examples is given in Table 9.

Based on the data of table 9 it can be concluded that considerable gains of nutrients are made by using TMW and biosolids with higher nutrient concentrations. It can be seen that the profit gains in nitrogen phosphorus, zinc, and Boron fertilization are 100% in the case of the wastewater and biosolids rich in nutrients, contents.

These results show in a specific and concrete way how the application of the inorganic fertilizers to cops can be reduced, and underline the economical profit gain that the farmer can have from the application of the reuse in his crops.

Table 9. Nutrient doses calculated by the DSS suggested for application to potato crops for the two examples respectively

Nutrient	Example 1 Nutrient $dose_1$ (kg/ha)	Example 2 Nutrient $dose_2$ (kg/ha)	Suggested nutrient dose gain [1] (kg/ha)	Percent of suggested nutrient dose gain (%)
N	101.28	91.06	10.22	10
P_2O_5	22.64	0.00	22.64	100
K_2O	93.02	0.00	93.02	100
MgO	0.00	0.00	-	-
Fe	1.12	0.31	0.81	72
Zn	1.43	0.00	1.43	100
Mn	9.80	9.38	0.42	4
Cu	1.79	1.59	0.20	11
B	1.34	0.00	1.34	100

[1] Suggested nutrient dose gain = Nutrient $dose_1$ – nutrient $dose_2$

CONCLUSION

The scientific community with the help of the State, and of the society, is expected to accomplish the removal of the toxic pollutants from the wastewater and biosolids, transforming them into safe substances. However, for the time being, human societies have no other choice from being optimistic, expecting that the scientific community is always on alert, and having in their disposal the support of the governments, the necessary infrastructure including the needed funding, as well as the experienced personnel, hopefully, will eventually be able to give a definite answer to this worldwide problem, and transform the wastewater and biosolids into a real "blessing".

For the time being, the use of the DSS could effectively alleviate the problems related to the reuse, till a cost-effective removal of toxic heavy metals will be possible to transform the TMW and biosolids in agriculture and generally in the ecosystem as safe as possible protecting the human life and the environmental quality.

PART II

THE DSS USER MANUAL

VERSION 1.5

DECISION SUPPORT SYSTEM

FOR WASTEWATER AND BIOSOLIDS REUSE IN AGRICULTURAL APPLICATIONS

USER MANUAL

VERSION: 1.5

This software development project is part of the research projects implemented through the Special Account for Research Funds, Hellenic Open University. (Self-financed project).

Director: *Professor Dr. Ioannis K. Kalavrouziotis*

Research Group: *Prodromos Koukoulakis, Spyridon Kyritsis, Ioannis Kalavrouziotis*

DESCRIPTION

This Decision Support System (DSS), is an expert system (ES), containing a knowledge base with a plethora of multicriterial rules, that analyses and evaluates input data of soil, treated municipal wastewaters (TMWW) and treated form of sludge (biosolids) and provides rational fertilization advice for crops and information for the determination of the optimum nutrient dose for N, P_2O_5, K_2O, MgO, Fe, Zn, Mn, Cu, and B.

GOALS

The present DSS is a special software solution, with a multitude of goals. It is expected to contribute to the utilization of the wastewater and sludge produced by the Wastewater Treatment Plants (WTPs), both alone or in combination with each other, and to supply plant nutrients and organic matter to soils many of which are depleted of these important constituents.

FEATURES

The DSS is capable of making decisions in relation to safe wastewater and sludge reuse, evaluating:

- The heavy metals soil pollution level due to long term reuse of the above inputs, and alerts the user to take promptly necessary measures to avoid the adverse consequences.
- The optimum fertilization of crops, in order to minimize the use of fertilizers, and protect the agroecological environment from unnecessary nutrient load, which otherwise could have unfavorable effects on the soil and life quality.

The current version processes analytical input data of soil, treated wastewater, and of sludge,

providing information about the elemental pollution index for the evaluation of soil heavy metal pollution level, and the rational fertilization of crops by determining the optimum nutrient dose to be applied, contributing to the protection of the environment, especially of the soil from the accumulation of heavy metals and possibly of pharmaceuticals in the long run.

The system supports three operation modes:

- Reuse of only Treated Wastewater
- Reuse of only Sludge (Biosolids)
- Reuse of both Treated Wastewater & Sludge

The DSS is taking advantage of current web technologies for its user-friendly interface. It is modular, flexible and easily upgradable, in order to accommodate new features and functions.

The current version is built as a web application with PHP, MySQL, and JavaScript. It uses a simple, lightweight and easy to use web interface even for a novice computer user. Its core engine is modular flexible and customizable enough to accept and incorporate specific requirements, future changes, new technologies or upgrades.

Upon request, custom configurations may be provided, in order to meet certain client requirements, i.e.:

- Language translations.
- Special crops.
- Specific guidelines suggested by national agencies.
- Interfacing with local weather stations[2], in order to take advantage of FAO 56 Evapotranspiration method, etc.

[2] If appropriate API is available

START THE SOFTWARE APPLICATION

The DSS is controlled, by the user, through a web User Interface (UI). Its web address is http://wdss.eap.gr/ and it can be opened in any major web browser running on a personal computer (Figure 2).

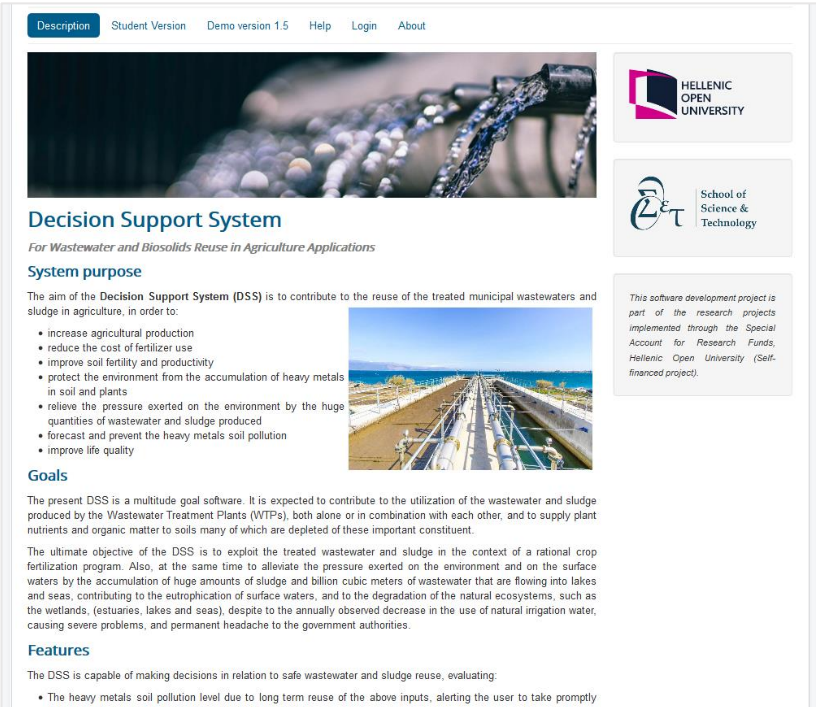

Figure 2. DSS homepage

The user can access the login screen by clicking on the Login button on the navigation bar (Figure 3).

Figure 3. Navigation bar

login[3] by entering a valid username and password at the login screen (Figure 4).

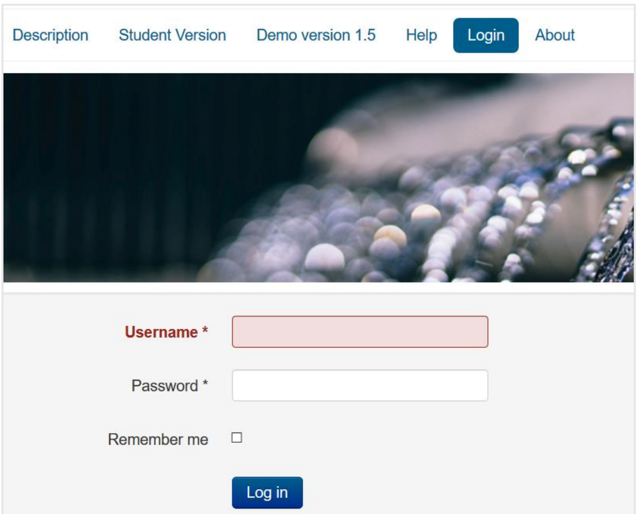

Figure 4. Login screen

[3] There is also a demo version accessible from the "Demo version 1.5" link without login where the user can load and run predefined examples.

After a successful login, the data entry form (Figure 5) appears on the screen.

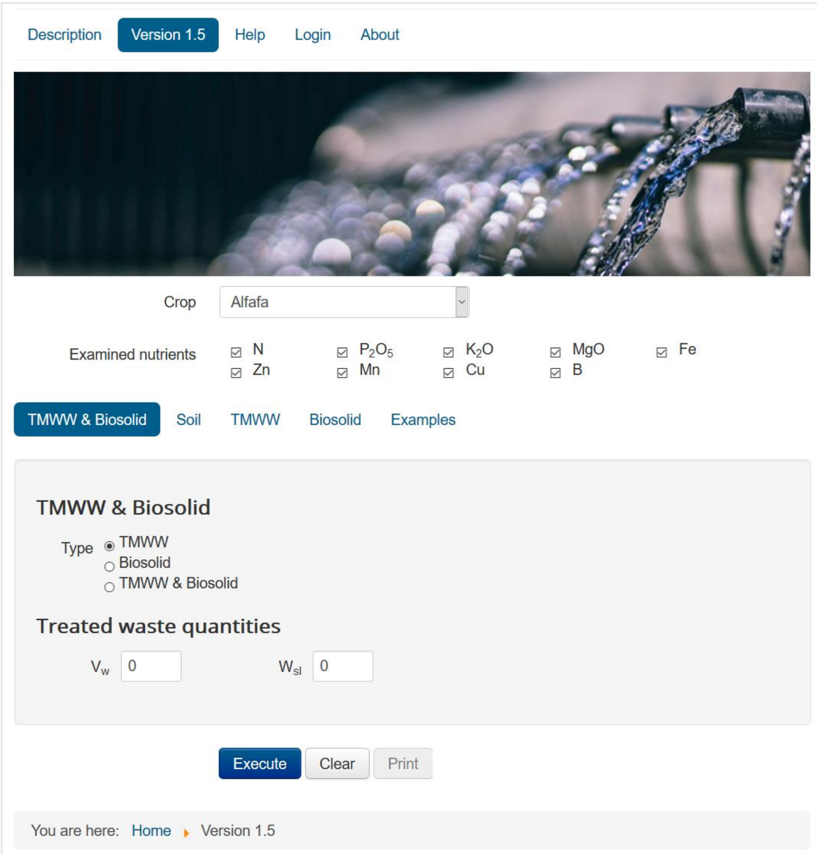

Figure 5. Data entry form

DATA ENTRY

At the input fields where we can enter our data, **the system accepts only numbers, integers or decimals**. As a **decimal point,** the system accepts **the period symbol (.)**. i.e.: 1.25

Note: The system does not accept symbols (i.e. measurement units) in the input fields. It accepts only numerical values that correspond to the measurement units described below in the tables with the input variables.

Input form fields accept strictly values starting with a numerical symbol. Values with only the decimal part must **always include zero (0)** before the decimal point. i.e.:

0.25 **correct** format

.25 **wrong** format (*missing leading 0*)

HOW TO ENTER DATA

1. Select the crop on which the treated waste is to be applied from the **"Crop"** dropdown menu (**Figure 6**).

Figure 6. Crop dropdown menu

2. Select or deselect macro-micro nutrients for which the fertilization advice is to be advised by clicking the corresponding checkboxes from the **"Examined nutrients"**. By default, the form has the fertilization advice enabled (checked) for all nutrients, (Figure 7).

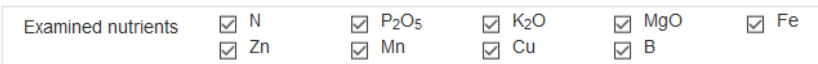

Figure 7. Examined nutrients checkboxes

3. On the tab **"TMWW & Biosolid"** (Figure 8) first the waste type is selected, and second, the

corresponding numerical data are entered (Table 10).

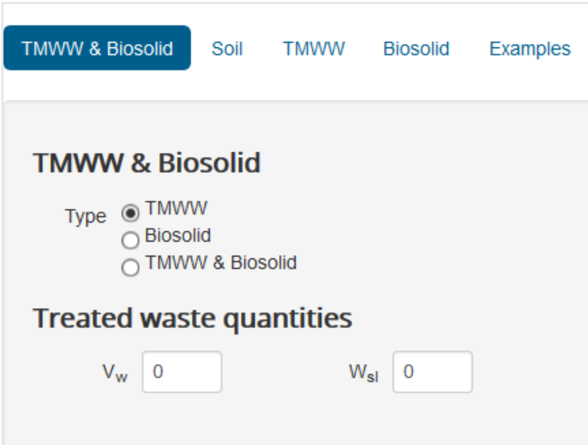

Figure 8. TMWW &Biosolid

Table 10. Treated waste quantities

Field	**Description**	**Units**
V_w	Treated wastewater volume	$m^3/10^3m^2$
W_{sl}	Biosolid (or sludge) mass	$kg/10^3m^2$

4. The **"Soil data"** tab opens by clicking the **"Soil"** button (Figure 9). The soil type is selected and the

numerical data of soil values are entered in the corresponding fields as described in

5. Table 11 and Table 12.

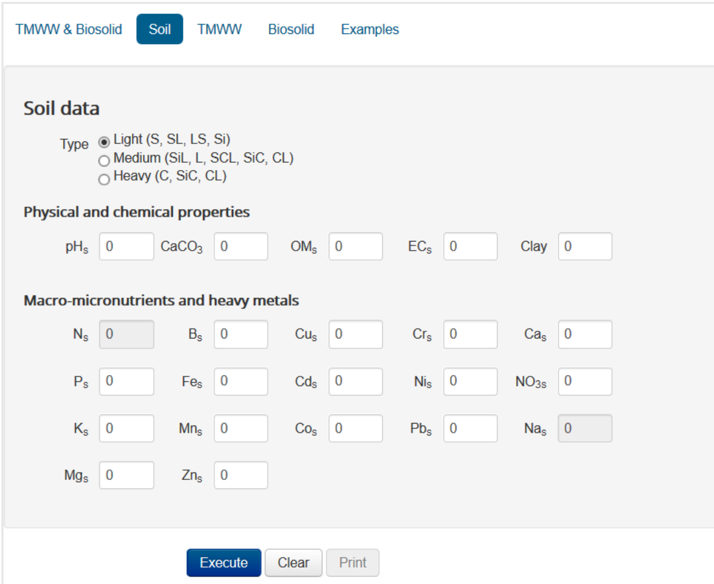

Figure 9. Soil Data

Note: Subscript (s) at the names of the input fields suggest that they correspond to soil characteristics, i.e.: N_s or P_s.

Table 11. Soil physical and chemical properties

Field	**Description**	**Units**
pH_s	Soil's pH	
$CaCO_3$	Soil's calcium carbonate	%
OM_s	Soil's organic matter	%
EC_s	Soil's electrical conductivity	mS/cm
Clay	Soil's clay	%

Table 12. Macro-micronutrients and heavy metals

Field	Description	Units
N_s	Disabled[4].	
P_s	Soil available Olsen P	mg/kg
K_s	Soil available K	mg/kg
Mg_s	Soil exchangeable Mg	mg/kg
B_s	Soil available B	mg/kg
Fe_s	Soil DTPA[5] extractable Fe	mg/kg
Mn_s	Soil DTPA extractable Mn	mg/kg
Zn_s	Soil DTPA extractable Zn	mg/kg
Cu_s	Soil DTPA extractable Cu	mg/kg
Cd_s	Soil DTPA extractable Cd	mg/kg
Co_s	Soil DTPA extractable Co	mg/kg
Cr_s	Soil DTPA extractable Cr	mg/kg
Ni_s	Soil DTPA extractable Ni	mg/kg
Pb_s	Soil DTPA extractable Pb	mg/kg
Ca_s	Soil exchangeable Ca	mg/kg
NO_{3s}	Soil nitrate	mg/kg
Na_s	Disabled.	

[4] Disabled fields are not used in current version.

[5] DTPA: diethylenetriaminepentaacetic

6. By clicking the button **“TMWW”** the **“TMWW data”** tab opens (Figure 10), and the treated wastewater data can be entered by the user as described in Table 13.

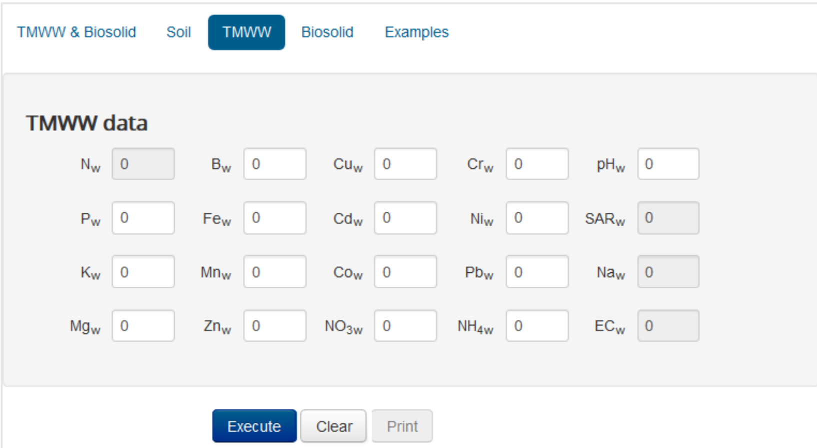

Figure 10. TMWW data

Note: Subscript (w) at the names of the input fields suggests that they correspond to the wastewater characteristics.

Table 13. TMWW data

Field	Description	Units
N_w	Disabled.	
P_w	Treated wastewater P	mg/L
K_w	Treated wastewater K	mg/L
Mg_w	Treated wastewater Mg	mg/L
B_w	Treated wastewater B	mg/L
Fe_w	Treated wastewater Fe	mg/L
Mn_w	Treated wastewater Mn	mg/L
Zn_w	Treated wastewater Zn	mg/L
Cu_w	Treated wastewater Cu	mg/L
Cd_w	Treated wastewater Cd	mg/L
Co_w	Treated wastewater Co	mg/L
NO_{3w}	Treated wastewater nitrate	mg/L
Cr_w	Treated wastewater Cr	mg/L
Ni_w	Treated wastewater Ni	mg/L
Pb_w	Treated wastewater Pb	mg/L
NH_{4w}	Treated wastewater ammonium	mg/L
pH_w	Treated wastewater pH	
SAR_w	Disabled.	
Na_w	Disabled.	

7. By clicking the button **“Biosolid”** the tab **“Biosolid data”** opens (Figure 11), and there the data concerning the biosolids characteristics can be entered by the user, according to Table 14.

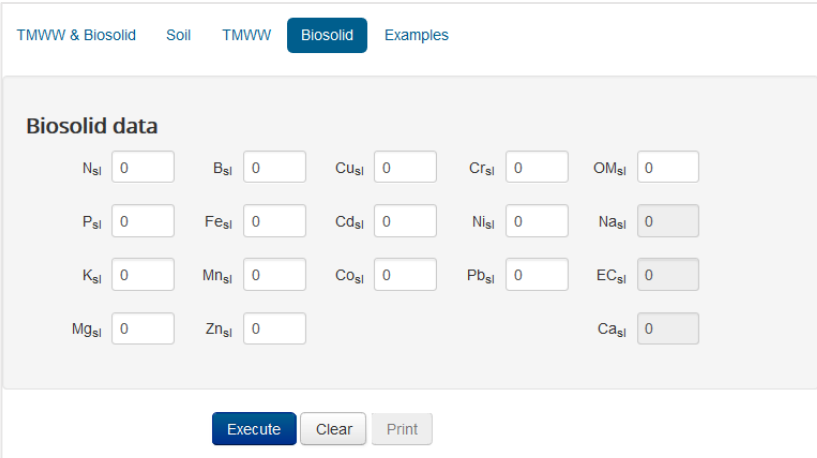

Figure 11. Biosolid data

Note: Subscript (sl) at the names of the input fields suggests that they correspond to biosolid characteristics.

Table 14. Biosolid data

Field	Description	Units
N_{sl}	Biosolid total N	%
P_{sl}	Biosolid extractable P	mg/kg
K_{sl}	Biosolid extractable K	mg/kg
Mg_{sl}	Biosolid extractable Mg	mg/kg
B_{sl}	Biosolid extractable B	mg/kg
Fe_{sl}	Biosolid extractable Fe	mg/kg
Mn_{sl}	Biosolid extractable Mn	mg/kg
Zn_{sl}	Biosolid extractable Zn	mg/kg
Cu_{sl}	Biosolid extractable Cu	mg/kg
Cd_{sl}	Biosolid extractable Cd	mg/kg
Co_{sl}	Biosolid extractable Co	mg/kg
Cr_{sl}	Biosolid extractable Cr	mg/kg
Ni_{sl}	Biosolid extractable Ni	mg/kg
Pb_{sl}	Biosolid extractable Pb	mg/kg
OM_{sl}	Biosolid orgranic matter	%

Warning: *The DSS in order to perform accurately, it must be fed with data in every enabled input field on the form. Despite the fact that some data may be missing the system will make a decision but in a negative case with many missing data, it will output error message/s,*

i.e.: Missing data for dosage estimation of a nutrient.

RUN CALCULATIONS

By clicking the **"Execute"** button (Figure 12) the system starts running and evaluates input data and outputs a detailed report with conclusions referring to the following:

- Soil physical and chemical properties.
- Soil macro – micronutrients and heavy metals.
- Treated wastewater chemical characteristics.
- Treated wastewater and biosolid macro–micronutrients and heavy metals.

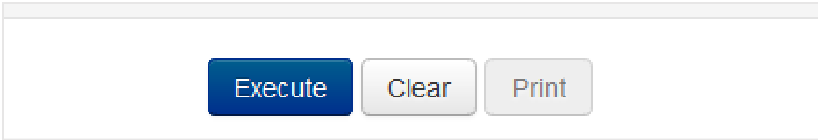

Figure 12. Execute calculations

The DSS checks whether the heavy metal concentrations of the treated wastewater are within the internationally recommended limits and presents with:

- Green color values within limits.
- Red color off-limits.

In a future upgrade, the system will also evaluate concentrations in biosolid.

Also, the system is able to evaluate soil pollution with the help of EPI (Elemental Pollution Index) before and after the wastewater and/or biosolids application.

Finally, the report contains the micro-macro nutrient dosages (kg/ha) for the rational fertilization of crops.

PRINTING

After the completion of the calculations, the button **"Print"** automatically is unlocked and by being pressed a printable form will be generated on a popup window, which can be printed by the user (Figure 13, Figure 14).

HELLENIC OPEN UNIVERSITY

DSS for wastewater and biosolid reuse

System report

1. Physical and chemical properties of soil

pH	$CaCO_3$ (%)	Org. Matter (%)	EC (mS/cm)	Clay (%)
6.52	0.00	1.47	0.83	15.00

2. Macro-micronutrients and heavy metals of soil (mg/kg)

N	P	K	Ca	Mg	Na	B	Fe	Mn	Zn	Cu	Cd	Co	Cr	Ni	Pb
0.00	112.00	159.00	2076.00	330.00	35.00	1.05	11.95	28.50	1.06	2.53	0.05	0.05	0.00	0.00	0.25

Concentrations limit evaluation: According to international guidelines

3. Properties of TMWW

- Macro-micronutrients and heavy metals (mg/L)
- Chemical characteristics

N	P	K	Mg	Na	B	Fe	Mn	Zn	Cu	Cd	Co	Cr	Ni	Pb
0.00	0.90	11.70	29.00	0.00	0.68	0.09	0.08	0.00	0.00	0.00	0.05	0.00	0.01	0.00

Result: **TMWW acceptable for irrigation.**

Notes:
- ***Red values*** *out of internationaly recommended limits.*
- ***Green values*** *within internationaly recommended limits.*

4. Macro-micronutrients and heavy metals of biosolid (mg/kg)

N	P	K	Ca	Mg	Na	B	Fe	Mn	Zn	Cu	Cd	Co	Cr	Ni	Pb
3.50	775.70	3333.00	0.00	309.00	0.00	0.00	221.50	43.60	152.00	22.70	0.36	0.61	0.32	0.37	322.30

5. Evaluation of soil pollution level

Soil pollution index	Value of pollution index before irrigation with treated wastewater	Value of pollution index after irrigation with treated wastewater	Evaluation of pollution level
EPI	0.1229	0.1345	No pollution

Figure 13. Sample printed report (1st page)

Calculated nutrient doses

Nutrient doses expressed in simple fertilizer doses

Recommended method and time for fertilizer application

6. Rational crop fertilization advice

Crop: ***Lettuce***

Nutrient	Dose (kg/ha)	Fertilizer	Guidelines for fertilizer
N	70.25	Dose 1/4 **65.05 kg/ha** Ammonium Calcium Nitrate 27-0-0 Dose 3/4 **260.19 kg/ha** Ammonium Calcium Nitrate 27-0-0	1/4 broadcasted and incorporated into the soil at transplanting, 3/4 applied in 2-3 doses per 10 days interval at the onset of the plant growth.
P_2O_5	0		No fertilization required for the current year. Excessively high soil phosphorus. It is estimated that fertilization with phosphorus will be conducted after 3 years.
K_2O	0		No fertilization required for the current year.
MgO	0		No fertilization required for the current year. Excessively high soil magnesium. It is estimated that fertilization with magnesium will be conducted after 7 years.
Fe	0		No fertilization required for the current year.
Zn	0		No fertilization required for the current year.
Mn	0		No fertilization required for the current year. Excessively high soil manganese. It is estimated that fertilization with manganese will be conducted after 1 year.
Cu	0		No fertilization required for the current year. Excessively high soil copper. It is estimated that fertilization with copper will be conducted after 2 years.
B	0.42	**3.65 kg/ha** Borax 11.5% or **2.05 kg/ha** Solubor 20.5%	Broadcasted mixed with other fertilizers.

The DSS is able to suggest suitable alternative fertilizers

Nutrients sufficiency calculation based on current crop needs

Despite the very small calculated boron dose the DSS avoided recommending application by spray because lettuce leafs are consumed by humans

Figure 14. Sample printed report (2nd page)

FORM RESET

The input form can be reset by pressing the **"Clear"** button.

HIGHLY ACIDIC SOILS

The software can detect soils with highly acidic pH, and makes recommendations for lime requirements with $CaCO_3$ or CaO.

Figure 15. Highly acidic soil alert message

If during calculations low soil pH is detected the user will be redirected to the soil data section, where the desired pH value can be entered (Figure 16).

Figure 16. Desired soil pH

Two new input fields appear in **"Physical and chemical properties"** section. The **"pH$_{desired}$"** field for the desired soil pH with default value 7, and the **"depth"** field with default value 0.2m.

By pressing **"Execute"**, after entering desired values, the system includes in the report lime requirement with $CaCO_3$ or CaO in kg/ha (Figure 17).

Lime requirement with $CaCO_3$ or CaO in kg/ha	
$CaCO_3$	1151.04
CaO	644.58

Figure 17. Report section with lime requirements

EXAMPLES

The system includes some preloaded examples in the **"Examples"** tab (Figure 18). The user can load an example by clicking on it. The data entry forms will be populated automatically with the example's analytical data and by clicking the **"Execute"** button the system starts running and evaluates them and generates the report.

Figure 18. Examples tab

Example 1 and Example 2 are the two examples used in Part I.

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